Post Closure Care (PCC) Termination Plans: Principles and Needs (11-27-12)

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Abstract: The requirements to establish a methodology for the determination of PCC termination are given in two parts; firstly with a discussion of the basic principles; and secondly, with a review of Allen County Landfill data as an example of using limited data which are typically available for Subtitle D landfills in Kansas. The final conclusion is that a successful PCC termination plan must be based on a predetermined monitoring plan designed to provide the data necessary for the methodology used to determine a PCC termination date.

Statement of Purpose

Traditional approvals for landfill's permit applications concerning a PCC plan have been typically general without any detailed information for the particular landfill site. General statements have included the following areas of concern (or needs) for the proposed PCC plan:

1. Definition of the final use(s) of the closed site.
2. Funding for the PCC period with supporting worksheets and a certificate of liability insurance.
3. Inspection and maintenance of site topography, access roads, final cover, and surface water, leachate and landfill gas monitoring and collection systems.
4. Monitoring plans for Item 3 systems to insure the protection of health and environment.
5. Contingency plans for system failures.
6. Preparation of a certification of PCC termination by a registered professional engineer.

A common omission to the proposed plan is a clearly defined approach to identify the actual termination date of the PCC period. It is the purpose of this presentation to provide a detailed outline for a PCC termination plan; its determination and implementation. Part I will discuss determination fundamentals and Part II will demonstrate the implementation part using Allen County Landfill data.

Basis for PCC

The PCC period begins after final closure of the landfill. It is required by State law to last for 30 years unless the director of KDHE determines that it can be shortened or should be lengthened. As stated previously, this document will provide the detail to make this determination.

Part I – Determination of PCC Termination Plan

Termination Prediction Methodologies

There are three possible approaches to determine when PCC can end without any future harm to human health and the environment.[1] These include the determination of the stability of the stored municipal solid waste (MSW) mass; the stability of the leachate and landfill gas (LFG) emissions emanating from the MSW to define it's stability, and a combination of the in situ (internal) and emission (external) approaches. The broad use of the term stability means that the state of the MSW will be such that it will not create any threats to human health or environment. An alternate and more inferred definition of MSW stability is one used by the State of Wisconsin that says a stable MSW is one with a reduced degradable organic material content.[2] Both describe a type of stability, but the presence of one does not prove the presence of the other.

Trend Analysis

Both states of stability of the MSW and/or emissions are determined by measuring quantity and quality changes over time, i.e., by using trend analysis.[3,4] In both cases, a stable situation would be one where there are no significant changes of the stored MSW and/or the emissions emanating from the MSWLF with time. Using the Wisconsin definition, various measurable parameters of organic content would be used to define the reduction in degradable organic content with time. It is normally expected that these various parameters would decrease with time until they approach some asymptotic and acceptable value which would signal the point in time when the landfill can be considered stable and ready to be certified for final closure. In the more general case, the degradable organic content of the MSW could remain unchanged with a similar result.

In Situ (Internal) Approach

The most direct way to determine if a MSW mass is stable is to measure the mass itself. This means that representative samples must be taken within the landfill mass and the samples must be analyzed for some characteristic of the MSW which directly relates to the potentially unstable part of the MSW. This is typically the waste's degradable organic material; its biodegradable paper, food items, etc. Because of the heterogeneous nature of the MSW and the large sample size required to perform the required analytical test (the large sample must be coned and quartered to produce the required sample for testing), the results of this approach can be quite variable and the ability to take subsequent samples which are directly comparable with the previously collected samples is extremely difficult. However, there are benchmarks and presumed statistical methods which can be used to attempt such a comparison.[1,,3, 4]

Another aspect of in situ sampling is the need to sample all the different phases of the closed landfill. This means that the closed landfill's horizontal and vertical phase boundaries must be known so that core samples can be taken within those zones and so that the stability of each phase can be determined. A complicating factor is the possibility that perched leachate may be present in the phase itself. Perched leachate can result from the application of intermediate and/or daily cover, or from low permeability compacted wastes. If perched leachate exists, then the leachate must be separated from

the MSW to determine the quality of the MSW itself. This would require separating the liquid using gravity rather than a laboratory approach like centrifugation or filtration.

Because of the preceding complications and the fact that emissions are actually a representation of the whole of the MSW mass, it is recommended that the testing of emissions be used to judge the stability of the MSW mass.[5] This recommendation also negates the third option which is a combination of the in situ and emission methods. Therefore the use of emissions to determine PCC termination will be the focus of this presentation.

Emissions (External) Approach

The two major emissions emanating from the landfill are leachate and LFG. It must be recognized that all the leachate may not find its way to the leachate collection sump (e.g., perched leachate mentioned earlier) and all the LFG is not removed by the LFG collection system, whether passive or active. Also, some quantity of leachate will leak through the landfill liner and/or escape as seepage from a covered and closed site.

The following discussion has to do with possible methods to quantify the typical emissions of leachate and LFG into constructed collection systems. The basic intent is to provide information which can be used to predict when PCC can end using trend analysis. The information will include quantity and quality data for a variety of emission parameters which result from the possible stabilization of the landfill mass. Leachate and LFG emissions will be discussed separately but it should be recognized that they are companion effects, i.e., the result of anaerobic stabilization of MSW and one generally doesn't happen without the other. An exception to this would be where the microbial life within the MSW is killed or retarted; resulting in the cessation of LFG production. Meanwhile, leachate generation would continue, especially in the presence of moisture addition due to physical and chemical reactions occurring within the MSW mass.

Leachate

a. Quantity (or Flows)

Leachate results primarily from the addition of precipitation to the landfill mass. This source, including recirculation of leachate, addition of storm water and/or RD&D liquids, enhance MSW stabilization and result in the further production of leachate.[6] Also, leachate is produced when water indigenous to the MSW results in bioactivity which produces leachate (In general, aerobic decomposition produces water while anaerobic consumes water). Groundwater intrusion can result in leachate production if it is not properly excluded from the landfill mass.

When evaluating landfill leachate quantity; precipitation, recirculation, surface water and RD&D liquid additions, and even groundwater flow inputs should be determined on an as added basis (if possible). On-site weather stations are preferred since precipitation is quite variable even in smaller watersheds. If site specific historical data are not available, then local weather station information can

be used.[7] Recirculation and/or RD&D or other possible liquid additions can be determined from pumping, hauling or weight station records. Also, these records should cite the locations where the liquids were applied to the working face. Groundwater intrusion is more difficult to measure but is only a concern if it enters the waste mass or is comingled with and undifferentiated from leachate after collection. Typically it is collected in "toe drains" external to the liner and is not part of a water balance.

As stated previously, liquid addition records are preferred but quarterly records are considered a minimum. It is believed that less frequent measurements will prevent important correlations from being developed which are necessary to determine PCC termination. However, this observation has not been validated. Obviously, too much time between measurements prevent a trend from being determined at all. Annually is the maximum time period between measurements.

Leachate is typically collected in a sump at the bottom of the landfill phase although gravity flow is possible depending on the topography of the area. When leachate is collected via a sump, the best measure of leachate flow is obtained by dividing the volume of leachate pumped by the time period between pumping periods. Flow measurement and recording devices should be installed for each phase of operation in order to distinguish between the different leachate sources. Oftentimes, combined leachate flows are the only values available. This complicates the interpretation of leachate quality data but is better than no data. Typically, closed phases will have diminished leachate production; especially if there is an impervious cover on the top of the phase.

Surplus leachate must eventually be disposed of and the most common method of disposal is in a Publically Owned Treatment Works (POTW). Prior to hauling to a POTW, it is usually stored in a tank and/or a storage and evaporation lagoon (SEL). It is important to measure the amount in the tank or the height in the basin on a weekly basis since it will be important that a leachate production value can be estimated if leachate flow measurements (as mentioned previously) and precipitation records are not available. Ouputs from a SEL include evaporation which can be estimated from county evaporation maps. Seepage should not be a problem since the SEL must have an impervious liner. A leachate tank is more expensive but for water balance purposes it has the advantage of not being affected by evaporation or precipitation. Collection of storage volume or depth data is a backup to leachate flow measurement data but is best used to manage the level condition in the storage units.

b. Quality (or Concentrations)

There are suggested parameters to measure for the determination of the degree of stabilization occurring in the MSW mass itself and how it is manifested in the leachate leaving the landfill.[8] Similar to in situ sampling, the parameters measure organic materials which are biodegradable or the byproducts of the degradation process. The key to such measurements, besides being reflective of the MSW stabilization process, is the need to have a representative sample of the leachate.[9] Typically, this is a grab sample of such size as to meet the analytical needs of the testing laboratory.

