

BURLINGTON COUNTY BIOREACTOR LANDFILL STUDY – FINAL REPORT

PREPARED BY
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The purpose of this Study is to provide the Burlington County Resource Recovery Center (BCRRC) management and staff with information related to operational efficiencies of the Burlington County Bioreactor Landfill. Reproduction of this document in whole or in part is illegal without expressed written permission from the BCRRC.

I. EXECUTIVE SUMMARY

Burlington County Resource Recovery Center (BCRRC)

II. BACKGROUND

In 2003, the United States produced 236 million tons of municipal solid waste (MSW), of which 131 million tons were placed in landfills (USEPA 2003). Due to the difficulties encountered in finding acceptable locations for new MSW landfills in the densely populated northeast corridor, as well as the post-closure costs associated with existing landfills, it is of critical importance to New Jersey municipalities to find ways to maximize the degradation of landfill material. Numerous benefits in management of MSW have been associated with the operation of landfills as bioreactors. These benefits include increased organic degradation rates, a decrease in the strength of leachate after recirculation, and the more efficient capture of methane (CH_4) gas produced by microbial degradation processes (Berge et al. 2005).

Despite the presumed superiority of the bioreactor design, scientific and engineering issues related to this technology persist. A definitive assessment of the effectiveness of current bioreactor operations on waste degradation is still lacking (Benson et al. 2005), and the current monitoring data are inconclusive. Better monitoring data are needed to identify more efficient and effective ways to operate bioreactor landfills, and a detailed understanding of the biogeochemical processes within bioreactor landfills is needed. Examples of unanswered questions include: 1) Which processes result in the production of desirable nitrogen (N) species versus undesirable N species (for Review see Berge et al. 2005); 2) Can the recirculated leachate be controlled to improve methane production (e.g., recirculating leachate from older cells into newer cells); 3) Is there a sequence of aerobic/anoxic/anaerobic processes that can bring about desirable operational endpoints; 4) Are there enhanced ways to determine desirable endpoints? A better understanding of overall abiotic and microbial processes occurring within bioreactors, as well as the interaction of various engineering options with these processes, is critical for maximization of bioreactor landfill operation and cost efficiency.

LANDFILL MICROBIAL PROCESSES OF INTEREST

Decomposition of MSW involves several biological reactions that are carried out by various microbial communities. Optimization of bioreactor landfill processes that produce energy (LFG methane) or eliminate toxic nitrogen species (denitrify) require both methane producing archaea and nitrogen transforming bacteria that are typically found in landfill systems (Huang et al, 2002, 2005). There is quite probably competition for resources between these microbial communities (Fig. 10). To optimize the overall operation of a bioreactor landfill, specific microbial processes need to be stimulated.

Microorganisms are introduced into the landfill with the waste and cover material; however, the microbial community composition changes as the waste decomposition processes proceed. There are five basic phases of MSW degradation in bioreactor or classical landfills (for review see Reinhart & Al-Yousfi 1996): Phase 1 when fresh waste is placed in the landfill and oxygen is consumed; Phase 2 when oxygen is depleted and anaerobic conditions are established; Phase 3 when volatile fatty acids, alcohols, carbon dioxide, and hydrogen are produced; Phase 4 when the methanogenic community is established (10% of the total anaerobic population) and methane production increases (Barlaz et al., 1989).

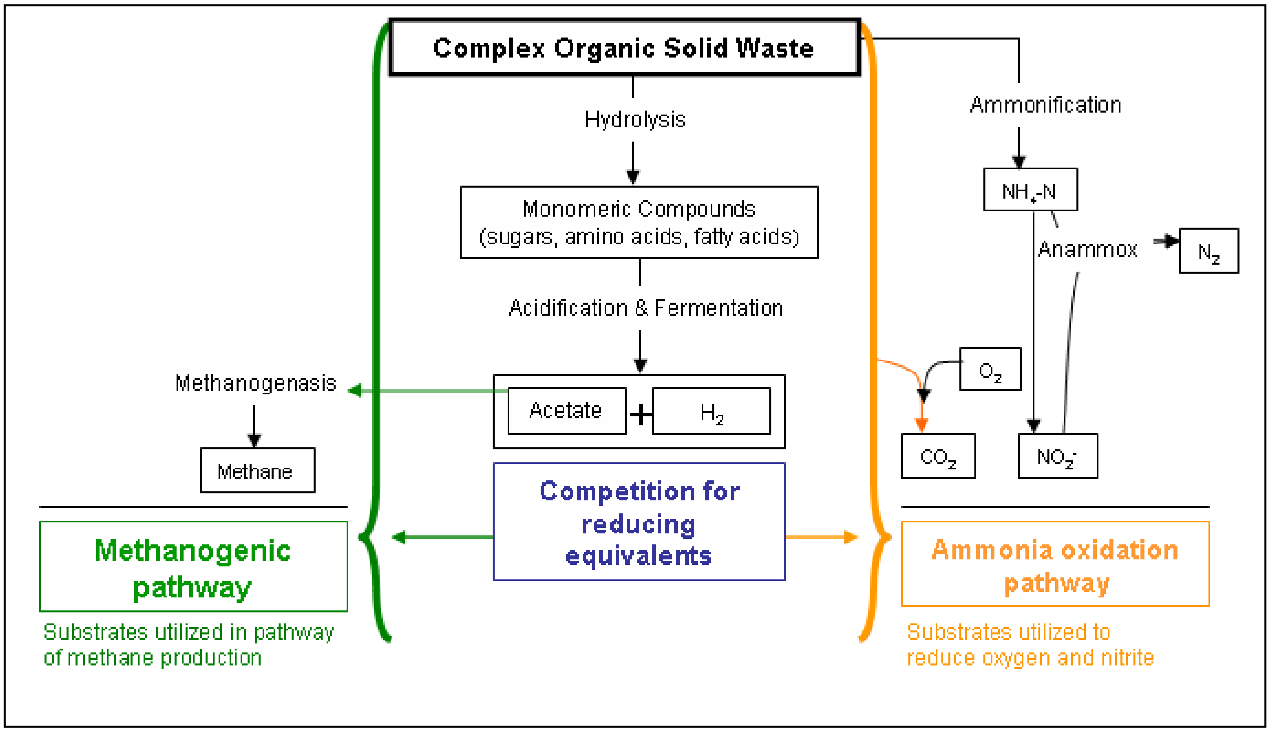


Fig. 10. Potential anaerobic degradation pathways.

The fourth "methane fermentation" stage is the longest non-terminal phase within a landfill system, and is the time when gas production is at its peak (Barlaz et al., 1989). A leachate-recirculating landfill can develop a methanogenic community more quickly than a conventional dry landfill. Recirculation keeps the waste moist, warm and anaerobic, leading to a more rapid stimulation of methanogens and other microorganisms, which thrive under reducing conditions (Kim & Pohland, 2003). The microbial communities may be similar, but in a bioreactor landfill the time until methane production may be shortened (Kim & Pohland 2003). While landfill methanogens will remain active for decades, decomposition processes will eventually begin to slow when most of the organic material is consumed. During "maturation" (Phase 5) landfill gas production significantly decreases (Barlaz et al., 1989).

While leachate recirculation may produce the benefit of more efficient methane production a potentially negative aspect is an increase in the ammonia concentration as a result of recirculation. Ammonia can be converted to nitrite by aerobic nitrifying bacteria. Under anaerobic conditions, denitrifying bacteria can use the nitrite to convert ammonia to dinitrogen gas. This reaction ($NH^{4+} + NO^{2-} \rightarrow N_2 + 2H_2O$) has been termed "Anammox" (anaerobic ammonia oxidation), and is a natural process that decreases the amount of ammonia and nitrite present in a system (Fig. 10). To date, this microbial process has been demonstrated to occur in wastewater treatment systems and in marine environments, but has only been hypothesized to occur in landfills. Only a few bacterial species capable of the anammox reaction have been isolated (*Brocadia anammoxidans*, *Kuenenia stuttgartiensis*, *Scalindua brodae*, and *Scalindua wagneri*).

These organisms thrive in the interface between aerobic and anaerobic habitats; they gain nitrite from the aerobic processes, and consume ammonia under anaerobic conditions. Based on an analysis of conditions required by anammox species, it is probable that Anammox bacteria could potentially be active in the BCRRC bioreactor landfill system. If this is the case, there exists the possibility of developing a beneficial process train – first by stimulating the efficient microbial production of methane, followed by stimulating the Anammox community to reduce the concentration of ammonia. Successful application of this approach would decrease the long-term monitoring and closure costs of the BCRRC bioreactive landfill.

The Burlington Resource Recovery Complex (BCRRC) operates an active landfill as a bioreactor. This project was: 1) investigating the current operating parameters of the bioreactor landfill, with the purpose of improving operational efficiencies, and 2) implementing a scientific research program to characterize specific biogeochemical aspects of the Burlington County bioreactive landfill. The specific objectives of this research were to:

1) Analyze operational data currently available from the BCRRC bioreactor landfill and to compare this date with data from other bioreactor landfills in New Jersey,

2) Identify data currently lacking in these data suites and design a monitoring and sampling plan to collect a more complete data set,

3) Based on this data design an operational plan for the BCRRC bioreactor landfill to maximize landfill effectiveness,

4) Conduct preliminary laboratory experiments regarding nitrogen conversion/processes in the BCRRC bioreactor landfill, and

5) Prioritize bioreactor research questions and develop a research plan to assist in optimization and control of the BCRRC bioreactor landfill (and other NJ bioreactor landfills).

III. DATA COLLECTION & CURRENT PRACTICES

A. ENGINEERING

CHARACTERIZATION OF THE EXISTING LANDFILL

Burlington County operates and maintains an active bioreactor landfill that was initiated in 1999. The final area of the landfill will cover 28 ha, and the final height will be 35 m. In addition to the bioreactor Landfill 2 there is a closed dry tomb Landfill 1. The gas collection system of the two landfills is linked, but the leachate collection systems are not. The BCRRC system also collects water from a composting facility and a greenhouse that are located on site. The wastewater stream is not currently treated onsite; excess leachate and water generated within the BCRRC complex are hauled off-site for treatment at the Passaic Valley Sewage Commission (PVSC). The BCRRC currently has water storage capacity of approximately 400,000 gallons (personal communication BCRRC staff).

Landfill Gas (LFG)

The BCRRC landfill gas (LFG) is captured in horizontal laterals and vertical wells maintained under negative pressure, and the collected LFG is subsequently flared. LFG recovered from Landfill 1, a closed dry-tomb landfill, and Landfill 2, the operating bioreactor landfill, is combined and flared together. Figure 1 shows the combined (Landfills 1 and 2) average LFG flow and standard deviation from January 2002 to January 2007.

The total quantity of gas produced has increased from an initial flow about 1600 scfm in 2002 to about 2700 scfm in early 2007 (Fig. 1). Maximum LFG flows have been recorded as high as 4650 scfm in late 2003, but the trend subsequent to the 2003 peak shows LFG generation decreasing. The current operating assumption is that about 50% of the recorded flow can be attributed to each landfill respectively, but the actual contributions of each landfill are not necessarily monitored individually. Therefore, the flow associated with the bioreactor landfill (Landfill 2) is not being quantified on a regular basis. Using the total flared LFG volume for a given year LFG volumes can be normalized to identify potential monthly trends in gas production (Fig 2). Somewhat lower LFG volumes were recorded in the late spring and summer months (April to September), but these slight monthly variations do not appear to be statistically significant.

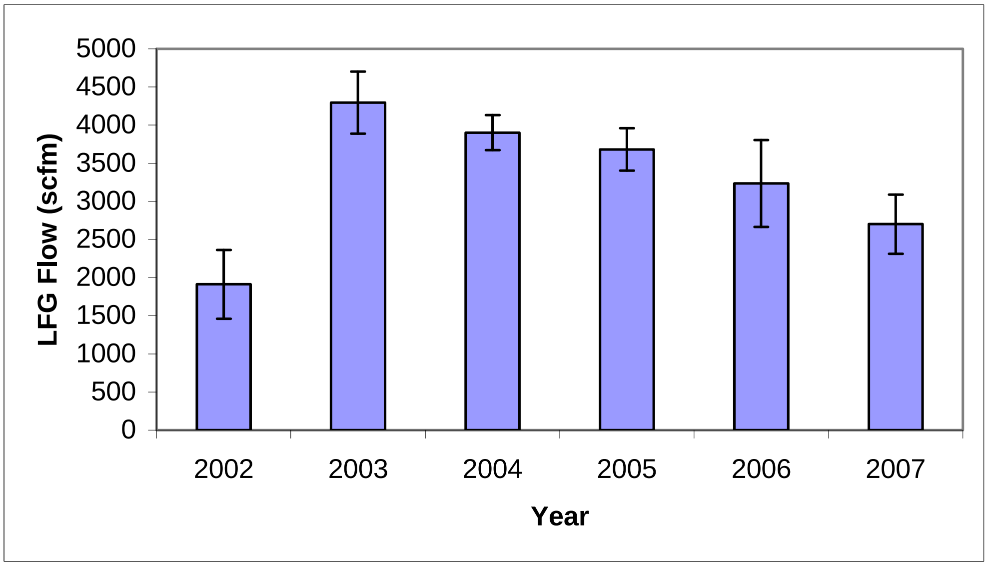


Fig. 1. Total average BCRRC landfill gas flow 2002 – 2007.

