Phytoremediation of Organics Action Team

Designing, Building, & Regulating Evapotranspiration (ET) Landfill Covers

RTDF

Speaker and Poster Abstract Booklet

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Landfill ET Covers –
Past Myth, Current Fact, Possible Future

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Dr. Louis Licht is founder, president and CEO of Ecolotree® Inc., North Liberty IA. He is interested in the use of plants to clean both air and water while creating productive landscapes. Ecolotree proposed and planted the first ET poplar tree cover in 1990; today projects also include: leachate plume interception buffers, cleanup spilled organics using root-zone reactors, urban and farm runoff nutrient removal, municipal effluent tertiary treatment, and manure lagoon closure. Dr. Licht owns two patents and five trademarks related to phytoremediation. Dr. Licht also manages a tree nursery, 450 acres of Iowa farmland, serves on two academic advisory boards, and lectures internationally. Ecolotree® Inc., North Liberty, IA, www.Ecolotree.com, Louis-Licht@Ecolotree.com

Landfill ET Covers– Past Myth, Current Fact, Possible Future

Louis A. Licht
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The evapotranspiration (ET) landfill cover can be considered a subset of plant-augmented bioremediation, also called phytoremediation. This field is relatively new; yet a critique of the early-promised benefits and fears can now be based on research and instrumented prototype ET covers. Since 1990, approximately 20 sites have been installed that use a tree overstory and grass understory design for permitted final closure.

Data from measured demonstration sites and the ACAP program are developing the facts and statistics now used in ET cover designs. Legislative acceptance (such as the US EPA RD&D ruling) provides more flexibility to regulate, implement, and manage an ET closure that better-protects both the environment and human heath.

This speech will look back in time on the projected outcomes of the early installations, and evaluate in retrospect what is myth and what is fact. Then this paper will look at two questions:

1. Based on these measured "facts" – what cover options exist and are possible for a finished landfill cell closure?
2. Based on the ongoing research – what are possible future scenarios for a landfill now operating but eventually going to ET closure?

This speech will also introduce the other conference speech topics that will contribute to understanding the future of ET cover designs.

Design Methodology for Alternative Covers

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Craig H. Benson PhD, PE is Professor of Civil & Environmental Engineering and Geological Engineering at the University of Wisconsin-Madison, where he has been a member of the faculty since January 1990. Dr. Benson has a BS from Lehigh University and MSE and PhD degrees from the University of Texas at Austin. All degrees are in Civil Engineering, with the MSE and PhD degrees specializing in geo-engineering. Dr. Benson is a licensed professional engineer.

For the last 20 years Dr. Benson has been conducting experimental and analytical research on barriers to flow and contaminant transport, and is regarded as one of the leading international experts on the performance of barrier systems. Dr. Benson has been conducting research on the effectiveness of alternative earthen final covers (AEFCs) for waste containment as one of his primary scholarly thrusts. This research has included laboratory studies, large-scale field experiments, and modeling. Dr. Benson also consulted on the first AEFC approved for a composite-lined facility in the United States.

Dr. Benson has received several awards for his work, including the Presidential Young Investigator Award from the National Science Foundation and the Distinguished Young Faculty Award from the US Dept. of Energy. Dr. Benson has also received the Huber Research Prize as well as the Croes, Middlebrooks, Collingwood, and Casagrande Awards from the American Society of Civil Engineers. Dr. Benson is an active member of the Geo-Institute, is chair of ASTM committee D18.04 on Hydrologic Properties of Soil and Rock, and is Editor-in-Chief of the *J. of Geotechnical and Geoenvironmental Engineering.*

Currently, Dr. Benson is one of the principal investigators for USEPA's Alternative Cover Assessment Project (ACAP). He was intimately involved in design of the ACAP test sections, selection of the instruments used for monitoring, and served as the engineer-of-record.

Design Methodology for Alternative Covers

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This presentation describes a design methodology developed based on more than a decade of experience designing and evaluating alternative covers. The procedure consists of five sequential steps: (1) site characterization, (2) preliminary design based on storage, (3) design refinement using numerical models, (4) design details (runoff, erosion, desiccation, frost, biota intrusion, etc.), and (5) performance evaluation and monitoring.

Site characterization includes identification of meteorological conditions, defining potential borrow sources for soils, and determining the type of vegetation that is native to the area. Meteorological data are compiled from historical records and soil samples are collected and tested to define their mechanical and hydraulic properties (compaction, saturated hydraulic conductivity, soil water characteristic curve, and shear strength). Information describing the coverage, growing season, and rooting characteristics of the vegetation is also collected and the design meteorological period is selected.

Preliminary design consists of analytical calculations to determine the soil water storage capacity of the soil and the required thickness of the cover to meet a performance goal. These calculations also indicate whether a monolithic design is satisfactory or if a capillary barrier is required. The analytical calculations are checked with more realistic numerical models during design refinement. Based on the outcome of the numerical modeling, the cover profile may be refined to be more efficient or conservative.

Design details are similar to those encountered when designing conventional covers. Design details are aspects other than the barrier system that are needed to sustain adequate performance and/or to satisfy regulatory requirements. In some cases, the outcome of this step may require additional analytical calculations and numerical modeling.

The final step is performance evaluation and monitoring. In this step, a method is selected to confirm that the design goal has been achieved. The method may consist of water content monitoring, lysimetry, physical observations, or a combination thereof. Of these methods, lysimetry is preferred.

Revegetation Design on ET Covers – An Ecological Approach

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Amy Forman is a plant ecologist for S. M. Stoller Corp. She currently works in the Environmental Surveillance, Education, and Research Program at the INEEL. In addition to managing the Protective Cap/Biobarrier Experiment, she is involved with research on sagebrush steppe recovery subsequent to fire, sagebrush demography, plant community structure and classification, and land application of sewage wastewater.

Revegetation Design on ET Covers – An Ecological Approach

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Evapotranspiration (ET) covers have two primary, and equally important, components. The first is a soil cap sufficient to store precipitation that falls while plants are dormant and the second is a plant community sufficient to deplete soil moisture during the growing season. The configuration of the soil cap generally receives more consideration than the elements of the vegetation community during the design process; however, the plant community is at least as important to the long-term effectiveness of an ET cover as the soil cap. The Protective Cap/Biobarrier Experiment (PCBE) was established in 1993 at the Idaho National Engineering and Environmental Laboratory (INEEL) and consists of four soil cap configurations, planted in two vegetation types, subjected to three precipitation regimes. Ultimately the PCBE demonstrated that with a thoughtful and comprehensive revegetation design, native plant species can be quickly established and typically perform better than exotic monocultures on ET covers in semi-arid regions. Results from the PCBE illustrate the importance of carefully considering revegetation as an integral part of a complete cap design. Three aspects of revegetation are especially important for designing a plant community for a final cover; choosing appropriate plant materials, implementing effective planting and establishment techniques, and considering long-term plant community change and associated water use. The ability of a landfill cap to function effectively and contribute to the long-term land management goals of a particular site is largely a consequence of the materials planted there. Therefore, decisions pertaining to plant materials should address use of seed compared to seedlings, the genetic makeup of the plant material used, compiling a species mix with desired root distributions, and choosing species with growth habits that contribute to the functional stability of the cover. An effective revegetation design should also incorporate strategies to increase planting success and facilitate establishment and may include; planting in densities and distributions similar to adjacent plant communities, using mulch, controlling undesirable weeds, and using supplemental irrigation. Finally, factors affecting long-term vegetation change such as global climate change, invasion of undesirable species, and catastrophic disturbances should be considered as part of a revegetation design.

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A Case Study of the US Army-
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Borrow Soil Characterization,
Design, & Construction Considerations

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A Case Study of the US Army-Fort Carson Evapotranspiration Cap

Borrow Soil Characterization, Design, & Construction Considerations

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The Resource Conservation Recovery Act (RCRA) requires that a regulated landfill have hydrologic barrier cover that complies with prescribed design criteria or an alternative with equivalent performance. In arid and semi-arid climates, alternative covers rely on soil water storage, establishment of vegetation, and soil water loss through evapotranspiration to restrict deep drainage. The borrow soil characterization, design, post-construction analysis, and construction of a 6.1 ha (15 acre) evapotranspiration landfill cover (ET cover) are described. The ET cover is located at the U.S. Army-Fort Carson site located in Colorado Springs, Colorado. A soil characterization of the borrow area was conducted to inventory suitable and unsuitable soils based on hydraulic and productivity properties, to develop numerical model input values, and to establish a target soil compaction range based on the undisturbed borrow area condition. The borrow soil is predominantly clay loam, based on the United States Department of Agriculture soil classification, that formed in alluvial and eolian deposits. The dry bulk density of the relatively undisturbed borrow area was typically less than 1.3 g, cm^{-3} (81 pcf). A numerical water balance model, UNSAT-H, predicted that annual drainage through a 122-cm (48-in) thick clay loam, based on four continuous years of high annual precipitation at 53 cm (20.8 in), was near or less than 0.1 mm (0.004 in). The ET cover was constructed by placement of four soil lifts, each 30 cm (12 in) thick. During construction, haul routes were defined to reduce the cover impact area and low ground pressure dozers were used to work soil. Following lift placement, when necessary, cover areas were tilled to achieve a compaction that did not exceed 80 percent of the Proctor test maximum dry density. Construction of the ET cover and planting of native prairie grasses were completed in October 2000. Management practices to establish the permanent plant cover included incorporation of biosolids, soil fertilization, straw mulching, use of erosion blankets, and irrigation. A post-construction analysis of the cover indicates a relatively uniform soil type that is consistent with the borrow soil characterization. The in-place ET cover is predominantly a clay loam. The measured dry bulk density of the constructed cover, based on limited sampling, was typically less than 1.50 g cm^{-3} (93 pcf) or less than 90 percent of the Proctor test maximum dry density. The measured water storage capacity of the 122-cm (48-in) thick clay loam is about 43 cm (17 in). The vertical hydraulic potential and soil water content data measured outside of lysimeters suggests upward unsaturated flow and wicking of soil water from the ET cover surface. Presently the dominant native grass that has established on the ET cover is western wheatgrass.

