New Jersey Meadowlands

LANDFILL TO GOLF COURSE - LEACHATE & TURFGRASS STUDY

PREPARED BY RUTGERS ENVIRONMENTAL RESEARCH CLINIC

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FINAL PROJECT REPORT

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The purpose of this research is to provide the New Jersey Meadowlands Commission (NJMC) management and staff with information related to recovery of usable 'grey water' from the Meadowlands District leachate, and to test the ability of turfgrass cultivars to utilize this water source for irrigation.

I. EXECUTIVE SUMMARY

In preparation for closing the 1-E Landfill and possible conversion of this land to public open space, the New Jersey Meadowlands Commission (NJMC) engaged Rutgers University to conduct a study to determine the feasibility of recovering water suitable for irrigation from the leachate generated in the Meadowlands' landfills. Overall objectives of this two year study were to design a treatment process to recover the 'grey water,' identify and test possible turfgrass species that could utilize this water source, and determine Best Management Practices (BMPs) for irrigation and maintenance of a public Meadowlands' golf course.

In the first year of the research, bench top laboratory trials were conducted to recover a 'grey water' product derived from Meadowlands' leachate The evaporation process proved capable of removing heavy metals, PAH and PCB contaminants, and the majority of organic compounds from the 'grey water' recovered after evaporation. The recovered 'grey water' was analyzed for various water quality parameters, including pH, chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), nutrients, and organic contaminant compounds. The 'grey water' produced by the benchtop evaporation process was then used to test the tolerance of various turfgrasses species to withstand irrigation using this water source under ideal laboratory growth conditions.

Concurrent with the leachate evaporation tests, a number of turfgrass species were screened for their response to salt stress. Based on measurements of turf quality, electrolyte loss, and relative water content of leaves, the species that were best adapted to high levels of salt included ***Alkali grass*** and ***Tall fescue***, while ***bentgrass*** species were most susceptible to salt stress. ***Creeping bentgrass*** plants were grown in the laboratory growth chambers using the leachate evaporation product as the irrigation water. The results of the greenhouse trials constituted the basis for setting up field plots in year 2 of the study to test turfgrass response under field conditions to irrigation with 'grey water' recovered from Meadowlands' leachate.

The golf course field plots, built atop the 1-E Landfill in the late spring of 2008, were constructed using standard USGA specifications for fairways and putting greens. An underground drainage system was placed in the base of the plot system, which was constructed by covering a soil layer with a layer of sand. All plots were segregated by plastic dividers to prevent cross plot movement of the water treatments.

While the golf course plots were being constructed, a pilot-scale evaporation unit was set up at the base of the 1-E landfill adjacent to the NJMC leachate pumping station. Using a pump submersed in the leachate wet well, the leachate was pumped into the evaporator, where it was heated under pressure to 150 – 175 degrees F, evaporated, and recollected as 'grey water.' The 'grey water' product was pumped to a holding tank that was transferred to the top of the landfill adjacent to the turfgrass field plots.

After the various cultivars of seeded turfgrass were well established in the field plots, different watering regimes were tested on the turfgrass cultivars to determine the effects of leachate 'grey water' irrigation. Water pumped from the 1-E precipitation-fed and lined pond served as the freshwater control. The field test demonstrated that short-term (one season) use of recovered leachate 'grey water' was a viable water source. Use of this 'grey water' resulted in higher turfgrass performance characteristics (biomass, chlorophyll content, water content, macro- and micro-nutrient concentrations) when daily evapotranspiration (ET) water loss was replaced with the 'grey water' versus fresh water. Creeping bentgrass cultivar 'L93' outperformed other turfgrasses tested in the field plots.

Based on the results obtained from the field tests, Best Management Practices for a golf course utilizing 'grey water' recovered from Meadowlands' leachate begin with a careful selection of cultivars that can thrive with this water source. Based on the results of this study, we recommend creeping bentgrass varieties 'L93,' '007,' 'Memorial,' and 'Tyee' be considered for the putting green areas. Cultivar 'L93' performed well on the fairway plots, and would be an acceptable species for use in fairways also. We recommend an irrigation regime at 80% of ET water loss replacement. However, we caution that this recommendation is based on a single season only, and so additional water might be required to flush out soil salts should they build up after a longer period of watering with 'grey water.'

Because the recovered 'grey water' contains relatively high levels of organic nitrogen, fertility management is critical in maintaining turfgrass plant health. A plant growth regulator would be required weekly or biweekly to reduce the rate of plant growth. Topdressing, verticutting, rolling, and core cultivation will be needed to maintain a healthy turfgrass cover and reduce thatch. Core cultivation will be necessary at least two to three times a season to sustain turfgrass health through reduction of compaction, thatch removal, and improvement of filtration and oxygen supply to the root zone.

We believe that additional phosphorus, potassium, and micronutrients will be needed to supplement the nitrogen in the 'grey water,' and so incomplete fertilizer products could play an important part in a turfgrass management program. The pH of the 'grey water' must be lowered to a slightly acidic range of 6.5 – 7.0 from the 9.0 pH observed in the field studies. It is recommended that pesticides be applied preventatively on a weekly basis throughout the growing season because the high nitrogen loadings will cause the turfgrass to grow rapidly. We note that the preliminary recommendations for BMPs could be modified based on data collected after multiple seasons of 'grey water' usage.

The field tests confirmed that at least over the short-term (one growing season), the daily use of recovered leachate 'grey water' as an irrigation source for golf course turfgrass species can be successful. The information gained from this project suggests that there may exist the potential for a beneficial re-use and/or treatment of landfill leachate. Application of the thermal evaporation process is highly dependent upon the capital and operating costs of the full-scale treatment process, including the future cost of energy. Based on the costs we were able to determine, we estimate that it would cost approximately $.01 to treat a gallon of Meadowlands' leachate. However, we note that these are not firm costs and could potentially be higher with additional system components or conversely, could be lowered with a change in the system design. The single highest cost is associated with the cost of supplying energy to the evaporation system.

We strongly recommend bringing together all interested parties to develop a holistic site design that integrates 'grey water' production with golf course design and irrigation needs. The location and aesthetic incorporation of the proposed solar panels should also be considered as part of this holistic design process. Because the field data from this project are of a short term nature, we cannot at this stage predict plant or soil response to longer term leachate 'grey water' use.

Should the evaporation process be seriously considered by the NJMC as a method for treating Meadowlands' leachate, further discussions with evaporation equipment design firms are needed to determine the best methods for controlling the tendency of leachate to foam. Further, a treatment to remove any residual compounds that volatize after the foaming is eliminated, would need to be tested. Discussions would also need to be conducted with the appropriate departments within NJDEP to identify the permits required for an evaporation process to treat leachate, and to consider various disposal options for the residual waste material produced by the treatment process. The cost to dispose of the sludge residues generated by the leachate recovery process would be very high if the material is categorized as 'Hazardous Waste.' However, it is not possible to know at this time if the residue would be categorized as hazardous without conducting Toxicity Characteristics Leaching Procedures (TCLP) analyses.

II. PROJECT BACKGROUND

A. LANDFILL RE-DEVELOPMENT

To improve the quality of life for residents living within Bergen and Hudson Counties, the New Jersey Meadowlands Commission (NJMC) is involved in a number of activities related to environmental improvements. A major goal of the NJMC is to complete the closure of the 1-E Landfill. One of the strategies being employed to convert old landfills to new usages is to allow development of golf courses on landfill sites once they are properly closed. Such a conversion to a public golf course was proposed for the 1-E Landfill after its projected closure.

Due to the high water demand of a typical northeastern golf course (15-20 million gallons of water annually, J. Snow, *personal communication*) it is highly desirable to identify potential sources of irrigation water that are non-potable. We estimate the water requirements of a Meadowlands' public golf course to be as high as 10,000 gal per acre or more during the summer months when water usage would be at its height. The landfills within the Hackensack Meadowlands District are currently producing leachate at the rate of millions of gallons annually, and the water content of leachate is typically greater than 99%. If treatment protocols for a large scale system to extract 'grey water' from this leachate can be developed, it may be possible to recover enough usable water from the leachate to irrigate a redeveloped landfill site, including the irrigation and maintenance of a public golf course.

Long-term use of recovered 'grey water' can alter soil physical and chemical properties, since it often contains higher concentrations of dissolved solids, nutrients (N, P), and other elements versus what is typically present in potable water (Harivandi 1993, Qian & Mecham 2005, Thomas et al., 2006). Nutrients in 'grey water' can have a positive impact on turfgrass growth, potentially reducing the application of fertilizers (Thomas et al., 2006, Ninemire 2007). However, potential problems can also develop with the use of recovered 'grey water' that can have negative effects on plant growth. These problems include osmotic stress induced by the accumulation of salts in the soil, toxicity of Na and Cl, and excess concentrations of bicarbonates, which elevate the soil pH (Ninemire 2007). These negative effects can cause turf grass quality to decline and lower the plant's ability to tolerate other stresses such as wear (Carrow & Duncan 1998). Previous research has evaluated the effects of 'grey water' irrigation on turfgrass visual quality (Hayes et al., 1990, Harivandi 1991, Qian & Mecham 2005, Thomas et al., 2006). However, little scientific data are available related to the physiological effects of 'grey water' use on actual golf course putting greens and fairways. The majority of the research that does address this issue has been conducted in the southern and southwestern USA where environmental conditions are very different from those found in the northeastern NJ Meadowlands District. To the best of our knowledge, landfill leachate has not been tested as a potential source of irrigation 'grey water.'

Finding a use for leachate within the Meadowlands District would eliminate the need to send the leachate to the Passaic Valley Sewerage Commission wastewater treatment facility, potentially saving the costs associated with leachate treatment. If 'grey water' recovered from the leachate were to be utilized to irrigate a golf course, it is critical to select appropriate turfgrass species that can survive both the use of this water source as well as the climatic conditions found in the Hackensack Meadowlands.

B. RESEARCH OBJECTIVES

The overall objectives of this project were three-fold:

1) Engineer a treatment process capable of recovering 'grey water' from the leachate produced by landfills in the Hackensack Meadowlands,
2) Identify turfgrass species and cultivars that are capable of thriving under Hackensack Meadowlands' environmental conditions using this 'grey water' source for irrigation, and
3) Determine Best Management Practices (BMPs) for irrigation and management of a Meadowlands' public golf course if recovered 'grey water' is used as the irrigation source.

Project deliverables include the recommended engineering design for a full-scale leachate treatability and 'grey water' recovery system.

III. YEAR ONE LABORATORY EXPERIMENTS

LEACHATE 'GREY WATER' RECOVERY – LABORATORY EXPERIMENTS

Design of the 'grey water' recovery process focused on existing proven technologies that could potentially be methods suitable for recovering irrigation water. To the best of our knowledge, these technologies have not been employed in treatments to produce 'grey water' from landfill leachate. After evaluating several processes, including membrane filtration systems, flash evaporation, and thermal evaporation to treat the leachate, we have selected thermal evaporation as the most efficient process for recovering usable water from the Meadowlands' leachate. We selected this method because we believe a thermal evaporation system would be more energy efficient than flash evaporation, and potentially less problematic to operate than a membrane filtration system. Thermal evaporation can also treat the large volumes of leachate that would be required to meet the projected irrigation needs of a golf course. However, landfill leachate often contains various volatile and semi-volatile organic and inorganic chemicals. Two drawbacks of using evaporation to recover leachate 'grey water' are the potentially high concentrations of volatile chemicals and the potential corrosion of evaporator components.

Thermal evaporation employs heat energy that can be derived from electricity or liquid natural gas (LNG) to heat the leachate to its boiling point. When the boiling point of the liquid is reached, water is evaporated as steam, leaving behind a residue that contains the inorganic constituents and potentially a mixture of non-volatile organic compounds. While the process does require energy inputs to heat the wastewater to its boiling point (often above the boiling point of pure water due to the presence of high salt concentrations), the energy requirements are less than those of a flash evaporation treatment. As an example, heating one gallon of pure water from room temperature (20 ^{0}C) to its boiling point (100 ^{0}C) requires 302.8 kcal of heat; subsequent heating to convert the gallon of water to steam at 100 ^{0}C requires 2,040 kcal of heat. The total energy consumed is about 2,343 kcal/gal, or 9301 BTUs (British thermal units). If using a flash evaporation process that combusts the leachate material, additional energy would be required to raise the leachate temperature to 300 to 400 ^{0}C. It should be noted that these calculations assume an unrealistic 100% energy conversion efficiency, and are for comparison purposes only.

Characterization of the Meadowlands' leachate before and after thermal evaporation was required to determine the treatment's effectiveness, and to determine whether post-treatment would be necessary to meet the water quality standard required for a golf course. The possibility of corrosion due to high salt contents in landfill leachate would increase the capital investment for installation of the evaporation system because expensive corrosion-resistant materials would need to be used for construction of the evaporator compartment(s) that are in direct contact with the leachate. In the first year of this project, we addressed the following engineering objectives by establishing a bench-top evaporation system to process batches of leachate in the laboratory:

1) Characterization of the landfill leachate in terms of its organic and inorganic constituents,
2) Quantification of the phase separation behavior of the leachate constituents under a thermal evaporation treatment strategy,
3) Characterization of the chemical composition of the products produced in the treatment processes, and
4) Determination of an optimal treatment technology.

In spring and summer (2007) samples of landfill leachate were collected from the 1-E landfill. Upon delivery to the Rutgers laboratory, a 1-liter subsample was immediately obtained for chemical tests, which included analyses of pH, chemical oxygen demand (COD), total dissolved solids (TDS), suspended solids, nutrients (N and P species), trace elements including heavy metals, and organic compounds. The leachate was stored in a walk-in cooling room (4 ^{0}C) prior to the thermal evaporation bench top experiments.

Batch evaporators were set up in the laboratory to test Meadowlands' leachate response to the thermal evaporation process. The system included a heating element, 1-liter flask, condenser, cooling water system and product water collector (Fig. 1). Each individual system was set up to produce approximately 1 liter of recovered water per day. The distillate produced by the system was sampled to analyze the same chemical parameters as those analyzed in the original leachate samples.

Chemical analyses of the liquid condensate indicated that thermal evaporation effectively removed the majority of the heavy metals and organic compounds found in the untreated leachate (Tables 1 and 2). The recovered distillate was nearly colorless (Fig. 2), but a slight odor was noted. Qualitative analysis indicated that the distillate contained a minimal number of low molecular weight organic compounds (Fig. 3), and could possibly require post-treatment for removal of these chemicals. Using gas chromatography and mass spectrometry (GC-MS), we identified the organic compounds in both the leachate and the distillate (Table 3). The distillate was also found to contain high concentrations of nitrogen in the form of ammonia (Table 1). The compounds remaining after thermal evaporation suggested that concentrations of the more volatile contaminants could be enhanced by the distillation process. Based on this initial screening, concentrations of PCBs, PAHs, BTEX, and dioxins did not appear to be problematic in the condensate produced by the evaporation process.

Fig.1. Benchtop thermo-evaporation system.

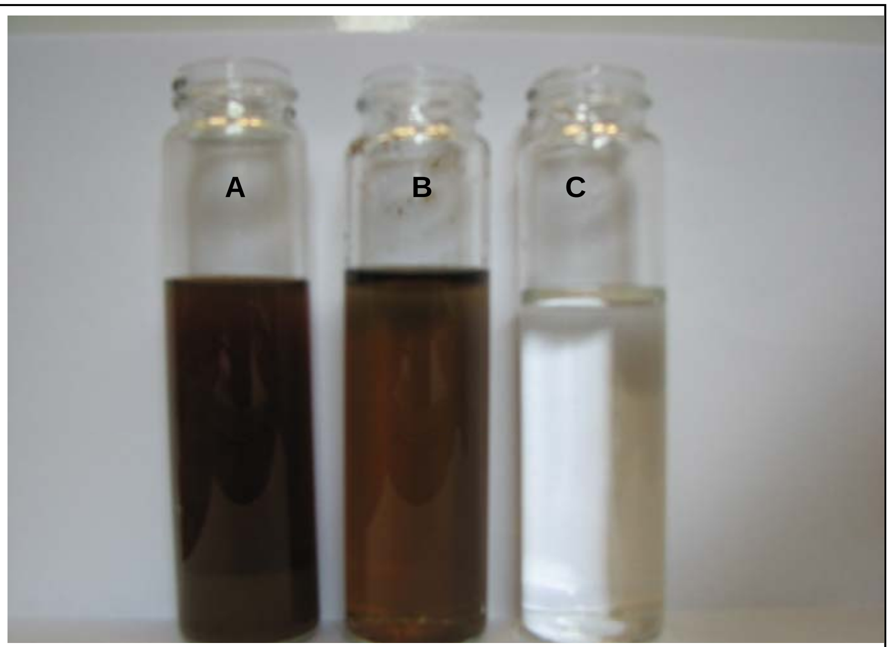


Fig. 2. Thermo-evaporation a) post-treatment residue; b) original leachate; and c) distillate.

Table 1. Leachate Chemical Properties Before and After Distillation.

Properties	Leachate	Distillate
Color	Dark brown	Colorless
pH	7.92	8.45
Conductivity	9.994 (mhos/cm)	3.422 (mhos/cm)
Total Dissolved Solids (TDS) converted from conductivity	5716 mg/L	1872 mg/L
Total Dissolved Solids (TDS) measured	4994 mg/L	ND
Suspended Solids (filtered > 0.45 μm)	122 mg/L	ND
Chemical Oxygen Demand (COD) (mg/L)	1158	223
Ammonia (NH_4^+) (mg/L)	560	636
Total Nitrogen (TKN) (mg/L)	567	667
Total Phosphorus (mg/L)	2.51	0.08

Table 2. Leachate Metal Concentrations Before and After Distillation (μg/L).