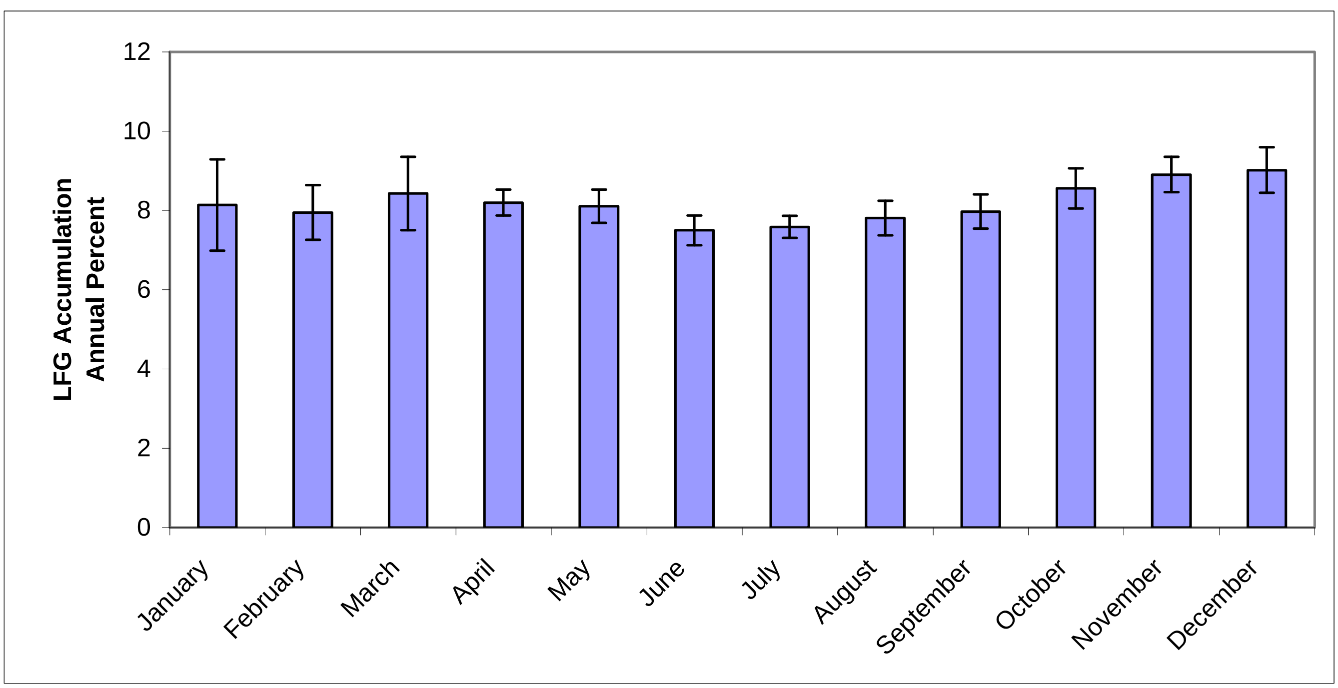


Fig. 2. Average percentage of monthly contribution to BCRRC landfill gas flows.

Assuming each landfill is contributing 50% of the LFG flow, and using a simple decay model to predict expected LFG flow values, we compared the observed LFG flow to the flow predicted by the model (Fig. 3). This comparison shows that from 2002 to 2005, the observed flow deviated from the expected flow by a small marginal value, and that gas production followed the predicted trend. The deviation observed could indicate that the predicted values were overestimated, that the assumed contribution of Landfill 2 to the total flow (50%) was overestimated, or some combination of the two.

Subsequent to 2005, the model predicted a doubling of LFG production, while the actual LFG volume exhibited a slight downward trend. The deviation from expected LFG production indicates a fallacy in the predictive model or an operational change from the model that is resulting in less LFG generation. Comparison of the actual LFG production versus the model can be useful for identifying operation problems, and can also be used to measure the affects of new or changed operational practices on LFG production volumes.

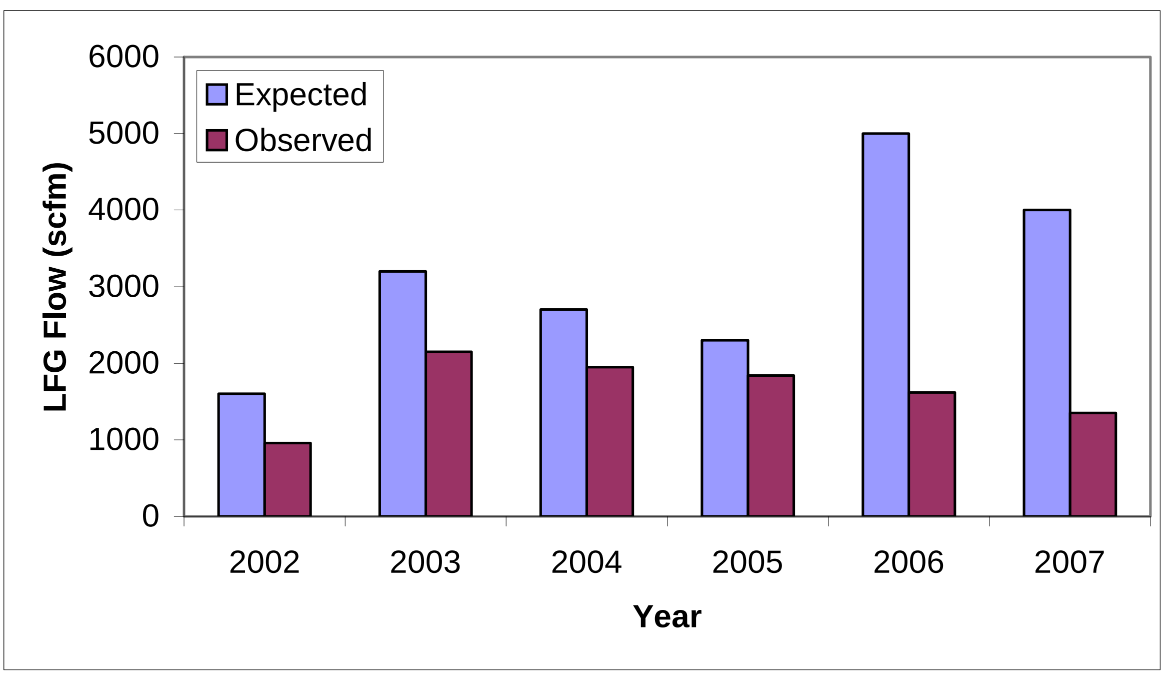
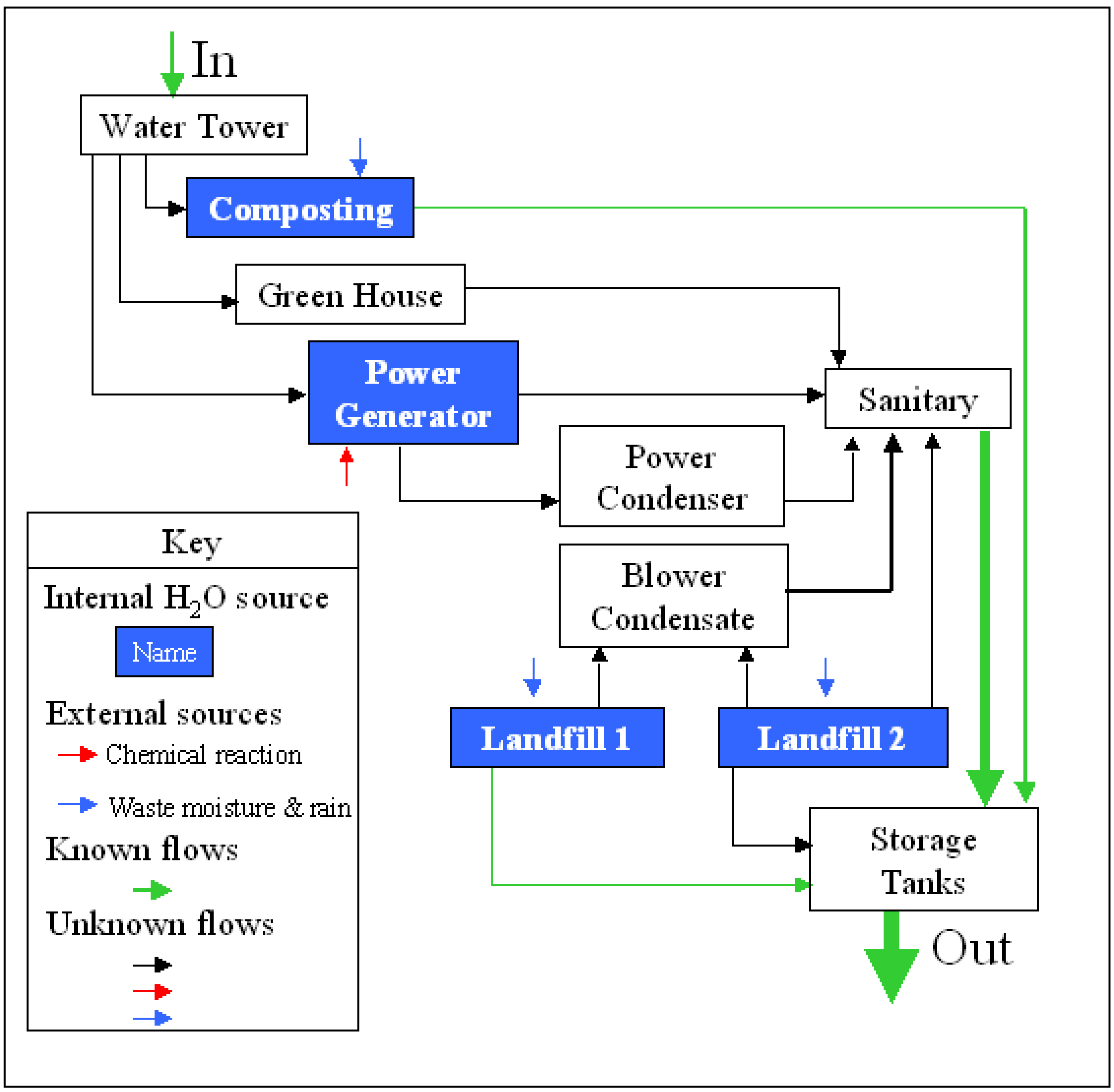


Fig. 3. Predicted landfill gas flow versus observed flow assuming a 50% contribution from bioreactive landfill 2.

Landfill Leachate

The bioreactor landfill leachate collection system is designed to intercept water that passes through the waste deposited in the bioreactor landfill, and to route this water for recirculation or removal from the site for treatment (Fig. 4). The collection system consists of 12″ PVC leachate collection laterals, oriented in a north/south direction parallel to the longitudinal axis of the landfill, and spaced 100 ft apart along the bottom of the landfill. This plumbing directs leachate to manholes downstream of the pipes.



Excess wastewater is accumulated in the holding tanks, and is subsequently removed from the BCRRC site in tanker trucks to be treated at the PVSC sewage treatment facility. The annual volume of water removed from the site has exhibited large variations since 2001 (Fig. 5). We note that weather patterns over this time period have alternated (http:/climate.rutgers.edu/stateclim) between drought and intense flooding, and that the amount and intensity of precipitation events will directly affect the volume of water processed through the BCRRC system. To address the annual volume of wastewater treated offsite, numerous other factors such as annual precipitation, the extent of recirculation for given time periods, evapotranspiration and *in-situ* moisture content must be considered (Fig. 4).

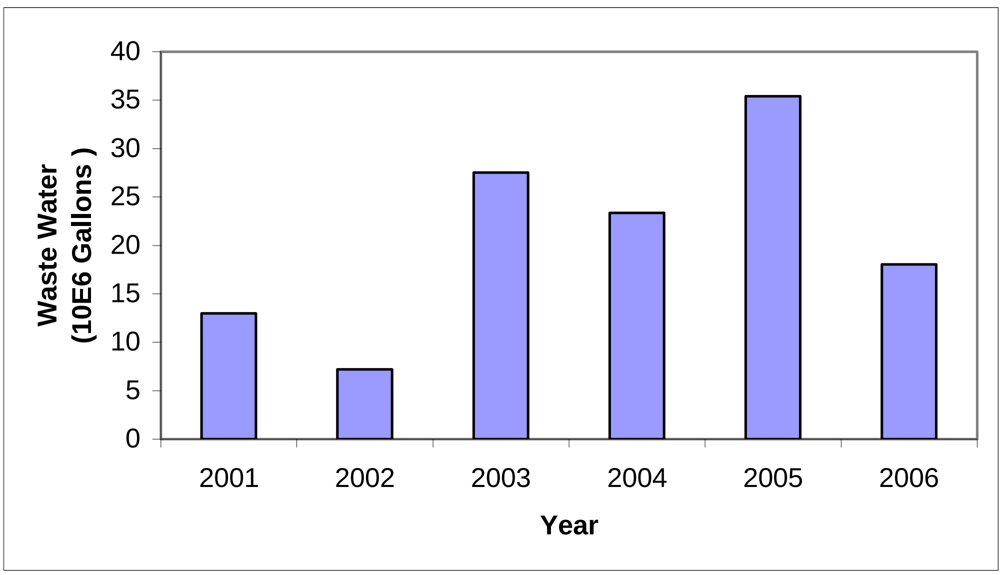


Fig. 5. Annual volume of contaminated wastewater removed from the BCRRC.