Experience with Placement of Alternative Final Covers

Leonard Butler

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Mr. Butler has worked with landfills in the Western United States for almost 30 years as a solid waste regulator, consultant and private engineer. He has a B.S.C.E. and M.S.C.E. from California State University at Sacramento. Some of his most recent responsibilities have included project management of the Douglas County Landfill ACAP near Omaha, Nebraska and demonstrations of alternative final covers at four municipal solid waste landfills in Colorado. During the last several years, he has been involved with development of the final cover designs and construction activities at these landfills.

Experiences with Placement of Alternative Final Covers

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Placement of Alternative Final Covers (AFC) is currently ongoing at three municipal waste landfills in Colorado by Waste Management of Colorado, Inc. The Denver Arapahoe Disposal Site (DADS) has been selected for this presentation to highlight experiences with placement of AFCs.

There were seven lessons learned from placement of AFC at DADS that can be applied to other disposal facilities planning construction activities. These lessons can be summarized as follows:

1. Designate the soil borrow areas to be used for cover material and conduct testing to determine percent weight finer than the #200 Sieve according to design specifications.
2. Develop workable construction specifications that allow compaction to between 80% to 90% of maximum density dry of optimum moisture content as determined by Standard Proctor (ASTM D 698). The ability to construct AFCs by reducing the compaction range, e.g., 85% to 88% is more difficult and costly and does not necessarily model natural in-situ soil placement.
3. Retraining of heavy equipment operators is important since existing covers are heavily compacted in thin lifts and an AFC is lightly compacted at full thickness.
4. Selection of a vegetative mix is critical to success of AFC. The mix must be carefully assembled to include both cool and warm weather germinating grasses along with deeper rooted plant species. Periodic inspection of seeded area is critical to AFC success.
5. No changes to drainage structures to accommodate overland flow on 4:1 side slopes or flatter have been necessary
6. Slope stability issues have been fewer because of the diversity of the vegetative mix with more deeper rooted plant species that hold soil, once established than the compacted clay cover.
7. A Construction Quality Assurance (CQA) program helps streamline construction and provides the required documentation to show compliance with construction specifications.

The experience gained at DADS confirms that the keys to successful AFC placement are (1) identification of borrow areas; (2) workable specifications; (3) heavy equipment operator retraining from past cover projects; (4) careful selection of seed mix; and (5) a CQA program that will comply with construction specifications and record documentation requirements.

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ET Cover Modeling Introduction
(NO ABSTRACT)

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Beth A. Gross, P.E. is a Senior Engineer with GeoSyntec Consultants in Austin, Texas. She has been a consulting engineer with GeoSyntec since 1987. Ms. Gross received BSCE and ME degrees from the University of Florida and is completing her doctoral degree in civil engineering at the University of Texas at Austin. Her research focus is the reliability of ET cover design in the southwest U.S.

Ms. Gross' practice has focused on waste containment, including landfill design and performance. She has played a significant role in developing technical support and guidance documents for the U.S. Environmental Protection Agency, including "Evaluation of Liquids Management Data for Double-Lined Landfills", "Waste Containment System Problems and Lessons Learned", and "Technical Guidance for RCRA/CERCLA Final Covers" (in draft). Ms Gross has been a key participant in ET cover design, monitoring, and performance assessment projects in the western and eastern U.S.

ET Cover Modeling Introduction

Beth Gross

NO ABSTRACT

Monitoring versus Modeling ET Covers for Performance Evaluation

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Bridget R. Scanlon PhD, PG is a Senior Research Scientist at the Jackson School of Geosciences at the University of Texas at Austin. She has been a researcher at the university since 1987. Dr. Scanlon has a BS from Trinity College (Ireland) and PhD from the University of Kentucky, These degrees are in Geology and the graduate degrees specialize in hydrology.

Dr. Scanlon's research for the past 15 years has focused on vadose zone hydrology and includes physical, chemical, isotopic, and modeling approaches for quantifying flow and transport through unsaturated systems. She is regarded as an international expert in vadose zone hydrology. Her research during the past 10 yr has focused on evaluation of engineered covers for waste containment. This work included design, monitoring, and modeling of various cover designs, including capillary barriers, ET barriers, and asphalt barriers. Dr. Scanlon has conducted detailed comparisons of several different codes for simulating engineered covers using data from Idaho and Texas. She is PI of a project evaluating monitoring and modeling issues related to engineered covers funded by EPA. She is Associate Editor of Vadose Zone Hydrology journal.

Monitoring versus Modeling ET Covers for Performance Evaluation

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Assessing the performance of ET covers is complicated; therefore, it is important to apply many different approaches, including monitoring and modeling, to assess performance because of limitations associated with each approach. Detailed monitoring and modeling of ET covers in Texas and New Mexico provide valuable information on different approaches for assessing ET cover performance. The covers ranged from 1.1 m silty sand (New Mexico) to 2 m thick silty clay loam (Texas site). Both sets of covers were vegetated with grasses.

The main components of the water balance were monitored at these sites. The monitoring results showed 3 D variability in water storage related to topography: generally low water storage in upland areas and high water storage at the base of the slopes. Temporal variability in the water storage was controlled by precipitation and evapotranspiration. The importance of vegetation in controlling water storage was shown by substantial reductions in water storage related to establishing vegetation at the Texas site. Large water storage reductions also correlated with increases in vegetation productivity in the spring at both sites. The studied sites are particularly suitable for ET covers because of the dominance of summer precipitation when ET is maximized. The pressure data indicate that water movement is upward throughout much of the time. Measured drainage was zero at both sites.

Modeling analysis included simulation of the cover performance during the monitoring period and extending this analysis to 30 yr using long-term meteorological data. The simulations generally reproduced the measured water balance parameters. Underestimation of runoff at the Texas site was offset by including a low permeability crust in the simulations. Long-term simulations in response to 30 yr (1961 – 1990) meteorological forcing provided similar results to the short term (4 – 5 yr) simulations of the monitoring period and provided confidence that the covers should perform adequately over the long term.

The performance studies at these sites provide valuable insights that can be used to guide future monitoring and modeling studies. Important factors with respect to monitoring include drainage monitoring, length of monitoring record, spatial variability, and emphasis on vegetation monitoring. The capillary barrier effects created by lysimeters result in underestimation of drainage and overestimation of soil water storage and should be recognized. Short term monitoring is dominated by the effects of initial conditions (i.e. construction effects etc). Vegetation monitoring should be expanded because of the dominant role of vegetation in controlling the water budget of these systems. Modeling analysis should be expanded beyond the traditional 1D analysis to capture 3D flow effects. Codes should be developed to better simulate vegetative effects on the water balance beyond simply prescribing vegetation parameters as input to the models. The Texas and New Mexico studies provide confidence that ET covers should perform well in these semiarid regions and provide suggestions for future improvements in monitoring and modeling analyses.

Fact or Fiction: Comparing Model Predictions and Field Data from ACAP

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For the last 20 years Dr. Benson has been conducting experimental and analytical research on barriers to flow and contaminant transport, and is regarded as one of the leading international experts on the performance of barrier systems. Dr. Benson has been conducting research on the effectiveness of alternative earthen final covers (AEFCs) for waste containment as one of his primary scholarly thrusts. This research has included laboratory studies, large-scale field experiments, and modeling. Dr. Benson also consulted on the first AEFC approved for a composite-lined facility in the United States.

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Fact or Fiction: Comparing Model Predictions and Field Data from ACAP

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Numerical models are often used during alternative cover design to evaluate the sufficiency of a cover profile or to demonstrate that an alternative cover meets an equivalency criterion. A variety of models exist that can be used in this manner. The most common are UNSAT-H, HYDRUS-2D, Vadose/W, and LEACHM. Each of these models has been evaluated with field data to some degree, but none has been subjected to an evaluation where all of the input parameters and output quantities have been measured.

This presentation describes a comparison between water balance measurements made at four sites in the Alternative Cover Assessment Project (ACAP) and predictions made with the two most commonly used models, UNSAT-H and HYDRUS-2D. The four sites are in semi-arid and sub-humid climates and range from seasonal without snow to widely varying conditions including hot summers combined with freezing winters with snowfall. Input to the models was measured to the greatest extent possible. Meteorological data were collected and properties of the soil and vegetation were extensively characterized.

UNSAT-H generally provided more accurate predictions of the water balance than HYDRUS-2D. However, predictions generally were in poor agreement with field water balance data. Surface runoff generally is over-predicted, which results in under-predictions in evapotranspiration and soil water storage. Percolation generally is under-predicted appreciably.

Sensitivity analyses show that the three most influential parameters are the saturated hydraulic conductivity of the cover soils, the n-parameter in van Genuchten's equation, and intensity of the precipitation relative to the saturated hydraulic conductivity. More reasonable predictions can be obtained by increasing the saturated hydraulic conductivity by a factor between 10 and 20 and by ensuring the intensity of the precipitation closely resembles that occurring in the field. Nevertheless, even with these changes, percolation can only be predicted with an accuracy on the order of ±10 mm/yr.

Overland Flow Implications on Surface Cover Designs

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Overland Flow Implications on Surface Cover Designs

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Water flow and solute transport on a hill slope is a complex nonlinear problem. Rainwater initially infiltrates at a rate equal to the rainfall rate. Once the soil infiltration capacity is reached, surface runoff is generated redistributing water along sloped surfaces. More water usually infiltrates at the lower parts of a hill slope, even for homogeneous soil profiles, because of generally longer surface ponding times and vegetation density. The variable infiltration along a hill slope has significant consequences for plant growth and the overall water balance of evapotranspiration covers.