Metal	Leachate	Distillate	Metal	Leachate	Distillate
Li	140	<0.51	**Se**	6	<1.7
Rb	144	<0.51	**Mn**	214	<0.51
Cs	1	<0.51	**Co**	16	<0.51
Mg	49,562	<51	**Ni**	54	<0.51
Sr	801	<0.51	**V**	21	1
Ba	667	<0.51	**Cr**	64	4
Al	75	<51	**Cu**	2	<0.51
Ti	30	1	**Zn**	<51	<51
Ga	21	<0.306	**As**	19	1
Tl	<0.51	<0.51	**Cd**	<0.51	<0.51
Fe	11,016	<51	**Pb**	12	<0.51
Hg	1.09	<0.102			

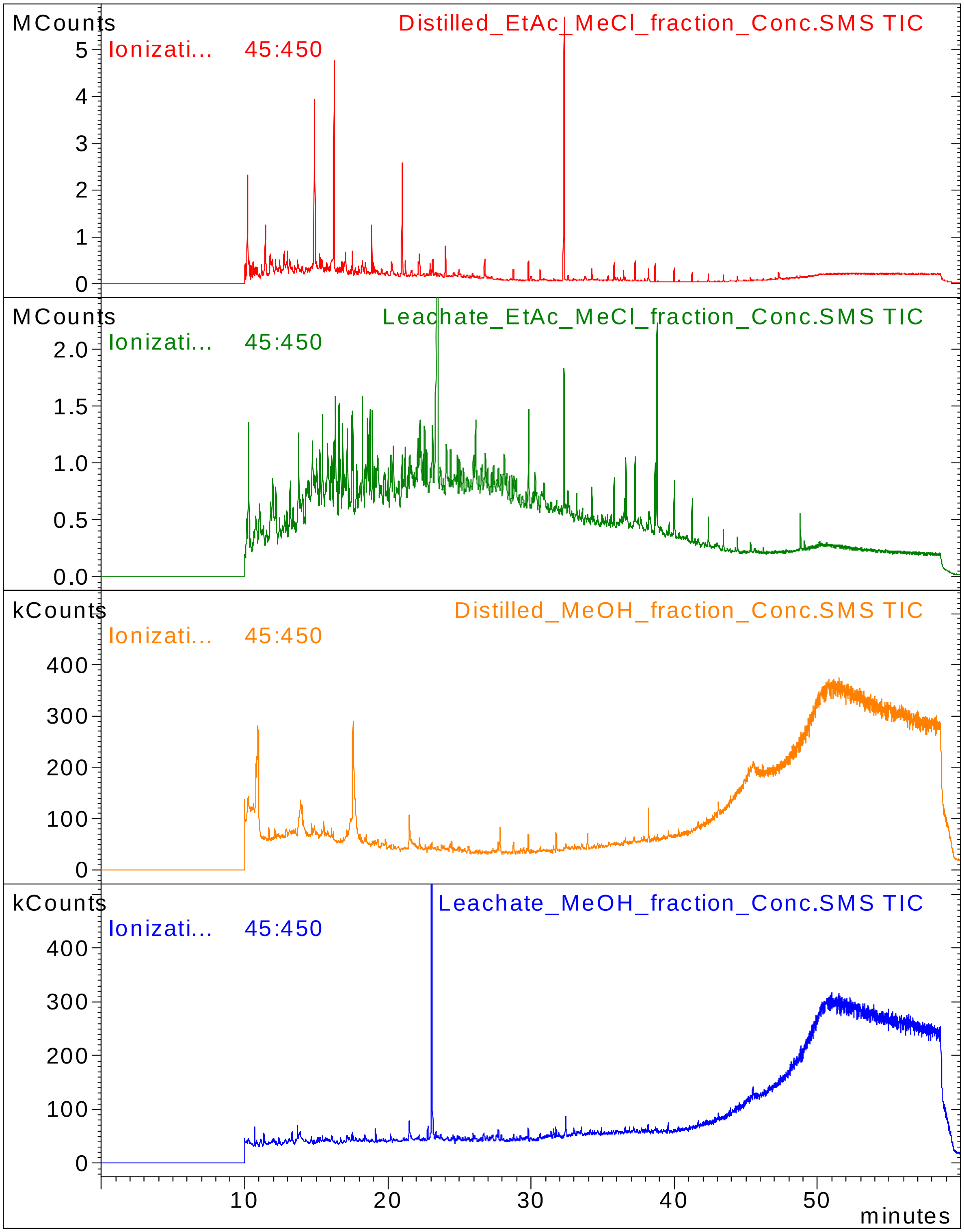


Fig. 3. GC-MS chromatographs of landfill leachate pre- and post- benchtop thermal evaporation (see Table 3 below).

Table 3. Identification of the Major GC-MS Peaks Found in Meadowlands' Leachate Before ('Leachate') and After ('Distillate') Thermal Evaporation.

Leachate Compounds

7-Hydroxy-2,4,6-trimethyl-8-oxazol-5-yloct-2-enoic acid
Isoindole
p-Hydroxybiphenyl
Benzaldehyde
Butylated Hydroxytoluene
2,4-Hexadienedioic acid
5-Amino-2-benzyloxypyridine
Phosphine
Cyclooctacosane
Phenol
Tetrapentacontane
4-Isothiazolecarbonitrile
Tritetracontane
1-Hexacosene
1,2,3,4-Tetrahydro-3-isopropyl-5-methyl-1-oxonaphthalene

Distillate Compounds

1,3-Dithiolane
Naphthalenone
Phenol
1,2,3,4,5,8-Hexahydroisoquinoline
4,6-Heptadienoic acid
Diethyltoluamide
1,2,4,5-Tetrazine
3,3,5-Trimethylcyclohexylamine
Cyclohexanamine
4-Amino-7-diethylamino
Lidocaine
2,4-Dimethyl-12-thia-1,5,6a,11-tetraaza-indeno[2,1-a]fluorene
Benzopyrazol
1,2-Benzenedicarboxylic acid

The 'grey water' recovered from Dr. Weilin Huang's laboratory evaporation experiments was then utilized by Dr. Bingru Huang's group to grow golf course turfgrasses under ideal laboratory conditions.

TURFGRASS DEVELOPMENT – LABORATORY EXPERIMENTS

'Grey water' typically has a high salt content, which can lead to salt toxicity and osmotic stress in plants. There are many different cultivars within each turfgrass species, which vary in their ability to tolerate both a 'grey water' source and harsh climatic conditions. This study tested turfgrass species and cultivars that are tolerant to both high salinity and osmotic stress. Cool-season turfgrass species (***Creeping bentgrass***, ***Kentucky bluegrass***, ***Perennial ryegrass***, and ***Tall fescue***) are best adapted to the climatic conditions in New Jersey, and are the most widely used species in this area for golf courses that irrigate with potable water. Each grass species has its own requirements with regard to the environment it favors and the maintenance regime it will tolerate. Specific objectives of the laboratory turfgrass studies included:

1) Identification of the turfgrass species and cultivars with the ability to thrive utilizing 'grey water' recovered from Meadowlands' leachate as the irrigation source, and
2) Identification of turfgrass species and cultivars with the ability to withstand the physical conditions in the Hackensack Meadowlands District, including wind, brackish water, and high summer temperatures.

A review of the literature suggested that the 'seaside' and 'mariner' varieties of ***Creeping bentgrass*** would most likely be suited to high salinity irrigation. The specific turf species included ***Perennial rye***, ***Tall fescue***, and ***Seashore paspalum***, which were tested under optimal greenhouse growing conditions. Several native plant species were also tested as to the feasibility of their use in golf course rough areas that might also be irrigated with recovered leachate 'gray water.' These experiments were followed by growth chamber tests using the actual 'grey water' recovered from the bench top thermal evaporation of Meadowlands' leachate as the irrigation source. A growth chamber experiment was also conducted to evaluate the potential toxicity of the recovered 'grey water' to creeping bentgrass cultivar 'L-93' (a grass considered moderate in salt tolerance). These initial studies evaluated the toxicity of the recycled 'grey water' to a moderately salt tolerant grass, growing under non-stressed conditions. These results were the basis for the Year 2 field study portion of the project.

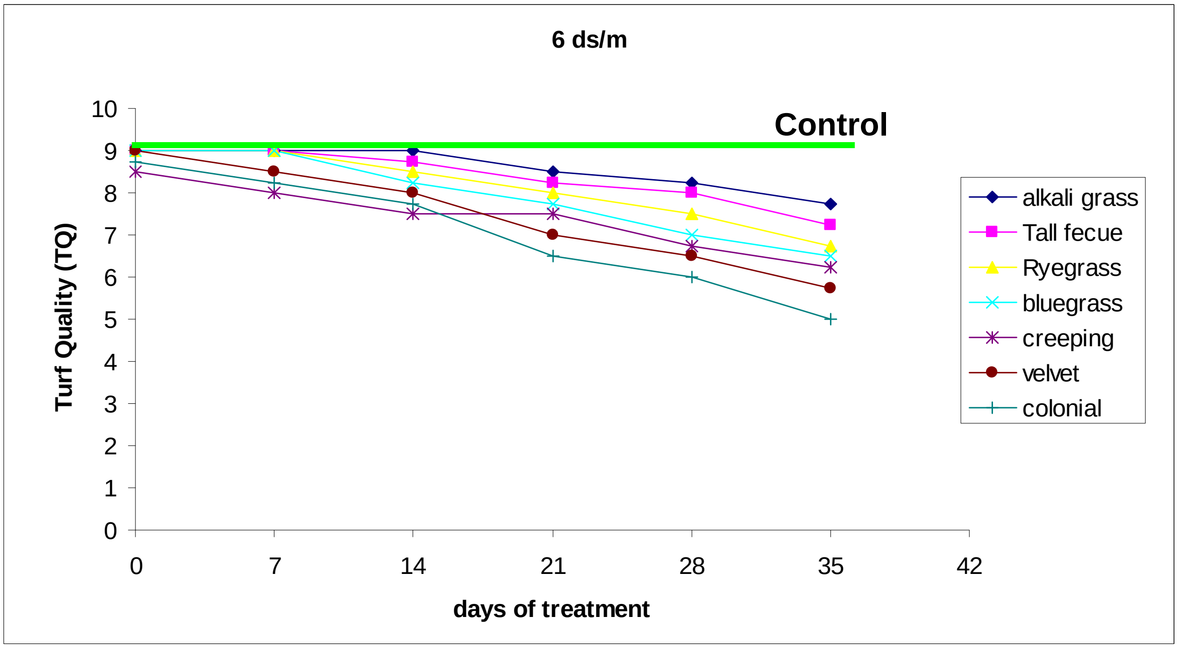
MATERIALS AND METHODS

Prior to production of recovered leachate 'gray water,' a greenhouse experiment was conducted to compare salt tolerance among different cool-season turfgrass plant species. This screening was done with the expectation that the recovered leachate might have a high salt content. A total of seven different species including ***Perennial ryegrass*** (cv. Palmer III), ***Creeping bentgrass*** (cv. L-93), ***Colonial bentgrass*** (cv. Tiger), ***Velvet bentgrass*** (cv. Greenwich), ***Kentucky bluegrass*** (cv. Diva) and ***Alkali grass*** were evaluated under salt stress conditions. The plants were grown in 100% sand and allowed to establish well under greenhouse conditions before the salinity treatments began. Treatments consisted of saline water with electrical conductivity values of 6 dS/m and 12 dS/m (equivalent to 3840 and 7680 mg/L, respectively) along with a potable tap water control. In order to avoid salinity shock, salinity levels were gradually increased by increments of 2 dS/m (1280 mg/L) and 4 dS/m (2560 mg/L) every alternate day, until reaching a final salinity level of 6 dS/m and 12 dS/m respectively. Irrigation waters of different salinity levels were prepared by dissolving Instant Ocean in ¼ strength Hoagland's solution to obtain the desired electrical conductivity values. The plants were irrigated with 2000 mL of water every alternate day for the duration of the experiment (35 days). The experimental design was a randomized complete block design with four replications of each treatment. Data on turf quality, relative water content, and electrolyte leakage was measured at weekly intervals (7 days) for the duration of the experiment (35 days).

RESULTS

Turfgrass Quality

Turfgrass quality is measured using a visual scale ranging from 1 to 9, with 1 equaling dead turf and 9 equaling the best green turf exhibiting a dense canopy. Turf quality declined under salt stress in all the species tested, with the decline being greater under the 12 dS/m treatment. At salt concentrations of 6 dS/m (Fig. 4), ***Alkali grass*** and ***Tall fescue*** were most tolerant to salt stress as manifested by higher turf quality. Few differences in turf quality were observed between ***Perennial ryegrass***, ***Kentucky bluegrass***, ***Colonial bentgrass***, ***Creeping bentgrass*** and ***Velvet bentgrass*** at electrical conductivity of 6 dS/m. However, plants treated with salt concentrations of 12 dS/m (Fig. 5) exhibited a greater decline in turf quality compared with the grasses in the 6 dS/m treatment. After 14 days of salt treatment at 12 dS/m, ***Creeping bentgrass*** was the first to exhibit decline, followed by ***Colonial bentgrass*** and ***Velvet bentgrass***. However, after 21 days of salt stress (12 dS/m), ***Colonial bentgrass*** showed a sharp decline in turf quality, while ***Creeping bentgrass*** maintained higher turf quality than the ***Velvet bentgrass***. ***Perennial Ryegrass*** maintained better turf quality than ***Kentucky bluegrass***. ***Alkali grass*** and ***Tall fescue*** maintained the highest turf quality among all the species evaluated, and were therefore considered to the most salt tolerant, while ***bentgrasses*** were found to be the most sensitive to salt stress. ***Perennial ryegrass*** and ***Kentucky bluegrass*** were judged to be moderately sensitive to salt stress. Control plants maintained turf quality of 9 over the course of the experiment.



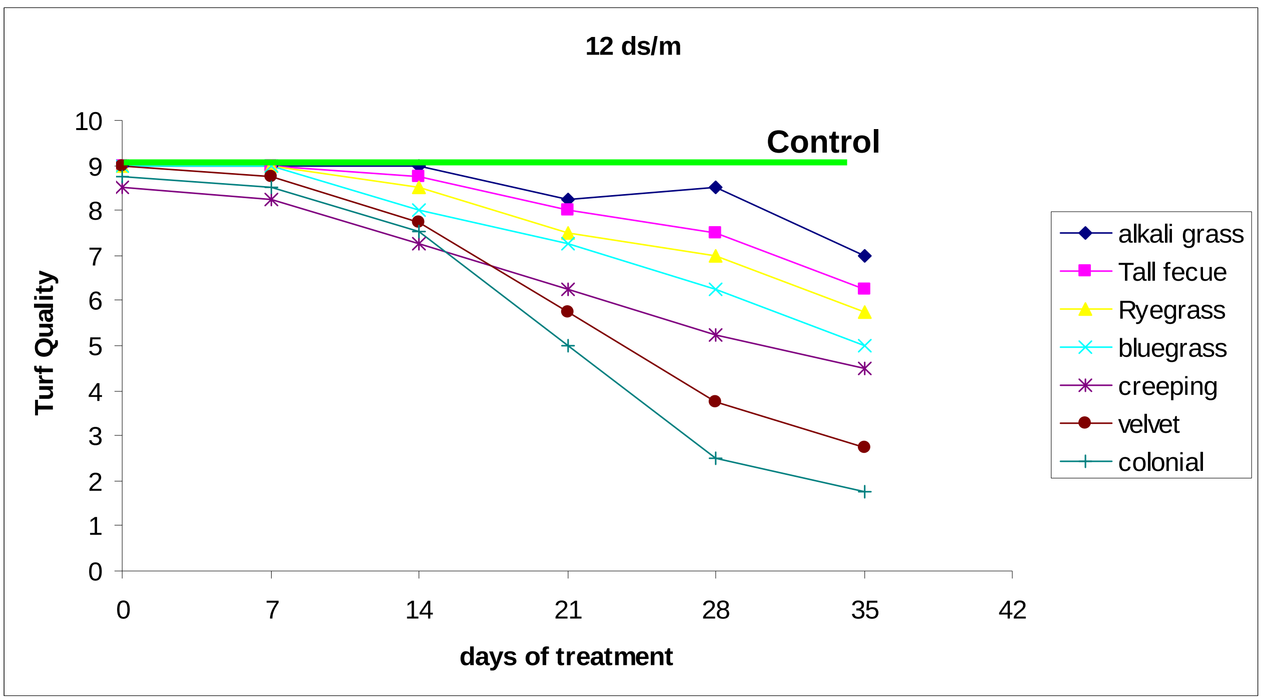


Fig. 5. Turfgrass quality under salt stress (12 ds/m).

Electrolyte leakage

Electrolyte leakage is calculated as a percentage of total electrolytes. Salt stress increased the electrolyte leakage in all the turfgrass species as compared to that of the control plants. At salt concentrations of 6 dS/m (Fig. 6), electrolyte leakage was greatest in ***Colonial bentgrass***. Higher salt concentrations (12 dS/m) resulted in greater loss of electrolytes for all the species evaluated (Fig. 7) compared to the results under the 6 dS/m treatment. ***Colonial bentgrass*** had the highest electrolyte leakage, followed by ***Velvet bentgrass*** and ***Creeping bentgrass*** at salt concentrations of 12 dS/m. At the higher salt concentration, ***Perennial ryegrass*** and ***Kentucky bluegrass*** had lower electrolyte leakage than the bentgrass species. ***Alkali grass*** and ***Tall fescue*** exhibited the lowest loss of electrolytes among all the species tested for salt stress at 12 dS/m. Electrolyte leakage in the control plants ranged from 10-12 over the course of the experiment.

