ABSTRACT

There is a demonstrated need for better wastewater alternatives, even in the United States. On-site septic systems serve approximately 25% of the US population (USEPA 1997), and in 1995 alone, over 2.5 million septic systems malfunctioned (NODP). Contrary to the belief that regional wastewater facilities are solving the nation's problems, more Americans are using septic systems now than in 1990 (NODP). Many areas currently served by failed or non-existent septic systems cannot be corrected through regionalization due to low population densities, low per-capita income, rugged terrain, and other barriers, leaving on-site and small cluster facilities as the only viable wastewater option (Drake, 2000). In addition, residential clusters are becoming more widespread as a land-planning tool (Arendt, 1999), resulting in the increasing need for community wastewater treatment facilities (Sykes & Kopischke, 1996).

Hydraulic failure is recognized as a leading cause of premature wastewater soil absorption system (WSAS) failure (Sherman et al. 1998). Often failure is caused by the slow or limited vertical movement and lack of adequate lateral movement of groundwater, resulting in "mounding" of the water table in the vicinity of the WSAS. Mathematical models are recognized as a potential solution to this design problem (Siegrist et al. 2000) but have not become established as a tool for WSAS designers due to a lack of understanding and field calibration.

In 2002, the NDWRCDP funded a proposal submitted by the Colorado School of Mines (CSM) to evaluate the application of hydrogeologic models to WSAS designs. This project is intended to complement the ongoing CSM effort. Up to five large-scale WSAS systems will be evaluated using a variety of field techniques. The objective of this effort will be to determine the accuracy and applicability of the information gathered through different field techniques as applied to the problem of WSAS mounding. Actual mounding will be measured; and different sets of field data will be input into the models recommended by CSM as being appropriate for the hydrogeologic setting. The relative accuracy of the model predictions vs. actual mounding will be used to evaluate the appropriateness of the field investigative method. The following field techniques will be evaluated:

- Use of soil survey and background information.
- Hand auger borings.
- Perc tests.
- Backhoe pits.
- In-situ hydraulic conductivity (Amoozometer) in conjunction with backhoe pits.
- Geotechnical borings; borings logs used as input data.
- Laboratory grain-size distribution tests to predict hydraulic conductivity used with geotechnical boring logs.
- Laboratory hydraulic conductivity tests used with geotechnical boring logs.
- Slug tests to measure hydraulic conductivity in existing monitoring wells.

RATIONALE

High density and cluster WSAS systems are increasingly employed to serve residential development areas due to land use, zoning requirements, and inability to cost-effectively regionalize wastewater services. Existing design guidance for WSAS systems was developed for single-family home septic systems where mounding could, in most cases, be ignored. Sophisticated computer models have been developed by hydrogeologists but these models have not been widely employed in the WSAS design field to date. NDWRCDP is currently funding a Colorado School of Mines project to evaluate existing modeling tools for application to WSAS design.

However, the most sophisticated computer models will not find widespread acceptance in the WSAS field if the model requires hundreds of data input points. WSAS designers must balance the relative accuracy of the field information they collect vs. the cost of obtaining this information. This same process will be applied to groundwater models. If a model requires onerous data inputs that can not be gathered cost-effectively in the field, the model will not be used, regardless of how accurate it is.

OBJECTIVE

By looking at the actual performance of large-scale WSAS systems, the relative accuracy of the data obtained by different field methods can be evaluated. The objective of this project will be to report how relevant and accurate the input data was for up to 5 large-scale WSAS systems, using different treatment and dispersal technologies and located in different hydrogeologic environments. This report will provide guidance to WSAS designers throughout the United States on the relative applicability of an investigative method for a given hydrogeologic setting.

PROJECT TEAM and MANAGEMENT

The project will consist of five team members, as outlined below:

Team Member	Role
Scott Wallace P.E. (NAWE)	Principal Investigator
Chris English P.E. (NAWE)	Senior Engineer
Ryan Brandt (NAWE)	Field Technician
Stuart Grubb, P.G.	Senior Hydrogeologist
Jennifer Olson	Field Hydrogeologist

The project will be managed by the Principal Investigator, Scott Wallace. Given the relatively short duration of the project (approximately 3 month), all project team members will report directly to Mr. Wallace.

Field investigations will be the primary responsibility of Mr. Brandt, with assistance from Ms. Olson. Interpretation of field data will be primary responsibility of Mr. English, while modeling efforts will be the responsibility of Mr. Grubb and Ms. Olson.

RESEARCH APPROACH

The NAWE team proposes to complete the project in three major tasks.

Task 1: Field Investigations

NAWE will assemble a list of operating large-scale WSAS systems operating in Minnesota. A list of 10 systems is included in Table 1. Additional information will be provided to the Project Steering Committee (PSC) to aid in the selection process. It is anticipated that the PSC will select up to 5 systems for field investigation.