Annual wastewater accumulation varies significantly from year to year, and the accumulation rate for any given year is not constant. Therefore, it may be useful to identify the time(s) of the year that corresponds to the greatest accumulation of wastewater. By normalizing water volume accumulation into a monthly percent based on the total annual accumulation, the contributions of the various months of the year were compared (Fig. 6). It should be noted that extreme weather conditions have a large affect on the ability of the BCRRC bioreactor system to store and process water. As an example, sever drought conditions were experienced during portions of 2001-2002. When the 2002 data is removed from the monthly wastewater analysis, the trend remains consistent, but the variance between months decreases slightly (Fig. 7). Based on the monthly contribution, the greatest water volume storage capacity appears to be required during the September through April period

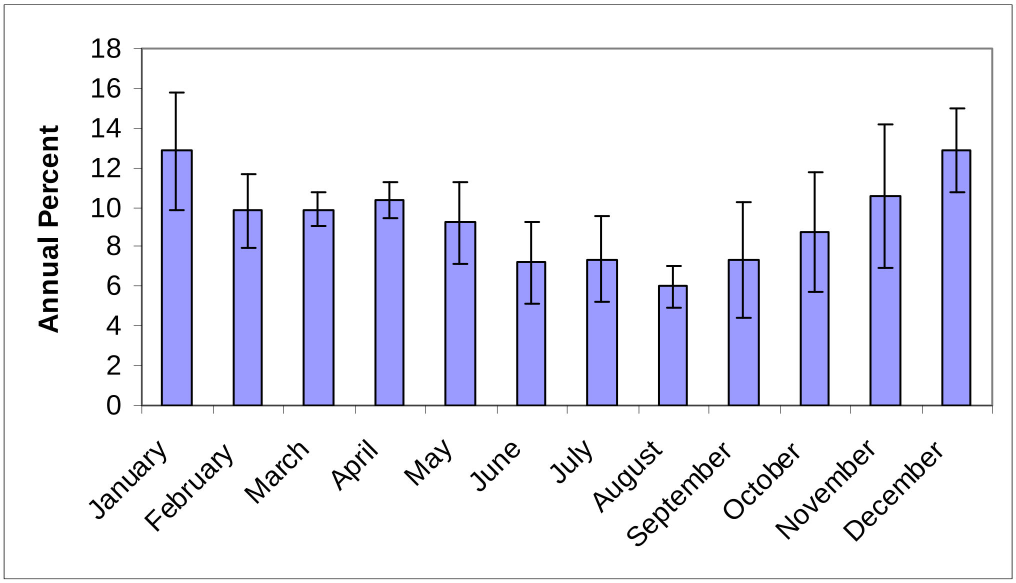


Fig. 6. Monthly proportion of wastewater accumulation at the BCRRC.

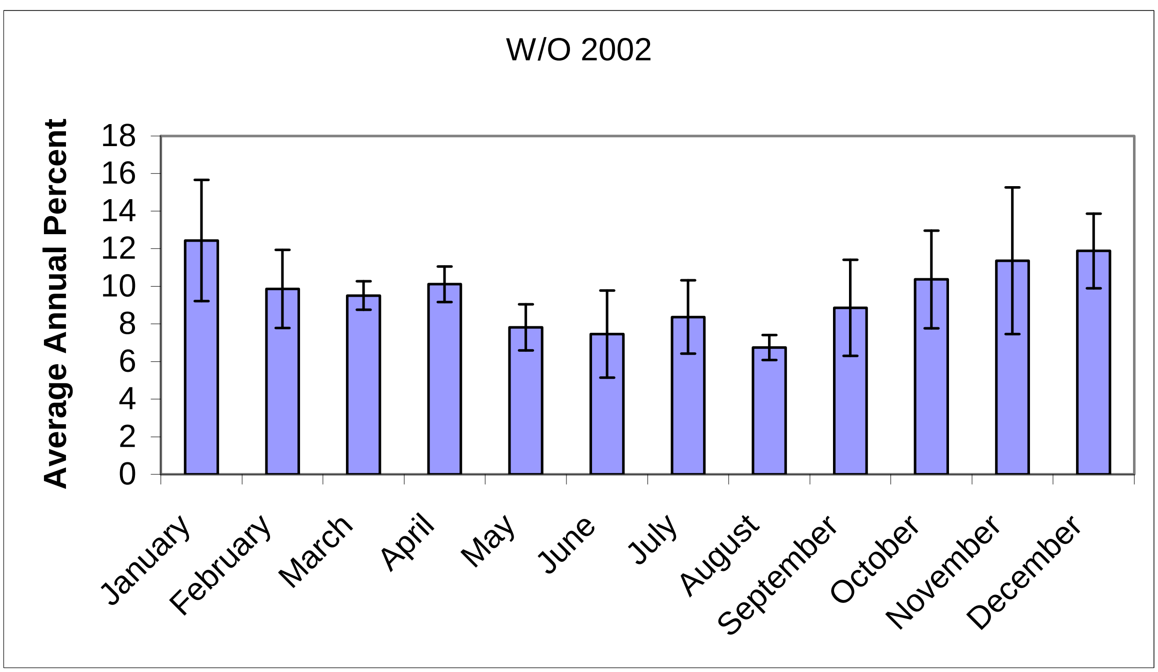


Fig. 7. Monthly proportion of wastewater accumulation at the BCRRC excluding date from the 2002 drought year volume.

Appendix 1 shows the percent of annual water volume accumulated during each month for the years 2003-2006. A review of this annual data indicates that the pattern observed when averaging multiple years' data will not necessarily occur during an individual year (Fig. 8, 9). This makes planning optimization strategies uncertain when relying on the averaged data.

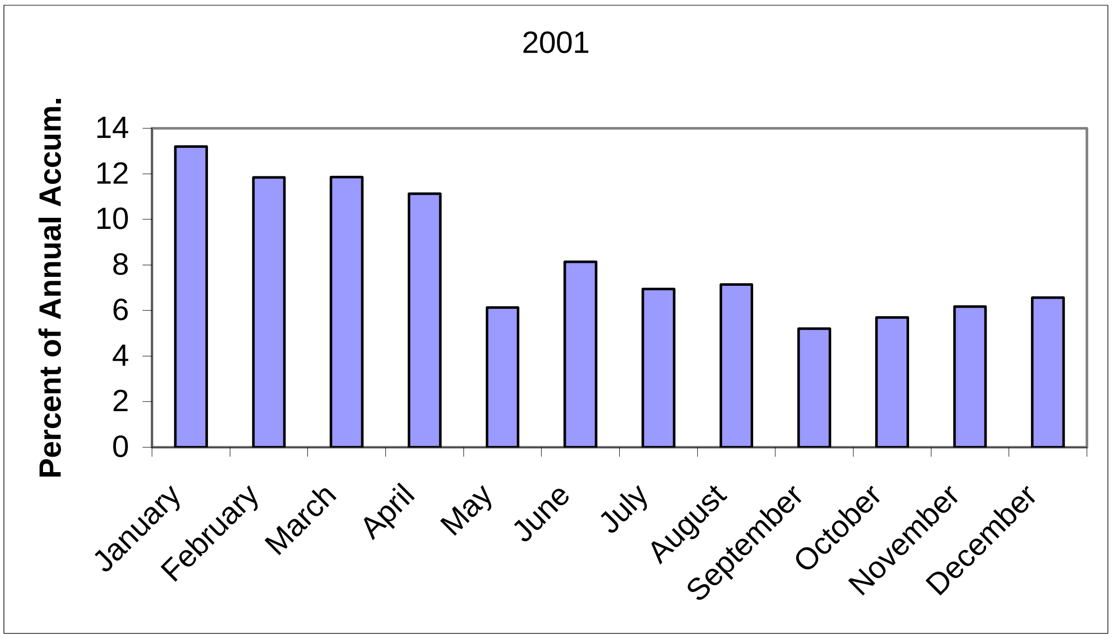


Fig. 8. Actual monthly proportion of wastewater accumulation at the BCRRC in 2001.

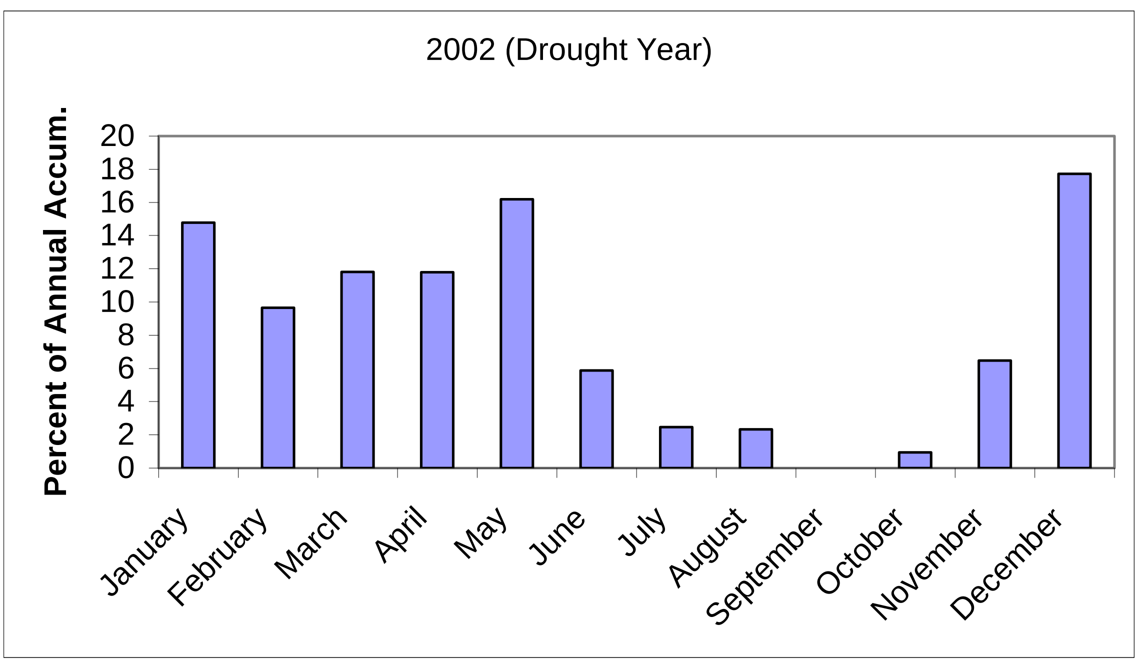


Fig. 9. Actual monthly proportion of wastewater accumulation at the BCRRC in 2002.

By applying the monthly proportion of accumulated wastewater to the annual water volume total, the actual storage capacity required during a given month can be determined. Analysis of the these monthly water volumes (Fig. 9, Appendix 1) demonstrates that the capacity required to treat all wastewaters generated by the BCRRC complex is much greater than the 400,000 gal currently available. In general, water management has been a major concern at BCRRC because of the limited wastewater storage capacity. Bioreactor landfills of comparable size, located in the relatively wet climate of the U.S. northeast can expected to require 60-80% more wastewater storage capacity to effectively handle storm events, while simultaneously operating with an effective recirculation strategy. Operators at BCRRC suggest that as much as 150% of the existing capacity might be required to eliminate the need to transport wastewater off site for treatment.

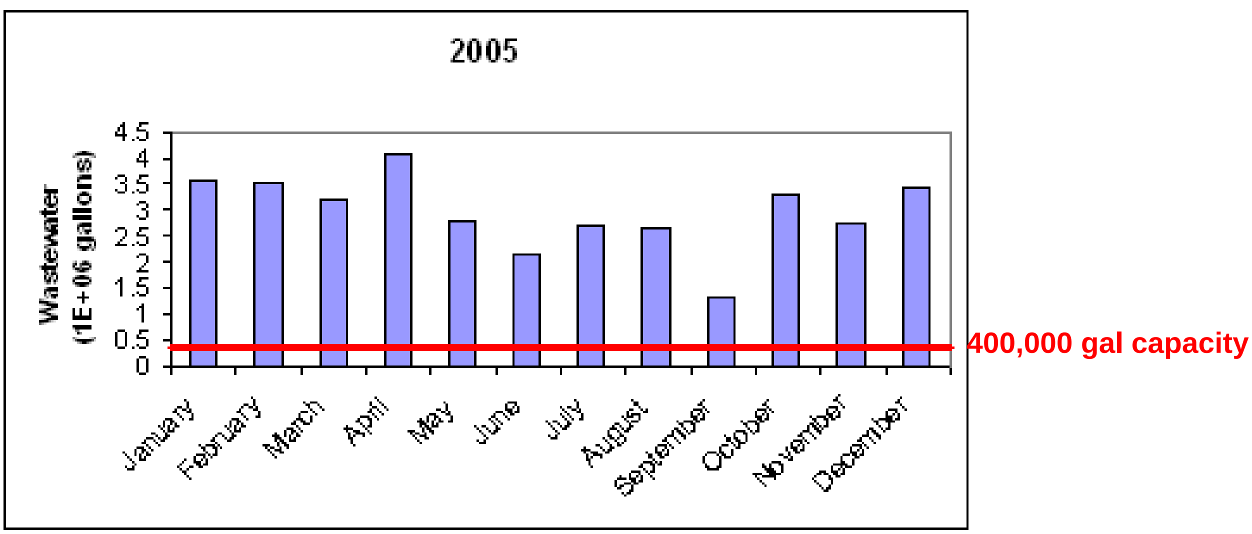


Fig. 9. Monthly accumulation of BCRRC wastewater during 2005.