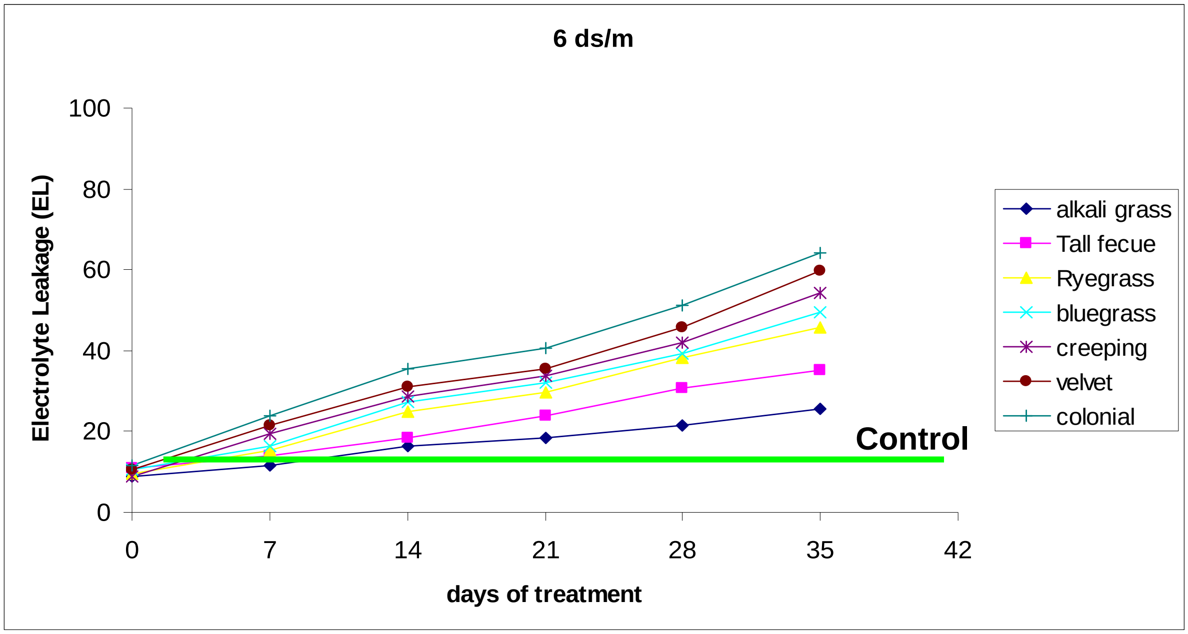


Fig. 6. Turfgrass electrolyte leakage under salt stress (6 ds/m).

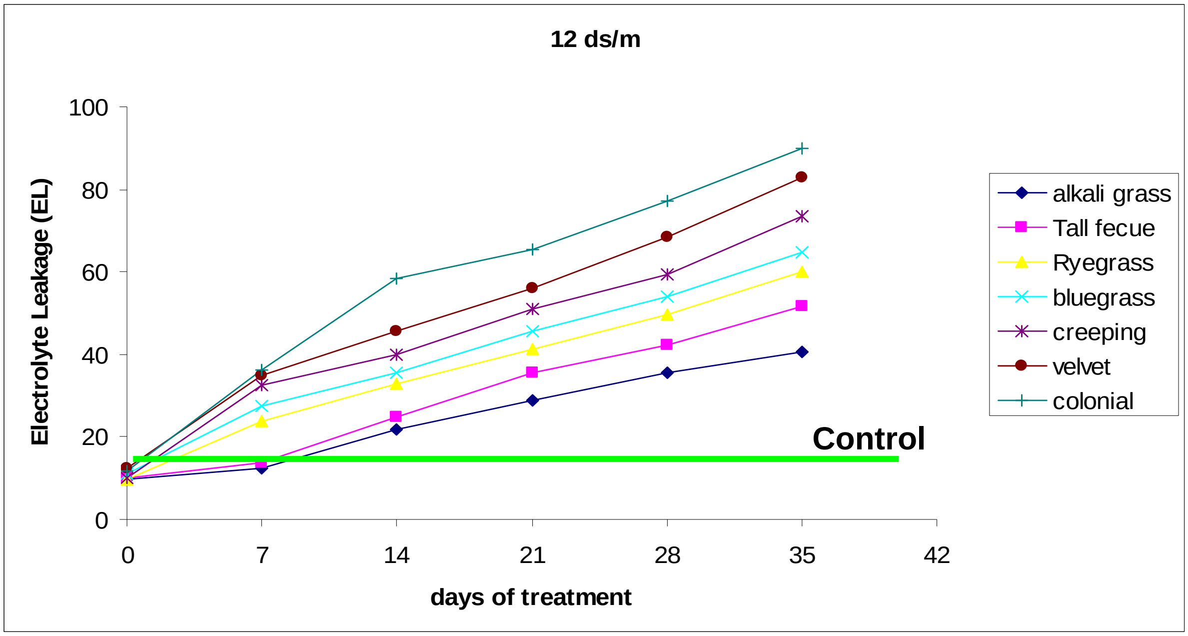


Fig. 7. Turfgrass electrolyte leakage under salt stress (12 ds/m).

Relative Water Content

Relative water content is measured as a percentage of the leaf mass. The relative water content of the leaves of salt stressed plants was lower than that of the control plants. At salt concentrations of 6 dS/m (Fig. 8), the highest relative water content was observed in ***Alkali grass*** and ***Tall fescue,*** while there were few differences in the relative water content observed between the other turfgrass species. Higher salt concentrations (12 dS/m) resulted in lower relative water content for all the species evaluated compared to the results observed under the 6 dS/m treatment. At salt concentrations of 12 dS/m (Fig. 9), ***Alkali grass*** and ***Tall fescue*** maintained the highest relative water content compared to the other turfgrass species studied. The relative water content in ***Perennial ryegrass*** was higher than that of ***Kentucky bluegrass***, while bentgrasses showed major declines in relative water content after 21 days of treatment at salt concentrations of 12 dS/m. At the higher salt concentration, ***Colonial bentgrass*** had the lowest relative water content followed by ***Velvet bentgrass*** and ***Creeping bentgrass***. Control plant leaf water content remained at 90 over the course of the experiment.

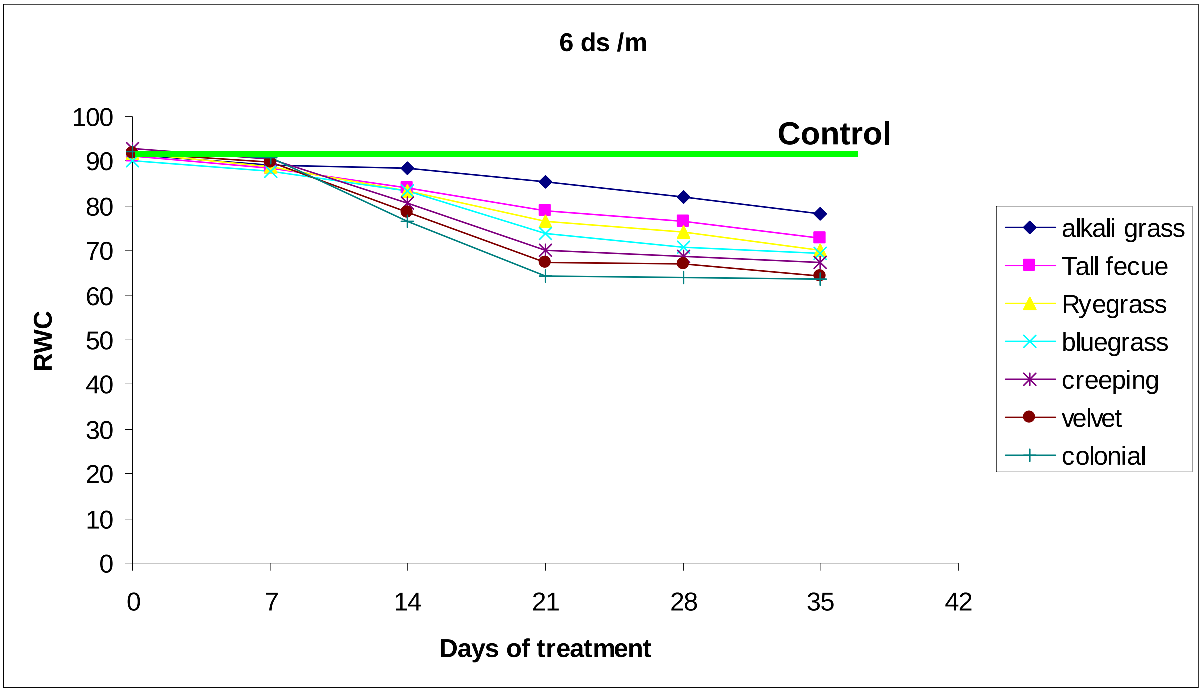


Fig. 8. Turfgrass leaf relative water content under salt stress (6 ds/m).

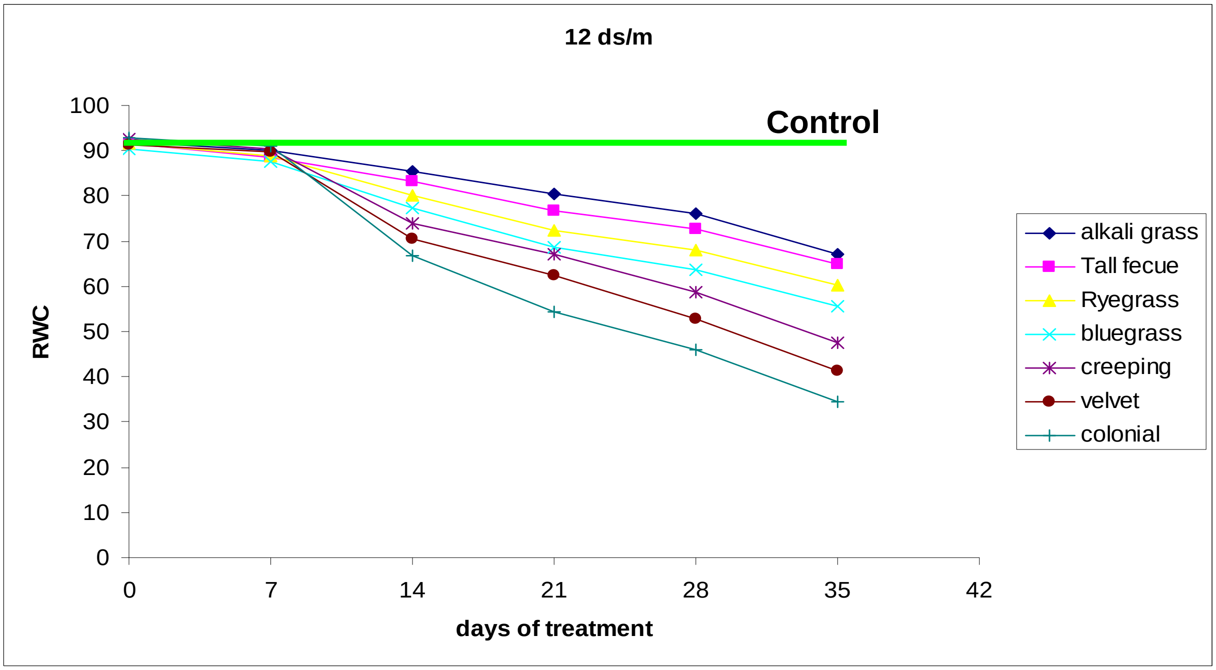


Fig. 9. Turfgrass leaf relative water content under salt stress (12 ds/m).

The results of this initial screening of various turfgrass species illustrated that under salt stress, turfgrass quality is directly related to the amount of electrolyte leakage in a given plant species, and that these properties are inversely related to the relative water content in the plant's leaves. ***Alkali grass*** and ***Tall fescue*** appear to be the species most able to tolerate the high salt conditions tested (Fig. 10). However, all species were susceptible to salt stress over time, and so irrigation BMPs that reduce potential salt stress under field conditions need to be developed.

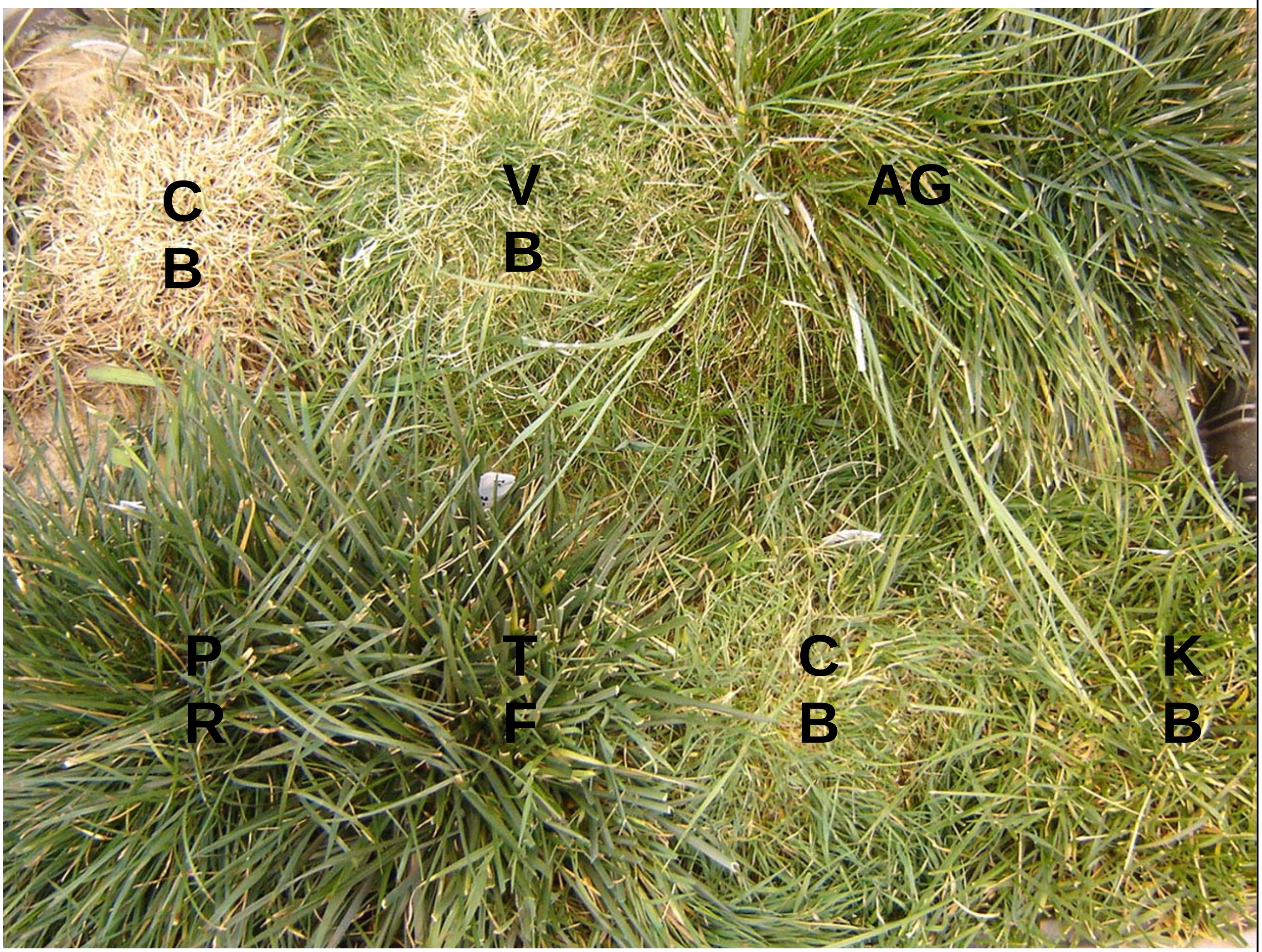


Fig. 10. Greenhouse experimental plants exposed to 12 ds/m salt concentrations. Grass species key: CB = *Colonial bentgrass*; VB = *Velvet bentgrass*; AG = *Alkali grass*; PR = *Perennial ryegrass*; TF = *Tall fescue*; CB = *Creeping bentgrass*; KB = *Kentucky bluegrass*.

Greenhouse experiments tested the effect of the actual 'grey water' recovered from Meadowlands' leachate in the laboratory on ***Creeping bentgrass***, a species that was sensitive to salt stress. After one month of irrigation with this water source, the grass was surviving well, although we did observe a slight yellowing of the leaves on some plants. This discoloration indicates that there may be a component in the distilled leachate that is contributing to 'burning' of the plant (Fig. 11).

Fig. 11. *Creeping bentgrass* grown for four weeks using 'gray water' recovered from Meadowlands' landfill leachate as the irrigation source.

Based on the greenhouse studies, the species that proved to be the most sensitive to the salts (*bentgrass*) that could be present in leachate 'grey water' were further tested under field conditions to determine their ability to withstand the climatic conditions in the Hackensack Meadowlands and irrigation with the 'grey water' recovered from the Meadowlands' leachate.

IV. YEAR TWO FIELD STUDIES

Based on the laboratory results obtained in Year 1 of the project, a field proof-of-concept study was conducted in Year 2. The field study consisted of a pilot-scale evaporation system supplied by Rosenblad Design Group, Inc. and a set of field plots that were constructed to meet typical golf course standards. Specific objectives of the Year 2 field study were to:

1) Recover leachate from the 1-E leachate collection system,
2) Evaporate the leachate on site to produce 'grey water' for irrigation,
3) Grow turfgrass species under golf course field conditions in test plots constructed on top of the 1-E landfill,
4) Compare turfgrass species and water regimes under field conditions using 'grey water' recovered from the Meadowlands' leachate as the water source,
5) Develop Best Management Practices (BMPs) for irrigation and management of a Meadowlands' golf course using 'grey water' recovered from landfill leachate, and
6) Complete a Cost/Benefit analysis of using a thermal evaporation system to treat Meadowlands' landfill leachate for beneficial re-use or discharge.

