# SUMMARY: INTERACTIVE DECISION SUPPORT TOOL FOR LEACHATE MANAGEMENT

Daniel E. Meeroff (PI)[1] and R. Teegavarapu (Co-PI)[2]

According to Nabil Muhaisen (Florida Water Environment Association) and Patrick Victor (American Water Resource Association), today's need for technological innovation has sparked a technical information revolution of endless change and continuous discovery, threatening to encompass all aspects of our lives. How will busy environmental professionals keep up with the accelerated pace of technological advances and deal with the challenges of an ever-changing regulatory environment is the question that must be answered for Florida to remain at the leading edge of socially and environmentally responsible management of solid waste going forward. This proposal describes the development of web-based, internet-accessible municipal solid waste leachate management decision support tool for utilities, consultants, and regulators. The tool will address the need for: 1) improving the measurement and evaluation of current leachate management practices, 2) improving the design and implementation of new or upgraded systems, 3) improving the regulatory framework to adequately deal with changing technologies and lessons learned, and 4) enhancing access to vital information on leachate management strategies and applications.

The key component of the decision support tool will be the online database application that will house a Best Management Practice (BMP) guide. This guide will be constantly updated with information collected from the user profiles entered into the web-based decision support interface, allowing access to the latest information on the performance of new innovative technologies or new applications.

An exhaustive survey of existing decision support systems revealed that no system exists for identification of best management strategies and solutions for the solid waste industry. The strong motivation for the proposed tool is based on the need to meet two main objectives: 1) the solid waste industry must become better informed about the new technologies and strategies that are becoming available to address their long-term needs and 2) the proposed tool will provide a methodology to design, implement, evaluate, and modify user-specific leachate management programs.

The goal is to collect, analyze, and make available technical data for use in developing effective and sustainable long-term solutions for the solid waste management industry. At the heart of the system will be the four module components: 1) user interface, 2) profile module, 3)best management practice module, and 4) report module. The tool will be accessed through a user login screen. The utility will be asked to input a user profile. The user will be prompted to answer detailed questions about critical

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characteristics needed to assess alternatives. These will include climate conditions, generation rates, waste characteristics, customer characteristics, age of facilities, size, type of landfill, regulatory requirements, costs of operation, and current disposal practices. It will also ask for subjective inputs such as desired range of costs and technologies to exclude, for instance. During this consultation phase, the tool elicits the user's objectives, resources, preferences, constraints, etc. that must be factored into the selection of the appropriate strategies for a particular application. As a knowledge-based system, the tool balances the multiple criteria that need to be weighted and prioritized to choose the best strategies from the BMP guide. The user profile will interface with the BMP database and match the best fit technologies to generate a recommended set of alternatives. Once the appropriate technology has been selected by the user and implemented, its performance must be tracked against the initial goals set by the user profile. The user will continue to update the profile with specific measures to provide the feedback necessary to keep the BMP database and ranking system current, thus closing the loop. Performance measures can then be assessed against other participating utilities, which will allow the database to be continually refined and adjusted to be as realistic and as useful as possible.

This proposal tackles the major technological need for addressing the communication gap in bringing sustainable, economical options for routine leachate management into the hands of the end users in the solid waste management industry. The Florida Atlantic University research team is uniquely positioned to deliver the proposed decision support tool because we have experience in assessing engineering alternatives for long-term leachate management from our recently-completed HCSHWM-funded two-year study entitled, "Investigation of Energized Options for Leachate Management, Report #0632018" (Meeroff et al. 2008), and we have extensive expertise relating to developing decision support and knowledge-based systems for similar applications.

The objective of the proposed research is to identify viable options for leachate management and rank them according to sustainability, performance, risk, and cost criteria. The assessment will not be limited to current practices. Futuristic technologies, such as plasma arc or photocatalytic oxidation using iron-mediated aeration or $TiO_2$-coated magnetite (under development at FAU), must also be evaluated to forecast which alternatives will be employed by the solid waste community in the years to come. Knowledge gained from these studies will also be included in the BMP database for the decision support tool. From the assembled matrix of engineering alternatives that are innovative, practical, and environmentally-sound, we propose to develop an interactive, web-based decision support tool to aid solid waste managers in long-term decision-making with regards to leachate management.