Comparison of Burlington County Landfill with other Bioreactor Landfills

Explicit comparisons between different bioreactor landfills are complicated by differing designs, waste types and compositions, topography, and local climate. However, comparing differences can reveal the effects of various operating practices and provide perspective on specific bioreactor landfill operations. Although, the most relevant comparison would be with other New Jersey landfills, the necessary data has been difficult to obtain from other landfill operators. Due to the scarcity of local data, operating data from the BCRRC was compared to data published in a USEPA (2005) report: "State-of-the Practice Review of Bioreactor Landfills." This report compared numerous bioreactor landfills from various geographic locations. One such bioreactor landfill was located in the northeast. For purposes of our comparison, values from the USEPA northeast bioreactive landfill and the BCRRC bioreactive landfill were normalized with respect to total waste mass (Table 1). The comparison between the BCRRC landfill(s) and the USEPA northeast bioreactive landfill showed only a 6% greater LFG production per ton of waste in the comparison landfill and a 38% greater production of landfill leachate per ton of waste/year (Table 1). BCRRC leachate production could potentially be affected by the removal of leachate from Landfill 2 and by the partial covering of the landfill with a plastic cover, which inhibits inputs of precipitation during storm events.

TABLE 1. BCRRC bioreactor landfill versus another northeast landfill (USEPA).

Bioreactor Landfill	Leachate Accumulation (Gallons/Ton•Year)	LFG Accumulation (SCF/ Ton•Year)
BCRRC	16	537
USEPA northeast	22	569

DATA NEEDED TO DETERMINE GREATEST OPERATIONAL EFFICIENCIES

DESCRIBE SAMPLING & ANALYSES

B. MICROBIAL PROCESSES

MOLECULAR ANALYSES

Sampling

Leachate samples were obtained from the main BCRRC leachate collection pipe (November, 2006). Degraded MSW at a depth of 90 ft was collected from Piezometer 4 (December 1, 2006). In the lab the MSW was converted to a slurry mixture of 1/3 refuse and 2/3 anaerobic medium. DNA was extracted from the leachate samples and the MSW samples. Amplification of the 16S rRNA gene sequences was performed using universal bacterial primers (Muyzer et al., 1993). Polymerase chain reactions (PCR) were employed to increase the amount of DNA.

Denaturing gradient gel electrophoresis (DGGE)

DGGE was performed on the landfill PCR products. The black bands seen in the DGGE analysis (Fig. 11) indicate that there is a diverse bacterial community, both in the MSW and the leachate fractions. Results of the microbial community analysis were presented by graduate student Jennifer Loudon at the 2007 regional New Jersey-Delaware SETAC conference, where her poster received an award.

Bench Top Bioreactor Systems

A goal of this research was to maximize the operation of a bioreactor landfill with respect to the efficiency of methane and dinitrogen generation. To further elucidate these microbially-drive processes, bench top reactor studies were conducted to:

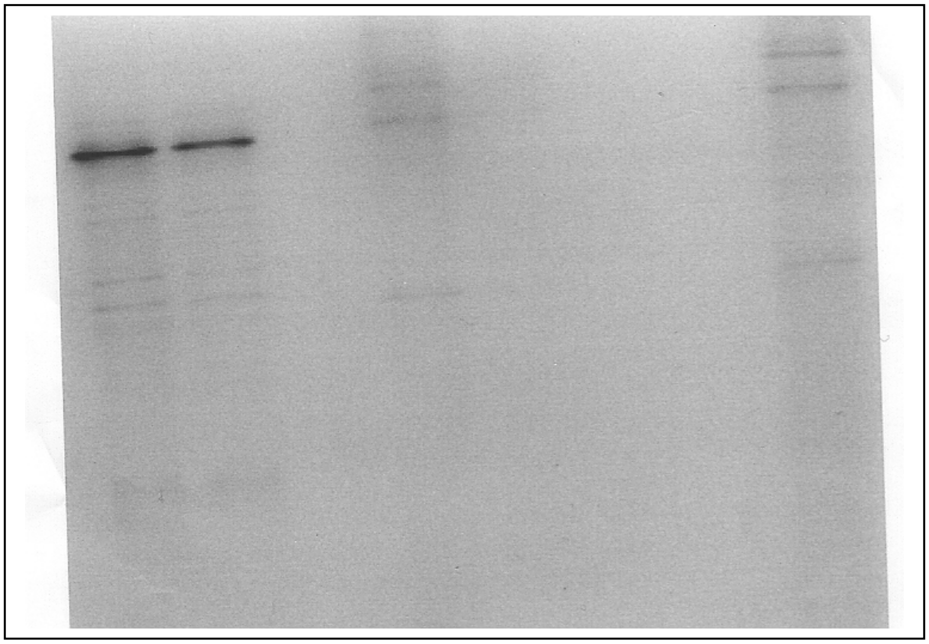


Fig. 11. DGGE image of landfill slurry (2 left lanes) and landfill leachate (2 right lanes).

IV. RECOMENDATIONS

The results of the bench top bioreactor systems suggest that relying on microbial processes to remove excess nitrogen from the BCRRC landfill wastewater stream would not produce a measurable difference in the composition of the final wastewater stream, or resolve the critical issue of waste water storage and disposal. Therefore, we are focusing our recommendations on non-biological solutions that could mitigate these issues.

WATER MANAGEMENT STRATEGY

Nitrogen Accumulation in Bioreactor Landfills

Limited information is available to quantify the fate of nitrogen species in landfill and bioreactor landfill systems; nitrogen loadings and fate in specific systems can vary widely from site to site (REF). Ammonia-nitrogen is a concern in landfill systems because it accumulates in leachate and creates the potential for environmental contamination. As a result, landfill leachate is commonly tested for nitrogen species, and the presence of nitrogen can be the main determinant requiring costly long-term monitoring at closed landfill sites. Another concern associated with ammonia-nitrogen accumulation in bioreactor landfill systems, where large quantities of high quality methane biogas can potentially be recovered, is that nitrogen accumulation can hinder methanogenesis because ammonia is toxic to microorganism responsible for the methane production pathways (REF).

Ammonia-nitrogen accumulates in anoxic systems because there are not significant transformation pathways for ammonia-nitrogen under anaerobic conditions (REF). This is a concern for both dry tomb and bioreactor landfills. However, the more rapid organic degradation achieved in bioreactor landfill systems enhances ammonification and exacerbates the problem. For the purposes of developing infrastructure and operating protocols for treating leachate at the BCRRC bioreactor landfill, it is more conservative to assume that natural microbial attenuation of ammonia is negligible, and that physical dilution based on natural circulation and forced recirculation of leachate is the main nitrogen removal mechanism.

Modeling the BCRRC nitrogen removal rate using the above assumption depends solely on the efficiency of nitrogen removal via the leachate physically leaving the landfill and/or being recirculated. If leachate recirculation were not occurring, the nitrogen removal rate would correlate directly to the amount of leachate moved off site.

BCRRC WASTEWATER FLOWS AND NITROGEN LOADINGS

Leachate generated by Landfills 1 and 2, as well as the wastewater stream from the onsite composting facility, are currently pumped to, and stored in, one of two 200,000-gallon storage tanks. Additional wastewater is generated by on site domestic sanitary sources. The total useable on-site storage capacity has been estimated to be around 386,000 gallons. Analysis of the needed storage capacity for landfills of the size of Landfill 1 and 2, in the relatively wet climate of New Jersey, has been estimated at over 2.5 million gallons (REF). Thus, wastewater management and storage are critical concerns that determine operating practices at BCRRC. Measures to optimize and control water circulation in the bioreactor landfill (Landfill 2) have been stymied by the BCRRC's need to manage wastewater and leachate volumes.

Currently, all wastewater and leachate generated at BCRRC is stored for subsequent transport offsite and a large fraction of this mixed waste stream is trucked to the Passaic Valley Sewerage Commission (PVSC), which is located approximately 70 miles from BCRRC. The relative volumetric contributions of the different BCRRC liquid streams to the mixed wastewater stream that is transported off-site for subsequent treatment are shown in Figure Y. These values were obtained either directly from flow meters or back-calculated using known minor and total flows. Best Management Practices (BMPs) for managing BCRRC's wastewaters involve considering not just the volume of the waste stream being generated, but also the associated nitrogen loadings (REF). More cost-effective and energy efficient strategies may exist to deal with these various waste streams if both the quality and the quantity from the various sources are considered.

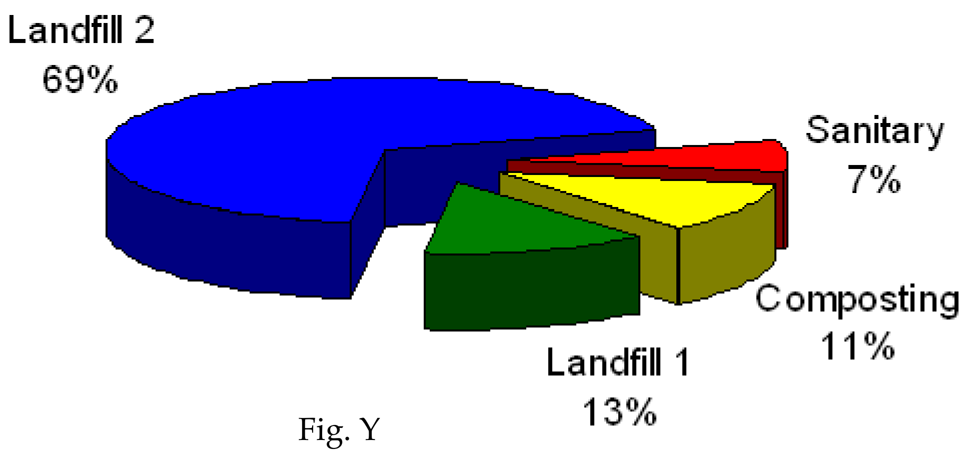


Fig. Y

On average 42,000 ± 17,000 gallons of mixed wastewater (from all source streams combined) is accumulated daily in the storage tanks, and is subsequently removed from BCRRC by tanker trucks. The associated dissolved nitrogen content of the various waste streams was analyzed in Rutgers University laboratories using ion chromatography (Appendix III METHODS). Table 1 shows the ammonium ion concentration values in each waste stream observed under high and low flow conditions.

Table 1. Ammonium Concentrations in BCRRC Waste Streams under Low and High Flow Conditions and Ammonium Concentration Means.

Ammonium Ion Concentrations (mg/L)				
	Landfill 1	Landfill 2	Composting	Storage Tanks
Low	209 ± 9	277 ± 10	3543 ± 339	560 ± 182
High	270 ± 16	916 ± 29	6745 ± 463	1328 ± 177
Mean	237 ± 27	611 ± 310	5144 ± 1238	946 ± 331

These values show that the composting facility generates a waste stream with an order of magnitude higher ammonia concentration than either Landfill 1 or Landfill 2. Ammonia concentration in the composting stream can range from 3,500 mg/L under high flow conditions to nearly 7,000 mg/L under low flow conditions. Ammonium ion concentration appears to be the most consistent in the Landfill 1 leachate stream. BMPs appropriate to manage the various wastewater sources require different treatments that can reduce the ammonia loads, while handling the fluctuations that occur in the ammonium concentrations.

A total nitrogen balance for BCRRC was constructed. The nitrogen balance over the lifespan of the bioreactor landfill was divided into two phases, where Phase I represents waste accumulation, and Phase II represents post closure. The nitrogen mass balance can be expressed explicitly (Equation 1).

$$N_{Accum} = N_{In} - N_{Out} + N_{Recirculated} \quad \text{Equation 1}$$

The right hand side of Equation 1 can be expressed in terms of the nitrogen fraction in the MSW, recirculation and exiting streams for both Phase I (Equation 2) and Phase II (Equation 3).

$$N_{Accum} = X_N \cdot R - C_{Nout} \cdot F_{Out} + C_{Nin} \cdot F_{in} \quad \text{Equation 2}$$

$$N_{Accum} = -C_{Nout} \cdot F_{Out} + R_{MSW} \cdot X_N \quad \text{Equation 3}$$

Variable	Description and Units	BCRRC Value (*Assumed value**)
N_{Accum}	Nitrogen balance as a function of time (kg)	Calculated time-dependent output
X_n	Weight percent of nitrogen (kg-N/kg-MSW)	*0.009**
R	Average annual MSW accumulation rate (kg/yr). Value is calculated annually	Phase I: Time-dependent input *356 10^6 kg MSW/yr for future predictions** Phase II: R = 0 kg/yr
C_{Nout}	Concentration of dissolved nitrogen species in exiting leachate stream (kg/m^3)	*1.5 kg/m^3**
C_{Nin}	Concentration of dissolved nitrogen species in recirculated leachate stream (kg/m^3)	Control variable for analysis; without removal mechanism *1.5 kg/m^3**
F_{out}	Volumetric flow rate of exiting leachate (m^3/yr)	Time-dependent input *Modeled output for future predictions** (Figure 3)
F_{in}	Volumetric flow rate of entering leachate (m^3/yr)	Control variable for analysis; zero for no recirculation

Several scenarios were modeled based on variations of the recirculation control variables (Figure Z). Nitrogen outputs under various recirculation strategies are calculated: 1) no recirculation (Natural); 2) continuous limited recirculation (Continuous); and 3) 1.5 and 3 times greater than the continuous value.