A. LEACHATE GRAY WATER RECOVERY – FIELD PILOT TEST

EVAPORATION SYSTEM

The evaporation equipment used for the field pilot study was a small-scale Falling Film Evaporator designed by Rosenblad Design Group, Inc (Fig. 12). This system was built to support field pilot projects that typically recover a condensed liquid product from industrial wastes, with steam released as a by-product of the treatment process. For our purposes of recovering the steam and converting it to usable 'grey water,' the system was reconfigured (Fig. 13) and a heat exchanger was added. As the system was configured for this experiment, it was capable of producing approximately 200 gallons of 'grey water' over an 8 hour period.

Fig. 12. Field pilot evaporation system constructed by Rosenblad Design Group, Inc.

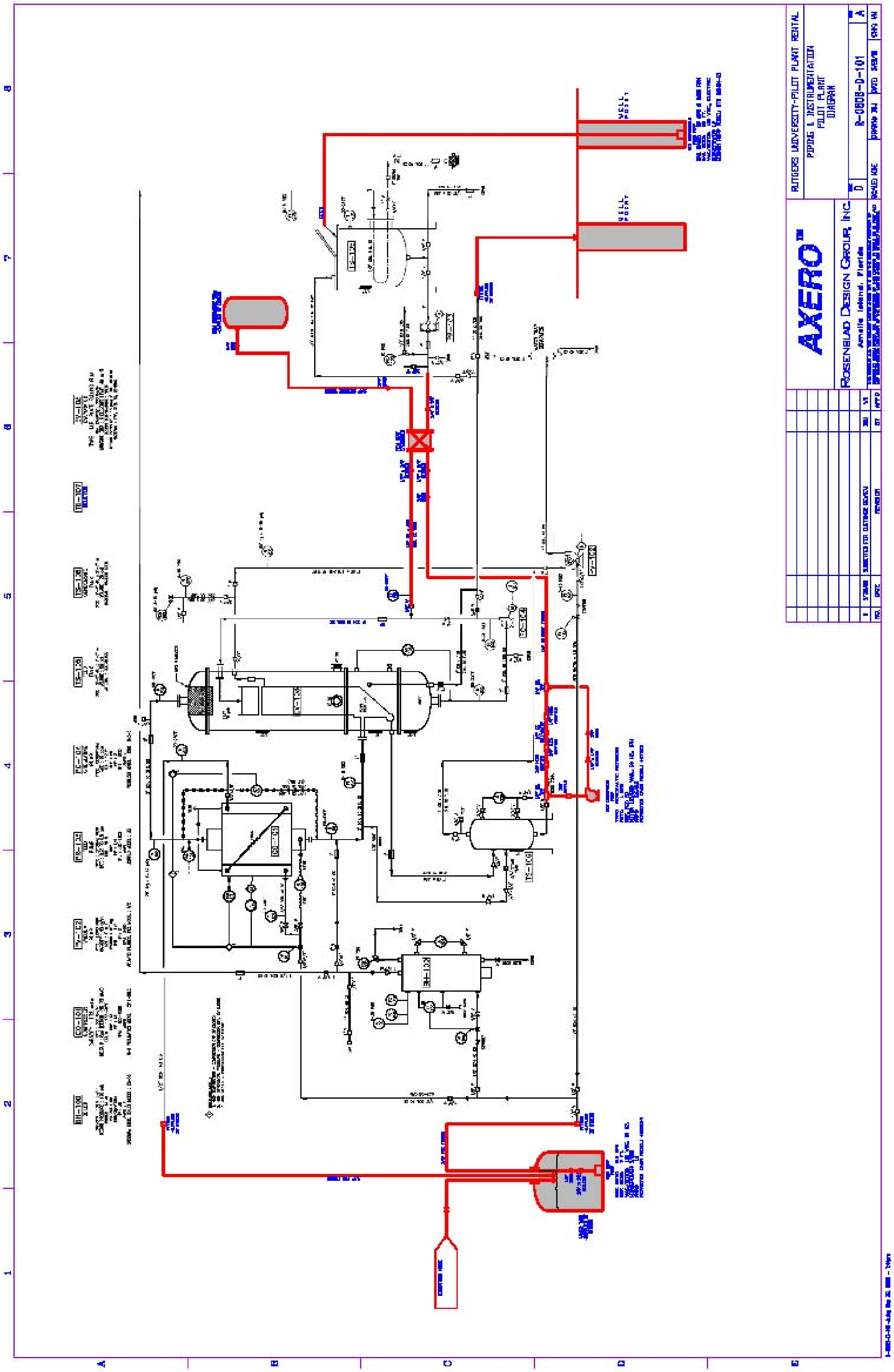


Fig. 13. Reconfigured Rosenblad Design evaporator system employed for field demonstration.

To operate the system (Fig. 14), leachate was pumped directly from the NJMC leachate wet well at the 1-E landfill into a feed tank, where it was heated to a temperature of approximately 100 degrees C. Once heated, the leachate entered the evaporation tank, where the temperature was maintained under pressure at 150 - 175 degrees F, causing the water to vaporize as steam that was then captured in the product tank where it was cooled to generate the 'grey water.' The water produced was then passed through a heat exchanger and pumped out of the evaporation system into a holding tank. The 'grey water' was then transferred to the field site at the top of the 1-E Landfill for application on the test plots.

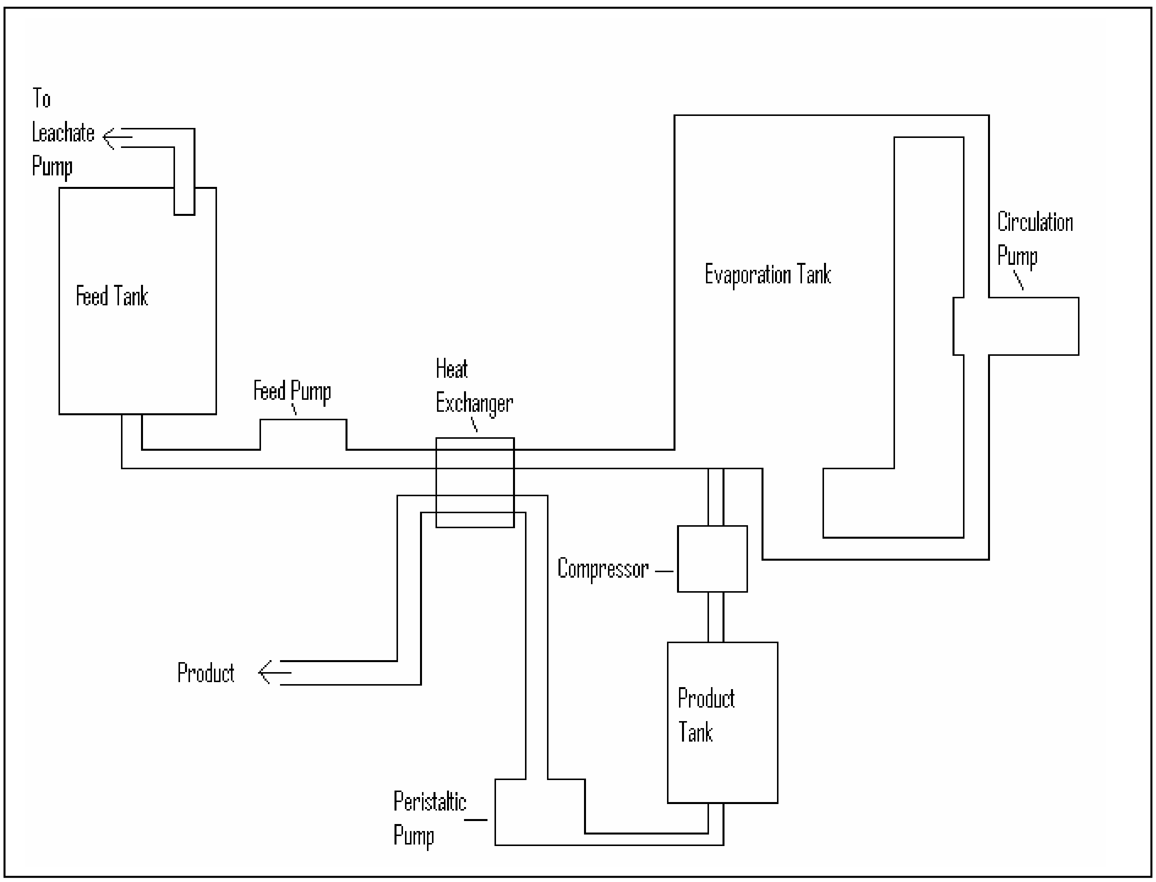


Fig. 14. Schematic diagram of the field evaporation system to recover 'grey water' from the Meadowlands leachate.

The thermal evaporation process utilized in the field study was successful in reducing heavy metal pollutants in the leachate (Table 4). We note that these pollutant concentrations differ somewhat from the benchtop studies. The leachate in the field test was collected at the 1-E leachate pumping station, rather than from the remote meter station where the benchtop samples were obtained. We also note an **increase** in the distillate fraction copper concentrations after the evaporation process, and believe this may be due to the presence of copper in the components of the evaporation unit itself.

Table 4. Field Leachate Metal concentrations (μg/L) before and after distillation.

Metal	Leachate	Distillate	Metal	Leachate	Distillate
Li	167	3.6	**Se**	25	0.5
Rb	267	3.7	**Mn**	569	6.7
Cs	1.4	<0.31	**Co**	22	0.3
Mg	66,586	2987	**Ni**	81	3.2
Sr	2053	48.8	**V**	34	1.1
Ba	696	36.3	**Cr**	99	2.7
Al	85	<31	**Cu**	**2**	**192**
Ti	65	1.9	**Zn**	100	97
Ga	43	2.0	**As**	22	0.6
Hg	1.35	.08	**Cd**	<0.10	<0.10
Fe	17,554	540	**Pb**	4.7	2.8

The ammonia concentration present in the benchtop leachate condensate was not detected in the condensate recovered from the field evaporation system. While the thermal evaporation process produced 'grey water' that could be used in this test, we note that residual organic compounds were found to be present in the recovered 'grey water.' This could be the result of the leachate foaming while in the evaporation tank, which allowed some particulate matter to enter the final condensate product. To address the foaming problem, a golf course de-foaming agent ('Defoamer' produced by Cleary Chemical, active ingredient *dimethylpolysiloxane*) was added to the leachate while it was in the holding tank prior to vaporization. This agent was effective in minimizing, although not totally eliminating, the amount of foaming that occurred during the evaporation process.

The presence of organic nitrogen and a limited number of small molecular weight organic compounds in the condensate could be the result of using the relatively unsophisticated pilot test system, rather than a system designed expressly for the treatment of Meadowlands' leachate and the recovery of steam. Should thermal evaporation technology be employed on a large-scale, we believe these issues can be resolved through the system design and controlled use of a defoaming product.

B. TURF GRASS – FIELD TESTS

TURFGRASS TEST PLOTS

Construction of both the putting green and fairway study plots utilized a sand based root zone (Fig. 15). This approach is not only typical in the normal construction of modern golf greens, it is necessary to allow for flushing of excessive salt buildup in the root zone. One potential challenge in using sand construction is its high rate of evapotranspiration (ET), the water lost through plant and soil respiration. A balance is required between a root zone composition capable of both flushing excessive salts and minimizing ET losses. To address this issue, guidelines provided by the United States Golf Association (USGA) were used in construction of the putting green area. USGA putting green construction guidelines are flexible, and can be adjusted to meet specific site needs. To address the unique conditions presented by both the environment atop a Meadowlands' landfill and the use of recovered leachate 'grey water' as an irrigation source, we constructed a green made of 90% sand and 10% sphagnum peat. Staying within USGA guidelines, we maximized the percentage of fine sands in the construction mix. Finer sands reduce the capillary pore space and help alleviate excessive ET loss. The use of sphagnum peat in the construction mix provides the beneficial effect of reducing water loss, as well as providing greater nutrient holding capacity that supports the growth and survival of the turfgrass.

The field plots consisted of a 1,023 ft^2 putting green with forty plots built to USGA-type construction, and a 2000 ft^2 sand-based capped fairway (Fig. 16). Underlying the plots was a USGA-type construction drainage system (Fig. 16d, e, f). The putting green plot was constructed with a 13 inch deep root-zone mix of 90% sand

and 10% sphagnum peat moss. The mix selected deviated slightly from the typical USGA mix because we used a slightly finer textured sand material. The fairway plot was built with 9 inches of deep Mason sand on top of 12 inches of soil. An impermeable plastic barrier that spanned the depth of each root zone separated all plots to prevent hydraulic exchange of both water and nutrients between plots. The field plot construction was completed in early summer 2008.

The leachate 'grey water' that was used to irrigate both the putting green and fairway areas was housed in 500 gallon water holding tanks adjacent to the field test plots. Water residing in a precipitation-fed lined pond located approximately 200 feet from the putting green and fairway areas was used as the irrigation fresh water control. We saw no evidence of contaminants in the pond water (Table 5). However, midway through the summer we found the pond water to have a pH of 9.0 that was damaging to the turfgrasses. This pH level was due to a high concentration of bicarbonate. The recovered 'grey water' was also alkaline with a pH of 9.0. To reduce the pH to the more desirable slightly acidic range of pH 6.5-7.0 we added citric acid to both the fresh and 'grey' waters before application to the field plots.

Table 5. Heavy Metal Concentrations (μg/L) in 1-E Freshwater Pond Sample.

Metal	Pond Water	Metal	Pond Water
Li	2	**Se**	1
Rb	14	**Mn**	159
Cs	<0.51	**Co**	<0.51
Mg	3,355	**Ni**	3
Sr	169	**V**	2
Ba	15	**Cr**	0.5
Al	<51	**Cu**	12
Ti	1	**Zn**	<51
Ga	1	**As**	4
Hg	0.11	**Cd**	1
Fe	<51	**Pb**	<0.51

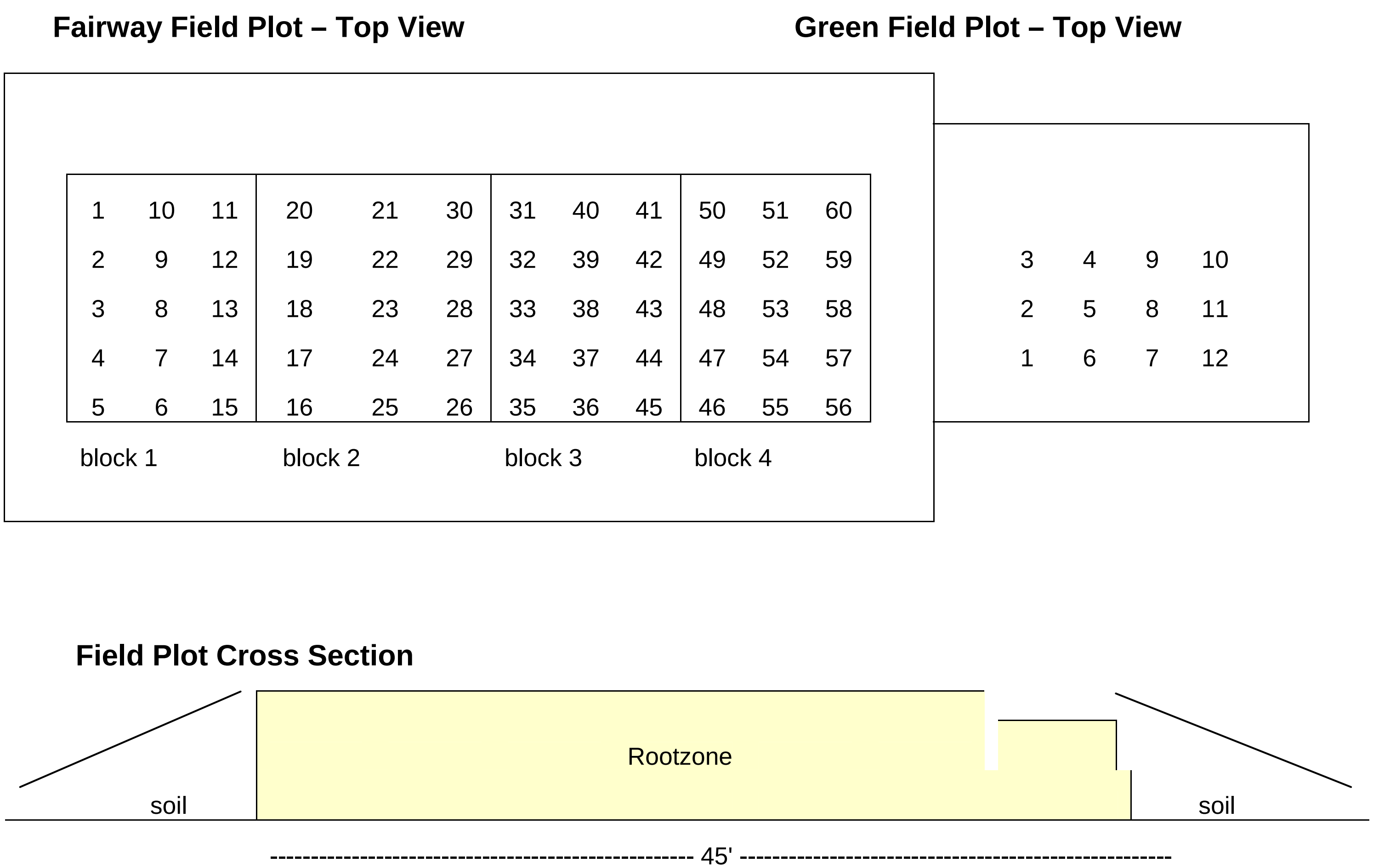


Fig. 15. Schematic top views and cross-section of field test plots.