Each system presented in Table 1 was designed by NAWE using some combination of hand auger borings, backhoe pits, or geotechnical borings. All systems have at least one monitoring well present at the site. Generally speaking, monitoring well locations were selected by the Minnesota Pollution Control Agency (MPCA) for compliance purposes and are not positioned to directly measure groundwater mounding below the WSAS. However, these wells do allow measurement of the water table elevation and provide valuable insight into the existing hydrogeologic setting.

Borings to Measure Current Mounding

For each site selected by the PSC, two geotechnical borings will be completed to measure the actual height and extent of the mounding below the WSAS. The actual mound height will be the "gold standard" by which the modeling results will be compared to. Model results that reflect actual mounding conditions will be deemed to be accurate; model results that over-predict or under-predict mounding will be consisted inaccurate. Since all candidate sites have flow monitoring, basic aquifer properties, such as transmissivity, can be determined from the flow rate and mound height.

Field Investigative Methods

Up to nine field methods are proposed to be evaluated, subject to PSC review. Generally speaking, these are methods that are commonly used by WSAS designers and/or hydrogeologists. This is not an exhaustive list. Alternate field methods exist, i.e. double-ring infiltrometers, flood pits, etc but these are not common practices in the WSAS community. We would like input on the PSC to determine what methods they would like to see added or deleted from the list, subject to NDWRCDP budget constraints.

At the present time, the following investigative methods are proposed:

Insert Table 1

- Use of soil survey and background information.
- Hand auger borings.
- Perc tests.
- Backhoe pits.
- In-situ hydraulic conductivity (Amoozometer) in conjunction with backhoe pits.
- Geotechnical borings; borings logs used as input data.
- Laboratory grain-size distribution tests to predict hydraulic conductivity used with geotechnical boring logs.
- Laboratory hydraulic conductivity tests used with geotechnical boring logs.
- Slug tests used to measure hydraulic conductivity in existing monitoring wells.

Field information was collected by NAWE during the design process; generally hand auger borings or backhoe pits in addition to soil survey information. This design information can be re-used to save costs. Once a final list of sites is selected by the PSC, we will revise the budget; at this time the budget is laid out assuming (conservatively) that all field methods would be performed at each site. Very few systems were designed using perc tests, which NAWE abandoned as soon as the MPCA discontinued the requirement to use percs. Systems designed using laboratory hydraulic conductivity or amoozometer readings generally are still in the permitting or construction stages, so these tests would have to be performed on the older systems that have been in operation long enough to generate mounding potential.

Task 2: Modeling

Once field data has been collected, NAWE will use the data as input for the model(s) recommended by CSM during their interim work product. It is anticipated that each site will be modeled multiple times (i.e., using hand auger borings as the input data, using backhoe pits as the input data, using perc tests as the input data, etc). The model output will be compared to the actual mounding (as measured by the piezometers) to determine the relevance and accuracy of the data generated by the field method.

Task 3: Report

After the modeling runs, NAWE will prepare a report to the NDWRCDP summarizing the outcomes of the field work and modeling efforts. This report will include recommendations for the use of different field methods in various hydrogeolgic settings and a summary of areas where additional investigation/research would be beneficial. It is anticipated that this will be a companion document to the report developed by CSM.

QUALITY ASSURANCE/QUALITY CONTROL

Field work methodologies will be documented in writing and with photos. Copies of the field methods and the raw field data will be provided to NDWRCDP upon request. A tracking system will be used to account for all model file names and will link written documents to model simulations. All input, output and source files will be catalogued with their relationship to one another recorded. If any other QA/QC needs arise, we will adhere to USEPA requirements and develop a QA/QC plan within 30 days of the time the need becomes apparent.

PROJECT SCHEDULE

It is anticipated that this work would start after the CSM interim work product is delivered in June. The following schedule for the project is anticipated:

Task	Timeframe
Field Investigations	July-August 2003
Modeling	September 2003
Report	October 2003 (February 2004)

This schedule may have to be updated immediately following review of the CSM interim deliverables to ensure that the NAWE product remains consistent and complimentary to the CSM work products. The final CSM work product is due February 2004. If revisions and/or modifications to the NAWE scope originate from the CSM work products, this could potentially delay delivery of a final work product until February 2004, which is when the final CSM work product is due.

LITERATURE CITED

Arendt R (1999). Crossroads, Hamlet, Village, Town. Design Characteristics of traditional neighborhoods old and new. American Planning Association. Planning Advisory Services Report Number 487/488.

Drake S. (2000). The Real World – How Wastewater Models are being Applied in Kentucky. *In* Proceedings of the Small Community Wastewater Management II Conference. National Rural Electric Cooperative Association.