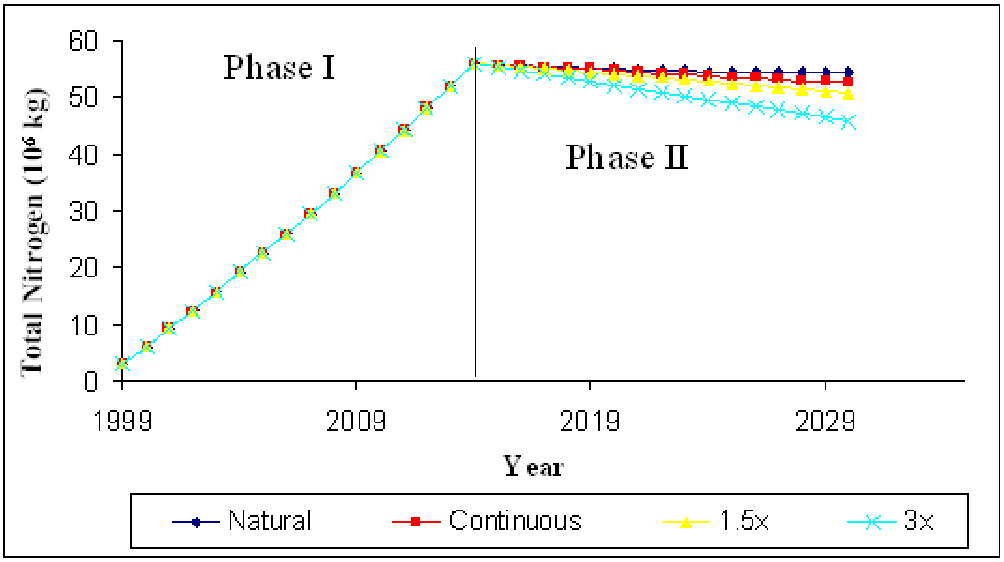


Fig. Z. Modeled nitrogen balance at BCRRC.

The amount of nitrogen increases linearly during Phase I, and then decreases at a slower linear rate during Phase II. However the amount of available nitrogen remains high, even under increased recirculation. This suggests that management efforts to use recirculation as a water storage mechanism should also be recognized as a practice that can generate an equal amount of leachate rich in nitrogen for the future. A total nitrogen balance for the BCRRC bioreactor landfill demonstrates that the amount of nitrogen in the landfill will remain high as long as leachate is being generated. This means that dissolved nitrogen species will be an on-going management concern.

Future Options

Modeling the total nitrogen balance is not useful for understanding the nitrogen treatment needs at BCRRC as a function of time because the landfill can become a nitrogen sink post closure. Predicting the wastewater accumulation volume as a function of time is more accurate than predicting the aqueous ammonia-nitrogen concentration as a function of time. The best way for managing aqueous nitrogen species over the long term is to predict the expected leachate accumulation rate as a function of time, and assume a reasonable and constant ammonia-nitrogen concentration. Then methods to treat the leachate expected to be produced can be designed. Nitrogen remaining that is not dissolved (because the moisture content is sufficiently low) will be assumed to be stored in the landfill long-term.

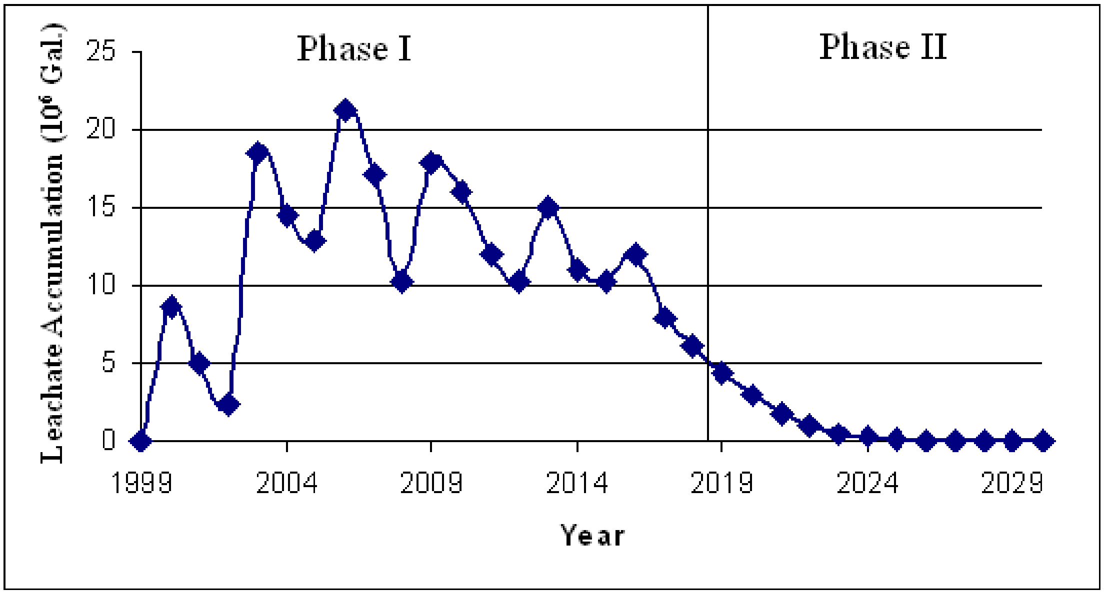


Fig. 3. Current projected leachate accumulation (Landfill 2 only) without recirculation and with continuing off site water transport.

Modeling various scenarios for recirculation shows that even under the most aggressive recirculation, large amounts of nitrogen species remain in the landfill even after many years of treatment, but this is not to say that the benefits of recirculation cannot outweigh the disadvantages of accumulating leachate. Thus, leachate recirculation, although seen as a means to enhance production of methane and space recovery, should be viewed as a tradeoff, which also simultaneously generates more nitrogen rich leachate that must subsequently be treated. Leachate accumulation data from BCRRC corresponding to landfill cell construction, completion and operation was studied. Patterns between MSW and leachate accumulation were identified and used to obtain predicted leachate accumulation volumes from Landfill 2 over time (Figure 3). The leachate accumulation rate will decrease continuously following landfill closure (assumes MSW accumulation ends in 2014).

A. TREATMENT OPTIONS

The leachate being generated must be treated onsite or offsite, and the amount of leachate accumulation is largely out of the control of operators at BCRRC. However, the management of the leachate onsite is desirable for a number of reasons, but this will require the BCRRC to develop new infrastructure (wastewater treatment) that would decrease its dependence on trucking leachate to PVSC.

B. RECOMMENDATIONS

The current wastewater management practices at BCRRC focus on managing the entire wastewater volume as a mixed stream. This approach does not consider the makeup of the individual wastewater streams contributing to the total accumulated wastewater volume or the source of high nitrogen loads, which limits efficient and optimal management of the various water streams. A potentially better strategy is to ***manage each wastewater stream separately*** to achieve maximum reuse and onsite treatment opportunities, and so avoid the need for offsite transport over excessive distances. STRENGTHEN

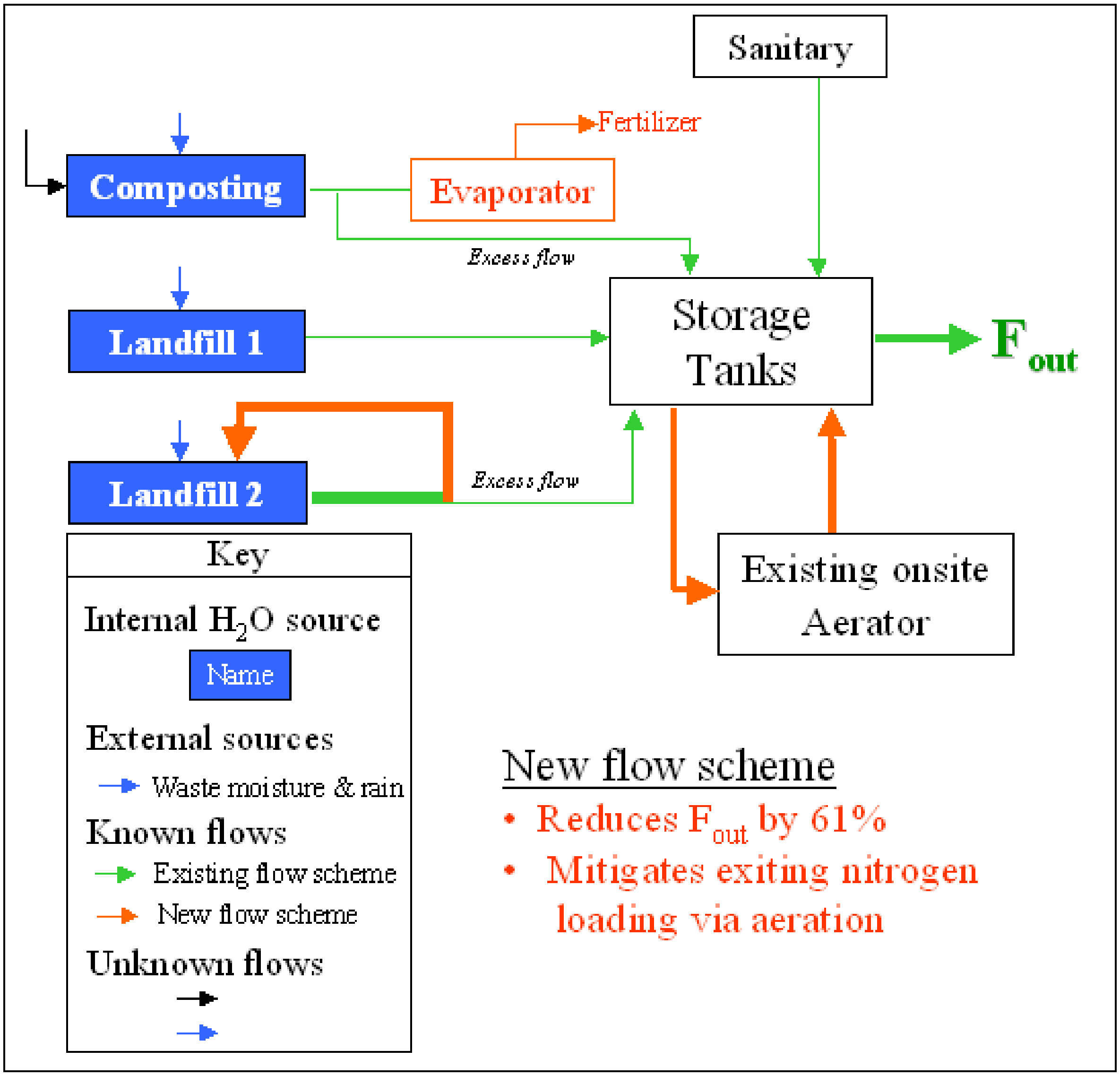


Fig. 4. Proposed water flow schematic for optimal BCRRC waste water management

➢ SEPARATE LANDFILL FLOWS FROM COMPOST FLOWS

Maximizing material recovery and reuse is a stated objective in dealing with all flows into and out of the BCRRC. The treatment and utilization strategies of water waste streams can be better optimized if the leachate from landfills 1 and 2 is not mixed with the waste water from the composting facility. The ammonium concentrations from the composting facility were an order of magnitude greater than those from either of the two landfills. In addition, the waste stream from the composting facility has had limited exposure to mixed wastes, which reduces the presence of toxic contaminants. Wastewater streams originating from "clean" organic operations such as the composting facility could potentially be processed for use as a fertilizer. Thus, it is useful to separate waste streams to be treated from waste streams that could be reused in some fashion. The benefits of separating the landfill and composting waste streams are that (1) the total leachate that is accumulated for treatment is decreased by as much as 12%; (2) the diverted stream could potentially be beneficially reused (possible revenue source); and (3) the nitrogen loading in the mixed stream is diminished somewhat, therefore decreasing the intensity of the subsequent wastewater treatment process (perhaps even providing the opportunity for further onsite treatment without leachate transport).

- TEST OF RECIRCULATION STRATEGIES

Bioreactor landfills, even in wet climates, have typically been able to handle recirculation of all associated leachate generated from the MSW, as well as leachate attributed to storm events. The continued use of the bioreactor landfill at the BCRRC in a water storage capacity is increasing the BCRRC's water handling, transport and offsite treatment requirements. The fear of side seepage and other operating problems has limited the facility's ability to seek solutions and implement appropriate recirculation strategies proposed in the bioreactor landfill's original design. Moreover the addition of an impermeable cover in 2007 has limited the contribution of leachate generated due to storm events. With the addition of the impermeable cover and separate treatment or disposal of runoff from the composting facility and leachate from Landfill 1, it is likely that accumulated leachate from Landfill 2 could be recirculated, eliminating the need for transport offsite for treatment. Enhancing the amount of recirculation could free up even more options for onsite treatment of leachate from Landfill 1 and runoff from the composting facility using structures that are currently used for leachate storage. This recirculation could also further enhance LFG generation from Landfill 2.