There are typically four leachate sampling options based on the leachate streams leaving an active phase, from individual closed phases or combined leachate streams from multiple phases. The first two options involve streams that flow by gravity into a leachate storage facility or into a wetwell where it must be pumped to a storage facility, typically at a higher elevation. The other two options are where leachate pumps (typically more than one since a standby pump is advantageous) are installed in a sump within the phase(s) and the leachate is removed intermittently depending on predetermined set points which are set to limit the maximum head on the impervious geomembrane and to prevent pump cavitation due to leachate drawdown. Leachate streams initiated by the discharge of leachate pumps can flow into a leachate storage facility or into a wetwell where another pump is used to transport the leachate to storage. This latter arrangement is uncommon and not preferred. The best arrangement for obtaining a representative sample of the "freshest" leachage is where the leachate flows directly from an individual phase into the leachate storage basin or into a wetwell. Combined flows are typical but not preferred since the state of MSW stabilization in the individual phases will vary and cannot be determined. On the other hand, the determination of PCC termination will be based on the collective emissions from all the phases.

In order to collect a representative or the "freshest" leachate sample, the sampler must know when the leachate pump is about to turn off since the liquid volume entering the pump at this time is closest in quality to the leachate exiting the MSW mass than prior to this time. The actual pump shutoff time is typically not known unless there is some type of recording or indicating system. It could be any time unless on/off times are known from recording, indicating or prior observations for a given installation. If they are not known, then observations must be made to determine the leachate pump's typical frequency of operation. Assuming that one knows when the pump will stop, a sampler could manually turn the pump on again so that a sample could be collected which is closer to being a "fresh" leachate sample than a sample taking during the normal pump operating cycle. Care must be exercised to insure that the pump does not cavitate.

It is realized that some samplers may believe that the leachate quality may not vary significantly during the time that the leachate pump is operating. However, given the fact that the leachate has settled during the time that the pump is not in operation, this would suggest that the TSS level is higher in the first part of the discharges than in the latter. This should be confirmed by sampling the pump discharges with time. TSS measurements should be made, at a minimum; right after the pump starts its cycle, midway between and just prior to shutoff. The number of samples should increase proportionally with the length of the on-cycle. Samples can be taken at the point nearest the pump discharge, either in a manifold, a wet well or a discharge pipe leading into the leachate storage tank or SEL.

TSS measurements are not as easily measured in the field as are other parameters (e.g., turbidity, pH, conductivity, temperature, chloride and dissolved oxygen where direct reading probes are available). However, it is after the point where the TSS level becomes more constant when the leachate is the freshest.

Leachate samples should be taken quarterly at the start of a PCC termination determination sampling program. The annual leachate sample should be a part of this sampling effort. It is important that all samples should follow an established sampling protocol which is designed to produce the most representative sample possible as previously discussed. The quarterly sampling will provide results which can be used to see if short term trends exist and whether there is a large variation in leachate quality between short term samples, especially if there is an upset or change in the operation of the landfill which produces an noticeable increase or decrease in the leachate volume, e.g., landfill fire, unusual recirculation rates, changes in surface water diversion near the working face, or long periods of heavy precipitation. If there are no significant changes, then the interval between leachage samples can be increased. The maximum period is one year according to Kansas Regulations.[10]

Occasionally, leachate collection piping and/or a leachate sump is cleaned by blowing air and/or water into these units. The two together will create a turbulent backflow condition. When water is used, it contributes to the leachate volume so the amount of water used should be recorded. Air can affect the anaerobic conditions in the bottom of the landfill but it should be the most stable part of the landfill phase and any upset to the anaerobic conditions of the landfill should be restored inversely to the amount of air used. For either air or water flushing, the MSW mass needs to be allowed to return to normal anaerobic conditions prior to leachate sampling. For liquid flushing this would consist of recovering at least the flush volume of leachate. Also, for either flushing technique, checking to be sure the post-flush as-pumped leachate temperatures are at their pre-flush levels is suggested.

Landfill Gas

LFG quantity and quality measurements are complicated by the fact that not all landfills have collection systems to facilitate these measurements. Some landfills have systems on closed phases and even fewer have them on the active phase. Some have wells that go to different depths; others only withdraw gas from a shallow depth assuming that the gas migrates vertically to the gas collection location. Some have passive collection systems where the gases themselves provide the pressure to collect the gases. Others have active systems where a pump is used to remove the accumulated gases. The former will have less chance for air intrusion into the gas samples while the latter can be over-pumped resulting in air intrusion affecting gas samples. A recent paper discussing the quantification of LFG emissions is given in Reference 11. LFG collection with liquid addition is discussed in Reference 12.

a. Quantity (or Flow)

Individual gas wells should have flow and pressure meters along with a sample fitting. Modern LFG wellheads provide the necessary appurtenances to do this and to control LFG flow. Also, the gas collection system should have flow totalizers for each phase of operation or, at the very least, a totalizing flow meter at the LFG discharge point. It is important to know the atmospheric pressure and temperature in order to estimate the standardized gas flow. Meter readings should be made weekly and records kept of individual phase flows and total LFG flows at standard conditions. It is important

that readings be made before and after operational changes in gas well flow rates in order to judge the impact of these changes.

b. Quality (or Concentration)

LFG analytical parameters should include those listed in Reference 8. The design of a LFG sampling probe and procedure for getting a representative sample are discussed in Reference 13. Trend analysis for LFG quantity and quality should indicate whether stabilization is occurring or has subsided and an equilibrium condition exists. It is important to relate changes in LFG production and/or quality to operational changes in the landfill and LFG collection system operation.

Judging the End of PCC, Mass Flow Measurements and Combined Emissions

The best way to demonstrate that a landfill is nearing an acceptable PCC date is by comparing the emission values to see if they change within the normal precision of the given parameter, i.e., do the values stay within the standard deviation of the parameter as determined by reported laboratory studies and/or the deviation reported by the laboratory performing the emission testing. If they are not changing, then PCC termination can be predicted with greater assurance. Another requirement for identifying the conclusion of PCC will be the establishment of MCL's for the key stabilization parameters.[1] An MCL would be whatever value is acceptable in terms of disposing of the leachate and LFG to it final destination. For leachate, it is the pretreatment requirements of a POTW or an on-site treatment system with the MCLs required for disposal of the treated leachate to the environment. It is assumed that these latter constraints would be the current values according to the Clean Water Act (see 40 CFR 445) and the Clean Air Act (see 40 CFR 60 and 63) for leachate and LFG emissions, respectively. Another suggested leachate requirement for any discharge to a receiving stream is to conduct a static bioassay.[3] Although not required by CWA landfill regulations, this would assure that there is nothing in the discharge, not measure by conventional parameters, which would endanger aquatic species.

A final requirement is to determine the mass flow rate of the contaminant since this represents the actual amount of contaminant released to the environment (see **Part II**, **Subpart c**. **Mass Flow Rate**). For a receiving stream situation, this would determine the maximum daily load that would be allowable by the discharge. These latter two points reflect the concern for the release of the emissions to the environment, not the stability of the landfill as judged by the first criterion.

Obviously, both emissions sources are a reflection of what is going on in the landfill itself; hence, both should show similar trends as suggested by several authors.[14 to 16] However, **each landfill situation is unique and should be treated accordingly**. This is another reason for collecting quality data when making a prediction based on past measurements.

Part II - Implementation of PCC Termination Plan: A Case Study

The Allen County Landfill (ACL) will be used as the pilot project to demonstrate the implementation process. It is very important to note that the historical ACL data collection effort was not established using the preceding principles but their data are used in this document to demonstrate the correct method and to illustrate the kinds of data management problems associated with conventional data collection efforts as required by current State regulations. However, given this situation, it is important to note that the ACL data demonstrate definite trends in emission behavior even though the landfill is years away from closure and post closure. This could be used as an argument against more frequent emission testing (see opening paragraph on page 5). Planned sampling efforts at the ACL (and Johnson County Landfill) will provide clarifying information regarding this need.