**PROGRESS REPORT**
(August 2009)

**Project Title:** Interactive Decision Support Tool for Leachate Management
**Principal Investigators**: Daniel E. Meeroff, Ramesh Teegavarapu
**Affiliation**: FAU
**Phone number**: (561) 297-2658
**Project website**: http://labees.civil.fau.edu/leachate.html

**Progress to Date:**

**Task 1**. A list of available and experimental long-term alternatives and rankings continues to be refined based on comments from TAG members and industry representatives. The ranking criteria are based on environmental sustainability, efficiency, risk, feasibility, and economic factors:

- Efficiency of treatment, regarding pollutant removal performance
- Residuals, regarding solids or liquids generated during treatment
- Footprint, regarding space needed for a unit process design for a capacity of up to 1.0 MGD
- Other parameters, included in this category are environmental impacts, odor generation, dependency on climate conditions, etc.
- Preliminary cost estimates

This work is underway and ongoing. The selection criteria and the mapping of user profile information to the selection criteria is under development and is under refinement after peer review from the TAG meeting on April 14, 2009.

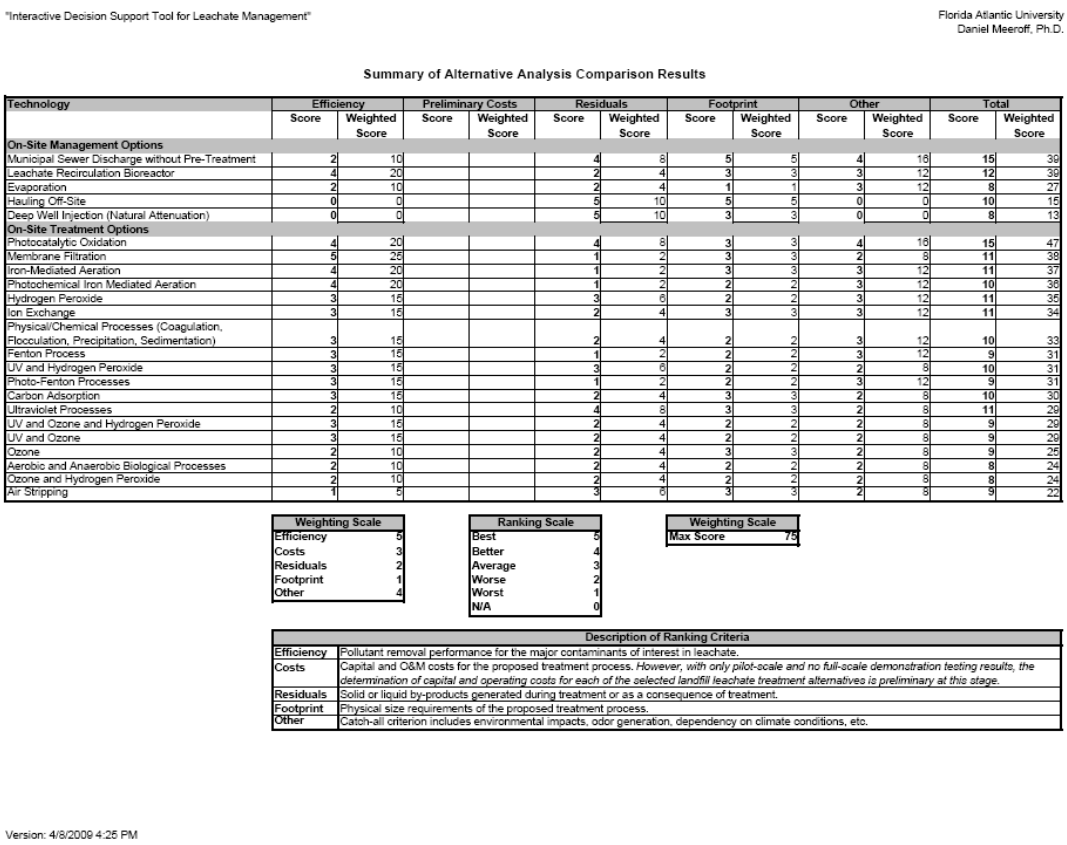
On July 21, 2009, Dr. Meeroff presented the work to the Florida SWANA Landfill committee. The meeting was organized by John Banks and Ray Lotito. A summary of the comments included:

- Inclusion of constructed wetlands as a separate management strategy (for the moment the technology was included under natural attenuation)
- The hauling offsite category was a subject of many comments, briefly it was decided to re-evaluate hauling offsite and use a scale to assess the “efficiency” of treatment (currently is receives a score of zero) based on mile-radius from the generation site to the disposal site. We are considering 0-50 = 5, 51-100 = 3, 101-150 = 2, and 151+ = 1.
- It was suggested that an “ease of operation” category be included.