- UTILIZE EXISTING AERATION TANK TO TREAT EXCESS LANDFILL LEACHATE

It the Landfill 2 leachate is recirculated, and the compost facility waste stream is recovered for beneficial reuse, then the limited remaining or occasional excess leachate could be treated onsite. The goal of onsite treatment would not be to achieve discharge standards, but rather to meet minimal requirements of local wastewater treatment plants, rather than trucking leachate 70 miles to PVSC. Opening the existing BCRRC aeration tank would increase the facility's leachate storage capacity by 150,000 gallons (37.5% increase in overall capacity), and could be powered by electricity now being generated at the new electrical station. NEED BENEFITS OF AERATION

Wastewater management at the BCRRC needs to be comprehensive, and should focus on handling the various waste streams individually to maximize reuse and to minimize the need for offsite transport and treatment. Dealing with each stream separately would allow the existing infrastructure to become fully utilized. This would enhance the operators' ability to manage an effective recirculation strategy for Landfill 2, which could then begin to realize many of the original stated design objectives, including providing more LFG and minimizing leachate accumulation and removal requirements.

SYSTEM ENERGY BALANCE AND OVERALL ENERGY EFFICIENCY

An 'Energy Balance' for the BCRRC bioreactor landfill has been produced. This model can potentially be utilized to answer fundamental operating questions that would help planners and operators assess decisions based on the total energy consumed to process MSW through the BCRRC landfill. This model was presented as an invited paper at the Eleventh International Waste Management and Landfill Symposium held in Sardinia (October, 2007), and a copy of this paper can be found in Appendix 2. The Energy Balance Model was also presented as a poster (Appendix 2) at the New Jersey Meadowlands Commission's *Meadowlands Symposium* (May, 2007). A paper is also in preparation for submittal to a peer-reviewed scientific journal. Should the BCRRC increase operating efficiencies of the bioreactive landfill(s), utilizing the Energy Balance Model would further increase overall energy efficiency associated with the disposal of MSW at the BCRRC complex.

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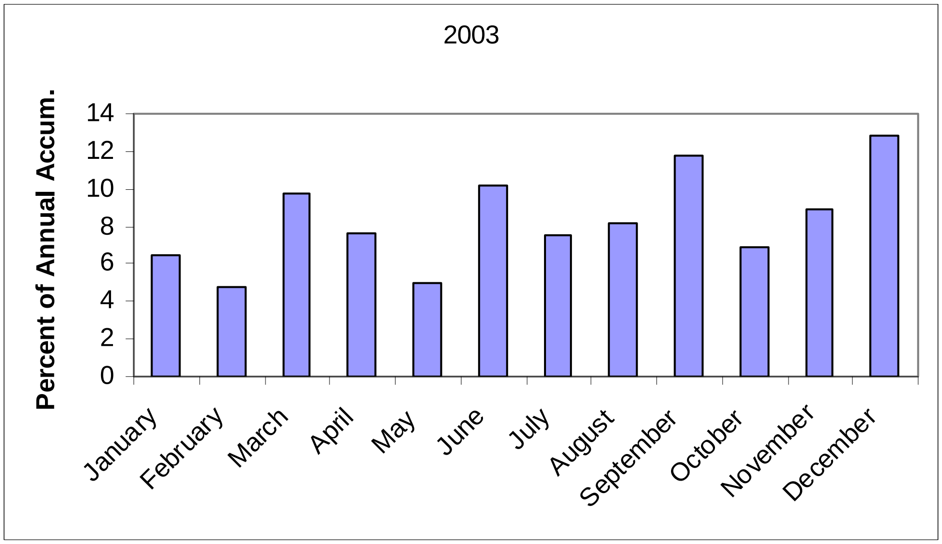
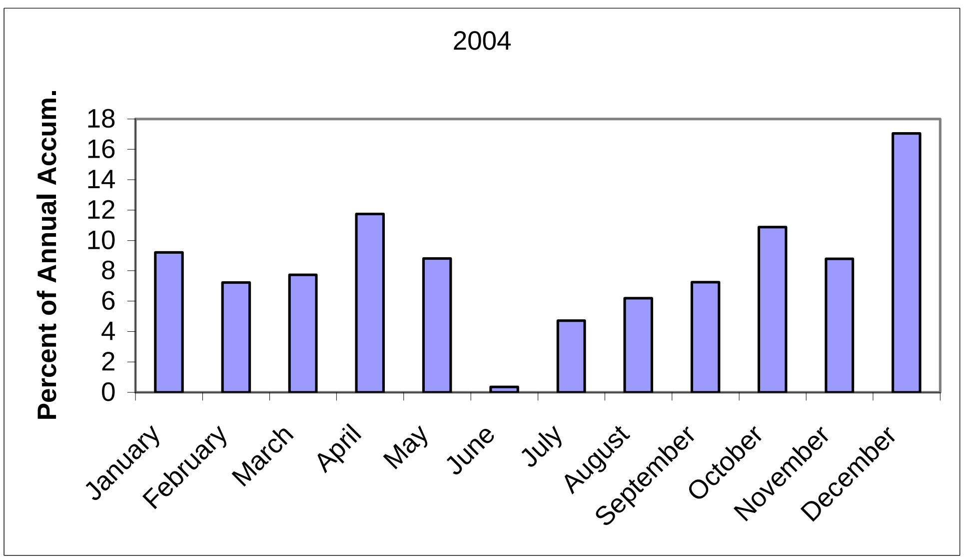
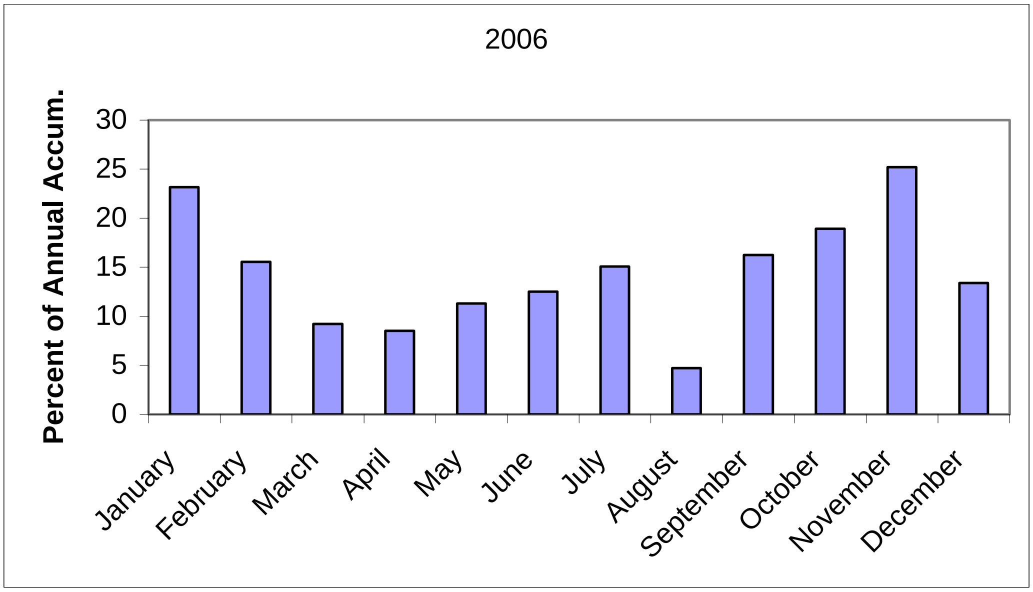
APPENDIX 1

Fig. 1. Monthly proportion of annual accumulated wastewater at the BCRRC from 2003 – 2006.