The reasons for selecting the ACL as a pilot landfill are because of the ease of cooperation with the landfill staff as approved by the County Engineer, the simplicity of the ACL site compared to the previously considered MSWLF pilot sites in Johnson and Shawnee counties, and the seven years of multiple or quarterly leachate sampling data available in eleven years of annual sampling data (actually 12 years of data are available but only the first 11 were used for this study).

Allen County Landfill

The ACL is located six miles east of Iola and one mile southeast of La Harpe, KS. It is surrounded by agricultural land and it operates adjacent to an active County owned limestone quarry. The ACL has been in operation since 1976 and it operates six days a week throughout the year with MSW being the primary waste although there are separate sites for industrial and C&D wastes. A June 2008 permit modification report stated that there is approximately 72 years of additional landfill capacity associated with the new landfill sites.[17]

The ACL includes a closed 12.5 acre pre-Subtitle D cell, two closed Subtitle D cells (Phases I and II) of about 4.5 and 8.4 acres, respectively; a 5.7 acre industrial waste cell and a 5.9 acre C&D cell. The existing 40+ acres and the June 2008 proposed new sites include Subtitle D Phases 1A and 1B expanding to Phases 4A and 4B with eight total phases in all (see Figure1). The cell sizes range from 4.4 to 5.9 acres each with an increased C&D acreage of 3.3 acres and an increase in the landfill footprint of about 40 acres.[17] The 2008 expansion also included the construction of two leachate SELs Nos. 1 and 2, having an area of about 2.3 acres for Cell 1A and B, and 2A and B including Phases I and II leachate, and 1.6 acres for cells 3A and B and 4A and B. Cell 1A is the currently active phase.

Past and Present Emissions Situation

a. Quantity (or Flow)

LFG emissions are collected from 16 wells located in the closed pre-Subtitle D, vertical expansion part of the ACL (Note that gas wells used as vents in Phase I are no longer functioning). The 16 wells provide gas to heat an on-site maintenance building or it is burned at a nearby on-site flare without any heat recovery. Leachate is collected from the close and active phases and is either recycled to the active

face in Cell 1A or hauled offsite for ultimate disposal to a local publically owned treatment works (POTW) in La Harpe, Gas City or Humbolt. La Harpe is the most commonly used treatment facility.

Allen County recirculates leachate at the working face to aide compaction. It should be noted that the ACL has historically used RWD No. 8 water on the active face of the landfill when leachate is not available or for some other reason, e.g., equipment accessibility. Attempts were made to collect water purchase data from the supplier and from the ACL to validate the amount of RWD used at the landfill face. However, there were very limited data because RWD No. 8 recently lost their historical usage data base and Allen County has only limited water payment information for their usage. ACL did not use RWD water or leachate when there were significant precipitation events (Note that no correction was made for this assumption in the water balance calculations. See discussion in **Subpart f**).

The LFG's temperature and methane, carbon dioxide and oxygen concentrations for each of the sixteen wells are checked monthly at the flare and at the wellheads. LFG is metered at the flare and a flow rate recorded on a monthly basis, but it is not adjusted to standard conditions and a cumulative gas production value is not recorded. These data are not considered in this analysis since they emanate from the pre-Subtitle D site where leachate data are not available. However, it should be recognized that the LFG quality and quantity data should be related to leachate volume and quality data for sites where the two emissions are quantified.

Leachate emissions from Phases I and II along with Cell 1A are pumped into SEL No. 1. Phases I and II leachate flows into a wet well by gravity and is then pumped to SEL No. 1 while Cell 1A leachate flow is pumped directly to the same basin. Liquid from the toe drain is treated as leachate and is pumped from a toe drain sump periodically. These leachate sources are applied to the working face or hauled off site for disposal. Indirect leachate flow values for Cell 1A and Phases I and II can be estimated from depth measurements in the SEL except these values do not reflect the effect of precipitation and/or evaporation on the depth measurements. There are recorders for Phases I and II flows going into the wet well, but there is only limited data which are questionable because of meter malfunctions.

A leachate haul log has been kept since 2002 to provide a daily record of leachate volumes for disposal or recycling. These are not leachate generation volumes since they are not adjusted for precipitation or evaporation. Days when leachate was not recycled were days when RWD No. 8 water was used at the working face. The reported recycled and disposed volumes are estimated volumes based on the size of the vehicle (tanker truck or hydroseeder) used to haul the leachate. The addition of water or leachate to the working face began in 2002 when the County purchased a hydroseeder.

Leachate addition to the working face depends primarily on logistics and site conditions, i.e., is equipment (e.g., leachate loading pump) available and/or does the pond level need lowering to provide more freeboard? Recirculation is limited to 10,000 gallons per day by the site's permit and is typically limited to 2,700 gallons per day (three hydroseeder tank capacities), while a truck can dispose over 8,000 gallons per trip to the POTW and make multiple trips per day. It has been recently recommended

that the weight of a typical hauled leachate load should be determined so that a more accurate measure of historical and future leachate volumes can be estimated.

b. Quality (or Concentration)

As stated previously, the LFG collection system is not installed in the area from which leachate is collected; and it is not known if a LFG system will be installed in the Subtitle D phases after final closure. If a system is installed, then LFG emissions can be used along with leachate data to evaluate the state of ACL's stabilization process although pre-closure comparisons are not possible.

Annual leachate samples have been collected since 2001 to comply with State monitoring regulations. On seven separate occasions, quarterly or multiple samples were taken and analyzed in order to satisfy the needs of the POTW receiving the leachate. All of the results were checked using ion and mass balances (see Figures 2 and 3, respectively). These ratios should be 1.0 if an ideal analysis is performed. The ion balance data tend to be consistently less than one while the mass balance data is consistently higher than one. The cation totals are higher indicating that there are anions that were not measured and/or some measurements were incorrect. The TDS data should be more consistent indicating that some of the assumed ions and/or molecules were insoluble and not actually dissolved. Typically the mass balance comparison is not as good as the ion balance comparison which is reflected in the greater deviation of the former from the 1.0 value. However, it should be noted Figure 3 is in error because the TDS values that were calculated from ion concentrations and not an analytical procedure to determine the total dissolved mass which would also include the molecular species. The point of this discussion is that the results of laboratory analyses should not be assumed OK; however, there is usually more error associated with the sampling effort to obtain a representative sample than with the laboratory determinations. On the other hand, each sample, regardless of how poorly sampled, should be electrically neutral for the total sample and the parts should equal the whole for the insoluble (TSS) and soluble (TDS) phases. Only the latter mass balance was estimated for the ACL data.

Leachate samples, prior to the startup of Phase 1A and the construction of SEL No. 1, were taken at the Phases I and II wet well. After this (between 1-25-10 and 4-14-10), grab leachate samples were taken from SEL No. 1. They were not individual samples collected and composited from Phase 1A and Phases I and II discharge points. This means that the reported leachate results represent the liquid contained in the basin and are not an indicator of actual leachate qualities since the basin contents are a non-uniform mixture of previous flows including precipitation inputs and evaporation outputs. Also, the leachate samples were taken from the surface of the SEB which means that the TSS profile in the basin was ignored.