- It was suggested that the consultants on the committee contact their landfill clients on the list to help obtain the information missing for the user interface tool.
- Dan Schauer of Geosyntec volunteered to gather information from the Naples landfill in Collier County.
- John Banks is working on putting together an appropriate list of consultants and their landfill clients on the list to help the research team.
- It was suggested that the specific goals of the project be listed on the questionnaire instead of a link to the website.
- The remainder of the discussion centered on reductive dissolution of iron and the shadow effect that is plaguing landfills in west central Florida.

On July 22, 2009, the research team attended a Symposium on Water Reuse and Microconstitutient Removal Using Advanced Oxidation Technologies sponsored by Air Products. A great deal of information was presented on the current state of knowledge of advanced oxidation processes and their full-scale performance, costs, and operation. Dr, Shane Snyder shared data from the Southern Nevada Water Authority experience with various technologies for water and wastewater treatment and indirect potable reuse. Dr. Khalil Atasi of CDM presented his experiences with AOPs in water and wastewater treatment applications. The possibility for future collaboration was discussed.

The working version of the BMP database, which is at the heart of the decision support tool, is posted on-line for public comment at http://labees.civil.fau.edu/LeachateMatrix.pdf (see Figure 1). Comments have been received (see above) and are in the process of being incorporated into a revised version of the BMP database.



"Interactive Decision Support Tool for Leachate Management"

Florida Atlantic University
Daniel Meeroff, Ph.D.

**Summary of Alternative Analysis Comparison Results**

| Technology | Efficiency | | Preliminary Costs | | Residuals | | Footprint | | Other | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **On-Site Management Options** | | | | | | | | | | | | |
| Municipal Sewer Discharge without Pre-Treatment | 2 | 10 | | | 4 | 8 | 5 | 5 | 4 | 16 | 15 | 39 |
| Leachate Recirculation Bioreactor | 4 | 20 | | | 2 | 4 | 3 | 3 | 3 | 12 | 12 | 39 |
| Evaporation | 2 | 10 | | | 2 | 4 | 1 | 1 | 3 | 12 | 8 | 27 |
| Hauling Off-Site | 0 | 0 | | | 5 | 10 | 5 | 5 | 0 | 0 | 10 | 15 |
| Deep Well Injection (Natural Attenuation) | 0 | 0 | | | 5 | 10 | 3 | 3 | 0 | 0 | 8 | 13 |
| **On-Site Treatment Options** | | | | | | | | | | | | |
| Photocatalytic Oxidation | 4 | 20 | | | 4 | 8 | 3 | 3 | 4 | 16 | 15 | 47 |
| Membrane Filtration | 5 | 25 | | | 1 | 2 | 3 | 3 | 2 | 8 | 11 | 38 |
| Iron-Mediated Aeration | 4 | 20 | | | 1 | 2 | 3 | 3 | 3 | 12 | 11 | 37 |
| Photochemical Iron Mediated Aeration | 4 | 20 | | | 1 | 2 | 2 | 2 | 3 | 12 | 10 | 36 |
| Hydrogen Peroxide | 3 | 15 | | | 3 | 6 | 2 | 2 | 3 | 12 | 11 | 35 |
| Ion Exchange | 3 | 15 | | | 2 | 4 | 3 | 3 | 3 | 12 | 11 | 34 |
| Physical/Chemical Processes (Coagulation, Flocculation, Precipitation, Sedimentation) | 3 | 15 | | | 2 | 4 | 2 | 2 | 3 | 12 | 10 | 33 |
| Fenton Process | 3 | 15 | | | 1 | 2 | 2 | 2 | 3 | 12 | 9 | 31 |
| UV and Hydrogen Peroxide | 3 | 15 | | | 3 | 6 | 2 | 2 | 2 | 8 | 10 | 31 |
| Photo-Fenton Processes | 3 | 15 | | | 1 | 2 | 2 | 2 | 3 | 12 | 9 | 31 |
| Carbon Adsorption | 3 | 15 | | | 2 | 4 | 3 | 3 | 2 | 8 | 10 | 30 |
| Ultraviolet Processes | 2 | 10 | | | 4 | 8 | 3 | 3 | 2 | 8 | 11 | 29 |
| UV and Ozone and Hydrogen Peroxide | 3 | 15 | | | 2 | 4 | 2 | 2 | 2 | 8 | 9 | 29 |
| UV and Ozone | 3 | 15 | | | 2 | 4 | 2 | 2 | 2 | 8 | 9 | 29 |
| Ozone | 2 | 10 | | | 2 | 4 | 3 | 3 | 2 | 8 | 9 | 25 |
| Aerobic and Anaerobic Biological Processes | 2 | 10 | | | 2 | 4 | 2 | 2 | 2 | 8 | 8 | 24 |
| Ozone and Hydrogen Peroxide | 2 | 10 | | | 2 | 4 | 2 | 2 | 2 | 8 | 8 | 24 |
| Air Stripping | 1 | 5 | | | 3 | 6 | 3 | 3 | 2 | 8 | 9 | 22 |