To describe these complex interactions we have coupled the HYDRUS-2D software package, simulating water flow and solute transport in variably saturated porous media, with a newly developed overland flow routine. The overland flow solver uses fully implicit four-point finite difference method to numerically solve the one-dimensional kinematic wave equation, with overland fluxes evaluated using Manning's hydraulic resistance law. A Picard iterative solution scheme, similar to one used for solution of the Richards equation, is invoked to solve the resulting system of nonlinear equations. The subsurface flow module determines the main time step for the coupled system. If required for numerical stability, the overland flow module can use multiple smaller time steps during the main time step. This type of time management considers the fact that overland flow and variably-saturated subsurface flow often run at quite different time scales.

We will present several evapotranspiration landfill cover examples of the updated HYDRUS-2D program showing the development of overland flow as a function of storm intensity and slope angle. Simple examples will verify the correctness of the numerical implementation against an analytical solution. More complex examples will examine infiltration with and without the overland flow modifications along a hill slope. The interaction of runon, vegetative growth, and permeability changes will be examined through these simulations.

Prediction of Water and Energy Balance in Surface Covers and Protective Side-Slopes Using the STOMP Simulator

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Andy Ward is a Senior Research Scientist in the Hydrology group at the Pacific Northwest National Laboratory (PNNL). He received a B.S. in Agriculture from the University of the West Indies in 1986; an M.S in Soil Science from the University of Guelph in 1989; and a Ph.D in Soil Physics from the University of Guelph in 1993. Postdoctoral studies were conducted at the Center for Groundwater Research at the University of Waterloo. His research is focused mostly on vadose zone hydrology with a special interest in characterization methods for unsaturated soils. He is currently PI of an EMSP project aimed at developing new methods for describing flow in the strongly anisotropic soils at Hanford. He is Co-PI for the Hanford Site Science and Technology Vadose Zone Transport Field Study in which a team of scientists from DOE National Laboratories are developing methods and models for describing field-scale flow and transport processes in the vadose zone with a goal of developing an improved understanding on contaminant transport in Hanford's Tank farms and other waste management areas. He currently leads a team of scientists who are extending the capabilities of the STOMP code to optimize the design and evaluate performance of candidate barriers for long-term waste isolation at Hanford. Dr. Ward is a member of the Soil Science Society of America; the American Geophysical Union; the International Soil Science Society; the National Society of Black Engineers; and the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers. He recently retired as an Associate Editor of the Soil Physics Division of the Soil Science Society of America Journal. He is the recipient of patent No. 6,474,176, issued for Fluid Flow Measuring Devices and Methods for Determining Fluid Flow Rates in Soils.

Prediction of Water and Energy Balance in Surface Covers and Protective Side-slopes using the STOMP Simulator

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Surface barriers are being considered for final closure within most of the U.S. Department of Energy (DOE) complex. At the Hanford Site alone, some 200 barriers will be deployed to cover over 1,000 acres. However, existing tools are limited in their ability to represent the multidimensional, non-isothermal, multiphase transport of mass and energy that govern the performance of the field-scale cover systems. The STOMP simulator was recently extended for application to water and energy balance predictions in surface barrier and their protective side-slopes. Unique features of the simulator include (1) use of the Shuttleworth-Wallace sparse canopy evapotranspiration model, extended to account for potential evapotranspiration rate, ET_p, from multiple plant species; (2) independent computation of root uptake and transpiration rates from the evaporation rates as a function of plant type and atmospheric condition; (3) the use of spatially and temporally variable plant area index to partitioning of ET_p into potential evaporation, E_p, and potential transpiration, T_p; (4) explicit calculation of the depth to the evaporating surface to circumvent arbitrary selection of evaporative depths; and (5) condensation and evaporation in the plant canopy with interception being influenced storm intensity and leaf area index. The model has been coupled with UCODE to facilitate automatic calibration and sensitivity analysis. Calibration and validation exercises show very good agreement between simulated and observed water and energy balance components in candidate designs for the Hanford Site.

Coast to Coast: Performance Data from the 11 ACAP Field Sites

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Bill Albright has 20 years of research experience in environmental science. His research interests have included arid lands soil physics, regional air pollution, atmospheric chemistry and weather modification, plant ecological physiology. He has been active in field and laboratory estimations of recharge in dry soils. He has participated in the development of landfill facility design for the disposal of radioactive waste for the U.S. Department of Energy at the Nevada Test Site. He has been involved in the development of alternative landfill cover designs for sites in the arid and semi-arid portions of the country. He is currently investigating processes related to recharge in the Great Basin.

Bill Albright is a principle investigator for the USEPA's Alternative Cover Assessment Program (ACAP). The primary goal of ACAP is to establish a cooperative program with federal, state, and private sector entities to conduct a regional evaluation of landfill cover facilities. ACAP is currently conducting field-scale testing of landfill covers at several sites across the country. Data collected from the program will guide the development of improvements in cover design and evaluation.

Coast to Coast: Performance Data from the 11 ACAP Field Sites

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Craig H. Benson, University of Wisconsin – Madison
Glendon W. Gee, Battelle Pacific Northwest Laboratories

Landfill covers constitute a major expense to landfill operators, yet performance of specific cover designs has not been well documented and seldom compared in side-by-side testing. In 1998 the EPA initiated the Alternative Cover Assessment Program (ACAP), a comprehensive study to evaluate conventional and alternative covers, over a range of climates from humid to arid, in order to test the ability to control landfill water-balance and minimize drainage through the cover. At 11 field sites in seven states, from Georgia to California, we monitored conventional covers employing resistive barriers (soil layers with low saturated hydraulic conductivity or composite barriers consisting of a geomembrane over a soil barrier) as well as alternative covers relying on water-storage principles. Surface runoff from the covers was a small fraction of the water balance (0-10%, 4% on average) and was nearly insensitive to the cover slope, barrier type, or climate. Lateral drainage from internal drainage layers was also a small fraction of the water balance (0-5.0%, 2.0% on average), but was typically a larger fraction of the water balance at humid sites. Average percolation rates for the conventional covers with a composite barrier typically were less than 1.4% of precipitation (12 mm/yr) at humid locations and 0.4% of precipitation (1.5 mm/yr) at sites in arid/semi-arid/sub-humid locations. Conventional covers with soil barriers in humid climates had percolation rates ranging between 6-17% of precipitation (52 and 195 mm/yr). The high rates were attributed to flow through cracks and other defects in the soil barrier. Average percolation rates for alternative covers ranged between 6 and18% of precipitation (33 and 160 mm/yr) in humid climates and generally less than 0.4% of precipitation (2.2 mm/yr) in arid/semi-arid/sub-humid climates. One-half (five) of the alternative covers in arid/semi-arid/sub-humid climates transmitted less than 0.1 mm of percolation. Two of the alternative covers have percolation rates much higher than anticipated due to inadequate storage or limited transpiration capacity.

Design and Construction of and ET Cover System in the Eastern U.S.

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Beth A. Gross, P.E. is a Senior Engineer with GeoSyntec Consultants in Austin, Texas. She has been a consulting engineer with GeoSyntec since 1987. Ms. Gross received BSCE and ME degrees from the University of Florida and is completing her doctoral degree in civil engineering at the University of Texas at Austin. Her research focus is the reliability of ET cover design in the southwest U.S.

Ms. Gross' practice has focused on waste containment, including landfill design and performance. She has played a significant role in developing technical support and guidance documents for the U.S. Environmental Protection Agency, including "Evaluation of Liquids Management Data for Double-Lined Landfills", "Waste Containment System Problems and Lessons Learned", and "Technical Guidance for RCRA/CERCLA Final Covers" (in draft). Ms Gross has been a key participant in ET cover design, monitoring, and performance assessment projects in the western and eastern U.S.

Design and Construction of an ET Cover System In The Eastern U.S.

Beth A. Gross, P.E.
GeoSyntec Consultants

Due to problems with long-term compacted clay barrier performance in certain settings and potential cost savings, ET barriers, rather than compacted clay barriers, are being increasingly used in cover systems at semi-arid and arid sites. ET barriers are also used in cover systems for sites in humid climates, but to a lesser extent than for sites in drier climates and generally only when a relatively high level of percolation is acceptable (e.g, 10 to 100 mm/yr percolation in a humid climate versus 1 mm percolation in a semi-arid climate).

A series of ET cover systems were designed for sludge impoundments located at an industrial facility in the eastern U.S. Average annual precipitation at the site is approximately 860 mm. The cover systems consisted of, from top to bottom: 15 cm topsoil; 45 cm on-site soil; and 60 cm flyash. Three types of planting schemes were developed to accommodate the site conditions and end-use: (i) upland forest plants for higher elevations; (ii) marsh edge plants for lower elevations; and (iii) short upland forest plants along a utility easement. The long-term average annual cover system percolation for the cover systems was evaluated using UNSAT-H and ranged from 90 to 130 mm/yr. Cover system construction began in 2003 and is still ongoing. After the impoundments are closed they will be incorporated into a 100-ha park.

Field Performance Monitoring of Evapotranspiration Cover Systems at Mine Sites in Australia, Canada, and the USA

A Summary of Fundamental Processes, Lessons Learned, and Reseearch Requirements

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Mike O'Kane has a B.Sc. in Civil Engineering, and an M.Sc. in Geotechnical Engineering, both received from the University of Saskatchewan, as well as nearly 10 years experience in applied academic research and consulting. He is the managing director of O'Kane Consultants with offices in Canada and Australia who develop conceptual and detailed closure plans for mine waste storage facilities worldwide.
Mr. O'Kane's particular area of expertise is the design, implementation, and performance monitoring of cover systems for mine waste under a wide variety of climate conditions. The focus of his work is on the application of unsaturated zone hydrology to closure of tailings and waste rock storage facilities. Recent and current projects are located in Australia, Canada, the USA and Argentina.