It should also be pointed out that there were no corresponding leachate flow measurements for the leachate quality measurements, i.e., sump meter readings and SEL volumes measurements were not taken and recorded on the same day or at the same time when the leachate samples were taken. This situation is complicated by the fact that all leachate flows are initiated by leachate levels in the leachate sumps which means that leachate may not be flowing when the samples are taken from the SEB or the

wet well (instead of the discharge pipe into the wet well). Or, if the leachate sample was taken at the point of discharge into the SEB basin or the wet well, the leachate flow is not the true flow since it is not the flow entering the sump but the flow rate of the pump moving leachate out of the sump. Prior to the 2008 expansion and the wetwell's installation leachate flows were not metered. Meters for the Phase I and II wetwell discharge and for Phase 1A's discharge were installed with the expansion concurrent with the SEB. However, as stated previously, meter malfunctions have resulted in incomplete flow data.

c. Mass Flow Rate

The reason that the flow measurement is important is because the mass flow rate of the various parameters can be determined. Flow rate data allows determination of the actual amount of leachate components leaving the landfill as opposed to a concentration measurement which only identifies the magnitude of the substance present. Theoretically, the mass flow of concerned substances should decline with time as the MSW emissions approach equilibrium. For example, the BOD_5 will approach a minimum value concentration-wise, but the important fact is whether the mass flow is decreasing because of reduced leachate flow rate?

d. Climatological (Temperature and Precipitation)

The closest weather station for the ACL is Chanute's. Daily values of temperature and precipitation were available.

e. Frequency of Data Collection for Optimal Data Reduction

ACL reported tonnage data for MSW, special and industrial wastes on a monthly basis; leachate haul data were estimated daily; leachate analyses data were reported quarterly or at multiple times and annually by certified laboratories; leachate SEL data were estimated periodical or intermittent by ACL personnel as was leachate flow recorder data; and off-site climatological (temperature and precipitation) data were measured daily by a government weather station and reported as per Reference 7.

The ability to use trend analysis when comparing different variables will depend on a common data recording period. The use of ACL data were limited by the annual leachate quality data (except for those years where quarterly or multiple samples were taken). It is apparent from the quality plots that quarterly data added confidence to the results. This would be especially true for situations involving changes in the operation of the landfill. Therefore, It is preferred that all the data collection efforts should be geared to provide quarterly comparisons until it can be established that less frequent monitoring is satisfactory. More frequent monitoring of other data can be done, e.g., climatological, leachate production, etc., if it is economical and serves another purpose besides the prediction of PCC termination.

F. Trends and Trend Analysis

The key trend parameters for establishing the stability of the ACL are leachate volume and flowrate, BOD_5, COD, NH_3, TSS and pH. Figure 4 is a plot of the BOD_5 and COD data which shows a typical decay in the surrogate organic concentrations of the leachate. This would be indicative of the changing MSW organic content which results in the production of substances measurable by the two tests. This can include products related to the biostabilization reactions (hydrolysis and oxidation of the biodegradable organic material); production of solutes leached and chemical reaction products resulting from the interaction between water and the MSW. Another way of saying this is that the incoming liquid BOD_5 and COD concentrations are increased because of the transformation of MSW to substances measurable by the two tests even though they are not a measure of the MSW itself. Also, the trend data would suggest that the leachate contributions from Cell 1A are minor compared to the other leachate sources since the trend curves are decreasing. This conclusion cannot be substantiated because separate leachate volumes and qualities from the different phases were not measured.

The change in TSS concentrations, based on samples taken from SEB (on line in 4-4-10) and the leachate storage tank, are shown in Figure 5. Like Figure 4, there are obvious outliers, but the general trend in TSS data is similar to the BOD_5 and COD data. A limited study was made of TSS levels in the leachate from Phase 1A after the leachate pump started pumping leachate (Note that this is the best location to determine the actual or "fresh" leachate quality). The purpose was to determine if the TSS levels dropped the longer the sump pump remained on. The results of this study are shown in Table 1. The results show a TSS decay indicating that, even though the TSS level is quite small, there is a leveling out to an equilibrium "fresh" leachate value; hence, the need to sample the pump discharge after the TSS level has stabilized. Since each landfill leachate removal system is unique, it would be useful to validate the conclusion of Table 1 to confirm the possibility of sedimentation prior to the leachate removal operation. Although not proven from Table 1, it is believed that the leachate TSS level (and quantity or flux value) was affected by antecedent precipitation. This conclusion is based on observations of gravity leachate flow from Phases I and II which actually stopped at times. No record was kept to determine the extent of the stoppage.

The change in NH_3 is shown in Figure 6. This parameter should increase with time due to the endogenous respiration of microbial mass formed from the metabolism of biodegradable MSW organic matter during the stabilization process. Endogenous respiration releases ammonia. Figure 7 is a plot of the leachate pH. The gradual rise in pH is a better indication of the increase in NH_3 since this would cause the pH to increase due its combination with hydrogen in the leachate; the result being the formation of NH_4^+.

An even better indication for all these parameters would be mass flow plots but the corresponding concentration and leachate flow rates were not available. A crude estimate for BOD_5 mass flow is shown in Figure 8.

BOD_5, TSS, NH_3 and pH results are compared with 40CFR 445.21 requirements in Table 2. This is an unrealistic comparison since the ACL leachate data are not representative of the true leachate as

stated earlier, i.e., they are based on grab samples from the SEL No.1. However, it does show the required MCLs for the leachate if it were to be discharged into a receiving stream. The comparison table also demonstrates new requirements for sampling frequency and the different parameters that must be measured if the leachate is to satisfy the stated MCLs. It should be recognized that a major concern of leachate from closed landfills is the possibility of increasing NH_3 (see Reference 19), although other researchers noted a downward trend.[4] Another concern is that the existing pH levels exceed the reported 6.6 to 7.4 range recommended for the final phase of anaerobic stabilization involving methogens.[20]

The leachate volume and tonnage plot (Figure 9) indicates that there is a strong relationship between leachate volume and MSW tonnage additions. This fact combined with the previous suggestion and the downward trend of the pollutant parameters suggests MSW stabilization is occurring. How long it will take until the pollutant levels are reduced to acceptable MCL values has to be determined.

Figure 10 is based on the water balance results for the ACL. It is assumed that the bulk of the input water (MSW moisture, precipitation, RWD No. 8 and recycled leachate) is absorbed into the MSW mass, principally the paper in the MSW. The estimated moisture levels shown in Figure 11 for the MSW are less than that required for bioreactor operation and the known moisture holding capacity of MSW. Although not conclusive from this plot, it appears that the leachate produced is a result of the moisture holding capacity of the MSW being exceeded in some portions of the landfill mass. Although not provable, another possibility is that preferential flow is responsible for leachate production in landfills. Either way, leachate is produced and has to be dealt with.

Summary and Recommendations

It is clear that despite the lack of a planned monitoring effort, the stability of the ACL can be approximated by the current data collection efforts used by the ACL. However, it is also apparent that there is a lot of scatter in the ACL data which would be less if a proper sampling and coordinated data collection effort had been conducted as described herein. It is recommended that the desired results would be more convincing if a planned data collection effort was made to confirm the proposed methodology. This would not require a lot of changes at the ACL , and likely at other landfills, if they want to improved the possibility of better defining their trend analysis based on landfill emissions. Basically, quality and quality leachate and LFG measurements must be coordinated to allow mass flow rates to be determined for the various contaminants of concern and these values must be compared with emission MCLs controlling their discharge to the environment. An ideal data collection plan is shown in Table 3 so that existing landfills can work to this goal as they make improvements in their operation and capital improvements.