| Weighting Scale | |
|---|---|
| Efficiency | 5 |
| Costs | 3 |
| Residuals | 2 |
| Footprint | 1 |
| Other | 4 |

| Ranking Scale | |
|---|---|
| Best | 5 |
| Better | 4 |
| Average | 3 |
| Worse | 2 |
| Worst | 1 |
| N/A | 0 |

| Weighting Scale | |
|---|---|
| Max Score | 75 |

| Description of Ranking Criteria | |
|---|---|
| Efficiency | Pollutant removal performance for the major contaminants of interest in leachate. |
| Costs | Capital and O&M costs for the proposed treatment process. *However, with only pilot-scale and no full-scale demonstration testing results, the determination of capital and operating costs for each of the selected landfill leachate treatment alternatives is preliminary at this stage.* |
| Residuals | Solid or liquid by-products generated during treatment or as a consequence of treatment. |
| Footprint | Physical size requirements of the proposed treatment process. |
| Other | Catch-all criterion includes environmental impacts, odor generation, dependency on climate conditions, etc. |

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**Figure 1. Screenshot of the alternative analysis comparison results.**

The database to organize information related to the existing landfill facilities in Florida is under development including geospatial shape files using ArcGIS platform. The geospatial information is gathered from Florida Geographical Data Library (FGDL) online source. The task of gathering spatial data is now completed. Incorporation of this data into the decision support system is being carried out. On May 15, 2009, Dr. Meeroff met with William “Lee” Martin and Clark B. Moore at FDEP in Tallahassee to discuss new available sources of data needed for developing the user interface. We are currently trying to populate the database for the 52 landfills that were randomly selected as a representative dataset for this process. Mr. Martin gave Dr. Meeroff a tutorial on using OCULUS and downloading data from electronic solid waste reports.

To date the landfill profile database is approximately 33% complete. Using the program OCULUS, a public records database maintained by FDEP, some of the landfill characteristics for each individual landfill was obtained and recorded. Documents examined thus far date back to March of 2009. Documents were selected by searching for the appropriate site identification number. Landfill characteristics found include:

- Gallons of leachate produced per year
- Gallons of leachate hauled off site, recirculated, and/or treated

- Tons of waste accepted per day
- Analytical analysis of leachate (pH, TDS, ammonia-nitrogen, BOD, metals)

Plans to complete the spreadsheet include using OCULUS to search back to August of 2008 and contacting the landfills for all other data.

On May 27, 2009 Dr. Meeroff received permission from Ray Schauer to conduct pilot testing at the SWA facility in Palm Beach Gardens, FL. The contact person for this work will be Mr. Carroll, Director of Project Management and Facilities Development, and we are to coordinate the details directly with him. Also, Dr. Meeroff presented the initial results on June 3, 2009 at the Central Broward Solid Waste Facility as a potential location for pilot testing. Later that same morning, Dr. Meeroff met with the administrator of the Waste Management facility on Sample Road, and he also gave the research team permission to conduct pilot testing on combined leachate and cooling tower water at their facility. On the same date, Dr. Meeroff presented a proposal for pilot testing at Geosyntec Consultants in Boca Raton, FL. Geosyntec agreed to provide a pilot testing platform and limited financial assistance for modifying the unit and supporting student time.