Field Performance Monitoring of Evapotranspiration Cover Systems at Mine Sites in Australia, Canada, and the USA

A Summary of Fundamental Processes, Lessons Learned, and Research Requirements

M. O'Kane, P.Eng.[1]

This paper will present evapotranspiration cover system field performance monitoring data over the past ten years from sites in Australia, Canada, and the USA. The field data presented will be discussed in terms of the fundamental processes controlling performance of evapotranspiration cover systems, the lessons learned through monitoring of full-scale and large-scale field trial evapotranspiration cover systems, and research required to develop defensible predictions of long-term performance.

The field presented data presented will focus on the lessons learned from the evapotranspiration cover system monitoring. The lessons learned that will be discussed include:

- Appropriate conceptual, analytical and numerical modelling tools for gaining further understanding for processes and characteristics that influence and control performance;
- Appropriate field performance monitoring systems for research scale and full-scale evapotranspiration cover systems;
- Physical, chemical, and biological processes affecting the long-term performance of an evapotranspiration cover system;
- Key cover system performance material properties impacted by the above noted physical, chemical, and biological processes;
- Cover materials will evolve over time in response to site-specific physical, chemical, and biological processes such that as-built performance, and possibly performance after many years, does not represent long-term performance;
- Appropriate automated field performance monitoring is required, supplemented with manual *in situ* measurements, to properly understand the evolution of the cover materials and provide some sense of the time frame over which the cover system will "come into equilibrium" with its environmental setting;
- Above average and extreme wet climate years, particularly when they occur over successive years, can have a significant negative impact on the performance of an evapotranspiration cover system;
- Precipitation characteristics (duration, intensity, form (snow or rain), and timing of the year) have a significant, if not controlling, influence on the annual performance of evapotranspiration cover systems, and therefore predictions of performance must be based on site-specific daily climate conditions;
- The presence of vegetation provides a significant positive influence on the performance of evapotranspiration cover systems; however, there is little fundamental knowledge and ability to model the interaction and linkage between the physical and biological aspects of evapotranspiration cover systems; and
- Segregation, which will occur during placement of cover material, can have a significant adverse effect on the performance of an evapotranspiration cover system.

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1 O'Kane Consultants Inc., Saskatoon, SK., and Calgary, AB., CANADA, Brisbane, Queensland, Australia.

The field data will be presented to highlight the "lessons learned" as a result of analysing field performance monitoring data generated from the various full-scale and large-scale field trial cover systems, as opposed to simply presenting and discussing the field data. The objective is to determine whether one would have designed the cover systems differently (or utilised a different design methodology), if the knowledge gained through field performance monitoring was known at the time the cover systems were designed.

A potential fatal cover system design flaw is simply applying a successful design from one site to a second site, when in fact material properties, slope angles, slope lengths, and in particular climate conditions are much different at the second site. Hence, the key idea(s) behind presentation of the field performance monitoring data and discussion of the lessons learned is that it is the design methodology that is transferable from one site to the next, and not the actual design itself; and that the methodology should be updated constantly as new information is developed.

The Quest for Consistency Among Regulatory, Design, and Post-Closure Monitoring Frameworks

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The Quest for Consistency among Regulatory, Design, and Post-closure Monitoring Frameworks

Jorge G. Zornberg, Ph.D., P.E.
University of Texas at Austin

Although evapotranspirative (ET) cover systems are becoming acceptable alternatives for hazardous and municipal waste landfills located in arid climates, design methods and post-closure monitoring approaches are not yet well established. This is partly due to the lack of consensus on how to translate regulatory requirements (equivalence demonstration) into criteria for design and post-closure monitoring. *Equivalence demonstration* approaches have included the use of either numerical simulations or field monitoring demonstrations. Numerical simulation strategies have involved comparison of the performance of an ET cover with that of a prescriptive cover (comparative criterion), while field monitoring demonstration approaches have involved definition of a maximum acceptable percolation for the ET cover (quantitative criterion). The *design* of ET covers should quantify the parameters that minimize the infiltration of liquids into the cover soils, enhance the storage of moisture during the rainy season, and promotes the subsequent release of moisture during the dry season. However, there is lack of consensus regarding the design parameters that govern the performance of the system. This often arises from the need to compromise between soil conditions that correspond with enhanced hydraulic properties with those that correspond with enhanced vegetation development. *Post-closure monitoring* programs have been evaluated for assessment of long-term ET cover performance as well as for extended equivalence demonstration. As the overall objective of any type of cover system is to minimize liquid percolation, post-closure monitoring programs often involve flux rate monitoring. However, the overall performance of an ET cover relies on its ability to store moisture, which can be assessed by monitoring changes in moisture profiles. This presentation discusses the rationale of criteria recently used or proposed for some ET covers in an attempt to achieve consistency among regulatory requirements, design methods, and post-closure monitoring.

Challenges in Monitoring ET Covers

Glendon Gee

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Dr. Glendon Gee is a Laboratory Fellow at the Pacific Northwest National Laboratory in Richland Washington. He is interested in the design, construction, and monitoring of landfill covers, having worked for the past 25 years in testing covers designs, ranging from ET covers to highly-engineered multilayer-cover system. He has recently developed a simple method to measure small drainage fluxes from ET cover systems.

Challenges in Monitoring ET Covers

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An evapotranspiration (ET) landfill cover is a vegetated soil that acts like a sponge by storing excess precipitation during wet periods and removing water via ET during dry periods. An effective ET cover greatly limits drainage through the soil and minimizes leaching of the landfill waste. If and when leachate is generated it drains to the water table, where by law it is monitored in down-gradient wells. In contrast, actual monitoring of ET covers is not required by law but is needed to prove that ET covers are equivalent in performance to more conventional resistive-layer covers. In arid and semi-arid locations, where the water table is deep and contaminant travel times are long, cover monitoring can be used as an early warning of potential groundwater contamination. While drainage rates through the cover and resulting leachate production rates may not be as important as actual risk, some regulatory groups have set target limits for drainage ranging from 1 to 3 mm/yr for ET covers. How to verify low drainage fluxes from ET covers and demonstrate their equivalency to conventional covers is currently being debated. Water content and water potential sensors are generally inadequate, because they do not measure flux rates directly. Water sensing data must be coupled with estimates of the soil's unsaturated hydraulic conductivity, giving rise to drainage estimates that are uncertain, often by more than an order of magnitude. Similarly large uncertainties exist with water balance models, used to predict drainage, particularly at low flux rates. Tracer tests offer some promise for indirectly estimating drainage flux. The only direct way to verify drainage rates is by lysimetry. Test sections with drainage collection systems have proven useful for evaluating ET cover performance, detecting drainage rates of less than 0.2 mm/yr. With proper care, drainage also can be measured directly on the ET cover using a new device called a water fluxmeter or "drain gage". This device is also capable of measuring drainage rates of 0.2 mm/yr or less.

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Sustainability of Conventional and Alternative Landfill Covers

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Dr. Waugh is Principal Scientist with S.M. Stoller Corporation at the U.S. Department of Energy office in Grand Junction, Colorado. He has more than 20 years of experience monitoring the performance of existing covers for uranium mill tailings; designing, testing, and constructing alternative covers; and projecting the long-term performance of both. He is currently working on long-term stewardship issues for the DOE Office of Legacy Management.

Sustainability of Conventional and Alternative Landfill Covers

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Most conventional covers rely on the low permeability of a compacted soil layer (CSL) to limit water movement into landfills. Evapotranspiration (ET) covers rely on a thick soil *sponge* to store precipitation while plants are dormant and on ET to dry the sponge during the growing season. Regulators may allow ET covers as an alternative to low-permeability covers if performance equivalency can be demonstrated. However, current cover design approaches and evaluations of equivalency fail to address effects of near-term and long-term ecological processes on performance. Conventional covers, as designed and constructed, often fall short of permeability requirements. Some designs inadvertently create habitat for deep-rooted plants and burrowing animals. Biological intrusion and soil development can increase the saturated hydraulic conductivity of CSLs several orders of magnitude above design targets. Therefore, the low-permeability requirements for conventional covers may not be achievable, or may require high levels of maintenance or retrofitting to sustain long-term performance.

Alternative ET covers might be designed and constructed to accommodate ecological processes, and thereby sustain a high level of performance with little maintenance. Designing sustainable ET covers will require an *ecosystem engineering* approach that addresses the following types of issues:

- Meteorological variability representative of possible long-term changes in climate.
- Vegetation responses to climate change and to disturbances such as fire, grazing, pests, and invasion of exotic plants.
- Effects of vegetation patterns and dynamics on ET, soil permeability, soil erosion, and animal burrowing.
- Effects of soil development processes on water storage, permeability, and ecology.

Natural analogs can provide insights about how ecological processes may influence the performance of both conventional and alternative covers. Investigations of natural analogs can identify and evaluate likely changes in cover environments that cannot be addressed with short-term field tests and existing numerical models.

*The Environmental Sciences Laboratory is operated by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management under DOE Contract Number DE-AC01-02GJ79491.