Acknowledgements

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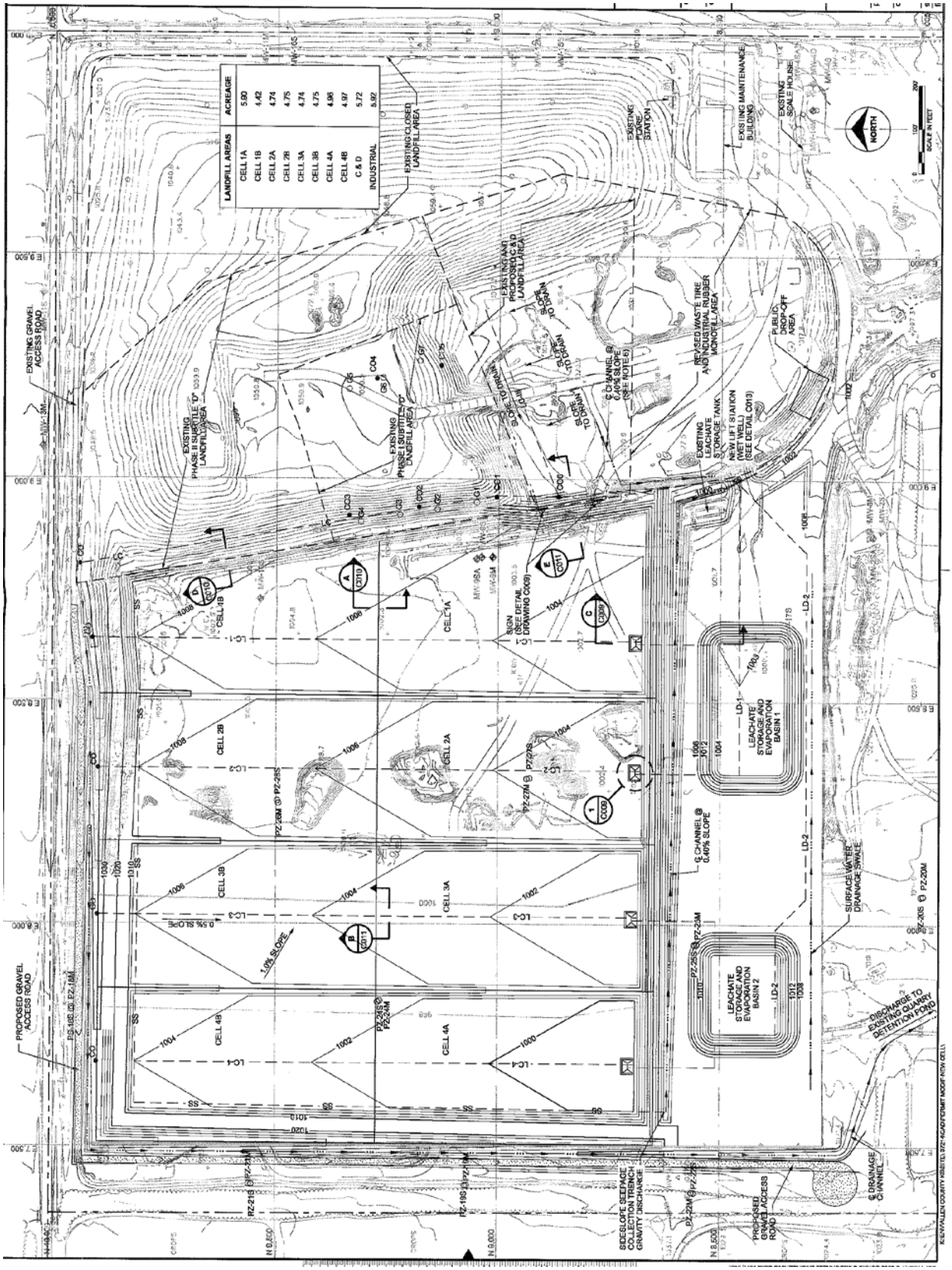
Figure 1 – Allen County Landfill Plat C003[18]



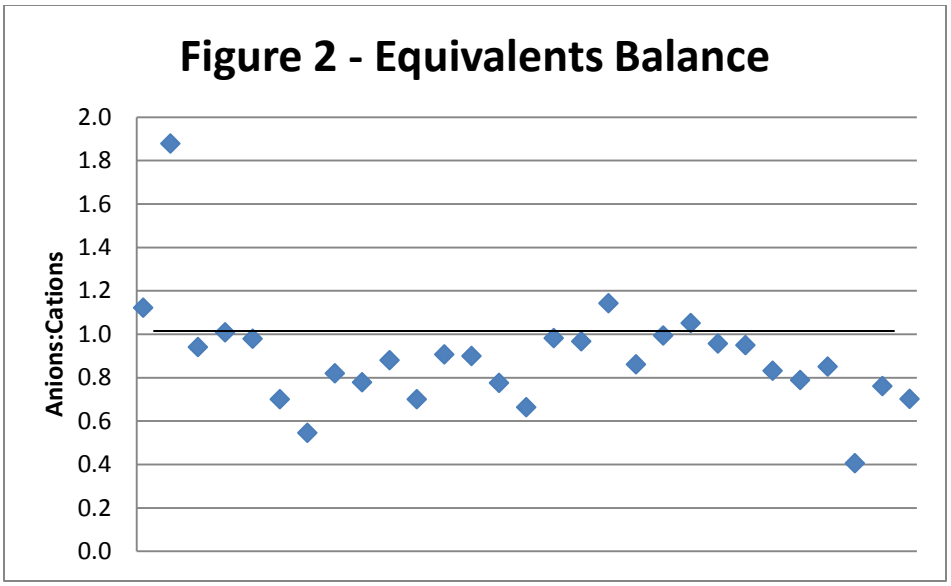


Figure 2 - Equivalents Balance
Anions:Cations
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

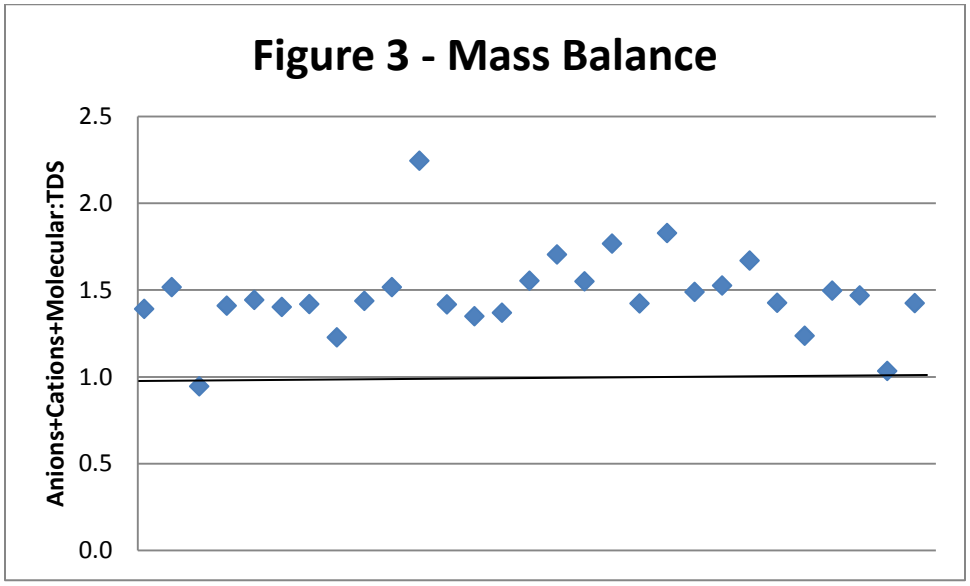


Figure 3 - Mass Balance
Anions+Cations+Molecular:TDS
2.5
2.0
1.5
1.0
0.5
0.0

Figure 4 - ACL Surrogate Organics (mg/L)