At the TAG Meeting on April 14, 2009, Joe Lurix of the Southeast District Office of FDEP agreed to assist the research team in obtaining the appropriate permits for pilot testing with his office. He assured the TAG that the process would take less than 30-60 days.

An ongoing literature review is being conducted focusing on viable leachate treatment methods, including the photochemically-assisted iron-mediated aeration (PIMA) process and the $TiO_2$-magnetite photocatalysis process. The review began with FAU graduate students, Courtney Skinner, Adriana Toro, François Gasnier, and Tammy Martin in 2005. A visiting researcher from the Indian Institute of Technology in Bombay, Mr. Swapnil Jain, continued the work by conducting an exhaustive search of the photocatalytic literature [1990 and beyond] with the aid of the FAU S.E. Wimberley Library Information Services Department. Mr. Jain prepared an annotated bibliography, which was refined by two other visiting scholars, one from Japan, Ms. Hatsuko Hamaguchi, and the other from Stanford University, Mr. Joseph Vasquez. Currently, Ms. Benazir Portal, Mr. Anthony Ruffini, Mr. André MacBarnette, and Mr. Richard Reichenbach are updating the existing annotated bibliography focusing on technological innovations of the past three calendar years including Dr. Hala Sfeir's work on a statewide survey of leachate management options that were presented at the SWANA Conference in July 2007.

The main focus of this targeted literature review is to identify precedents using $TiO_2$-magnetite and other advanced technologies for wastewater treatment applications. Specific questions to be addressed are: 1) advanced oxidation process efficacy for various pollutants, 2) appropriate UV intensity range, 3) appropriate reactor conditions (i.e. pH, temperature, etc.), 4) appropriate range of catalyst dose (in grams or $m^2$), 5) appropriate hydraulic retention times or reaction/exposure times, 6) catalyst

reconditioning, 7) reasons for catalyst poisoning, and 7) appropriate mixing regime. In addition, any factors that could impact the efficiency of the process such as catalyst poisoning, pH/temperature effects, etc. were identified in preparation for photocatalytic oxidation laboratory scale testing at FAU.

Between July 10, 2009 and August 14, 2009, six lab scale experiments have attempted to replicate the successful results of previous work using photocatalytic particles manufactured in our laboratory. The first experiments showed promising results. The contact time range was 0-4 hours. The lamp intensity was measured at 0.200 $mW/cm^2$ The most effective run had a starting COD concentration of 17,000 mg/L and a final COD concentration of 4600 mg/L (73% removal).

**TASK 2.** The web-based decision support tool will require a host and a manager when it is ready to be launched. This institution will be identified with input from the stakeholder group, which will consist of a technical advisory group (TAG) from regulatory agencies, water managers, consulting engineers, private industry, as well as other individuals and organizations. Operational aspects such as a reliable environment, support services, server requirements, security issues, database updates, client information storage, and ownership rights will be specified according to the host institutions needs. The availability of the host web-based server to install and launch the decision support tool is being investigated. Operational aspects such as a reliable environment, support services, server requirements, security issues, database updates, client information storage, and ownership rights will be specified according to the host institutions needs are currently being evaluated. Dr. Teegavarapu has initiated discussions with the Director of the Technical Services Group of the College of Engineering and Computer Science at FAU, Mr. Mahesh Neelakanta. These discussions will help to outline the possibility of hosting the tool through the College server and to identify any issues, obstacles, or contingency plans with regards to the host institution.

Several software and operating platforms were evaluated for the development of the decision support system. The software include: EXSYS, CORVID, CLIPS and others. Few standalone systems were also evaluated. The availability of host web-based server to install and launch the decision support tool was investigated in context with key operational aspects such as: reliability, support services, server requirements, security issues, database updates, client information storage, and ownership rights.

The system selected for the web-based portal is “expertise-2-go”. A temporary web site hosted at FAU has been set up to test the rules (http://www.civil.fau.edu/~ramesh/dss/dss.html). The temporary web site uses “e2gLite Expert System Shell” with Java interface. This web site and the expert system module is currently under testing. Rule base required for this shell is being developed. A simple

interface for the web-portal is successfully tested and work is ongoing to refine the interface.