Fig. 16 A-F. Construction of USGA-type golf course field plots atop the 1 E Landfill: a. Clearing and leveling the site; b. constructing individual field plot barriers; c. assembling sand and drainage materials; d. placement of soil and sand underlying layers; e. placement and construction of drainage system; f. subgrade soil compaction.

TURFGRASS SPECIES/CULTIVARS AND MANAGEMENT

The water volumes required for golf course irrigation using potable water are typically less than 100% of daily ET water loss replacement. However, when 'grey water' is used for irrigation, it may be necessary to replace 100% or more of the daily ET loss in order to leach out soil salt and/or avoid salt accumulation. Utilizing the field plots, different irrigation frequencies were examined to determine the optimum irrigation schedule for using the leachate 'grey water' on fairways and putting greens.

Recovered 'grey water' use was tested on two cultivars of creeping bentgrass ('L-93' and 'Penncross') under both putting green and fairway conditions. Two cultivars of perennial ryegrass that had demonstrated good salt tolerance in the laboratory studies ('Paragon GLR' and 'Applaud') were tested under different irrigation regimes on the fairway only. Both are widely used cultivars, or have the potential for increased use on putting greens or fairways in the northeastern US.

Both putting green and fairway turfgrasses were maintained according to standard golf course management practices with respect to mowing, fertility, and pesticide use. Diseases, weeds, and insects were controlled on a curative basis. The creeping bentgrass putting green was cut at 0.36 cm height and the creeping bentgrass and ryegrass fairway cutting height was 1.0 cm and 1.2 cm, respectively.

Irrigation-water treatments

Plant-needs based irrigation practices have been found to be most effective in managing turf with efficient water use. The actual ET in this highly urbanized system was measured at the Kearny Marsh surface level by Rutgers hydrologists (mean ET equaled 0.2 inches/day). ET onsite at the field plots was calculated by T. Sibicky using lysimeters. It was determined that the average daily ET at the field plots on top of the 1-E Landfill was approximately the same 0.2 inches/day, although there was a great deal of variation in the lysimeter readings. The following irrigation quantity and frequency treatments were tested to determine the best irrigation management program for maintaining quality turf on the USGA-specification putting green and sand-based fairways using recovered 'grey water' versus the fresh water irrigation control.

Irrigation quantity& frequency

Each irrigation treatment plot was 3 x 5 ft with a one-foot border alley established between plots to prevent misapplication (Fig. 16b, 17). The experimental design for both the putting green and fairway plots was a completely randomized split-plot design, with the irrigation quantity or frequency as the main plot and grass species/cultivars as sub-plots. Each treatment was replicated four times on each surface. All water treatments were delivered to the individual plots by hand watering to minimize cross contamination between plots.

Irrigation volume tested on the putting green included 100% of ET with freshwater (control), 80% of ET with 'grey water,' 100% of ET with 'grey water,' and 110% of ET with 'grey water' (with 10% leaching fraction). Each plot was hand watered daily. Fairway irrigation frequency tested 'grey water' treatments of 3 times per week, 4 times per week, and 2 times per week. These treatments were compared with the fresh water control of 3 times per week in order to determine the optimum irrigation schedule using the 'grey water.' The fairway irrigation scheduling test was carried out using 100% of ET replacement.

Fig. 17. Field test plots atop the Meadowlands 1 E landfill in September 2008.

Data collection

The physiological effects of 'grey water' irrigation on turf growth, water status, and nutrition levels were assessed at the end of the first growing season (late fall 2008). Soil samples were collected monthly using a 1.125" JMC soil coring probe (Fig. 18). Three samples were taken from each plot at each sampling interval. The samples extended to the depth of the root zone, which was 12 inches on the putting green and 9 inches on the fairway. Following extraction the cores were bagged, labeled and immediately transported back to laboratory where the roots and plant shoots were harvested for the various analyses.

Fig. 18. Collecting sample cores from the 1-E field plots October 2008.

Turf growth was evaluated by a visual turf quality rating and measurement of leaf chlorophyll content (indicator for leaf senescence), turf density, green leaf biomass, and root biomass. Effects of 'grey water' use on plant water relations were determined by measuring leaf relative water content and osmotic potential. Changes in plant nutrition were examined by quantifying the concentrations of various nutrient elements in leaf tissues (N, P, K, Mg, Ca, Fe, Cu, Mn, and Zn). Extracted samples of plant root and shoot tissues were sent for analyses to the Kansas State University Agronomy and Soil Testing Laboratory.

Turf quality was assessed weekly using a visual rating scale of 0-9 (9 being the best condition) based on color, density, and uniformity. The turf canopy was also measured weekly using a multispectral radiometer containing 16 wavelengths that measure the reflectance of the turf. This calculation was used to determine the green leaf biomass and leaf area index. The leaf chlorophyll contents were determined weekly at four locations within each plot to estimate the greenness of the turf canopy. Soil water content was measured weekly on site with a reflectometer; leaf water content and osmotic potential were measured weekly in fresh leaf samples brought back to the lab.

FIELD PLOT RESULTS

The putting green study showed significant statistical differences between the ET water loss replacement treatments. The 80% and 100% 'grey water' ET replacement yielded the best quality plots for both cultivars tested ('L93' and 'Penncross') on the putting green. The 110% 'grey water' replacement treatment level exhibited some of the best initial results during the first month and a half of treatment, but thereafter the turf quality started to slowly diminish when compared to the other water replacement treatments (Fig 19). The 110% ET plots were noticeably puffier from excessive plant growth and initial thatch buildup.

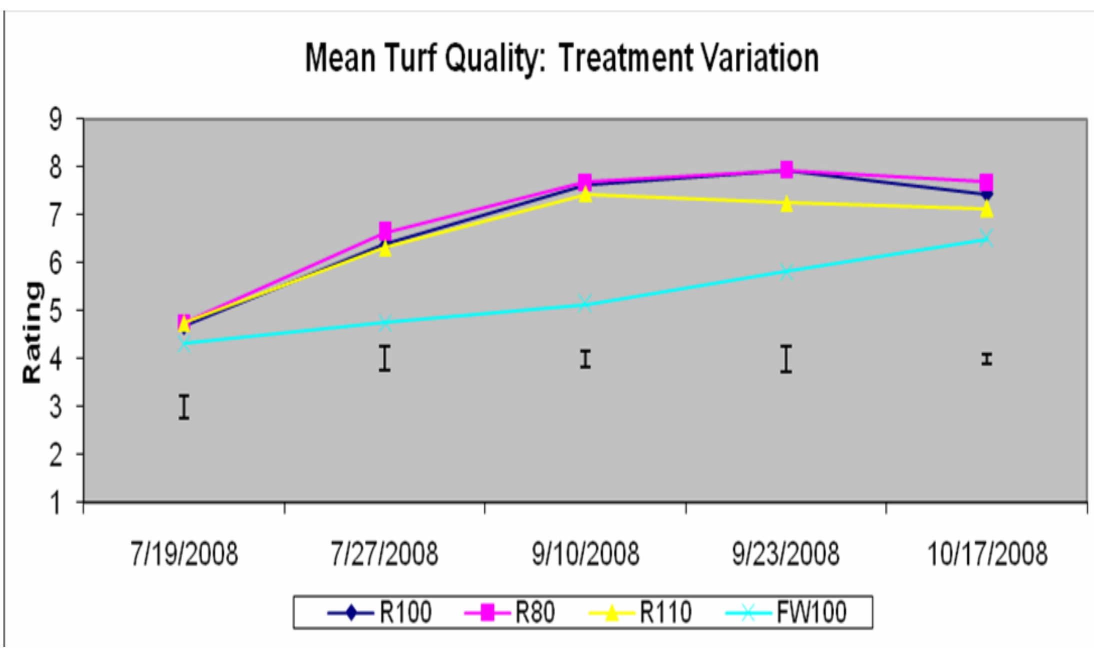


Fig. 19. Field test comparison of turf quality under three irrigation treatment regimes: 80%, 100%, and 110% of ET versus freshwater (FW) 100% ET replacement control.

The cultivar screening test yielded several high performing cultivars including '007,' 'Memorial,' 'Shark,' and 'Tyee.' The freshwater control had the lowest mean rating after the first week. All plots were initially exposed to the alkaline pH. The freshwater plots did recover, but at a much slower rate, due to the significantly lower nutrient concentrations available in their irrigation water as compared to the 'grey water.' Cultivar Comparison showed 'L93' was superior to the 'Penncross' at the beginning of the study, but as time progressed, these differences appeared to lessen (Fig. 20). 'L93' also displayed a higher green leaf biomass index and mean chlorophyll content (Figs. 21, 22).

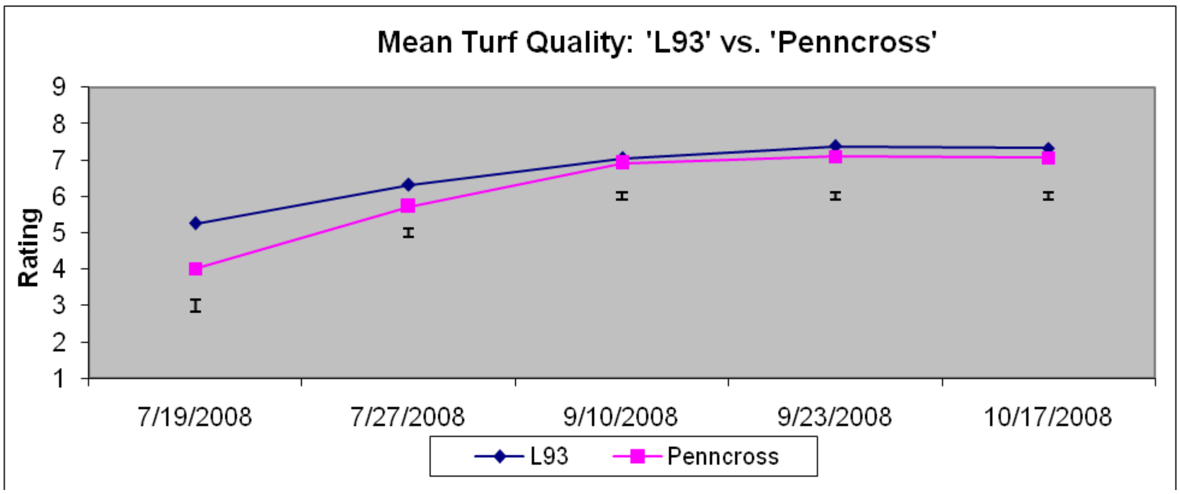


Fig. 20. Field test comparison of turf quality of two different turfgrass cultivars.

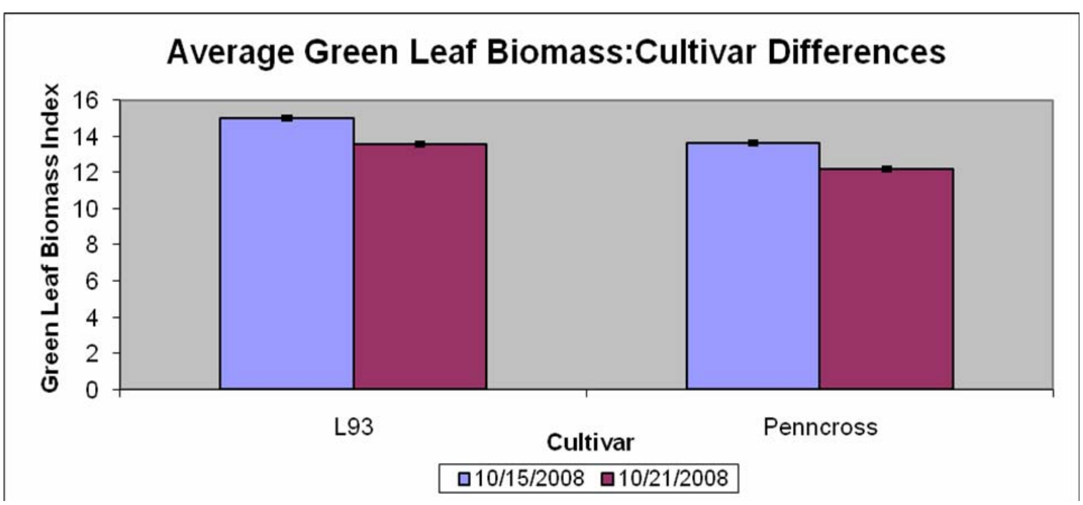


Fig. 21. Field test comparison of average green leaf biomass of two different turfgrass cultivars.

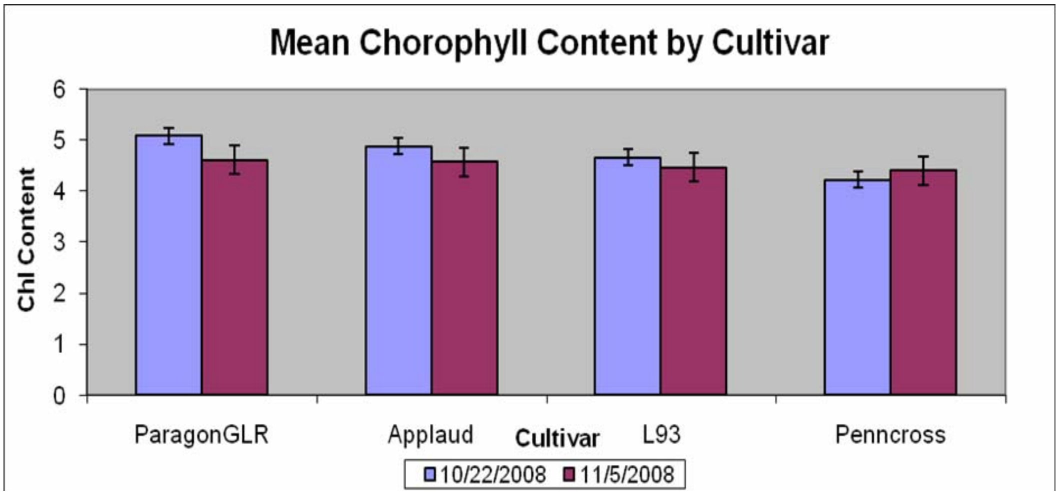


Fig. 22. Field test comparison of mean chlorophyll content of two different turfgrass cultivars.

Green leaf biomass index ratings coincided with the turf chlorophyll ratings for all the different treatment levels. As the index increased progressively from the freshwater to the 80%, 100%, and 110% 'grey water' ET replacement, the leaf biomass index level and chlorophyll content both gradually increased (Figs. 23, 24).

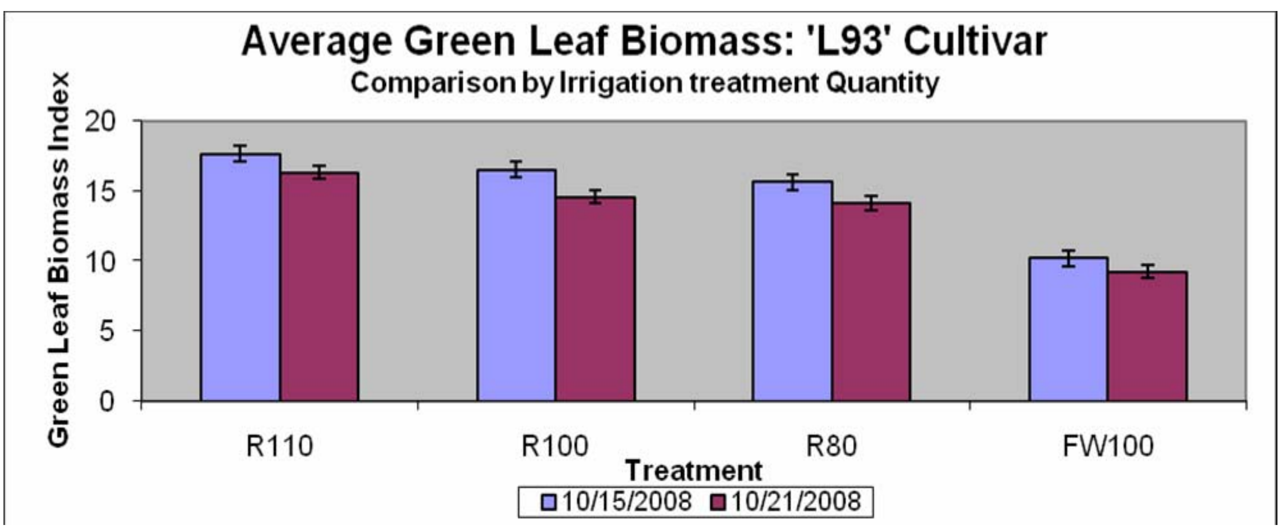


Fig. 23. Field test comparison of L93 cultivar green leaf biomass under three irrigation treatment regimes: 80%, 100%, and 110% of ET versus freshwater (FW) 100% ET replacement control.

Relative water content trend showed the highest water content among the 80% ET reclaimed and 100% ET 'grey water' treatments until the 110% ET treatment water increased in mid-November. This correlation was more obvious with the cultivar 'L93' (Fig. 25), but was also seen with 'Penncross' to a lesser extent (Fig. 26).