Landfill Gas Interactions with ET Covers

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Dr. Ankeny has fifteen years leading and conducting research and development and laboratory management; laboratory and field research concerning soil physical and hydraulic properties; synthesis of physical, chemical, and biological processes in environmental applications; and design of field and laboratory instrumentation. Dr. Ankeny holds seven US Patents for apparatus and methods for controlling or measuring surface water run-off, groundwater, and unsaturated media. Dr. Ankeny has ten years in research, design, and construction of landfill covers for Resource Conservation and Recovery Act (RCRA) Subtitle C and Subtitle D facilities at DOE, DOD, county, and municipal sites. Dr. Ankeny is currently working at the Idaho National Engineering and Environmental Laboratory conducting basis research in the subsurface sciences for the Department of Energy.

http://www.inel.gov/env-energyscience/geo/

Landfill Gas Interactions with ET Covers

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Landfill gas (LFG) inhibits plant growth on landfill covers. Well-established vegetation and deep root penetration are often critical to the success and effectiveness of vegetated landfill covers. Poor vegetative stands can result in reduced transpiration, increased percolation, and increased erosion regardless of the thickness of the cover. Therefore, it is important to evaluate the potential effects LFG may have on cover performance.

Bare (vegetation-free) areas are not uncommon on landfill covers. Often, shallow digging in these areas shows reducing conditions that are not present in vegetated areas at similar depths. Methane and carbon dioxide moving up from waste into an overlying soil cover displaces oxygen, which is required in the soil-rooting medium to maintain healthy root activity. In addition, soil microbes consume oxygen in the presence of methane that reduces oxygen available for plant root respiration. Typically, even low methane levels indicate minimal oxygen concentrations. The magnitude of these effects can vary dramatically with changes in barometric pressure.

Landfill gas also directly affects landfill cover water budgets because biological activity in landfill covers can consume, produce, and release water. Degradation of waste typically occurs in two steps: (1) anaerobic fermentation followed by (2) oxidation. Biological activity can result in biogenic water production on the order of centimeters of water per year. This amount of water is often larger than that calculated for percolation by standard cover water balance models. The implication is that standard hydrologic models that ignore both water production and consumption may result in significant water balance errors.

Installation of Low Permeability Covers and the Coincidental Affects on Gas Contamination of Groundwater at Solid Waste Sites

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Mr. Baker has been President of Alan Environmental since July of 2003. He provides environmental consulting services to a Federal facility,public and private landfills, and industry. He specializes in groundwater contamination investigations and state-of-the-art conceptual remedial designs, conceptual design of alternative caps, of treatment of landfill leachate with vertical wetlands, of odor control systems, and of leachate recirculation and bioreactor landfills. From 1980 to June, 2003, he served as Director New Technologies with Waste Management Inc. where he funded research on innovative systems for landfill optimization, supported 2 projects in EPA's ACAP program, involved in 12 bioreactor landfills, over 50 leachate recirculation projects and investigated over 60 landfills that had VOC contamination due to migration of gas to groundwater. Mr. Baker also was involved in peer review of numerous Superfund investigations and directed hydrogeologic and monitoring program design for 25 RCRA hazardous waste landfills. He previously worked for the State of California Water Quality Control Board in Lake Tahoe, California in the '70s. He has a BS in biology/chemistry and an MS in Environmental Engineering both from University of Illinois, Urbana.

Installation of Low Permeability Covers and The Coincidental Affects On Gas Contamination Of Groundwater At Solid Waste Landfills

by John A. Baker
President, Alan Environmental, LLC.

A detailed review of pre-Subtitle D landfills was conducted to evaluate the coincident timing of landfill cap installation with the occurrence of landfill gas migration and/or groundwater contamination. The presentation will review the types of interim cover on landfills before gas/groundwater contamination occurred and show the types of final low permeability caps that were installed after which gas/groundwater contamination was confirmed. Landfill gas contains numerous types of chlorinated and non-chlorinated VOCs at 10-500 ppmv range depending on the age of the waste. In certain permeable geology and site conditions, gas can migrate under or adjacent to the landfills that are unlined or lined with little knowledge of QA/QC information. When a low permeability cap is installed, it forces the gas to the path of least resistance through permeable strata and can diffuse VOCs into groundwater. Typically gas/groundwater contamination is seen as chlorinated VOCs at 10-100 ppb range as the major compounds. The presentation will discuss briefly how to confirm the origin of VOC contamination and review field techniques to assess the method of VOC diffusion. A model will also show affects of cap permeability on gas migration from an unlined landfill.

Methane Degradation in a Vegetated Cover Test System

Steve Rock

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Steve Rock manages field projects using various phytotechologies such as phytoextraction, phytodegradation, plume control and vegetative covers. He is the author of several phyto publications, including EPA's Introduction to Phytoremediation, and a chapter in the Standard Handbook of Environmental Engineering. He was part of the ITRC team the developed the Phytoremediation Decision Tree, and the Phytotechnolgies Technical and Regulatory Document. He co-chairs the RTDF Action Team on Phytoremediation, and has three subgroups researching the phytoremediation issues of petroleum hydrocarbons, chlorinated solvents, and vegetative covers for waste containment. He conducts field, greenhouse, and chambers research, and provides technical assistance to EPA Regional staff on questions of phytoremediation.

Methane Degradation in a Vegetated Cover Test System

Steve Rock
U.S. Environmental Protection Agency

The goal of any waste containment system is to protect human health and the environment by eliminating direct contact with waste and by preventing contamination of groundwater and air. ET covers prevent direct contact and limit infiltration if properly designed and installed, but research into the effect an ET cover will have on landfill gas escape has been limited. This test facility has been constructed to determine the rate and extent of gas consumption by unconsolidated soils with plants.

The two identical 12 ft by 12 ft by 12 ft, polished stainless steel, insulated Environmental Chambers, located at the Cincinnati municipal sewer district treatment plant, incorporate 16 light fixtures containing a total 32 light bulbs; one metal halide and one sodium vapor bulb in each fixture cover the photosynthetically active radiation (PAR) portion of sunlight spectrum (wavelengths between 400 nm and 700 nm). The chamber system is equipped with a powerful heating, ventilation, and air conditioning (HVAC) system that includes a 10-ton chiller, electric heater, and humidifier. In these Chambers it is possible to replicate a wide range of climate conditions, and to grow a variety of grasses and trees.

Four 100-gallon stainless steel tanks, 35-inch diameter by 34-inch tall, are located in the chamber. A gas distribution diffuser placed within a 4-inch layer of gravel at the bottom of each tank, feeds methane, carbon dioxide, or both from cylinders located outside the chamber to the soil via copper tubing. A manual control valve and rotometer, located at the cylinder, are used to control the flow of methane into the tank. Felt is placed above the gravel to prevent soil from entering the gravel layer and to aid in dispersing the gas.

Gas samples are collected from slotted PVC pipes positioned at different depths within the soil, and from static control chambers on the soil surface. Ambient air samples are collected above the tank. Samples are analyzed by direct injection of a GC/FID located in the adjacent control room.

This presentation shows the results of a study that compares the methane degradation in three treatments: sand, soil, and soil with grass and poplar trees. Two gas flow rates were used over the five-month study.

Biological Functions of a Vegetative/Compost Landfill Cap

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Lori P. Miller, PE is a licensed civil engineer registered in the state of Maryland. Ms. Miller, who earned her engineering degree from the University of Maryland at College Park, has over 18 years experience in the environmental industry. Ms. Miller has been involved in the design and construction of numerous remediation projects, including several landfill caps and groundwater treatment systems. Ms. Miller is currently serving as the Senior Remedial Project Manager for Superfund cleanup at the USDA Beltsville Agricultural Research Center's 7,000 acre Superfund site in Beltsville, Maryland. Ms. Miller is actively pursuing the research and use of sustainable technologies as applied to environmental remediation.

Biological Functions of a Vegetative/Compost Landfill Cap

Lori P. Miller
U.S. Department of Agriculture

The USDA Beltsville Agricultural Research Center (BARC), Beltsville, Maryland, is on the National Priorities List as a Superfund site. One site at BARC is the College Park Landfill, which is a 30-acre municipal landfill which was active from 1955 to 1978, and has never been capped. Although the presumptive remedy is a standard RCRA cap, BARC's Environmental Unit has opted to investigate the use of a sustainable vegetative/compost cap.

To show that the vegetative/compost cap will perform as well as a standard cap, BARC's Environmental Unit is performing a three-year pilot study in partnership with a team of scientists, led by Dr. Patricia Millner, a BARC researcher. The researchers are studying a number of aspects of the system, including:

- Plant water usage;
- Plant carbon sequestration;
- The role of microbes in carbon sequestration; and
- The optimal compost composition to maximize water holding capacity and support plant and microbial growth.

These aspects will be optimized to maximize performance of the vegetative/compost cap.

Poster Abstracts

Sensitivity Analysis as a Design Tool for Alternative Final Landfill Covers

William H. Albright, Michael H. Young, Karl F. Pohlmann, and Stephen F. Zitzer

Numerical simulations are an important part of final landfill cover design. Regulatory permitting procedures often require evaluation of a proposed cover with a model that evaluates system responses to environmental stresses to the soil profile. A number of recent studies have compared simulated results to field-scale performance data and found that models often lack the level of accuracy needed in the permitting process. Given these results, a reasonable question may be "Can modeled results add value to the design process?"

We conducted an extensive modeling exercise for a site in the Mojave Desert of SE California. Several sources of borrow soil were tested for hydraulic parameters, and those results were used to generate stochastic distributions of those parameters, primarily saturated hydraulic conductivity. A 10-yr climate dataset was selected to represent a rigorous test of the proposed cover designs. Covers of six different soil thickness configurations were simulated along with four levels of plant cover. Monte Carlo simulations were run using 100 realizations for each combination of soil thickness, plant cover and surface soil type, with the saturated hydraulic conductivity as the stochastic variable. A total of 7200 2-dimensional simulations were performed with HYDRUS-2D, 2400 simulations for each of three general soil types identified.