**Task 3.** The database system to organize the collected information related to existing landfill facilities in Florida is being developed using geospatial shape files within an ArcGIS platform. The geospatial information was gathered from the Florida Geographical Data Library (FGDL) online source.

**Task 4.** The development of decision trees (Figure 2) in their simplest forms is now completed based on available knowledge from the case studies, literature review, and laboratory performance testing (and also from the TAG member feedback). A set of questions are already prepared that relate to several alternatives. The decision trees are developed in such a way that these trees can be used for knowledge base development for the envisioned decision support system. A matrix of alternatives along with a preliminary ranking scheme is developed and refined.

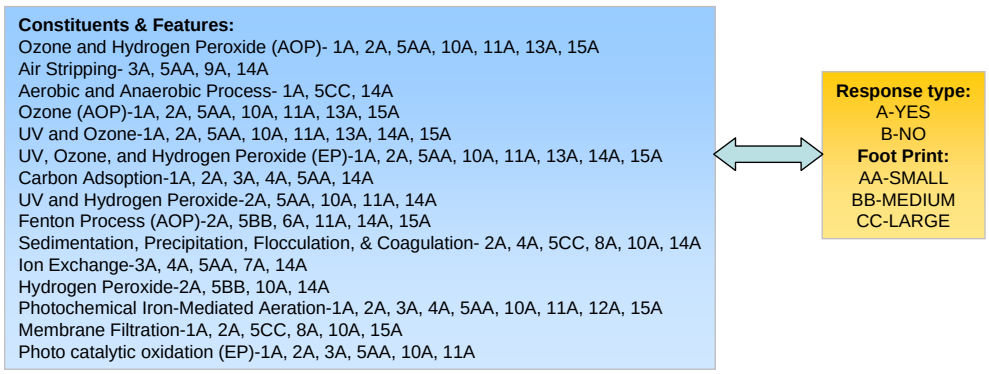


Figure 2: Constituents and responses linked in a simple decision tree

The prototype decision support system is being developed and will be completed on this web site http://www.civil.fau.edu/~ramesh/dss/dss.html. Figure 3 shows the screen shot of the system under development.


Figure 3. Screen shot of A typical web-based expert system/Decision support system being developed

The decision support/expert system is developed using a web-enabled expert system platform using the Java applets and already developed empty shell available from eXpertise2Go.com. The shell is referred to as "e2gRuleEngine Expert System Shell". The expert system based rules developed will follow the below IF-THEN-ELSE structure.

**Leachate knowledge base – example rule**

**RULE [Best Management Option?]**
**If [] = "" or**
**[] = ""**
**Then [the recommended action] = "Option # 1"**

The development of rule-base considering all management options with the help of decision tree is underway. Approximately 400-500 rules will be developed when the rule-base is completed. Rule-base can be altered based on new knowledge and responses from TAG.

The status of the web-enabled decision support system is provided by the following constituents:

- Decision trees (draft completed)
- Knowledgebase for management options (draft completed)
- Rule-base development(currently under development, 40% completed)
- Development of Web Portal for hosting the decision support system (completed)
- Interface for Web portal – (under development)
- Experiment Testing of the Rules under decision support system platform (under development)

**Task 5**. Dr. Meeroff, Mr. Ruffini, Mr. MacBarnette, and Mr. Richard Reichenbach are currently assembling a list of questions that will be useful for the development of the user interface module. These questions are mapped into a database for Florida landfills that was developed during our previous two-year study. This database was constructed with the support of the TAG members and in particular the efforts of Joe Lurix, FDEP Southeast District Solid Waste Management Program Director. The database collects information from major Florida landfills regarding:

1. Facility name
2. Location
3. Contact information
4. Facility class
5. Capacity in tons/day of MSW and permitted acreage
6. Service area characteristics
7. Years of operation
8. Liner systems
9. Leachate management history
10. Volumes generated
11. Assessment of performance
12. Leachate water quality
13. Identification of issues

The draft user profile information list was approved by the university Institutional Review Board for the Institutional Animal Care and Use Committee (IACUC), which governs the collection of data from human subjects, on February 18, 2009 (h09-38xm). We sent out the survey to the TAG members for comment and discussed its content at the TAG meeting on April 14, 2009 and also at the HCSHWM research review committee meeting on May 15, 2009. The survey has also been presented at Geosyntec Annual Meeting on June 3, 2009 and the Florida Section SWANA meeting of the landfill committee on July 21, 2009. The survey is located on the web site at http://labees.civil.fau.edu/DST-tool.pdf (and is an interactive pdf form as shown in Figure ). The comments and data will be collected and posted on the project web site for TAG members and interested stakeholders to supply information and feedback.