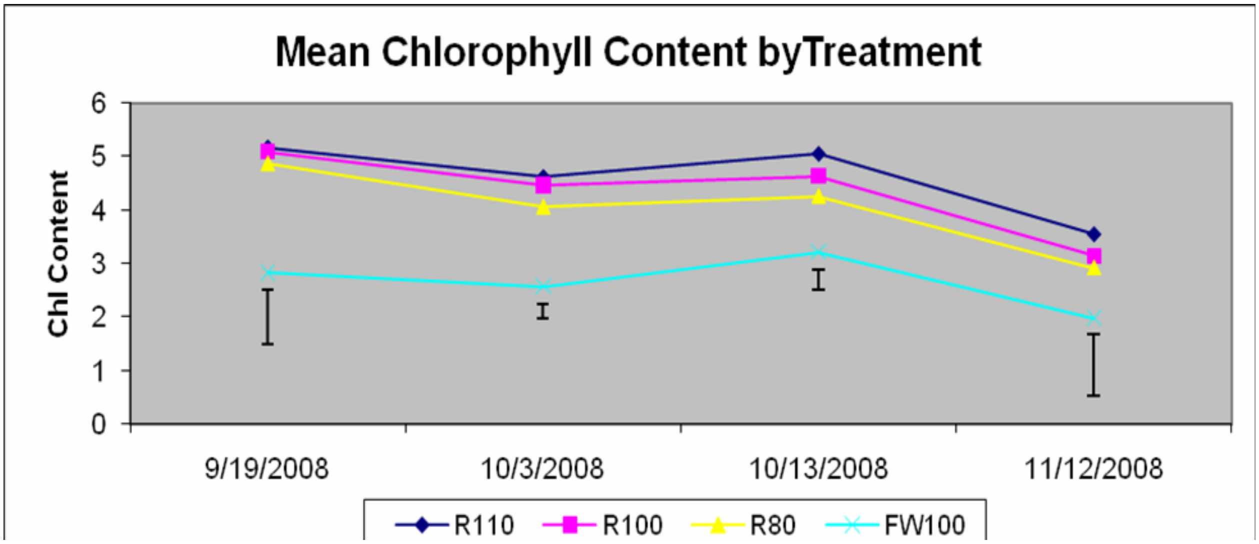


Fig. 24. Field test comparison of chlorophyll content under three irrigation treatment regimes: 80%, 100%, and 110% of ET versus freshwater (FW) 100% ET replacement control.

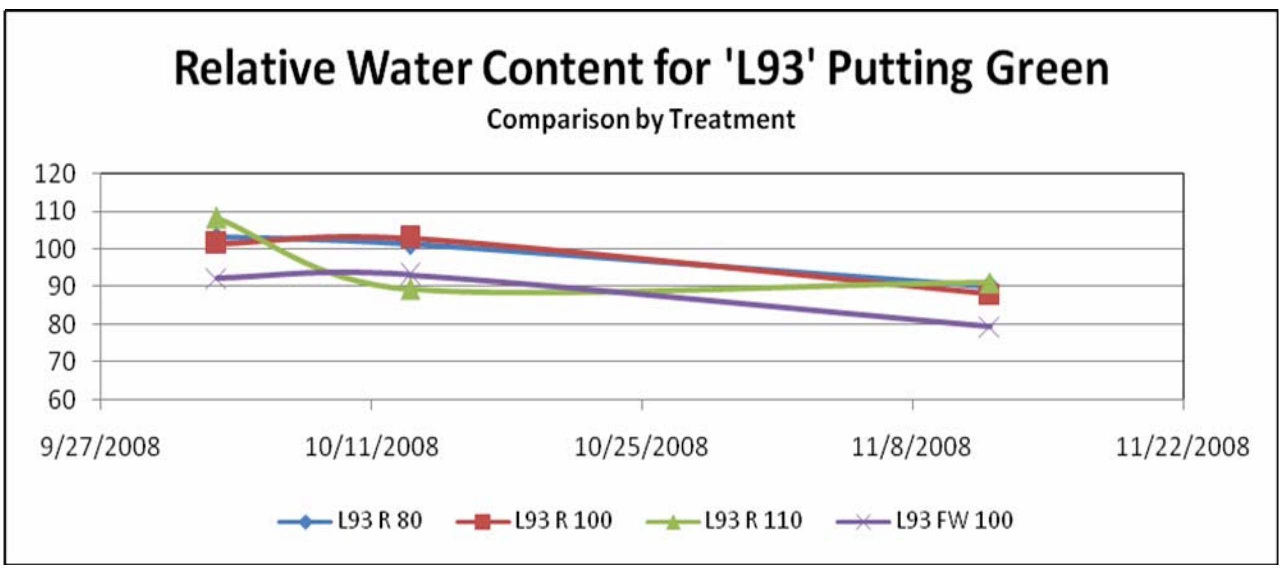


Fig. 25. Field test comparison of L93 cultivar relative water content under three irrigation treatment regimes: 80%, 100%, and 110% of ET versus freshwater (FW) 100% ET replacement control.

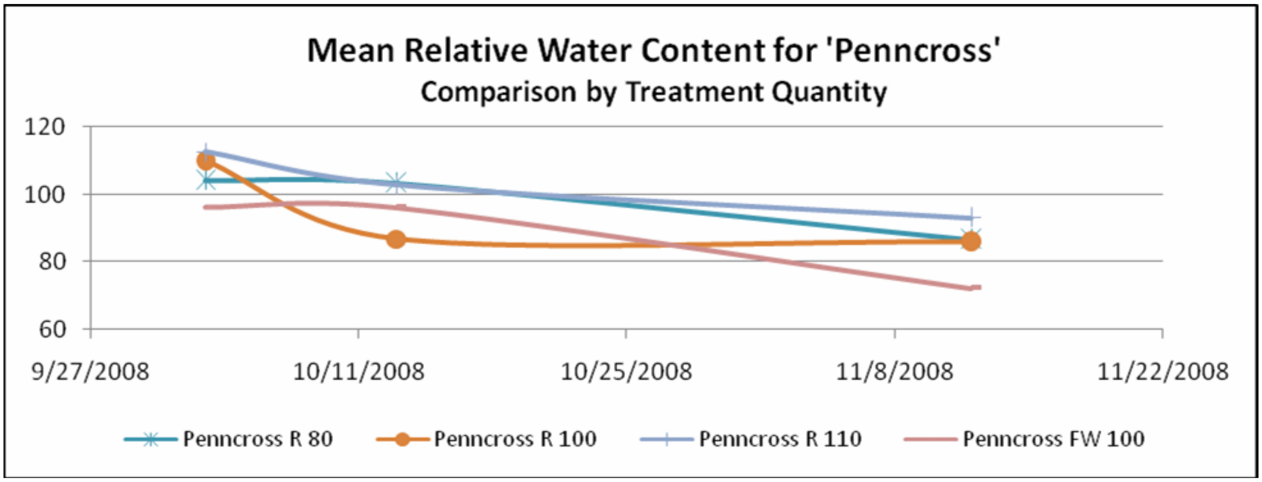


Fig. 26. Field test comparison of Penncross cultivar relative water content under three irrigation treatment regimes: 80%, 100%, and 110% of ET versus freshwater (FW) 100% ET replacement control.

Osmotic data for the putting green (Fig. 27) showed the highest adjustment rates initially occurred with the 'grey water' 100% and 110% ET replacement treatments, but from October through November, the highest adjustments indicating higher levels of associated stresses, were seen in the freshwater 100% ET and the 'grey water' 80% ET.

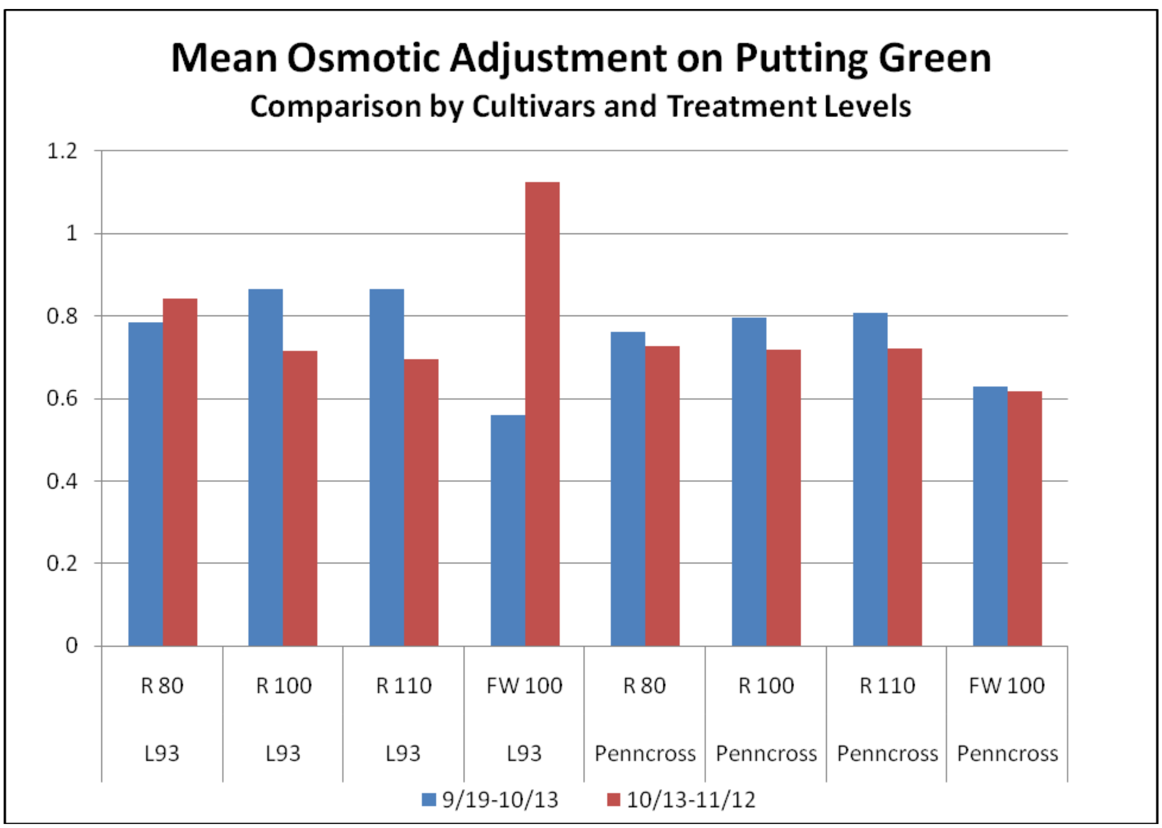


Fig. 27. Field test putting green osmotic adjustment for cultivars L93 and Penncross under three irrigation treatment regimes: 80%, 100%, and 110% of ET versus freshwater (FW) 100% ET replacement control.

Macronutrient analyses under the 100% ET replacement regime showed an increase over time in the proportion of plant tissue nitrogen under both 'grey' and fresh water treatments, but the nitrogen increase using 'grey water' replacement was twice the increase observed in the fresh water control (Fig. 28). Phosphorus analysis showed a comparable decline in the proportion of phosphorus in plant tissue under both 'grey' and fresh water treatments during the 4 month irrigation period. Percentages of plant tissue potassium increased over time, and larger increases were seen in the 'grey water' treatment plots than the fresh water controls (Fig. 29).

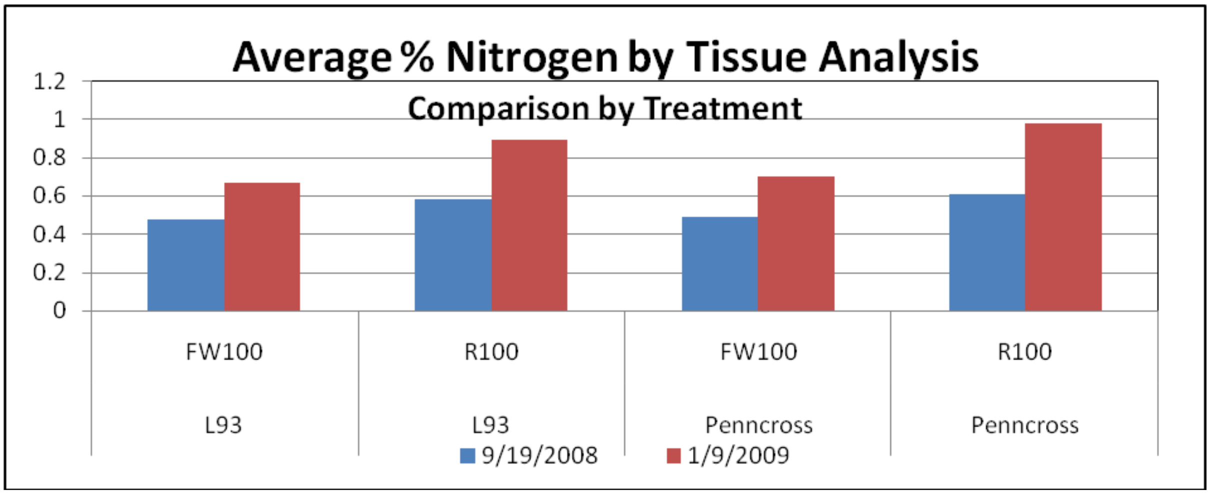


Fig. 28. Field test plant tissue nitrogen concentrations for cultivars L93 and Penncross under 100%irrigation replacement of ET with 'grey water' versus freshwater (FW) control.

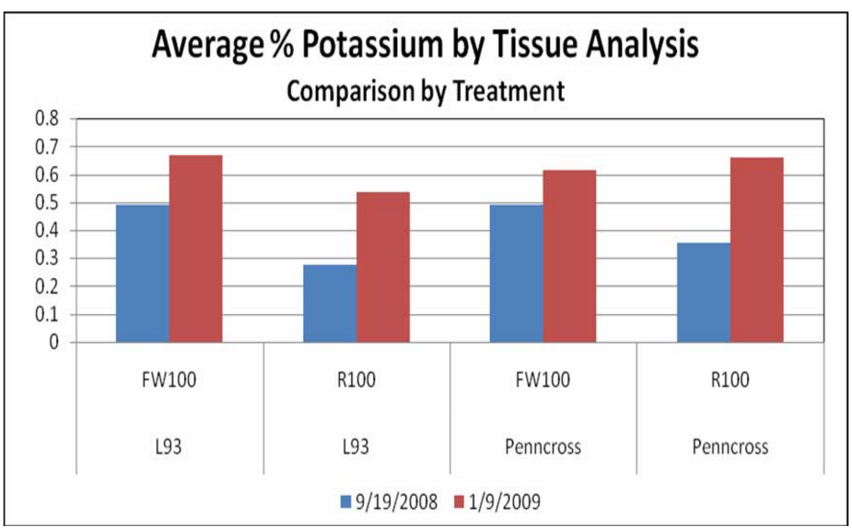
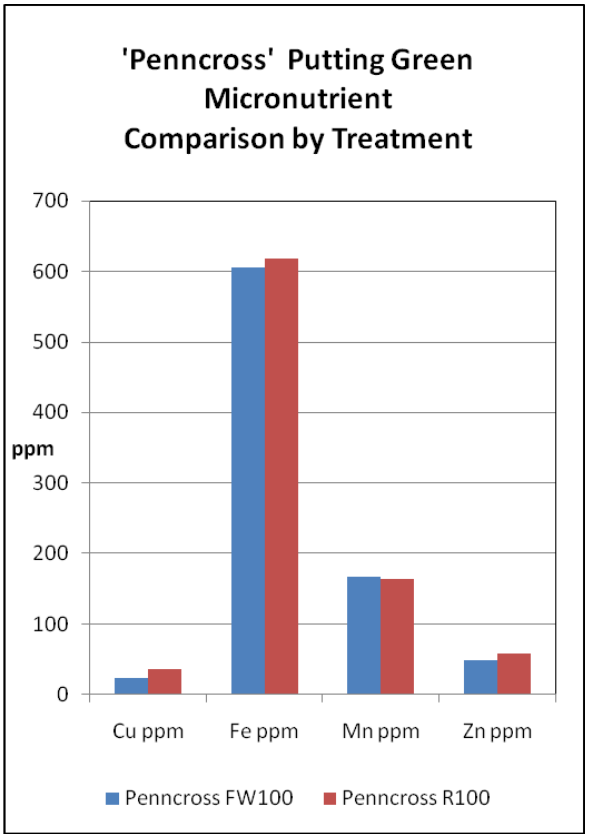


Fig. 29. Field test plant tissue potassium concentrations for cultivars L93 and Penncross under 100%irrigation replacement of ET with 'grey water' versus freshwater (FW) control.

Micronutrient analyses (Fig. 30) showed a high iron concentration in the ‘L93’ and ‘Penncross’ cultivars for both the ‘grey water’ and freshwater control plots. Copper, manganese, and zinc all fell within acceptable concentration ranges under both treatment regimes for both cultivars.



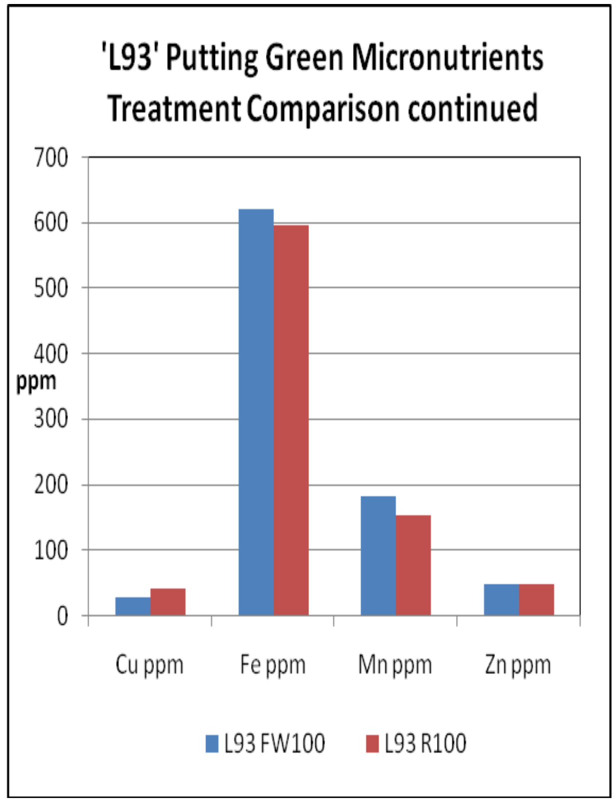


Fig. 30. Field test plant tissue micronutrient concentrations for cultivars L93 and Penncross under 100%irrigation replacement of ET with ‘grey water’ versus freshwater (FW) control.