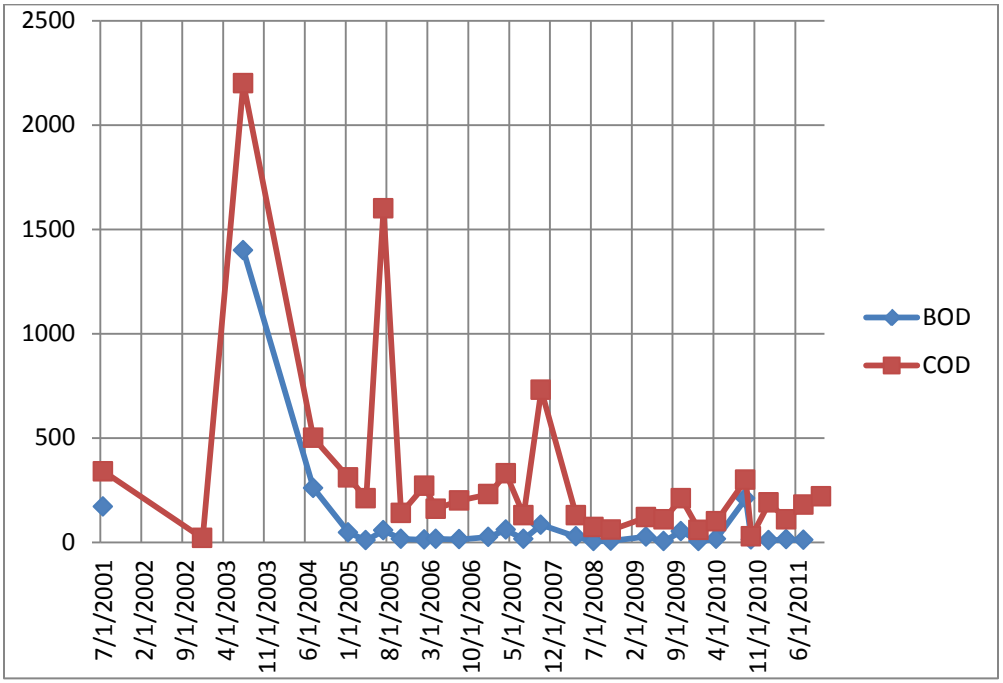
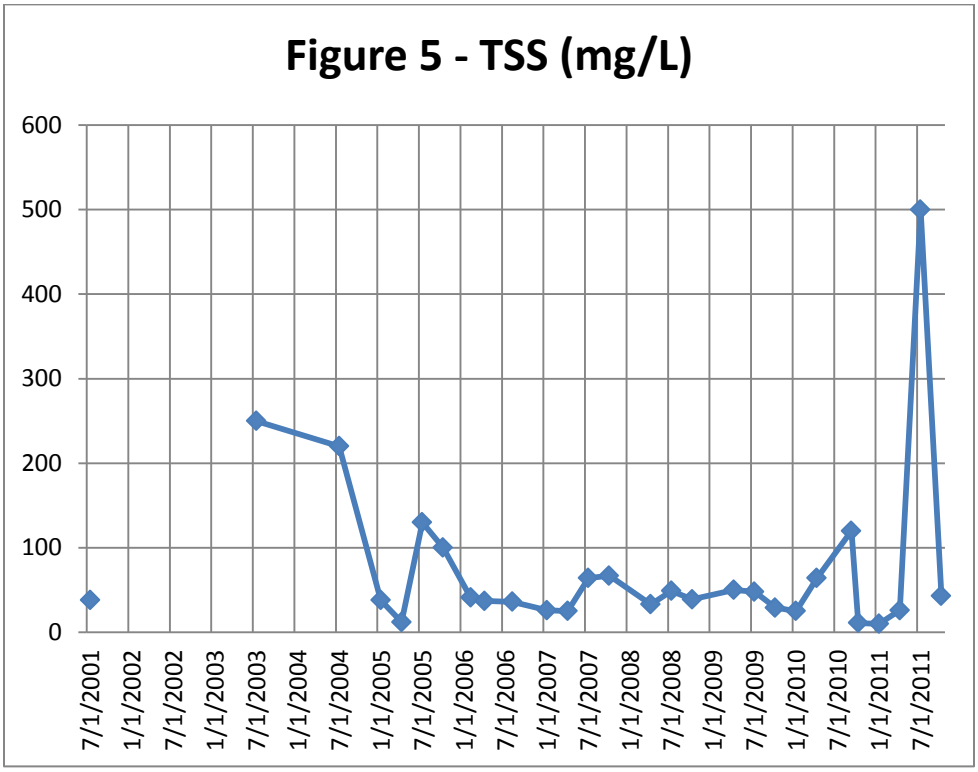


Figure 5 - TSS (mg/L)



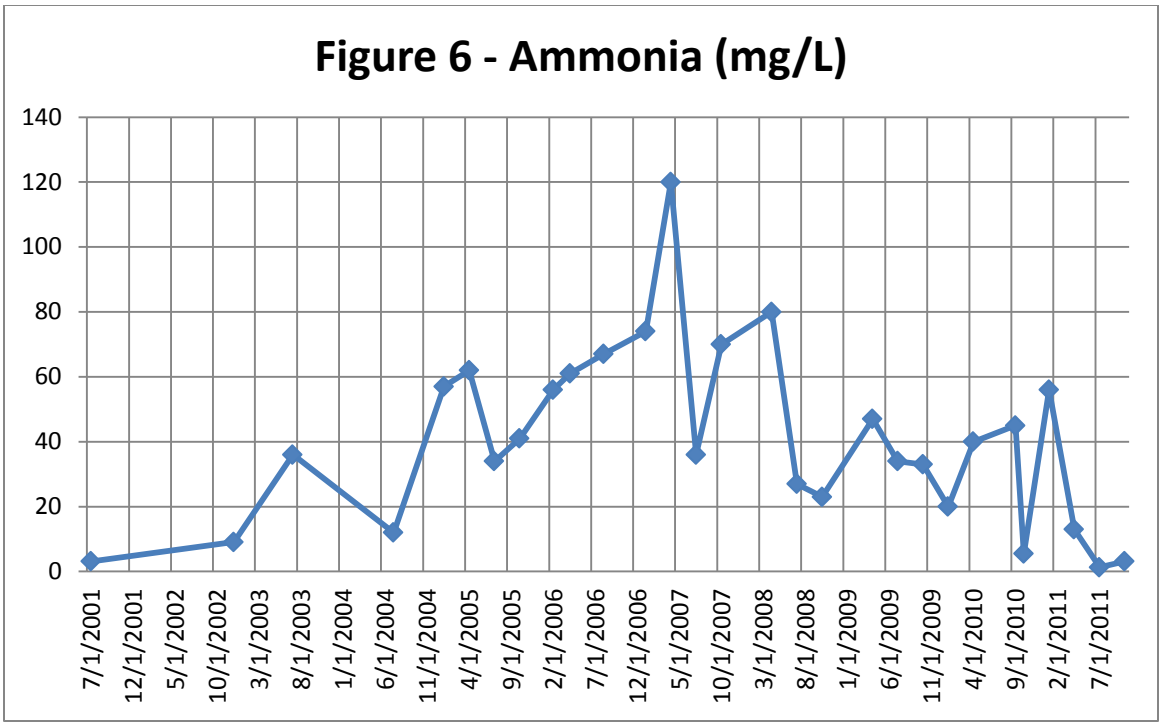


Figure 6 - Ammonia (mg/L)
140
120
100
80
60
40
20
0
7/1/2001
12/1/2001
5/1/2002
10/1/2002
3/1/2003
8/1/2003
1/1/2004
6/1/2004
11/1/2004
4/1/2005
9/1/2005
2/1/2006
7/1/2006
12/1/2006
5/1/2007
10/1/2007
3/1/2008
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1/1/2009
6/1/2009
11/1/2009
4/1/2010
9/1/2010
2/1/2011
7/1/2011

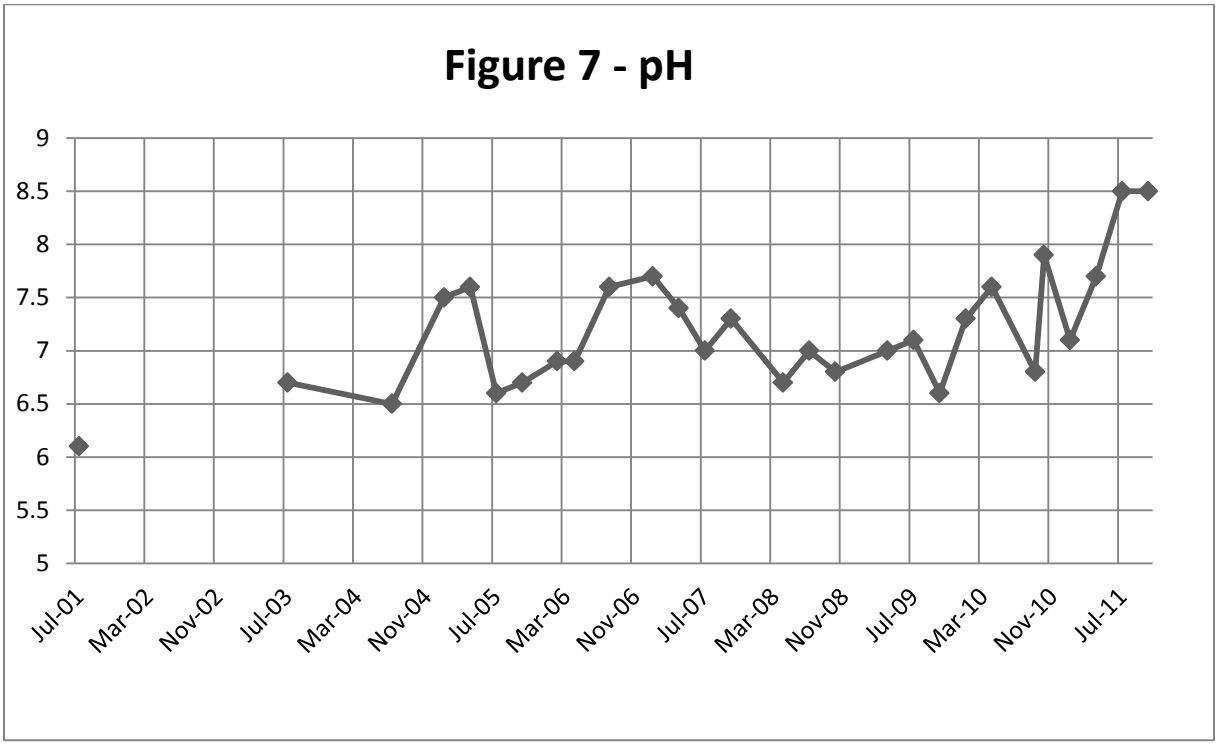
Figure 7 - pH
9
8.5
8
7.5
7
6.5
6
5.5
5
Jul-01
Mar-02
Nov-02
Jul-03
Mar-04
Nov-04
Jul-05
Mar-06
Nov-06
Jul-07
Mar-08
Nov-08
Jul-09
Mar-10
Nov-10
Jul-11