The results of the simulations contributed to the design process in three ways: (1) they clearly showed the response of simulated cover performance to systematic changes in important design variables (soil thickness, plant coverage), (2) they included an evaluation of the uncertainty introduced by variable soil hydraulic parameters, (3) they indicated the range of important design parameters over which large changes in performance were realized. The overall approach can be used to better understand system responses to changes in design criteria, so that stakeholders and regulators can negotiate with a stronger technical foundation.

Forensic Evaluation of a Conventional Cover with a Compacted Clay Barrier

C. H. Benson[1], W. H. Albright[2], T. Abichou[3], S. Rock[4], E. MacDonald[2], L. Li[1], X. Wang[1], and D. Powelson[3]

Test sections in Albany, GA from USEPA's Alternative Cover Assessment Program (ACAP) were recently dismantled to make way for construction of a full-scale cover and other remediation systems. During dismantling, the test sections were studied extensively. This poster describes some of the observations made when dismantling the test section simulating a conventional cover. A schematic of the conventional cover profile is shown in Fig. 1. This cover relied on a compacted clay barrier as the primary means to limit percolation of water into the underlying waste. Measurements made on large hand-carved block samples collected during construction indicated that the as-built clay barrier had a saturated hydraulic conductivity of 4.0×10^{-8} cm/s.

Tests were conducted with a sealed double-ring infiltrometer (SDRI) and two-stage borehole permeameters (TSBs) to define the field hydraulic conductivity of the clay barrier layer at the time of dismantling. The field hydraulic conductivity of the compacted clay barrier layer ranged between 3.2×10^{-5} to 3.1×10^{-3} cm/s at the time of dismantling, or approximately 3 to 5 orders of magnitude higher than the as-built hydraulic conductivity. Inspection of the clay showed that it was riddled with cracks, and these cracks likely were responsible for the large increase in hydraulic conductivity. In addition, dye added to the SDRI was observed in the drainage layer of the lysimeter in less than one hour, which strongly suggests preferential flow was occurring through the cracks.

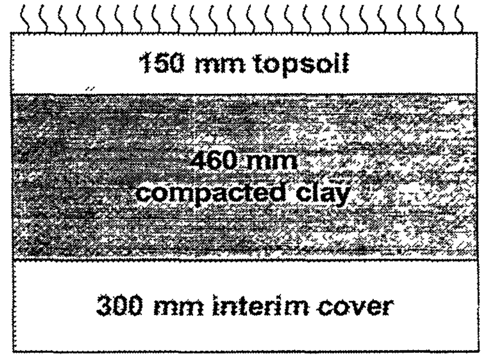

Fig. 1. Profile of conventional cover in Albany, GA.

the most that

An area where dye was pooled was excavated after the dye soaked into the test section. Dye was observed throughout the soil mass in the upper 150 mm of the cover. At greater depths, dye was found along crack surfaces, near the interface between soil and rocks, and in localized pores, all of which are indications that preferential flow was occurring in the clay barrier.

These test results and observations of the soil structure suggest that the clay barrier weathered extensively during the relatively short service life of the test section. Consequently, the cover was ineffective as a hydraulic barrier. Similar behavior is likely to exist in other covers employing unprotected compacted clay barrier layers.

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The phytostabilization demonstration at Building 755, Travis Air Force Base (AFB), California is part of an initiative being conducted by the Air Force Center for Environmental Excellence/Science and Engineering Division (AFCEE/ERS) in conjunction with Parsons. AFCEE/ERS is currently implementing a multi-site program to independently evaluate phytostabilization or phytohydraulics of contaminated groundwater. The primary goal of this multi-site initiative is to develop a systematic process for scientifically investigating and documenting the potential for hydraulic control of groundwater contaminant plumes by the use of tree plantings. Groundwater below and immediately downgradient of the former sump and leach field is contaminated with chlorinated aliphatic hydrocarbons (CAHs), including trichloroethene (TCE). Contaminated groundwater exists 5 to 8 meters below ground surface.

Initial investigation activities at the demonstration site were completed in 1998 and included the installation of 10 monitoring wells and the planting of 100, 15-gallon red ironbark (*Eucalyptus sideroxylon* 'Rosea') trees over an area of approximately 0.2 hectare. The planting area was expanded by 380, 1-gallon trees (480 total) in 2000 for a total coverage of approximately 0.91 hectare. Automated monitoring equipment installed in 2000 included a data acquisition system and weather station, which collects data remotely. In 2002, 13 additional monitoring wells were installed upgradient and downgradient of the site and within the secondary planting area. Cone penetration testing was utilized at each of the new monitoring well locations to characterize the soil by providing soil stratigraphy, relative density, strength and hydrogeologic information.

Data currently being collected at the demonstration site includes hourly meteorological conditions, hourly groundwater level fluctuations, and seasonal sap flow measurements. In addition, annual groundwater samples are analyzed for volatile organic carbons (VOCs) and natural attenuation parameters, and annual plant tissue samples are analyzed for TCE and TCE metabolites. Lastly, stable isotope (hydrogen and oxygen) samples are being collected to better define the source of water being utilized by the trees.

Through the fourth growing season, there is no evidence that the plant stand is significantly impacting the groundwater system. However, the negative water balance estimated for 2002 and beyond would increase the likelihood of groundwater uptake by trees in the future. The plant tissue sampling suggests that the trees at the demonstration site are being exposed to TCE via direct uptake of groundwater or subsurface vapor.

An Innovative Modeling Approach for Engineering Landfill Natural Attenuation Systems

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As late as 1990, approximately 25% of the sites on the Superfund National Priority List were municipal landfills which accepted hazardous waste, including chlorinated aliphatic hydrocarbons. A principal concern associated with these landfills is the impact to underlying groundwater resources. An innovative remediation strategy under consideration for unlined municipal landfills, where natural attenuation is shown to be effective in neutralizing risks to downgradient receptors, involves the placement of an aerobic, permeable landfill cap. The permeable cap must be carefully engineered to control the moisture percolation rate into the refuse and the resulting leachate flux through the base of the landfill, so that landfill-derived pollutants such as chlorinated aliphatic hydrocarbons will continue to be effectively attenuated within and below the landfill.

An Integrated Landfill Modeling System (ILMS) has been developed to provide an important predictive tool for evaluating the effects of various design parameters on the performance of this integrated landfill bioenhancement strategy. The ILMS includes a model for predicting the hydrologic performance of various landfill cap configurations, a leachate composition model for predicting long-term trends in leachate constituent concentrations, and a groundwater biodegradation-redox model (BIOREDOX) for predicting the extent of redox zones and chlorinated aliphatic hydrocarbon plumes in underlying aquifers.

This study presents an application of the ILMS for evaluating the performance of this innovative remediation strategy for a hypothetical landfill site, with an emphasis on the effects of landfill cap permeability on the extent of PCE, TCE, DCE, and vinyl chloride plumes below the landfill. Model input parameters are based on field conditions reported in the literature. Simulation results indicate that this innovative landfill remedy may be more effective than conventional strategies because it maintains favourable conditions for the bioattenuation of chlorinated ethenes. A limited sensitivity analysis identifies key parameters that must be characterized for this type of landfill remedial design evaluation, including leachate source concentrations, redox- and substrate-dependent biodegradation rates, and methane and manganese oxidation rates.

Evaluating Evapotranspiration (ET) Landfill Cover Performance Using Hydrologic Models

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Mitretek Systems

The evapotranspiration (ET) landfill cover is a new, complete landfill cover and it offers opportunities for improved performance and low construction and maintenance cost. The ET landfill cover design problem differs from conventional practice. It includes complex relationships between climate, soil and vegetation and is best solved with the aid of a computer model. This report presents a discussion of cover requirements, design issues, currently available hydrologic models, and an assessment of two engineering models.

Prediction of likely future performance of an ET cover requires a sophisticated model; it should:

- Contain a stochastic climate generator.
- Realistically estimate daily plant and soil response to variable generated climate.
- Realistically estimate all components of the daily water balance including deep percolation, ET, surface runoff and change in soil water storage.

This paper presents currently available models, important features of each that are pertinent to ET landfill cover design and an evaluation of:

- Accuracy of estimated evapotranspiration, surface runoff, and deep percolation.
- Plant parameter inputs and their use within the model.
- Soil parameter inputs and their use within the model.
- Climate parameter inputs or generation.
- Completeness of the hydrologic system evaluation.

High quality data were available from the Agricultural Research Service (ARS) of the United States Department of Agriculture at two locations. At Coshocton, Ohio the ARS measured the hydrologic response of meadow for a 17-year period with a lysimeter. At Bushland, Texas ARS measured the complete hydrologic response of alfalfa and corn for 2 years in a dry climate under irrigation with modern lysimeters.

We used quantitative methods employing statistics to compare performance of two models with these measurements. These model evaluations demonstrate that using tested engineering models for design of ET landfill covers is a valid practice. The errors in model estimates for ET were less than 3.6 percent of the measured value based on annual precipitation and those for deep percolation were less than 2.5 percent.

These evaluations demonstrate that the EPIC model is adequate for ET cover design and that the HELP model has limited usefulness.

Automated Heat Dissipation Sensor System for Monitoring Moisture Flux through Landfill Covers

James Kelsey and John Kay, Daniel B. Stephens & Associates, Inc.

Daniel B. Stephens & Associates, Inc. (DBS&A) has developed a cost effective, robust, and accurate monitoring system for determining moisture flux through landfill covers. Soil moisture flux can be monitored alone or conjunctively with gas and heat monitoring. Installation of the monitoring system can be done during or after construction of the cover, allowing for data collection in new covers as vegetation is being established or in covers that have been in place for years. DBS&A has installed systems in California, Idaho, and Texas, and the system in Idaho has achieved nearly uninterrupted data collection for more than three years.