The fairway plots collectively exhibited fewer differences between cultivars and the treatment regimes. We believe this was due to the delayed start of treatment when the fairway had to be reseeded after a major storm event in the summer of 2008. Few visual turfgrass differences were noted in the fairway plots, and these were not deemed to be statistically significant. Loss of water production from the evaporation system due to a broken compressor in October, 2008 created lapses in the application of the interval water treatments. While the equipment was out of service, treatments were administered using the freshwater source only at each plot's designated watering frequency interval.

TURFGRASS BEST MANAGEMENT PRACTICES (BMPS)

To determine the optimum water use Best Management Practices (BMPs), plants in the field plots were irrigated using as our water sources leachate 'grey water' and fresh water from the pond (control). Daily water demand was estimated using the rates of evapotranspiration obtained from the Rutgers Kearny Marsh hydrology study and from direct measurement taken in the constructed field plots. As evidenced by this research, 'grey water' recovered from landfill leachate has the potential to serve as an irrigation source for golf course putting greens, tees, fairways and roughs. Through careful selection and management of quality cultivars, irrigation practices, nutrient availability and sound cultural practices, it may be possible to control any negative effects that accompany the use of this water source.

Cultivar Selection

Recommendations for cultivar selection are dependent on an array of factors that include, but are not limited to, overall turf quality, color, leaf texture, density, mowing height, establishment, disease resistance, salt tolerance and price. The National Turfgrass Evaluation Program (NTEP) is an organization that provides reliable data on current and new turfgrass varieties from all regions across the United States. Resources provided by this organization can aid in the selection of the best commercially available cultivars on the market today.

Our study indicated that there were some cultivars that perform well under recovered 'grey water' conditions, while the performance of others was not as good. Based on the field experiments, the recommended creeping bentgrass (*Agrostis stolonifera*) cultivar tested in this study would be the variety 'L93' versus the variety 'Penncross' because 'L93' outperformed in nearly every test at all treatment levels. Of the additional seven creeping bentgrass cultivars tested, '007', 'Declaration', 'Shark', 'KingPin', 'Memorial', 'HTM', 'Tyee' and 'Legendary', a velvet bentgrass (*Agrostis* *canina*) cultivar, the recommended top three would be the '007', 'Memorial' and 'Tyee'. We strongly recommend against the selection of velvet bentgrass due to the growth habit of this species as a thatch builder.

In the limited time-frame fairway study, the same two bentgrass species, 'L93' and 'Penncross' were again the best performers in addition to the two perennial ryegrass (*Lolium perenne*) cultivars 'Paragon GLR' and 'Applaud.' However, a longer testing time is needed before a fairway recommendation can be confidently made. After the short fairway test, a very general recommendation can be made to use the creeping bentgrass species rather than the perennial ryegrass, due to their ability to recover more quickly under drought conditions and the fact that they provide a denser, more uniform playing surface for the golfer.

Although native grasses suitable for rough areas of a golf course were not part of this experimental design, there are species that have been tested in Dr. B. Huang's lab that have performed well with a high salt regime. We suggest the consideration of alkali grass and sheep fescue (*Festuca ovina*) for use in lower maintenance rough areas.

Irrigation practices

During the August-November 2008 experiments on the putting green plots, 80%, 100%, 110% 'grey water' ET replacement treatments were compared to a 100% ET replacement freshwater treatment. We found that the 80% and 100% ET replacement 'grey water' treatments yielded the best turfgrass quality. Based on these results, it would be our recommendation to replace 80% of the calculated ET because the lower water volume will provide a slightly firmer, more consistent playing surface for golfers. The irrigation schedule for the putting green is daily ET replacement. ***We note that this study did not address the possibility of long-term salt build up from the 'grey water' that could require additional water to flush out soil salt buildup.*** Longer-term field studies using recovered 'grey water' are needed to determine whether there might be a future need for greater water usage to protect against salt build up.

Working with the Water Source

We note that while the leachate analyses conducted at different time periods were similar, they were certainly not homogeneous. Fertility management is critical in monitoring turfgrass plant health and it is important that the recovered leachate 'grey water' be frequently tested to quantify nutrient levels and possible toxins, at least on a weekly or bi-weekly basis. Frequent testing would also provide information on fluctuations during rainy and dry periods throughout the year so that management programs can be modified accordingly. The golf course superintendent or manager is able to use this information and combine it with soil testing data to formulate a balanced nutrition program that makes up for any nutrient deficiencies by the addition of a foliar or granular fertilizer application. Preliminary testing of the recovered leachate 'grey water' used in this study indicated very high levels of organic nitrogen in the water, such that each time an irrigation application was made to replace a 0.1 inch of ET loss, the equivalent of 0.33 lbs of nitrogen per 1,000 ft^2 was applied. This is high given the industry recommendation that putting greens be maintained at 2-3 lbs. of nitrogen per 1,000 ft^2 per year. Even though 'grey water' nitrogen is more than sufficient to meet the plant needs, additional phosphorus, potassium and micronutrients may be needed to supplement the fertility of the 'grey water.' When making regular preventative pesticide applications, a foliar fertilizer like 'TKO Phosphite 0-29-26' produced by Growth Products, Inc. can be added to provide a readily available source of phosphorus and potassium. Incomplete fertilizers may be a very important part of a management program; they allow the manager to apply only what the plant growth requirements are at any given time.

In addition to testing irrigation water for nutrients, heavy metals, and other contaminants, it is also very important to have the pH tested regularly. As pH increases or decreases the levels of available essential elements for plant growth fluctuate, which can cause deficiencies or toxicities to the plant. Without the addition of citric acid to lower their naturally occurring pH, the two irrigation water sources in this study had a pH of approximately 9.0, which initially caused a large reduction in both root and shoot growth, as well as other visible plant deficiencies. Lowering the pH allowed the turfgrass to recovery quickly. If a golf course was to use the tested 'grey water' source, it would be imperative to have an acid injection system to reduce the pH to the desirable range of slightly acidic (6.5-7.0).

Pesticide management and Growth Regulation

A standard recommendation is for pesticides to be applied preventatively on a weekly basis throughout the growing season. If high concentrations of organic nitrogen are applied through the irrigation source, plant growth rates will increase, therefore diluting the pesticide through the rapid expansion of cell tissue. As the plants grow taller the pesticide would be removed at an increased rate due to mowing and collection of the clippings. Removal of clippings on tees, greens and fairways would reduce the amount of plant matter that would otherwise aid in creating an excessive thatch layer.

To reduce the rate of plant growth, a plant growth regulator such as 'Primo Maxx' (*Trimexapec ethyl*) would be applied weekly or biweekly throughout the growing season. This growth regulator is labeled as a Type 1 inhibitor that blocks the pathway for giberellic acid synthesis, which is required for plant cell elongation. The plant responds to this treatment by growing more slowly and having a denser, darker, more consistent canopy, along with prostrate growth. Establishing a sound plant growth regulator program would be essential for having consistent plant growth.

Cultural Practices

Cultural practices play an important role in the reduction of thatch, compaction, shoot density and overall quality of playing conditions. Maintaining a limited thatch and mat layer, or layer of decaying plant tissue mixed with soil of approximately 0.25 inches, will provide improved wear tolerance and reduced soil compaction. However, when a thatch layer greater than 0.25 inches is retained, there will be a higher susceptibility to localized dry spots, reduced infiltration, insect damage, disease damage, and reduced pesticide efficacy. Aggressive cultural practices involving topdressing, verticutting, rolling, and core cultivation will need to be incorporated into the management regime to maintain a healthy turfgrass cover.

Topdressing greens lightly with sand each week throughout the growing season with a light and frequent application is one of the most effective and least invasive ways to aid in the reduction and dilution of thatch. The material used should be of a composition, texture and consistency that is comparable with the underlying root zone material mix.

Verticutting is another very important way to reduce thatch. By establishing a program that uses light and frequent vertical cutting every other week, a reduction in overall plant density will be achieved. By removing the excess plant material, there will be less plant biomass that ends up in the thatch and mat layers, producing a firmer and more consistent playing surface.

Rolling is another cultural practice that can aid in the improvement of the surface playability. Research has proven that light weight rolling on greens up to three times per week can be done without seeing any soil compaction problems.

Core Cultivation is by far one of the most invasive, but essential practices that is required by all golf courses to sustain a good turfgrass health and a quality level of playing conditions. It serves to reduce compaction, remove thatch, improve infiltration, and increase oxygen supply to the roots. The use of 'grey water' and the projected excessive growth associated with this water source may necessitate cultivation two or three times annually to keep the system healthy. Our recommendation is to cultivate in early April and again in middle October in order to avoid the critical times for weed seed germination of *Poa annua* and others. Depending upon the summer status, cultivation in early August might also be necessary. The nutrients in the 'grey water' will speed up recovery after cultivation and fill in the aeration holes at a much faster rate, which may help to reduce golfer complaints.

V. ENGINEERING & COST BENEFIT ANALYSIS

This study has demonstrated that the potential exists to recover 'grey water' from landfill leachate that could be a useable golf course irrigation source. If an evaporation treatment process were found to be cost effective, it might be worthwhile to utilize evaporation as a method of leachate treatment, rather than sending the leachate to a wastewater treatment plant. The largest cost would come from the physical treatment of the leachate, which would need to achieve a regulatory standard applicable to surface water discharge, public space irrigation, and public exposure. The treatment facility itself, the 'grey water' distribution infrastructure, and the energy source to power the actual recovery process would require the greatest investments, followed by the sustained costs of operation and plant maintenance. We have consulted with our project engineering and electrical partners to try to determine the financial feasibility of a leachate 'grey water' recovery process. To quantify expenses associated with an evaporation treatment process for Meadowlands' leachate, we have considered the data obtained in this field study, typical northeastern US golf course irrigation needs and practices, engineering data supplied by Rosenblad Design Group, Inc. and Cates Electric, energy sources and leachate volumes as defined by the NJMC staff.

The water utilization requirements of a golf course depend on the rate of ET, which is temperature and humidity dependent. Peak water demand occurs during the hottest summer months. The Meadowlands' leachate evaporation system would need to be capable of supplying the amounts of water required during the highest demand time period, as well as production of additional water as a buffer against drought conditions. A simple water demand calculation for a Meadowlands' golf course can be performed based on the typical summer weather conditions in Northeastern New Jersey.

For this calculation, we are assuming that 'grey water' produced by the evaporation process will supply all the irrigation water volume required (Table 6) for a 'typical' northeastern golf course acreage using normal watering practices (J. Snow, *personal communication*). This assumption supposes a golf course of approximately 120 acres, with specific turf distribution, watering practices, and irrigation ET replacement water volume required for each turf type. ***We note that based on the BMP recommendations (80% ET water loss replacement) the water requirement of 90 - 100% ET replacement is conservative. We are taking this more conservative approach in the calculation because we have <u>only one season's worth of field data</u>, and do not know if higher water volume would be required over a longer time period to flush out any salt build up in the soil.***

Conditions assumed in the water needs analysis include:

1. Average ET of 0.20″ per day,
2. Maximum ET of 0.25″ per day,
3. Maximum ET duration of 14 days, and
4. Replenishment period of 4 days of average ET.

Table 6. Average Northeastern Golf Course Turf Acreage & ET Water Loss Replacement.

Golf Course Turf	Area (acres)	ET Replenishment (%)
Fairway	35	90
Irrigated Rough	19	100
Green	3	80
Tee	3	90
Non-Irrigated Rough	60	0
Total	120	

The following formula was used to calculate the amount of water required for each golf course area:

$$I = \frac{A_t(acre)}{} * \frac{43560(ft^2)}{(acre)} * \frac{ET(inch)}{(day)} * \frac{(ft)}{12(inch)} * \frac{(gal)}{7.48(ft^3)} * \frac{R}{100} \qquad \text{Formula 1.}$$

Where:

I = Irrigation water required (gal day^{-1})

A_t = Area of turf (acres)

ET = Evapotranspiration (inch day^{-1})

R = ET Replenishment (%)

The daily water volumes required under average and maximum high summer demand ET conditions are summarized in Table 7.

Table 7. Northeastern Golf Course Water Volume Requirements.

Golf course	Irrigation Water (gal/day) (Normal ET)	Irrigation Water (gal/day) (Maximum ET)
Fairway	171,060	256,590
Irrigated Rough	103,179	154,768
Green	13,033	19,549
Tee	14,662	21,993
Non-Irrigated Rough	0	0
Total	301,935	452,902

Based on the projected water demand, we determined that the best approach was to design a leachate water treatment system that was capable of treating a volume of 500,000 gal day^{-1} to be discharged as treated 'grey water', and building in the option of diverting some or all of the water produced as needed during the months when a golf course requires irrigation (i.e., combine leachate water treatment and irrigation 'grey water' potential into one system).

The proposed system (Fig. 31) would include a leachate storage equalization tank, a commercial grade evaporator, connectors to the discharge water body or wetland, and a pumping system to move recovered 'grey water' up to the top of the landfill to a central irrigation station located adjacent to the golf course. Included in the golf course irrigation system design would be additional storage tanks for 'grey water' to be used during periods of low precipitation, as well as 'water hazards' placed at each hole to provide additional water during drought periods. The 'grey water' storage tanks would have two purposes; the primary tanks would store enough 'grey water' to irrigate the golf course during times of average ET (0.20" per day). A set of secondary tanks would store enough 'grey water' to supplement the evaporator daily irrigation production during times of max ET (0.25") over a prolonged period of 7 days. The evaporator would be capable of refilling the primary tanks in a single day along with enough extra gray water to refill the secondary tanks over a period of 3 days if they are exhausted.

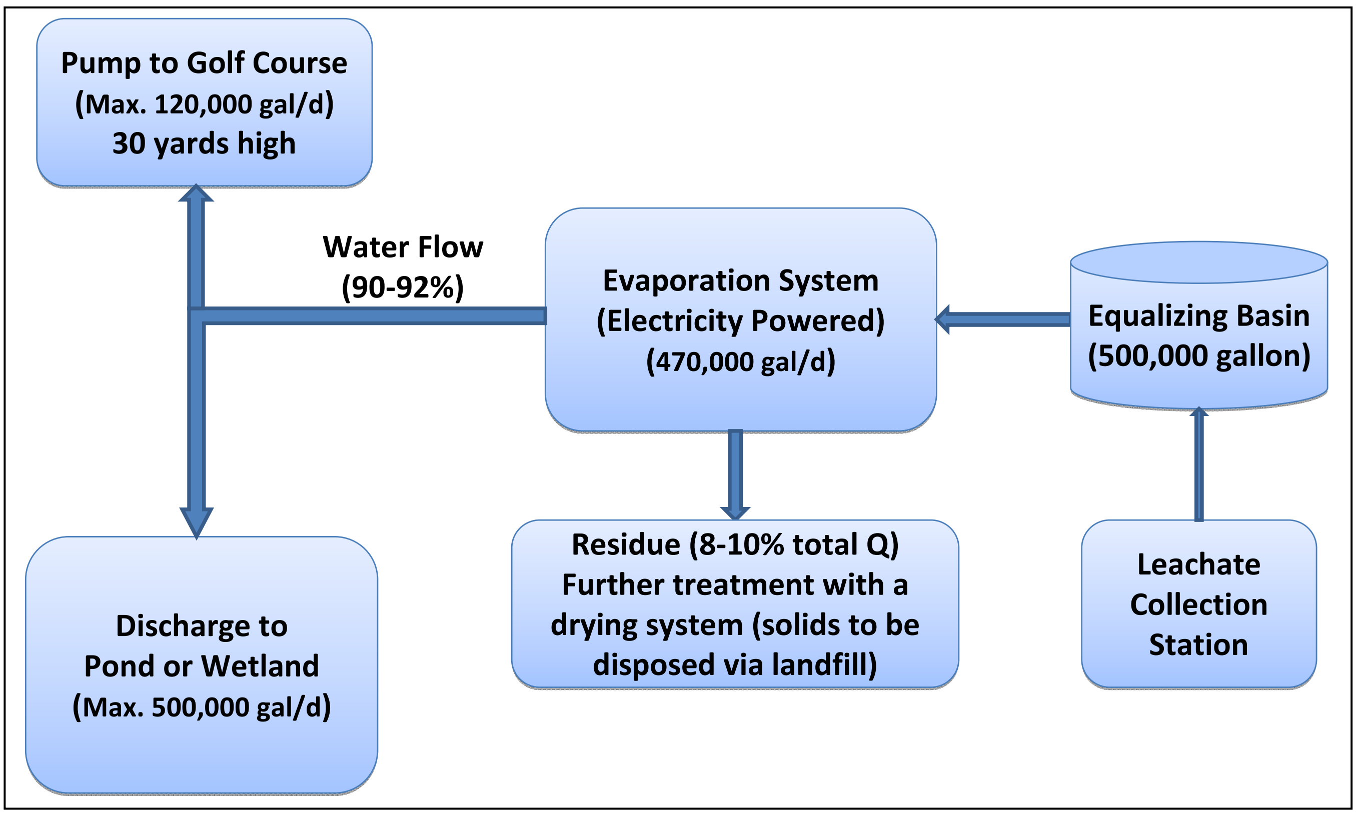


Fig. 31. Schematic representation of an evaporation system to treat Meadowlands' leachate and recover usable 'grey water' for irrigation.

To solve for the evaporator production requirement and the size of the secondary storage tanks the following two equations were used.

$Q_2 t_2 = V + Q t_2$ Formula 2.