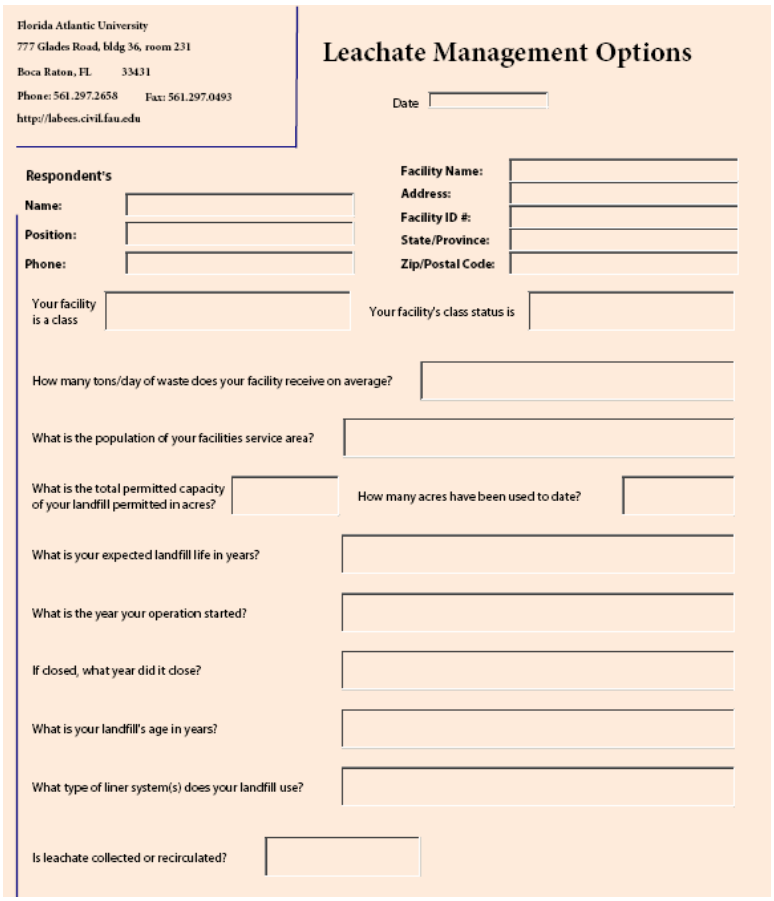


**Figure 4. Screenshot of the decision support tool survey for landfill managers.**

We took the initial comments and conducted an online TAG meeting (http://labees.civil.fau.edu/MeeroffSP.wmv) that was broadcast as a web-based video file hosted on the project website. The FAU long distance learning department agreed to produce the video and convert it for use on the web for this project.

Mr. MacBarnette, Mr. Ruffini, Ms. Portal, Mr. Neal and Mr. Richard Reichenbach are also working to compile a list of data results from innovative treatment technologies conducted at laboratory scale. This data will be used to fill in the gaps required for performance testing of experimental technologies for ranking purposes to create the decision trees that are at the heart of the management tool.

**Research planned for the upcoming months:**

- Complete/refine the engineering alternative analysis of candidate technologies for the long-term management of leachate
- Collect/compile comments and feedback from technical advisory group
- Data collection from OCULUS and solid waste facility reports is underway and should be nearing completion

- Data gaps for the user interface will be filled by contacting the consultants or landfill managers on our representative list directly, since the survey has been online for 6 months and only 2 responses have been received thus far using this format.
- Map TAG/landfill manager responses to refine the matrix of technologies
- One the BMP guide has been linked to the user interface, we will conduct another TAG meeting to review the DST and solicit comments.
- Testing of photocatalysis with artificial leachates is underway to replicate the conditions of successful previous lab scale experiments in preparation for scale-up
- Testing of photocatalysis with actual leachates is underway
- Conceptual design of scale-up for pilot testing is underway