The soil moisture monitoring system consists of a series of calibrated heat dissipation sensors installed within a landfill cover at various depths. The number of sensors varies depending on site-specific needs, but may consist of heat dissipation sensors, heat flux plates, various gas sensors, and time domain reflectometry (TDR) sensors. DBS&A has developed a series of spreadsheet calculations that use data gathered from these instruments together with site hydraulic soil properties (determined in the DBS&A laboratory) to derive soil matric potentials and temperature gradient. This method enables highly accurate determination of hydraulic conductivity and flux of moisture through the cover.

A weather station at ground surface is used to record barometric pressure and precipitation. All data are collected hourly and stored in dataloggers. Data can be downloaded in the field or remotely, using radio telemetry and/or phone lines, as required. The entire monitoring system is powered by solar panels. Following initial installation, operation and maintenance of the system is minimal. Once decisions regarding data collection and presentation are made, reports can be saved and produced from a template.

DBS&A is currently running new calibrations on 40 heat dissipation sensors removed from a landfill cover after five years of moisture monitoring to determine the consistency of calibration. Wetting curves for these probes will also be derived to determine the effects of hysteresis.

Field-Scale Evaluation of Landfill Gas Emissions from an Instrumented MSW Bioreactor Cell

Milind V. Khire[1], Aruna Yellayi[2], and Xianda Zhao[3]

A 1.2 acre municipal solid waste (MSW) bioreactor cell located in central Michigan has been instrumented to measure water content, temperature, landfill gas and leachate quality at over 60 locations in the cell. The final cap of this cell has also been instrumented to measure water content, landfill gas concentration, and flux of landfill gases emitted to the atmosphere from the cap. The final cap has been instrumented at three locations to make such measurements. These locations are spaced at about 50 ft from each other. The configuration of the final cap varies at each location.

At Location 1, the final cap consists of, from top to bottom, a 400mm thick layer of loosely placed fine sand, a 1.5mm thick HDPE geomembrane (GM), and a 500mm thick layer of compacted clay. At Location 2 and 3, the final cap consists of, from top to bottom, a 450mm thick layer of loosely placed fine sand, a 1.5mm thick HDPE GM, and 450 to 650mm thick dense sand layer. At Locations 1 and 3, a 2m by 2m square window has been cut in the GM to simulate an earthen cap. At Location 2, a 10mm by 10mm square hole has been cut in the GM to simulate a composite cap with a defect. A flux box made of stainless steel is installed in the cap at these three locations above the openings created in the GM. Landfill gas concentration profile in the cap is measured using gas sampling ports consisting of hollow stainless steel tubes installed below and above the GM. Water content of the cap is measured using TDR probes.

Based on 4 rounds of sampling conducted since summer of 2003, key observations include that the concentration of methane below GM at all locations has increased from about 10% during Summer 2003 to about 30% during Winter 2004. Above GM, where GM is not breached, the concentration has stayed below 3%. The methane flux during the period from September to December 2003 has ranged from about 1 to 100 g/m^2/day for Location 1, 150 to 9,200 g/m^2/day for Location 2, and 30 to 60 g/m^2/day for Location 3. Highest flux has been observed for Location 2 where the 1 sq. cm hole has been cut in the GM. Gas flux at Location 1 where clay layer is present is almost equal to gas flux at Location 3 where only sand is used. Gas flux from all locations has been close to zero since the surface of the landfill cap is covered with snow since January 2004. Over 20 VOCs including butane, dichlorofluoro methane, pentane, and propane have been observed in the gas samples collected from the gas ports. Currently we are evaluating the flux of VOCs and methane as a function of water content of the cap, barometric pressure variation, and boundary conditions (snow, precipitation, evaporation, etc.).

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Presented at the *Designing, Building, & Regulating Evapotranspiration (ET) Landfill Covers*, RTDF, USEPA, March9-10, 2004, Denver

ET Covers in Kansas
The Natural Solution – From Concept to Reality

Michael S. Kukuk, P.G.
AQUATERRA Environmental Solutions, Inc.

Our poster presentation depicts the evolution of the first three Alternative Earthen Evapotranspiration Landfill Covers permitted in Kansas. Each was conceived, designed, modeled, approved and constructed in 2003. These projects were all full-scale projects and not pilot tests. The largest landfill cell closed with an alternative cover was 75 acres and the smallest was 7 acres. Two lysimeters were installed within each of the three covers. Early lysimeter results have been encouraging although it is still early in the game. The presentation provides technical as well as economic comparisons between the three cover designs . Items discussed/compared are:

- cover thickness and number of layers;
- soil properties;
- climate;
- vegetation selection;
- predicted drainage rates;
- cost per acre to construct; and,
- cost per acre to maintain (post-closure care).

Actual cost data between construction and maintenance of the ET covers compared to prescriptive Subtitle D covers is presented.

INEEL Subsurface Wireless Sensor Platform

Dennis C. Kunerth, John M. Svoboda, and James T. Johnson

The INEEL sensor platform is a versatile micro-power sensor interface platform for the purpose of periodic, remote sensing of environmental variables such as subsurface volumetric moisture, water potential, and temperature. The key characteristics of the platform architecture are that the platform is passive until externally energized thereby requiring no internal power source and that it communicates with a "reader" via short-range telemetry, i.e. no wires need penetrate to the subsurface. Other significant attributes include the potential for a long service life and a compact size that makes it well suited for retrofitting existing structures. Functionally, the sensor package is "read" by a short-range induction coil that both activates/powers the sensor platform and detects the sensor output via a radio frequency signal generated by the onboard programmable interface controller microchip. As a result, the platform has a functional subsurface communication range of approximately 10 to 12 ft. and can only accept sensors that require low power to operate.

Alternative Landfill (ET) Cover Sites Database

Kelly Madalinksi
U.S. Environmental Protection Agency

An on-line database, maintained by the U.S. Environmental Protection Agency (EPA), captures information about evapotranspiration (ET) covers and other alternative design covers at demonstration and full-scale applications (***http://cluin.org/products/altcovers***). Currently, the database lists 55 sites where ET covers have been proposed, tested, or installed throughout the United States, generally from Georgia to Oregon. Most of the ET projects are demonstrations; however, over 20 projects have been proposed or installed an ET cover at full-scale as part of the remediation and final closure for the site. Depending on the data available for each project, the database provides background information (e.g., site type, climate, precipitation), project information (e.g., purpose, scale, status), cover information (e.g., design, vegetation, installation), performance and cost information, point(s) of contact, and references. EPA established the database to provide additional information to site owners and operators, regulators, consulting engineers, and researchers on the use of ET covers and other alternative landfill covers.

Establishment of a tree cover to stabilize a landfill containing extremely acidic coal combustion wastes at the Savannah River Site, SC.

Donald Marx, PHC Reclamation; Christopher Barton, UKY;
Domy Adriano, UGA; John Blake, USDA Forest Service

Establishment of a vegetative cover to enhance evapotranspiration and to control runoff was examined as an economic and biologically sound method for stabilizing a landfill containing extremely acidic (pH 0.9 – 1.7) coal combustion waste. Studies to identify suitable plant species and pretreatment techniques in the form of amendments, tilling, and chemical stabilization were implemented. A randomized plot design consisting of three subsurface soil treatments (blocks) and five duplicated soil surface amendments (treatments) was developed. The three blocks included: (A) ripped and compost amended, (B) ripped only, and (C) control. Surface treatments on 15 x 15 m plots included: 1) 10-15 cm topsoil, 2) 10-15 cm, pH 5.3, ash, 3) 10-15 cm compost, 4) apatite (5 kg/ha), and 5) control. One hundred inoculated pine trees (*Pinus taeda* and *P. virginiana*), with ectomycorrhizae formed by *Pisolithus tinctorius* and *Scleroderma citrinum* in a container seedling nursery, were planted on each plot. Seedlings planted in preliminary studies without these fungal symbionts died. After three growing seasons, the treatments were shown to be essential for seedling establishment and growth on the basin. Seedlings located on Block A developed a root system that grew into the coal waste media without significant adverse effects to the plant. Seedlings on Blocks B and C displayed poor rooting conditions and high mortality, regardless of surface treatment. Water samples from lysimeters in Block C exhibited high acidity (pH 2.1), Fe, Mn, Al, sulfate and trace element concentrations. Water quality characteristics of the topsoil plots in Block A, however, were acceptable for tree growth. A significant decrease in soil moisture content was observed in the rooting zone of these plots that were vegetated with young vigorously growing trees, which suggests that the potential exists for considerable utilization of water with time by a maturing tree cover.

The results from this multi-year research has far reaching implications in dealing with such environmental issues that transcends industries that generate pyrite-related residues and mining wastes affecting virtually all regions of the world.

Dr. Donald H. Marx

Dr. Donald H. Marx is Chief Scientist of Plant Health Care, Inc. and PHC Reclamation, Inc., which are leading microbial biotechnology and mined-land reclamation companies. He got his Ph. D in Plant Pathology in 1966 from North Carolina State University in Raleigh, NC. In 1991, the King of Sweden awarded Dr. Marx the esteemed Marcus Wallenberg Prize (considered the equal to a Nobel Prize) for his practical work on beneficial mycorrhizal fungi and their role in tree growth and development. During his 37 years of service with the USDA Forest Service, Dr. Marx conducted extensive research on the practical use of mycorrhizal fungi to improve forest regeneration worldwide, as well as research on air pollution, mined land reclamation, stress relationships in trees, root diseases, use of organic soil amendments on adverse sites, exotic tropical forestry, urban forestry and nursery management throughout the US and in over 30 other countries. Dr. Marx founded and was Director of the Institute for Mycorrhizal Research and Development (1974), which later became the Institute of Tree Root Biology (1990) for the Forest Service. Dr. Marx has authored more than 300 scientific papers and presented more than 320 invitational lectures on plant biology in 34 countries. He retired from the US Forest Service in 1994.He co-founded PHC Inc. in 1995 and PHC Reclamation, Inc. in 1998. He is a Fellow of the American Phytopathology Society and a member of the International Society of Arboriculture TREE FUND.