Where:

$Q t_1 = V + Q_1 t_1$

Q = Required Evaporator production (gal day^{-1})

Q_1 = Gray water required to irrigate during average ET (gal day^{-1})

Q_2 = Gray water required to irrigate during max ET (gal day^{-1})

V = Volume of secondary storage tank (gal)

t_1 = Time of average ET irrigation and secondary tank replenishment (days)

t_2 = Time of max ET irrigation and secondary tank use (days)

Having two equations and two unknowns (V and Q) it is possible to solve for them though substitution yielding:

$$Q = \frac{t_2 Q_2 + t_1 Q_1}{t_1 + t_2}$$ Formula 3.

And

$$V = t_2 \left[Q_2 - \frac{t_2 Q_2 + t_1 Q_1}{t_1 + t_2} \right]$$ Formula 4.

Plugging in the values and solving for Q and V yields:

Q = 419,353 gal day^{-1}

V = 469,676 gal

Evaporation System Design

Three major factors constrain the design of an evaporation system. These factors include the average flow rate of the leachate to be treated, the energy source for powering the evaporation system, and the chemistry of the leachate to be treated. The volume of leachate will vary based on the amount of precipitation. According to data supplied by the NJMC the flow rate of the Meadowlands' leachate varies from about 250,000 gallons per day to over 500,000 gallons per day, with the lighter flows occurring during dry summer months. We selected a maximum flow rate of 500,000 gallons per day by assuming that an equalizer tank could be placed on site above ground, and that leachate would be pumped into the tank from the NJMC leachate collection system.

Tanks that are available for holding leachate (Fig. 32) can be obtained through http://www.liquidtanks.com/wastewater.htm. The cost of a 500,000 gal main tank, including deck and roof, set inside a second open tank (to prevent leakage of leachate into the environment in the event of a main tank failure) is approximately $328,000. This cost includes materials, protective coverings, freight, and installation. The cost does not include fittings and prevailing wage rates. It is probable that pilings and/or a concrete pad would be required to support the weight of the filled equalizer tank, and so without knowing these costs, it is only possible to approximate the full cost of the equalizer tank construction and installation.-+

Fig. 32. Examples of above ground wastewater tanks as shown on the Liquidtanks.coom web site. This company provides tanks for leachate storage.

The second factor is the energy source for powering the evaporator. One option might be to use the methane purified from the landfill gas. However, gas produced by the landfill contains other compounds besides methane, and gas production from the landfill will decrease over time when the landfill organic matter has decomposed and stabilized. At this time, natural gas-powered evaporation is not cost effective because the capital costs of such a system would be higher than the capital costs of an electricity-powered system. This is because if the gas is used directly in a gas turbine, the turbine would be too small to be either efficient (energy efficiency is about 24%) or clean burning (i.e., would not meet NJ exhaust gas discharge standards). A natural gas powered evaporator would require a gas fired boiler, a cooling tower and interconnecting piping, which all add to the total capital costs. Therefore, we believe the use of natural gas mined from the landfill or purchased from the open market is not a good choice for powering a Meadowlands' leachate evaporation system. For these reasons, a more cost effective alternative is to use electricity as the power source for the evaporation system. There also exists the possibility that solar cells will be installed at the 1-E Landfill to generate electricity, making electricity a better energy source. As a result, our design and costs are based on the assumption that electricity would be used as the power source for the evaporation process.

The chemistry of the landfill leachate determines what type of materials (alloys) the evaporator should be constructed with, because the leachate chemistry determines the corrosivity and therefore the selection of corrosion resistant alloys for building the evaporator. Based on our chemical analysis, the landfill leachate contains 2,000-4,000 mg/L of total dissolved solids. Therefore, we are assuming that titanium is not required for construction of the evaporator system and that all evaporator parts in contact with the leachate can be fabricated from 2205 duplex stainless steel.

The evaporator system as described above would be capable of treating approximately 171,550,000 gallons of leachate annually, resulting in the production of approximately 154,395,000 gallons 'grey water' plus 17,155,000 gallons of residual waste (estimated at 10% of total volume treated) annually. To further reduce the volume of the residual waste, Rosenblad is recommending the addition of a small dedicated section in the main evaporator body and a small concentrator, possibly utilizing a gas-fired drum dryer. Rosenblad believes that this is a minor addition, but requires more time to work out the schematic details and the incremental cost.

Process Design and Capital Costs

The Rosenblad vapor compression evaporator design is based on single stage high pressure fans as supplied by FläktWoods. The maximum rise in saturation temperature produced from a single stage fan is 10 degrees C with a specific power consumption of 11 KW hours per one thousand pounds evaporated. For the current project we are using a Δ T of 10 degrees F for a power consumption of 6 KW Hours per 1000 lbs.

The nominal evaporation capacity of the proposed system is 150,000 lbs per hour of water evaporated. This corresponds to **431,000 gallons per day**. The turn down can be up to 40% or 170,000 gallons per day. The power consumption will be near linear with the evaporation rate, with less than 1000 KW used for the compressor and pumps at the design capacity.

The engineers from Rosenblad Design Group, Inc. based in Amelia Island, Florida, provided specifications for an evaporator system capable of meeting the following criteria:

1. Feeding leachate at 160,000 lbs/hr @ 88 Deg F and 0.5% TDS
2. Production of grey water at 10,000 lbs/hr @ 100 Deg F and insignificant TDS
3. Maximum evaporation rate of 150,000 lbs/hr
4. Compressor Power 900 KW
5. Pump Power 60 KW
6. Vacuum Pump 10 KW

The Rosenblad price quotation for purchase, delivery, and installation of such a system is US $3,200,000 plus or minus 10%. This cost includes systems and components as follows (does not include the additional equipment to reduce the residual volume):

1. Evaporator body complete with about 34,000 square feet of heating surface
2. Compressor, Driver and Motor Control Center
3. Feed heaters for cooling concentrate, condensate, and vent gases

4. Interconnecting vapor ducting & Piping
5. Pumps and Motors
6. Platforms and Access Ladders
7. One set of instrumentation and controls
8. Operator training and operating manuals
9. Terminal points to be feed inlet, cooled condensate outlet, concentrate outlet, and vent outlet.

The system as configured is a representative compromise between capital and operating costs. The power consumption provides the necessary temperature differentials for the feed heaters, which dictate the operating costs. Less heating surface in the evaporator will result in higher operating costs but some capital cost savings. However, the costs for the auxiliary equipment remain fairly constant for different heating surfaces, so the potential savings resulting from the use of less heating surfaces are small compared to the overall capital costs.

As mentioned above, all parts in contact with the process water (influent, residue and steam) would be constructed of 2205 Duplex Stainless steel. The system described would be approximately 3,800 mm diameter by 14,000 mm straight side. Minimal space requirements would be approximately 25 L x 35 W x 65 H feet height. A warehouse would not be necessary to house the facility, but a shelter or fenced yard with a concrete foundation is recommended before installation of the evaporation equipment, and the evaporation equipment would require full insulation to withstand winter temperatures in northeastern NJ.

These capital costs do not include the pumping system required to transport 'grey water' to the top of the landfill for distribution or the golf course plumbing system, which we suggest should be paid for by a golf course developer as part of their construction costs. Additional capital costs we have included are for a system to pump the leachate to an above ground equalizer tank, and the cost of constructing a gravity-fed plumbing system from the equalizer to the evaporator and from the evaporator to a surface water body discharge point no farther than 200 ft from the evaporator system. We have estimated these costs to the best of our ability with input from Robert Cates, a general contractor experienced with wastewater treatment systems and construction costs in the NJ Meadowlands District. An additional line item that has not been included in the capital costs is the expense of insulating the evaporator.

Operating Cost

The major cost of the treatment process is the electricity for powering the evaporator system. Given the above design specifications the energy consumption rate is about 1000 KW or 2545 kBTU/h. This corresponds to 24,000 KWH or 6.11 $x10^4$ kBTU per day if the system is in operation 24 hours a day. The average retail price of electricity in the Meadowlands is about 15 cents per kWH for industrial use. Assuming a retail price of 15 cents per kWH, the cost of electricity is about $3,600 per day for powering the evaporator. This estimate does not include additional power that would be needed to reduce the volume of the residual material, which cannot be determined until Rosenblad configures the system additions.

Other operating costs would include any treatment necessary for removal of organic chemicals (at this point, we cannot determine if this would actually be necessary). Because we were not able to determine what the actual removal of organic compounds would be once the foaming problem is fully corrected, further tests would be required to determine the need for additional treatment. Line items that we note (but do not have actual costs for) would be waste disposal costs for the concentrated residues after evaporation/drying (see discussion below), and costs associated with obtaining discharge permits from the NJDEP.

We have calculated personnel costs based on an on duty engineer 24 hours a day. The evaporator system could be configured with an automatic start-up and shut-down mechanism, which would result in a slightly higher equipment cost, but might reduce personnel costs.

Maintenance Cost

The major equipment wear items are seals and bearings on pumps and compressors, and the vacuum pump. Based on information provided by Rosenblad Design Group, we estimate the cost of equipment maintenance to be approximately $30,000 per year. This would include $10,000 annually to service the seals and change the oil in the pumps, and approximately $10,000 for hydroblast followed by chemical cleaning of the evaporator internals. It is possible that the plates in the feed heaters would have to be changed annually, and suppliers of this equipment have exchange programs where they clean and re-gasket the plate packages. We do not have cost information for this process at this time.

Disposal & Discharge Issues

The nitrogen concentrations observed in the condensate produced by the field evaporation test (2.47 mg/L) should not be problematic in meeting the NJDEP water quality standard for discharging treated wastewater to surface water. However, the pH observed in the condensate produced during the field study is above the NJDEP surface water quality standard (pH 9.0 versus a standard of pH 8.5). We believe this could be easily and very cheaply corrected with the addition of an inorganic acid to the effluent.

There would be disposal costs to be considered in dealing with the residue left over after evaporation. Evaporating 90% of the leachate water would result in roughly a ten-fold increase in the concentrations of heavy metals remaining in the residue (Table 8). The total dissolved solid concentration in the leachate is about 5,000-6,000 mg/L. Assuming a second evaporation/drying step is added, the final dryness of the residue after this second stage of evaporation is about 6 grams per liter, or 18.93 grams per gallon of leachate treated. This means the treatment would yield approximately 7,570 kg (7.57 metric tonnes) of dry solids if the facility is operated at a capacity of 400,000 gallons per day. Further, assuming a density of 1.5 tonne/m^3 (1.5 kg/liter) for the dry solids, the total volume of solids produced each day would be approximately 5 m^3 or 6.6 cubic yards. If the solid is wet (70% moisture content), the total mass may increase to about 17 metric tonnes per day, and the volume would be 12-14 m^3 or 15.7-18.3 cubic yards per day (assuming a density of 1.2-1.4 kg/L for the wet solid).

According to our analysis of the leachate, the metals will most likely remain in the residual as solids. Determination of whether the residual sludge is 'Hazardous Material' is based on leaching potential, not on total pollutant concentrations (*personal communication*, T. Pilawski, NJDEP Division of Residuals & Hazardous Waste). The solids produced from the last stage of the evaporation are likely water soluble. Prior to disposing of this residual material in a landfill, Toxicity Characteristic Leaching Prodedure (TCLP) analysis, a standard US EPA test for classifying whether a solid is hazardous, must be performed by a certified laboratory. To decrease the leachability of the heavy metals associated with the solid material, phosphates could be added to the concentrated leachate before it enters the second stage of the treatment (drying process). Many heavy metals can form phosphate precipitates that are not soluble in acids or in the solvents used in the TCPL analysis (see Appendix for description of TCPL analysis). Therefore, if treated properly, the solids could potentially be disposed of in a landfill. However, further tests (including a TCLP analysis) using a pilot scale system are required for assessing the mobility and solubility of the heavy metals associated with a solid residue, both with and without the addition of phosphates.

Table 8. Estimated Metal concentrations (μg/L) in the Evaporation Residual Waste Prior to a Drying Process.

Metal	Leachate	Metal	Leachate
Li	1,670	**Se**	250
Rb	2,670	**Mn**	5,690
Cs	14	**Co**	220
Mg	665,860	**Ni**	810
Sr	20,530	**V**	340
Ba	6,960	**Cr**	990
Al	850	**Cu**	**20**
Ti	650	**Zn**	1,000
Ga	430	**As**	220
Hg	13.5	**Cd**	1
Fe	175,540	**Pb**	47

Table 9. Estimated Annual Costs to Produce 'Gray Water' from Meadowlands Leachate.

	Golf Course Construction	Leachate Treatment 500,000 gal day^{-1}	Comments
Capital Expenses			**10 year depreciation schedule**
Leachate pumping system[1]		$3,500	
Equalizer System[2]		$35,000	Estimated expense for equalizer tank (without firm cost for construction of structural support system)
Evaporation System[3]		$331,000	Total cost $3,200,000 ± 10% plus pad, electrical hook up costs Cost not available at this time (4/17/09) for second stage evaporation/drying of 50,000 gal/day wastewater
'Grey Water' Storage[4]	X		
Water Transport System[5]	X	$2,800	Discharge to surface water system
Maintenance Costs			
Repair[6]		$30,000	
Down time[7]		-$18,000	One week electricity savings
Facility Maintenance[8]		$6,000	
Operating Costs			
Evaporator Electricity[9]		$1,296,000	2010 estimated
Pumping Electricity[10]		$60,480	
Personnel[11]		$375,000	3 Individuals each working 8 hour shifts
Total Projected Annual Costs		**$2,134,780**	
Cost/gallon to treat leachate		**$0.012**	**Does not include disposal cost**

COST ASSUMPTIONS (Calculated Using Prevailing Wage Estimates)

Excluding Engineering and Utility Fees

1. Two pumps and connecting plumbing (8" pipe) to pump leachate from the Meadowlands' leachate collection system into the leachate equalizer holding tank ($50,000). Electrical hook up for a 3,000 amp service ($115,000) required for an exterior application.

2. Cost of used aboveground equalizer tank capable of holding 500,000 gal of leachate ($328,000). Includes plumbing ($5,000) to transfer leachate from the equalization tank to the evaporator system up to 20 ft. Does not include the cost of tank fittings or prevailing wage rates.

3. Cost of evaporation components as described in the above configured design. Price quote provided by Rosenblad Design Group, Inc., Amelia Island, Florida. Cost of concrete pad ($50,000 including site prep excavation) and electrical hook up ($60,000).

4. 'Grey Water' Storage located on top of the 1-E landfill adjacent to the golf course. Construction cost to be covered by the golf course developer.

5. Pump and plumbing system required to transport 'grey water' from the base up to the golf course at an estimated elevation of 30 meters. Construction cost to be covered by the golf course developer. Gravity-fed system plumbing ($8,000) and excavation ($20,000) to transport treated water discharge a maximum of 200 ft. to a surface discharge point.

6. Estimated annual maintenance of evaporator equipment, pumps, and plumbing system. Assumes continuous operation with a one week yearly shut down

7. Downtime estimated at one week annually. Electricity not required during this period.

8. General maintenance of the treatment area.

9. Estimated annual electricity cost to run the evaporation system equals $3,600/day based on 2008 industrial electricity rate of $.15/kWH. Since we have no way of knowing what the future cost of electricity will be, or if installation of solar panels will result in a reduced electricity cost, we have used the 2008 industrial electricity rate.

10. Estimated annual electricity cost to pump leachate from collection system to equalizer holding tank, from holding tank to evaporator, from evaporator to discharge equals $168/day based on 2008 industrial electricity rate of $.15/kWH.

11. Highly trained personnel capable of maintaining the evaporation system equipment. One Operating Engineer on site at all times during a 24 hour period calculated at $125,000 per individual (including fringe benefits).

VI. CONCLUSIONS

The year 2 field tests confirmed that at least over a short-term period (one growing season), the daily use of recovered leachate 'grey water' as an irrigation source for golf course turfgrass species resulted in successful plant growth. The information gained from this project suggests that the potential exists for a beneficial re-use of Meadowlands' leachate. A possible re-use is as an irrigation source for a landfill golf course. It is also possible that thermal evaporation could be utilized as a landfill leachate treatment process.

Future application of the thermal evaporation process is highly dependent upon the capital and operating costs of the full-scale treatment process, including the future cost of energy, the disposal method and cost of residual sludge, and the development of appropriate long-term golf course irrigation and management BMPs. The proposed system design is a starting point – to develop the most efficient and cost effective system(s) we strongly recommend bringing together all interested parties to develop a holistic design approach that integrates the 'grey water' production with the golf course design. For example, storing the 'grey water' from the evaporator in attractive water hazard ponds could provide additional storage capacity during low precipitation time periods. The location and aesthetic incorporation of the proposed solar panels should also be considered as part of this holistic design process. Although we consulted with a local general contractor to determine potential project costs, it is quite possible that the estimated costs can be creatively reduced with input from NJMC engineers and other contractors who are familiar with costs, terrain, and personnel available for construction work in the Meadowlands District.

It is not possible at this point to predict the longer-term effects of irrigating turfgrass species with this water source without additional 'grey water' treatments and data collection from the field plots. Rutgers is seeking support from new funding sources to continue to manage the field experiments to gain the longer-term data needed. Adaptation in the recommended BMPs based on further field plot research and an adaptive management strategy would be critical to the successful use of recovered leachate 'grey water.' Because the data obtained in this project is of a short term nature, we cannot at this stage predict plant or soil response to longer term leachate 'grey water' use.

Should the evaporation process be seriously considered by the NJMC as a method for treating Meadowlands' leachate, further discussions with evaporation equipment design firms is needed to determine the best methods for controlling the tendency of leachate to foam, and a treatment to remove residual compounds that do volatize when the foaming is eliminated would need to be tested. Discussions would also need to be conducted with the appropriate staff at the NJDEP to identify the permits required for an evaporation leachate treatment process and to consider various disposal options for the residual waste material.

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APPENDIX I.

Toxicity Characteristic Leaching Procedures (TCLP)