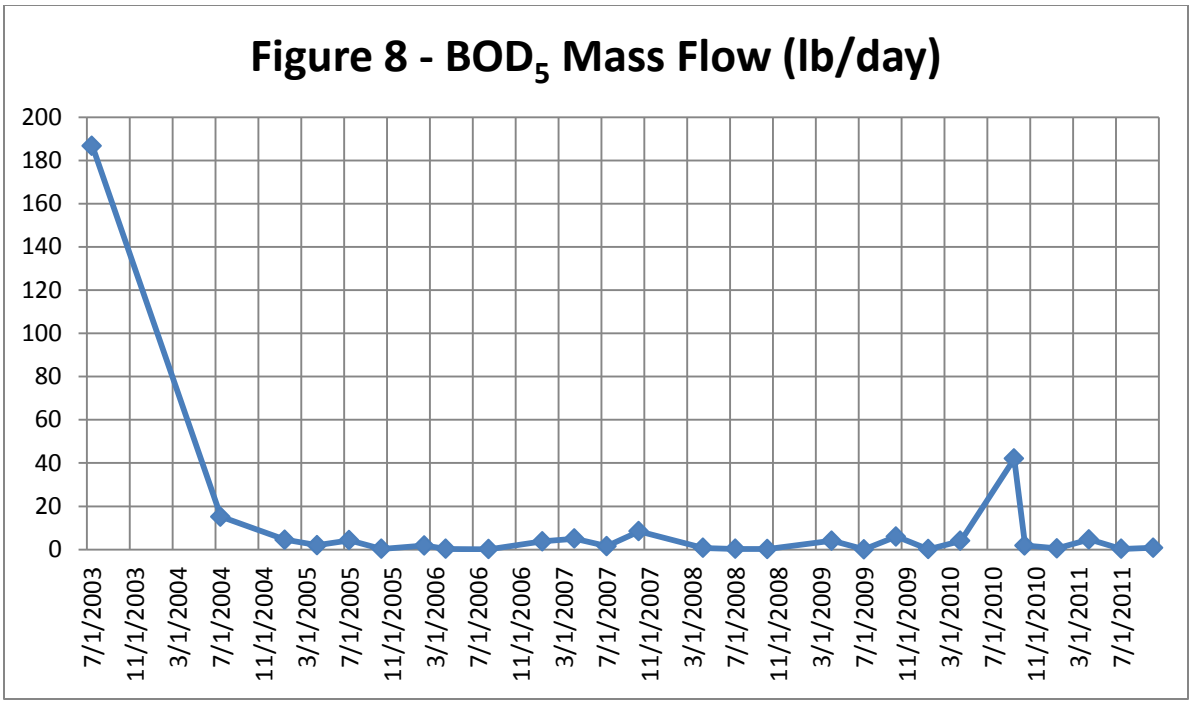
Figure 8 - BOD5 Mass Flow (lb/day)
200
180
160
140
120
100
80
60
40
20
0
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
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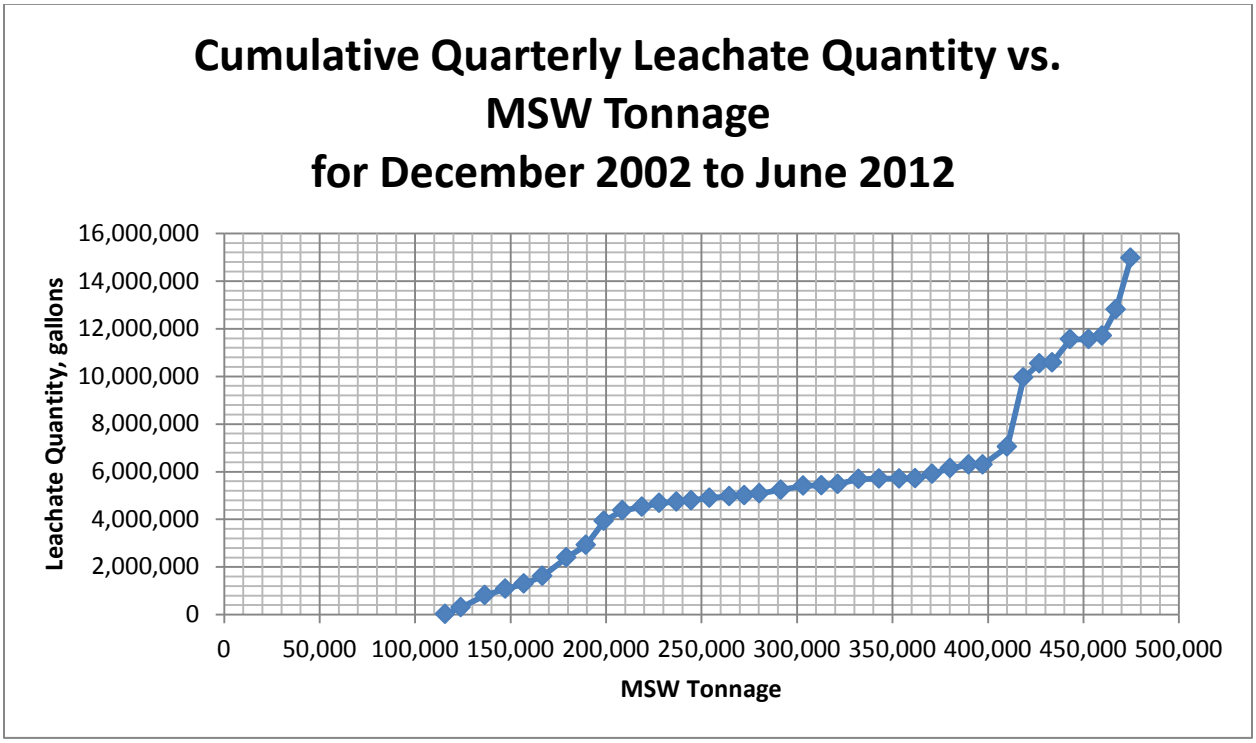
11/1/2010
3/1/2011
7/1/2011


Cumulative Quarterly Leachate Quantity vs.
MSW Tonnage
for December 2002 to June 2012
Leachate Quantity, gallons
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
400,000
450,000
500,000
MSW Tonnage