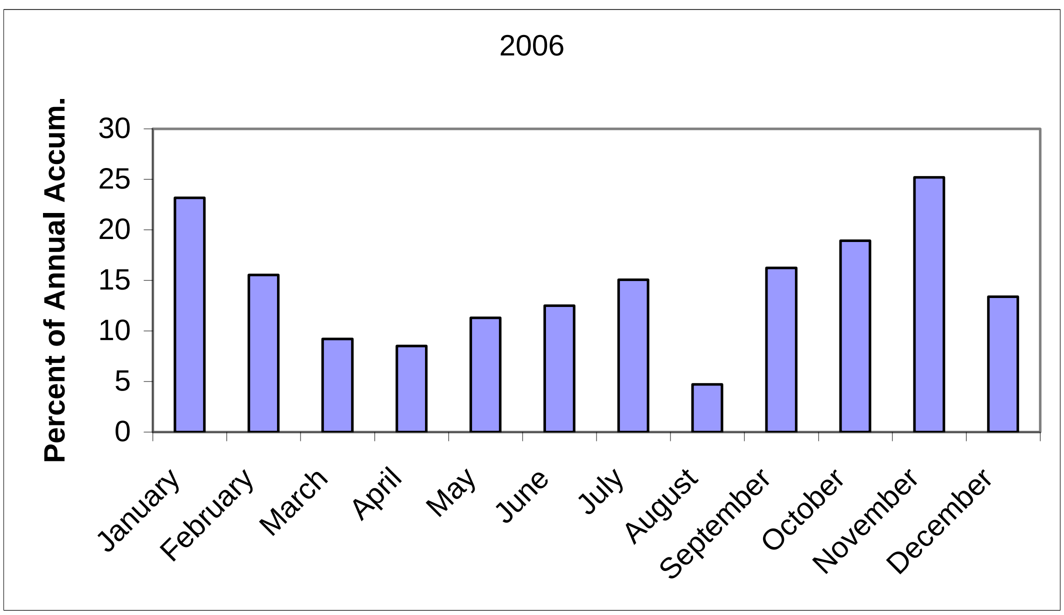
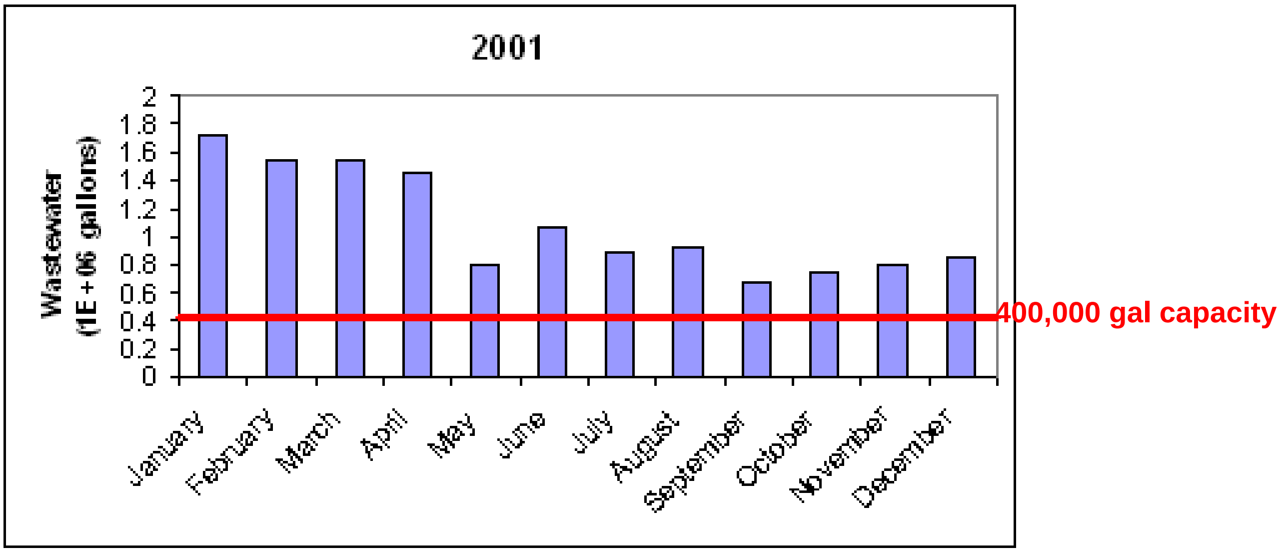
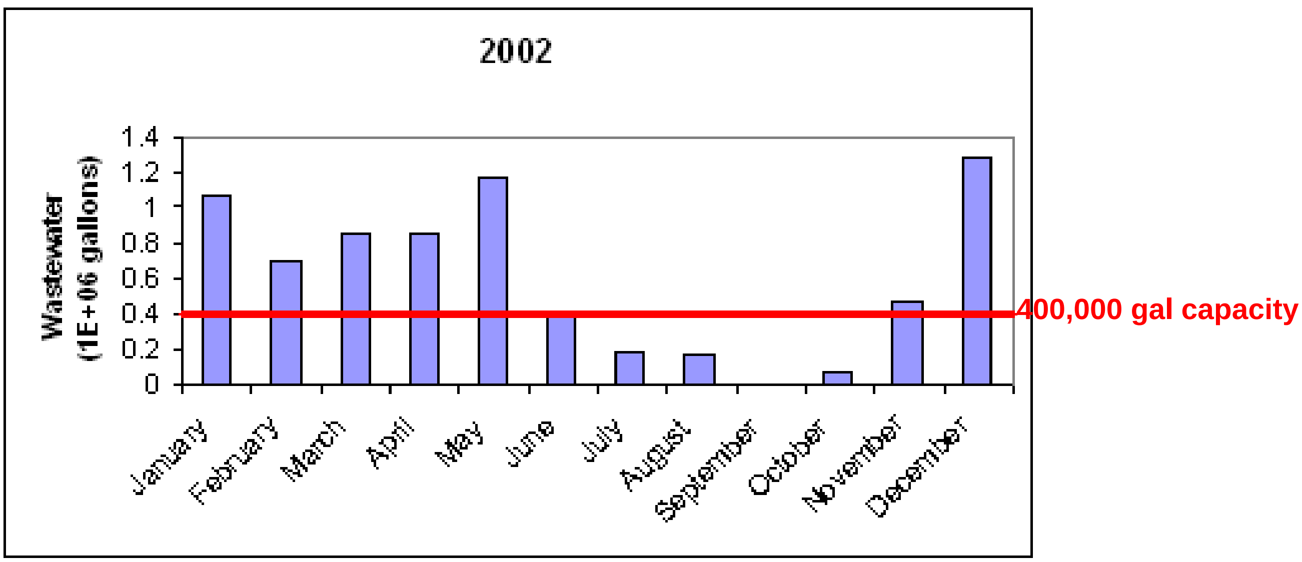
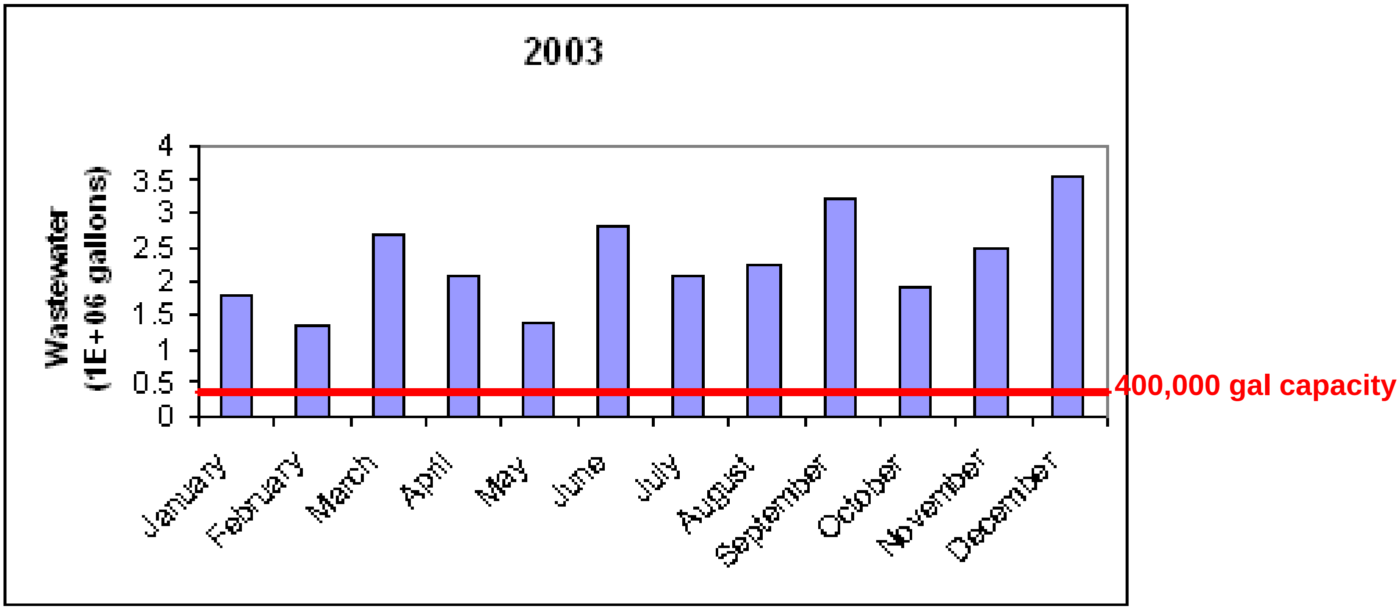
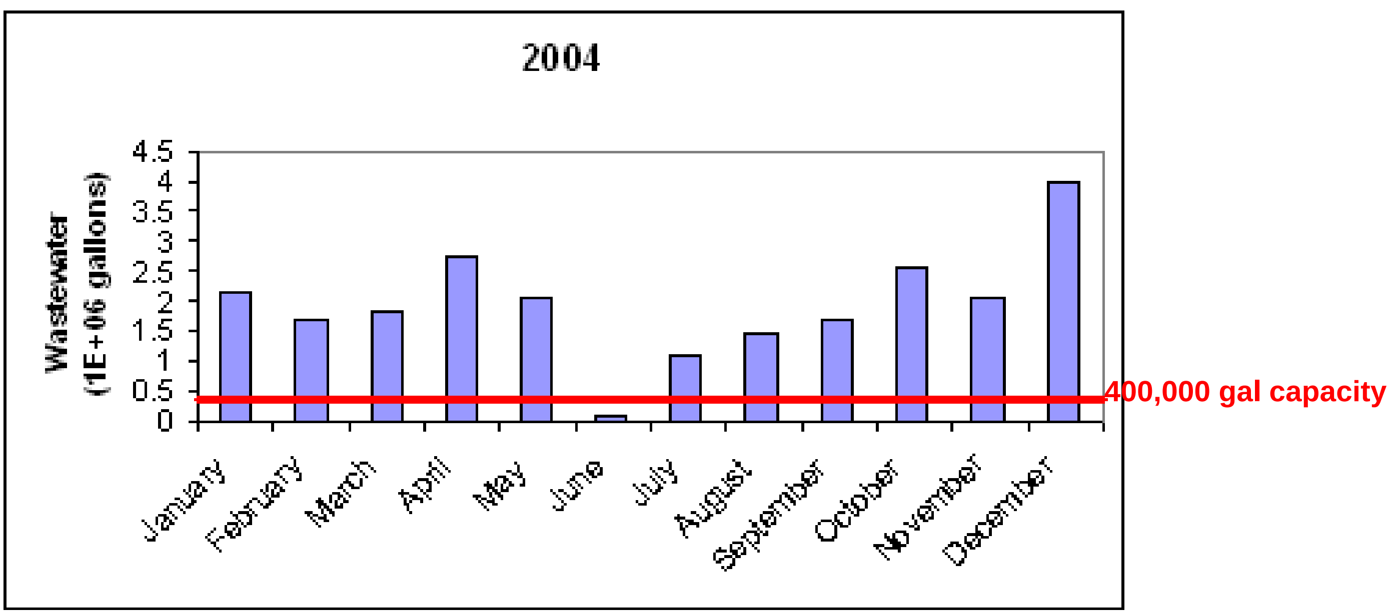


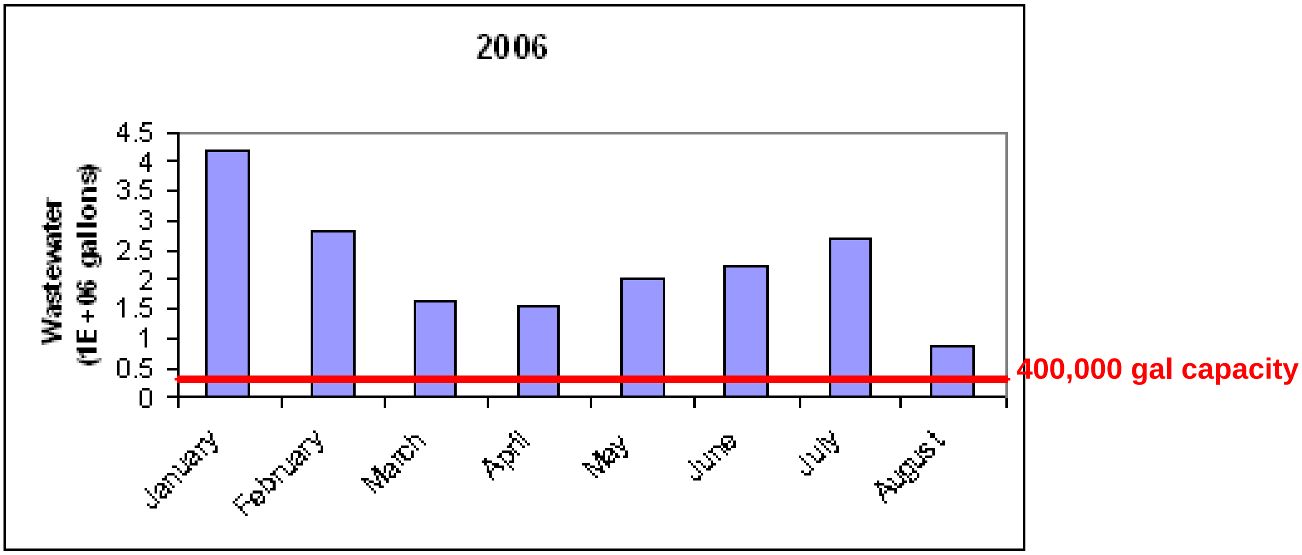
Fig. 2. Monthly accumulated wastewater volume at the BCRRC from 2001 – 2004, 2006.


2001
Wastewater (1E+06 gallons)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
400,000 gal capacity
January
February
March
April
May
June
July
August
September
October
November
December


2002
Wastewater (1E+06 gallons)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
400,000 gal capacity
January
February
March
April
May
June
July
August
September
October
November
December


2003
Wastewater
(1E+06 gallons)
4
3.5
3
2.5
2
1.5
1
0.5
0
400,000 gal capacity
January
February
March
April
May
June
July
August
September
October
November
December


2004
Wastewater
(1E+06 gallons)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
400,000 gal capacity
January
February
March
April
May
June
July
August
September
October
November
December


2006
Wastewater
(1E+06 gallons)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
January
February
March
April
May
June
July
August
400,000 gal capacity