NODP (National Onsite Demonstration Project) (No Date). SepticStats™ An Overview. Environmental Services & Training Division, West Virginia University, Morgantown West Virginia.

Sherman, K., Varnadore R., R. Forbes. (1998). Examining Failures of Onsite Sewage Treatment Systems in Florida. Proceedings of the Eighth National Symposium on Individual and Small Community Sewage Systems. American Society of Agricultural Engineers, St. Joseph MI.

Siegrist R., McCray J., Huntzinger D., Kirkland S., and S. Van Cuyk. (2000). Use of Modeling to Understand and Predict Wastewater Treatment for Onsite Wastewater

Systems. Proceedings of the NOWRA Annual Meeting. National Onsite Wastewater Recycling Association, Laurel MD.

Sykes R, and G. Kopischke (1996). New Scandia Township Visions for Open Space Development. University of Minnesota Department of Landscape Architecture.

USEPA (1997). Response to Congress on Use of Decentralized Wastewater Treatment Systems. United States Environmental Protection Agency Office of Water & Office of Wastewater Management, Washington DC.

BIOGRAPHICAL SKETCH

Name: **Scott D. Wallace, P.E.**

Position/Title: **Principal Investigator & Project Manager**

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FAX #: 651-255-5060

Education (Begin with baccalaureate or other initial professional education)

Institution and Location	Degree	Year	Field of Study
University of Iowa	B.S.	1986	Civil Engineering
University of Iowa	M.S.	1989	Environmental Engineering

Research and Professional Experience

(List in chronological order, present and previous employment, experience, and honors. Also list in chronological order, the titles and complete references to all publications during the past three years and those representing earlier publications pertinent to this application.) *Do not exceed two pages.*

Professional Endeavors

North American Wetland Engineering, P.A.	1997-Present
HDR Engineering, Inc.:	1994 - 1997
Shive-Hattery Engineers and Architects, Inc.	1991-1994
CH_2M Hill	1988 - 1991

Relevant Experience

Mr. Wallace is an environmental engineer specializing in the design of ecological systems including constructed wetlands for wastewater treatment. He has designed over 100 wastewater treatment systems, ranging in size from single-family homes to communities of over 10,000 people. Mr. Wallace is a founding partner and Vice President of North American Wetland Engineering, P.A.

Upper Sioux Community, Granite Falls MN. Design Manager responsible for overseeing the design, construction, and start-up of a pressure sewer system, vertical flow wetlands, and infiltration trench disposal. Areas serviced include a casino/hotel complex, a new residential housing development, a community center, and the tribal administrative offices.

City of Darfur MN. Design Manager responsible for overseeing the design of a pressure sewer system, constructed wetland, and infiltration trench disposal system for this community of 128 people in south-central Minnesota.

City of Palisade MN. Design Manager responsible for the design, permitting, and construction supervision of a new constructed wetland treatment facility for this community of 144 people in Aitkin County MN.

Saginaw Metal Castings, Saginaw MI. Design engineer responsible for the planning and design of a demonstration wetland pilot at this General Motors plant. The constructed wetland treats domestic wastewater and recycles it for use in a stream and waterfall with a fishpond. NAWE teamed with the local firm Designscapes for this project.

City of Spring Hill, MN. Project Manager responsible for the design, permitting and construction supervision of a constructed wetland and subsurface drip irrigation system for this community of 77 people. This project won the *1999 Minnesota Project of the Year* from USDA Rural Development.

Jackson Meadow, Marine-on-St. Croix, MN. Project manager responsible for the design and permitting of a subsurface flow wetland treatment system as an alternative to conventional onsite septic systems for 64 homes. This project won a *Minnesota Honor Award* from the American Institute of Architects.

Fields of St. Croix (Phase I), Lake Elmo, MN. Project manager responsible for the design and permitting of a subsurface flow wetland treatment system as an alternative to conventional onsite septic systems for 46 homes. This was the first large-scale constructed wetland treatment system permitted by the Minnesota Pollution Control Agency. The developer, Robert Engstrom Companies won the *1998 Minnesota Environmental Initiative Award* for this project.

Indian Creek Nature Center, Cedar Rapids, IA. Project manager for the design, construction, and operation of a subsurface flow wetland system for wastewater treatment. This system was featured in the May/June 1996 issue of *Land and Water Magazine,* the July 1997 issue of *Smithsonian Magazine,* and the January 1998 issue of *Public Risk Magazine.*

Selected Publications

Sparks, C., Wallace S. and A. Matthys. 2002. Management of Cluster Wastewater Systems. *In* Proceedings of the NOWRA Annual Meeting. National Onsite Wastewater Recycling Association, Laurel MD. 2002.