An Evapotranspiration Cover for Containment At the US Army Fort Carson Landfill Site

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The Resource Conservation Recovery Act (RCRA) requires that a regulated landfill have hydrologic barrier cover that complies with prescribed design criteria or an alternative with equivalent performance. In arid and semi-arid climates, alternative covers rely on soil water storage, establishment of vegetation, and soil water loss through evapotranspiration to restrict deep drainage. The design, post-construction analysis, and performance of a 6.1 ha (15 acre) evapotranspiration landfill cover (ET cover) at the U.S. Army-Fort Carson site located in Colorado Springs, Colorado are described. A soil characterization of the borrow area was conducted to inventory soil horizons that were suitable based on hydraulic and plant productivity characteristics, to develop numerical model inputs, and to establish a target soil compaction range based on the undisturbed borrow area. A numerical water balance model, UNSAT-H, predicted that annual drainage through a 122-cm (48-in) thick clay loam cover, based on four continuous years of high annual precipitation at 53 cm (20.8 in), was near or less than 0.1 mm (0.004 in). Construction of the ET cover and planting of native prairie grasses were completed in October 2000. Management practices to establish the permanent plant cover included incorporation of biosolids, soil fertilization, straw mulching, use of erosion blankets, and irrigation. The measured annual lysimeter drainage has typically been less than 0.2 mm. The measured ET cover water storage capacity in a lysimeter was more than 43 cm (17 in). The ET cover soil water storage for the three-year monitoring period ranged from 12.4 cm (4.9 in) to 29.9 cm (11.8 in). The vertical hydraulic potential and soil water content data measured outside of lysimeters suggests upward unsaturated flow and wicking of soil water from the ET cover surface. Presently the dominant native grass that has established on the ET cover is western wheatgrass.

Evapotranspiration (ET) Landfill Cover at Wollert (Victoria, Australia)

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A pilot study was conducted to assist in the identification of practical issues associated with the installation of an ET cover in the Wollert Landfill, Victoria, Australia. The site is located in a semi-arid and temperate Australian context. The proposed cover was to utilise the reject quarry material (scalps) stockpiled on site to sustain a selection of Australian native plants.

The scalps physical performance was analysed in relation to its moisture content and its theoretical ability to maintain adequate plant growth. The study found that the scalps in their present conditions were unsuitable. Unfavourable characteristics included; poor water retention, high pH, potential structural problems relating to sodicity, and an imbalance of exchangeable magnesium cations. However, soil enhancement based on further study is expected to greatly improve the substrate. Potentially, water retention and the total amount of water available to plants can be improved by reducing the gravel content of the scalps, which can be achieved through a single bulk screening. The performance of the scalps can be further improved by determining the optimal *in situ* dry bulk density and placement thickness of the proposed cap based on future field trials.

Desktop studies indicated that perennial Australian native tussock grasses show significant potential for use in an ET landfill cover at Wollert. Although they have a low rate of evapotranspiration, the water absorbing properties of their root networks could potentially act to prevent the ingress of water through the ET cover. They are also well adapted to the regional climate and tolerant of the high pH and low phosphorus conditions of the scalps. Furthermore, they will significantly enhance the organic matter and biological content of the scalps, through their 'root pruning' capabilities that will assist the formation of a well-structured substrate. Warm season C4 grasses *Poa labillardierei* and *Themeda Triandra* have been identified along with a selection of cool season C3 Wallaby grasses (*Danthonia spp.*) to promote evapotranspiration throughout the year. Further investigation based on field trials into the above grasses and the suitability and selection of 'mallee' eucalypts is being conducted to complete the plant selection for the vegetative component of the ET cover.

The pilot study has highlighted more questions than answers, however, it provoked a more comprehensive study that will include field trials using lysimeters, controlled pot trials and numerical modelling of the system.

Monitoring the Performance of Mono-layer Evapotranspirative Covers in the Southwestern United States

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In arid and semi-arid environments, infrequent precipitation, low subsurface fluxes, and evapotranspiration from below evapotranspirative cover systems create challenges to monitoring moisture flux. Furthermore, in contrast to landfill closures, mine waste closures are frequently an order of magnitude larger (thousands of acres). The large scale of these systems results in increased variability in waste and cover materials, and slope and aspect. Consequently, the use of highly controlled large-scale lysimeters is impractical for both cost and applicability considerations. Instead, simplified, inexpensive monitoring using in-situ soil water pressure potential sensors may be adequate to evaluate the efficiency of different cover systems in the semi-arid southwestern USA.

We have instrumented monolayer ET cover systems at several mine site locations in Arizona and Nevada with soil water pressure potential sensors. The most complete data set, and the focus of this paper, is from ET cover test plots constructed over copper mine tailings at Morenci, Arizona. Four different test plots consisting of two different ET cover depths and two different vegetation cover densities have been instrumented with heat dissipation sensor nests. The sensors measure the soil water pressure potential and allow hydraulic gradients to be determined within and below the cover systems to depths of 180 cm. Three replicate sensor nests were installed in each test plot to account for variability in materials and test plot treatments.

Weather from August 2000 to date was characterized by two months of abnormally high precipitation, followed by sequences of normal and abnormally dry precipitation patterns. Monitoring data indicate that deep percolation occurs in response to periods of extended precipitation. However, subsequent drying was observed to depths of 180 cm below the surface in all test plots. Using conservative assumptions regarding tailing hydraulic properties, one-dimensional downward flux predictions based on the monitoring data indicate very low average annual (< 1.5 mm/year) deep percolation rates. Prior to the abnormally dry period, greater cover depth and higher vegetation density reduced the amount of moisture reaching the deeper sensors. Subsequently, observed wetting and predicted deep percolation in the high vegetation density test plots was slightly greater than in the low vegetation density test plots for both cover thicknesses. Although these data indicate the ET cover system performance is dynamic, predicted deep percolation fluxes remain low. Data from other sites also confirm this observation. Monitoring is ongoing to develop a better understanding of ET cover system performance.

Soil Water Content Monitoring Using Electromagnetic Induction

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The use of electromagnetic (EM) induction measurements was evaluated to predict water content in the upper 1.50 m of a prototype engineered barrier soil profile designed for waste containment. Water content was monitored with a neutron probe, and bulk soil electrical conductivity was monitored with a Geonics EM38 ground conductivity meter at 10 locations at approximately monthly intervals over a 3-yr period. A simple linear regression model accurately predicted average volumetric water content of the profile at any location at any time (R2 = 0.80, s = 0.009) and spatially averaged volumetric water content over the entire area at any time (R2 = 0.99, s = 0.003). Although some temporal drift was present in the model residual values, the impact on predicted water content was negligible. Therefore, once the model is calibrated with the neutron probe over a sufficient range of water contents, further neutron probe measurements may not be necessary. EM induction has several advantages over traditional water content monitoring techniques, including non-radioactivity, speed and ease of use over larger areas, and noninvasive character.

SHAW Model Predictions of ET Cover Performance in South Central Alaska

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A modeling evaluation of evapotranspiration (ET) cover performance was conducted for a site near Anchorage, Alaska using the Simultaneous Heat and Water (SHAW) model. This site is being evaluated for landfill closure while also meeting requirements for moose habitat mitigation, requiring the development of a cover vegetated with poplar and willow species managed for moose browse. The SHAW model was selected because frozen soil and snowmelt conditions and the impact of a tree cover on the surface energy balance were expected to be significant influences on cover performance. Models were developed for an ET cover and a compacted clay liner (CCL) cover per Alaska regulations. Results of this analysis indicated that the ET cover could achieve lower percolation than the CCL cover in this region of Alaska. Model results highlighted the control of frozen soil and snowmelt conditions on the site water balance. Although the average annual precipitation is 15.7 inches, 4.3 inches fall in the months of November through March as snowfall. In late-March to early April, snowfall accumulated over the winter typically melts rapidly over a period of 1 to 2 weeks. With frozen soils below the snow accumulation, most of the winter snowmelt is lost to runoff. With an average annual reference evapotranspiration (ET_0)of 21.8 inches, precipitation over the frost-free period is largely lost to canopy interception, soil evaporation, and plant transpiration according to the modeled conditions. A pilot study planned for this site will be designed to validate these modeling results.

The Prospects for ET Landfill Covers in Australia

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Australia has one of the world's highest per capita levels of waste generation. Most of this waste is sent to landfills. Australia is also a world-significant producer of minerals and energy intensive materials - industries that produce large quantities of waste requiring final covering. Clay is generally used for landfill final covers in Australia and there are few ET covers. However ET covers may be able to provide a more cost-effective alternative in many locations. The climate is generally suitable for ET cover technology and inimical to clay and many native plant species have strong hydraulic performances. However the availability of suitable soil at acceptable cost is a possible constraint in some locations. The relevant regulatory regimes will adopt alternative cover technologies if their performance is demonstrated.

PhytoLink Australia is the country's first dedicated phytotechnology company. It was created in 1999 to facilitate the transfer of phytotechnologies, including ET covers, and has now managed several plant performance trials for siteowner clients. In 2003 PhytoLink managed a Waste Management Association of Australia (WMAA) seminar tour by US ACAP and phytoremediation experts to the country's five mainland State capital cities. The tour was timely and, for the first time, generated a strong national industry and regulatory awareness of, and interest in ET cover technology. As a direct consequence a group of industry stakeholders (siteowners, regulators, consulting engineers and researchers) is presently working, under the WMAA's aegis and with PhytoLink as project manager, to establish an Australian equivalent of the US ACAP. Simultaneously a number of siteowners have commenced or about to commence their own ET cover trials. The prospects for ET covers in Australia are promising.