APPENDIX 2

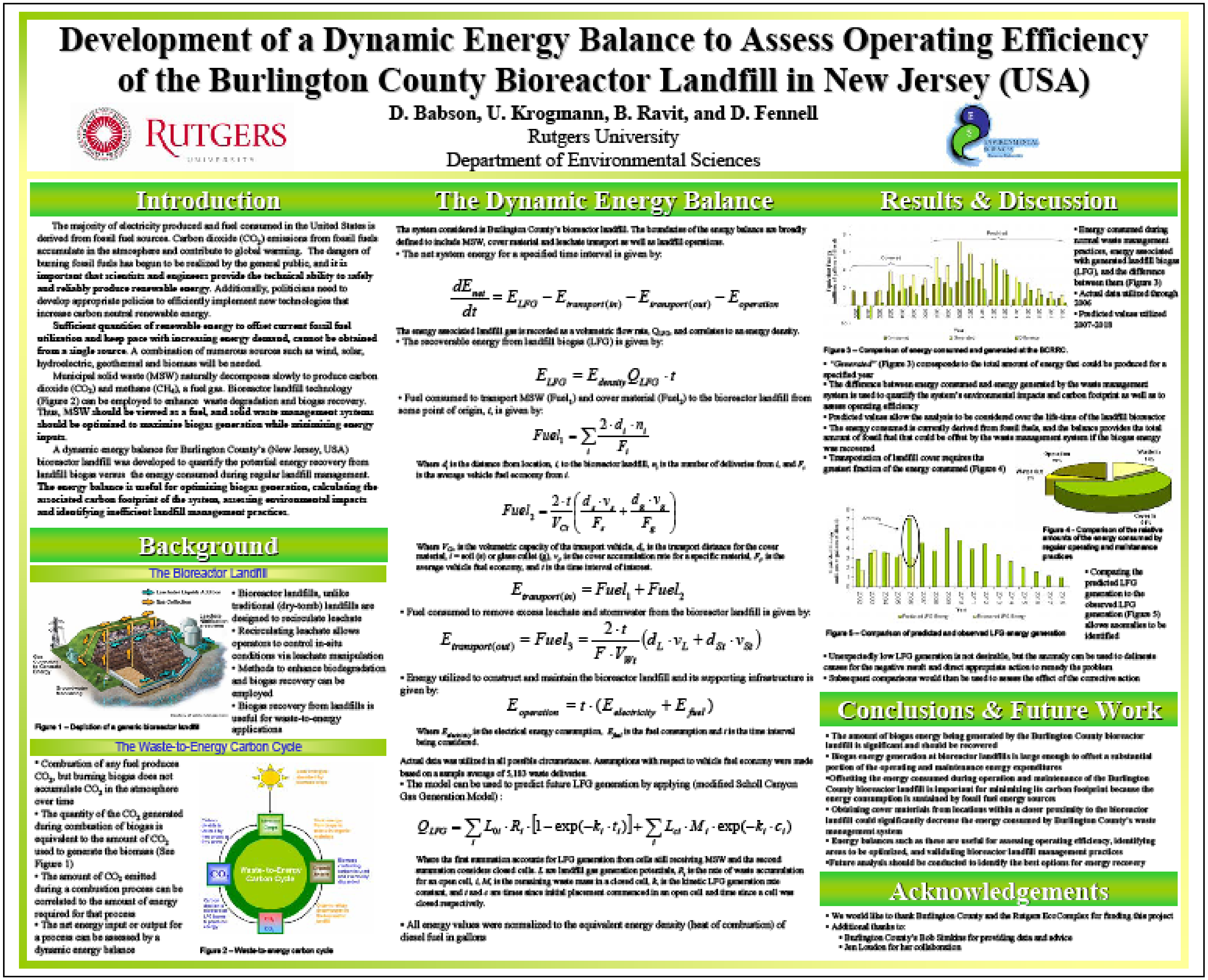
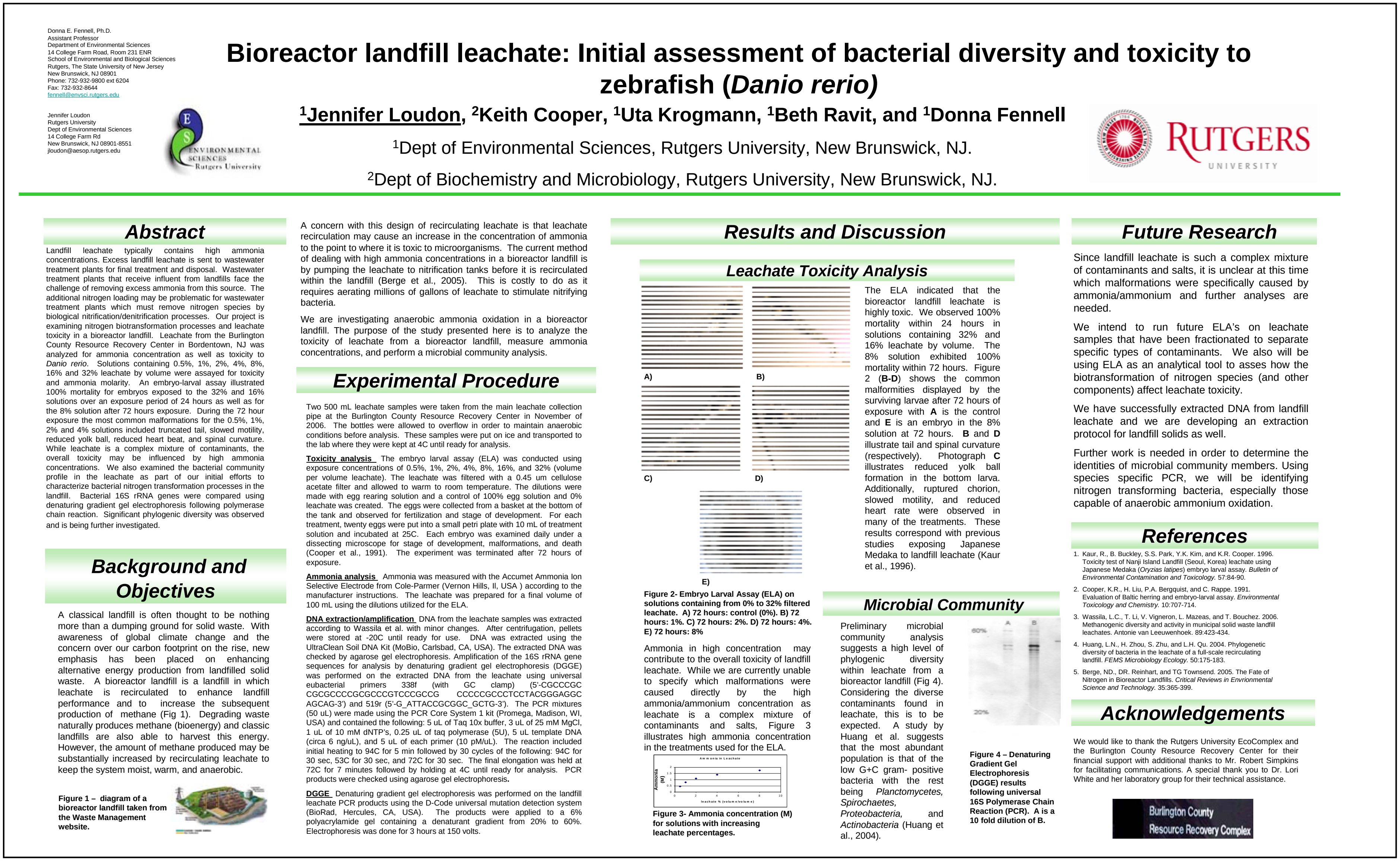


Fig. 1. Meadowlands Symposium Energy Balance Model (May, 2007)



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Bioreactor landfill leachate: Initial assessment of bacterial diversity and toxicity to zebrafish (*Danio rerio*)

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Abstract

Landfill leachate typically contains high ammonia concentrations. Excess landfill leachate is sent to wastewater treatment plants for final treatment and disposal. Wastewater treatment plants that receive influent from landfills face the challenge of removing excess ammonia from this source. The additional nitrogen loading may be problematic for wastewater treatment plants which must remove nitrogen species by biological nitrification/denitrification processes. Our project is examining nitrogen biotransformation processes and leachate toxicity in a bioreactor landfill. Leachate from the Burlington County Resource Recovery Center in Bordentown, NJ was analyzed for ammonia concentration as well as toxicity to *Danio rerio*. Solutions containing 0.5%, 1%, 2%, 4%, 8%, 16% and 32% leachate by volume were assayed for toxicity and ammonia molarity. An embryo-larval assay illustrated 100% mortality for embryos exposed to the 32% and 16% solutions over an exposure period of 24 hours as well as for the 8% solution after 72 hours exposure. During the 72 hour exposure the most common malformations for the 0.5%, 1%, 2% and 4% solutions included truncated tail, slowed motility, reduced yolk ball, reduced heart beat, and spinal curvature. While leachate is a complex mixture of contaminants, the overall toxicity may be influenced by high ammonia concentrations. We also examined the bacterial community profile in the leachate as part of our initial efforts to characterize bacterial nitrogen transformation processes in the landfill. Bacterial 16S rRNA genes were compared using denaturing gradient gel electrophoresis following polymerase chain reaction. Significant phylogenic diversity was observed and is being further investigated.

Background and Objectives

A classical landfill is often thought to be nothing more than a dumping ground for solid waste. With awareness of global climate change and the concern over our carbon footprint on the rise, new emphasis has been placed on enhancing alternative energy production from landfilled solid waste. A bioreactor landfill is a landfill in which leachate is recirculated to enhance landfill performance and to increase the subsequent production of methane (Fig 1). Degrading waste naturally produces methane (bioenergy) and classic landfills are also able to harvest this energy. However, the amount of methane produced may be substantially increased by recirculating leachate to keep the system moist, warm, and anaerobic.

Figure 1 – diagram of a bioreactor landfill taken from the Waste Management website.

A concern with this design of recirculating leachate is that leachate recirculation may cause an increase in the concentration of ammonia to the point to where it is toxic to microorganisms. The current method of dealing with high ammonia concentrations in a bioreactor landfill is by pumping the leachate to nitrification tanks before it is recirculated within the landfill (Berge et al., 2005). This is costly to do as it requires aerating millions of gallons of leachate to stimulate nitrifying bacteria.

We are investigating anaerobic ammonia oxidation in a bioreactor landfill. The purpose of the study presented here is to analyze the toxicity of leachate from a bioreactor landfill, measure ammonia concentrations, and perform a microbial community analysis.

Experimental Procedure

Two 500 mL leachate samples were taken from the main leachate collection pipe at the Burlington County Resource Recovery Center in November of 2006. The bottles were allowed to overflow in order to maintain anaerobic conditions before analysis. These samples were put on ice and transported to the lab where they were kept at 4C until ready for analysis.

Toxicity analysis The embryo larval assay (ELA) was conducted using exposure concentrations of 0.5%, 1%, 2%, 4%, 8%, 16%, and 32% (volume per volume leachate). The leachate was filtered with a 0.45 um cellulose acetate filter and allowed to warm to room temperature. The dilutions were made with egg rearing solution and a control of 100% egg solution and 0% leachate was created. The eggs were collected from a basket at the bottom of the tank and observed for fertilization and stage of development. For each treatment, twenty eggs were put into a small petri plate with 10 mL of treatment solution and incubated at 25C. Each embryo was examined daily under a dissecting microscope for stage of development, malformations, and death (Cooper et al., 1991). The experiment was terminated after 72 hours of exposure.

Ammonia analysis Ammonia was measured with the Accumet Ammonia Ion Selective Electrode from Cole-Parmer (Vernon Hills, Il, USA) according to the manufacturer instructions. The leachate was prepared for a final volume of 100 mL using the dilutions utilized for the ELA.

DNA extraction/amplification DNA from the leachate samples was extracted according to Wassila et al. with minor changes. After centrifugation, pellets were stored at -20C until ready for use. DNA was extracted using the UltraClean Soil DNA Kit (MoBio, Carlsbad, CA, USA). The extracted DNA was checked by agarose gel electrophoresis. Amplification of the 16S rRNA gene sequences for analysis by denaturing gradient gel electrophoresis (DGGE) was performed on the extracted DNA from the leachate using universal eubacterial primers 338f (with GC clamp) (5'-CGCCCGC CGCGCCCCGCGCCCGTCCCGCCG CCCCCGCCCTCCTACGGGAGGC AGCAG-3') and 519r (5'-G_ATTACCGCGGC_GCTG-3'). The PCR mixtures (50 uL) were made using the PCR Core System 1 kit (Promega, Madison, WI, USA) and contained the following: 5 uL of Taq 10x buffer, 3 uL of 25 mM MgCl, 1 uL of 10 mM dNTP's, 0.25 uL of taq polymerase (5U), 5 uL template DNA (circa 6 ng/uL), and 5 uL of each primer (10 pM/uL). The reaction included initial heating to 94C for 5 min followed by 30 cycles of the following: 94C for 30 sec, 53C for 30 sec, and 72C for 30 sec. The final elongation was held at 72C for 7 minutes followed by holding at 4C until ready for analysis. PCR products were checked using agarose gel electrophoresis.

DGGE Denaturing gradient gel electrophoresis was performed on the landfill leachate PCR products using the D-Code universal mutation detection system (BioRad, Hercules, CA, USA). The products were applied to a 6% polyacrylamide gel containing a denaturant gradient from 20% to 60%. Electrophoresis was done for 3 hours at 150 volts.

Results and Discussion

Leachate Toxicity Analysis

A) B) C) D) E)

Figure 2- Embryo Larval Assay (ELA) on solutions containing from 0% to 32% filtered leachate. A) 72 hours: control (0%). B) 72 hours: 1%. C) 72 hours: 2%. D) 72 hours: 4%. E) 72 hours: 8%

The ELA indicated that the bioreactor landfill leachate is highly toxic. We observed 100% mortality within 24 hours in solutions containing 32% and 16% leachate by volume. The 8% solution exhibited 100% mortality within 72 hours. Figure 2 (**B-D**) shows the common malformities displayed by the surviving larvae after 72 hours of exposure with **A** is the control and **E** is an embryo in the 8% solution at 72 hours. **B** and **D** illustrate tail and spinal curvature (respectively). Photograph **C** illustrates reduced yolk ball formation in the bottom larva. Additionally, ruptured chorion, slowed motility, and reduced heart rate were observed in many of the treatments. These results correspond with previous studies exposing Japanese Medaka to landfill leachate (Kaur et al., 1996).

Ammonia in high concentration may contribute to the overall toxicity of landfill leachate. While we are currently unable to specify which malformations were caused directly by the high ammonia/ammonium concentration as leachate is a complex mixture of contaminants and salts, Figure 3 illustrates high ammonia concentration in the treatments used for the ELA.

Ammonia in Leachate
Ammonia (M)
leachate % (volume/volume)

Figure 3- Ammonia concentration (M) for solutions with increasing leachate percentages.

Microbial Community

Preliminary microbial community analysis suggests a high level of phylogenic diversity within leachate from a bioreactor landfill (Fig 4). Considering the diverse contaminants found in leachate, this is to be expected. A study by Huang et al. suggests that the most abundant population is that of the low G+C gram- positive bacteria with the rest being *Planctomycetes, Spirochaetes, Proteobacteria,* and *Actinobacteria* (Huang et al., 2004).

A B 60% 20%

Figure 4 – Denaturing Gradient Gel Electrophoresis (DGGE) results following universal 16S Polymerase Chain Reaction (PCR). A is a 10 fold dilution of B.

Future Research

Since landfill leachate is such a complex mixture of contaminants and salts, it is unclear at this time which malformations were specifically caused by ammonia/ammonium and further analyses are needed.

We intend to run future ELA's on leachate samples that have been fractionated to separate specific types of contaminants. We also will be using ELA as an analytical tool to asses how the biotransformation of nitrogen species (and other components) affect leachate toxicity.

We have successfully extracted DNA from landfill leachate and we are developing an extraction protocol for landfill solids as well.

Further work is needed in order to determine the identities of microbial community members. Using species specific PCR, we will be identifying nitrogen transforming bacteria, especially those capable of anaerobic ammonium oxidation.

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Fig. 2. Poster presented at the SETAC 2007 New Jersey-Delaware Regional Meeting.