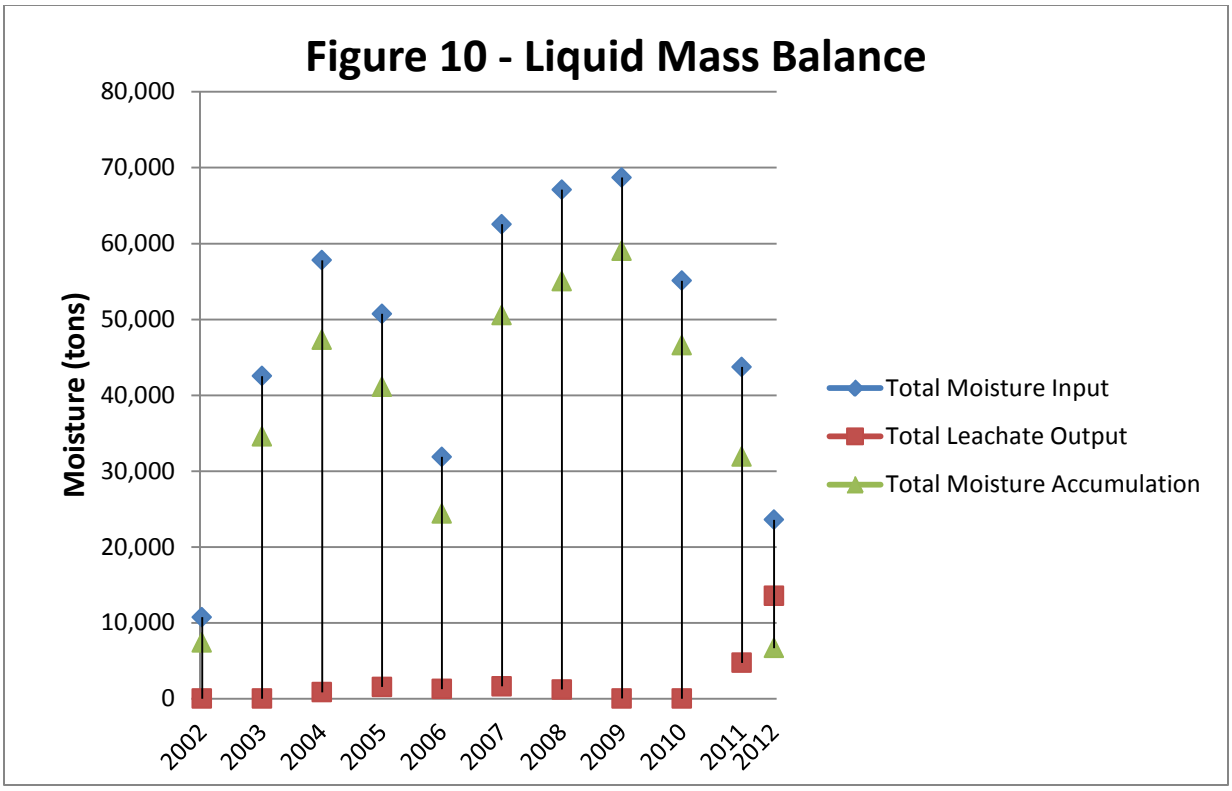


Figure 10 - Liquid Mass Balance
Moisture (tons)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Total Moisture Input
Total Leachate Output
Total Moisture Accumulation

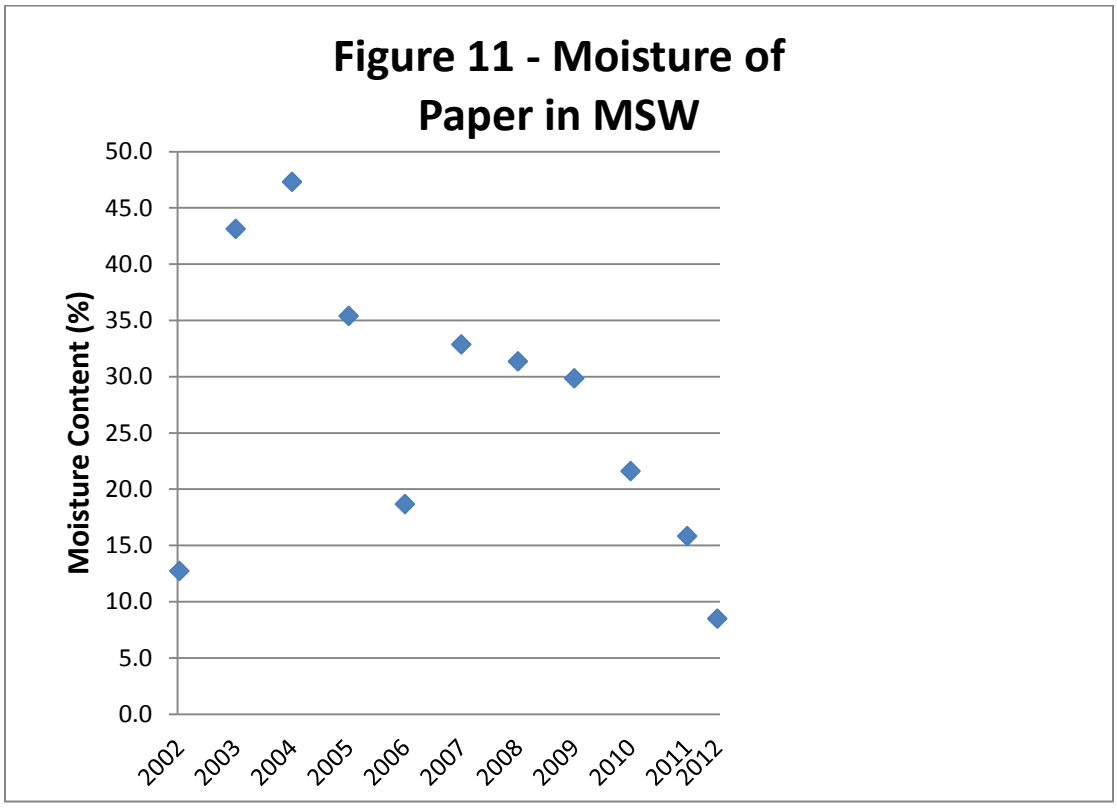


Figure 11 - Moisture of Paper in MSW
Moisture Content (%)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

Table 1 – Leachate TSS Field Test Results for Phase 1A (9-27-12)

AM Time	9:27	11:11	13:01	16:06
Δt (minutes)	-	104	110	125
mg/L	19	12	<10	<10

Table 2 - MSWLF Effluent Limitations vs. ACL Leachate Data

Regulated parameter	Maximum daily[1]	ACL Leachate[3]	Maximum monthly avg.[1]	ACL avg. Leachate[3]
BOD_5	140	5 to 51	37	16.8
TSS	88	10 to 120	27	45.7
Ammonia (as N)	10	5.5 to 56	4.9	23.4
α-Terpineol	0.033	NA	0.016	NA
Benzoic acid	0.12	NA	0.071	NA
p -Cresol	0.025	NA	0.014	NA
Phenol	0.026	NA	0.015	NA
Zinc	0.20	NA	0.11	NA
pH	([2])	6.8 to 8.5	([2])	7.7

[1]Milligrams per liter (mg/L, ppm) [2]Within the range 6 to 9. [3]Based on two years (2010 to 2011) of ACL data.

Table 3 – Ideal PCC Termination Data Collection Requirements

System Component	Accounting Or Monitoring	Measurement Frequency	Data Summary
MSW et al Inputs:	Tonnage	Daily	Monthly
	Phase Locations	As added	Daily Log
Liquid Inputs:	RD&D Liquids (gallons)	As applied	Quarterly
	Leachate Recirculation (tonnage or volume)	As applied	Quarterly
	Other Liquids (e.g., Toe Drainage)	As applied	Quarterly
Climatic: Inputs	Precipitation (inches as rain or snow)	As occurs	Quarterly
Ambient	Temperature	Daily (highs & lows)	Monthly
Local Weather Station	Various Data Available	Depends on Station	Internet
Leachate: Quantity	Individual Phases	Monthly	Quarterly
	Combined Phases	Monthly	Quarterly
Quality	Individual Phases	Quarterly	Quarterly
	Combined Phases	Quarterly	Quarterly
Temperature	Individual Phases	Monthly	Quarterly
	Combined Phases	Monthly	Quarterly
Storage: Tank(s)	Individual or Combined	Weekly	Annual
Lagoon(s)	Individual or Combined	Weekly	Annual
On-site Treatment	Individual or Combined	Daily or As Treated	Monthly
Off-site Disposal	Individual or Combined	As hauled	Monthly
LFG: Quantity	Individual Phases	Monthly	Quarterly
	Combined Phases	Quarterly	Quarterly
Quality	Individual Phases	Monthly	Quarterly
	Combined Phases	Monthly	Quarterly
Temperature	Individual Phases	Monthly	Quarterly
	Combined Phases	Quarterly	Quarterly
On-site Usage	Individual Phases	Daily	Monthly
Flare	Combined	As used	Monthly
Off-site Usage	Combined	As discharged	Monthly
Off-site CAA Migrations	Individual Sites	Daily	Monthly