Wallace S. 2002. Use of Constructed Wetlands for Nitrogen Removal. *In* Proceedings of the NOWRA Annual Meeting. National Onsite Wastewater Recycling Association, Laurel MD. 2002.

Wallace S. 2002. Method for Removing Pollutants from Water. United States patent 6,406,627. United States Patent and Trademark Office, Washington DC.

Wallace S. 2002. On-Site Remediation of Petroleum Contact Wastes Using Subsurface Flow Wetlands. *Wetlands and Remediation II: Proceedings of the Second International Conference on Wetlands and Remediation*. Battelle Press, 2002.

Hallahan D., and S. Wallace. 2001. Wastewater System Options; Providing Solutions for Small Communities. *CE News*, October 2001. Civil Engineering News Inc., Alpharetta GA.

Wallace S. 2001. Design & Performance of Drip Irrigation Systems in Freezing Environments. *In* Proceedings of the NOWRA Annual Meeting. National Onsite Wastewater Recycling Association, Laurel MD. 2001.

Wallace, S. 1998. Putting wetlands to work, *Civil Engineering Magazine.* American Society of Civil Engineers.

Wallace S, C. Sparks, and R. Micheletti. 1997. Nonpoint source trading creates new discharge opportunities; *Water Environment & Technology Magazine*; *Industrial Wastewater Magazin*e. Water Environment Federation.

BIOGRAPHICAL SKETCH

Name:	**Christopher D. English. P.E.**
Position/Title:	**Senior Engineer**
Address:	North American Wetland Engineering, P.A. 20 North Lake St., Suite 210 Forest Lake, Minnesota 55025 cenglish@nawe-pa.com
Phone #:	651-255-5053
FAX #:	651-255-5060

Education (Begin with baccalaureate or other initial professional education)

Institution and Location	Degree	Year	Field of Study
San Jose State University, CA	B.S.	1986	Civil Engineering

Research and Professional Experience

(List in chronological order, present and previous employment, experience, and honors. Also list in chronological order, the titles and complete references to all publications during the past three years and those representing earlier publications pertinent to this application.) *Do not exceed two pages.*

Professional Endeavors

North American Wetland Engineering, P.A.	2002 – Present
State Engineer, USDA Rural Development, MN	1998 – 2000
Chief of Design and Engineering, Yosemite N.P.	1992 – 1998
USGS Western Research Office, CA	1991 – 1992
NASA Aimes Research Center	1989 – 1991

Relevant Experience

Mr. English is a Senior Environmental Engineer and Project Manager at NAWE with 11-years of experience in wastewater, drinking water and general civil engineering project management and design. In addition, Mr. English has extensive knowledge and experience in the areas of public and private financing stemming from his 5-year tenure as the Minnesota State Engineer for USDA Rural Development.

Mr. English is also recognized as a national leader and expert in the area of Decentralized Wastewater Management. He is the author or co-author of several published articles and technical papers and travels extensively as a speaker on this subject.

He is President of the State NOWRA Chapter and a member of the EPA Decentralized Wastewater Management Speaker's Bureau, the Water Environment Federation Small Communities Committee, and the Central States Water Environment Federation Wastewater Collection System Committee.

Mr. English has worked as a computer programmer developing groundwater solute transport and fate modeling programs for the USGS and artificial intelligence programs for NASA.

Finally, he served 6-years as Park Engineer and Chief of Design and Engineering at Yosemite National Park, CA. During this time, he gained extensive knowledge and experience in the design, construction and operation of water and wastewater treatment systems for application in remote and environmentally sensitive areas.

BIOGRAPHICAL SKETCH

Name: **Stuart E. Grubb, P.G.**

Position/Title: **Senior Hydrogeologist**

Address: Emmons & Olivier Resources, Inc.
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Phone #: (651) 770-8448
FAX #: (651) 770-2552

Education

Institution and Location	Degree	Year	Field of Study
Carleton College, Northfield, Minnesota	B.S.	1985	Geology
University of Michigan, Ann Arbor	M.S.	1989	Water Resources Science

Research and Professional Experience

Professional Endeavors

Emmons & Olivier Resources, Inc.	1998 – Present
HDR Engineering, Inc.	1993 – 1998
Grubb Environmental Services	1992 – 1993
Delta Environmental Consultants	1990 – 1992
CH_2M Hill	1985 – 1989

Relevant Experience

Mr. Grubb is a hydrogeologist with over 15 years of experience in environmental consulting. His areas of expertise are groundwater hydraulics, hydrogeology, groundwater modeling. This resume is a partial description of his qualifications and experience, with emphasis on groundwater modeling.

Groundwater Modeling

Developed equations used to determine capture zones of wells in unconfined aquifers using the analytic element method. Equations have been promoted by the Minnesota Department of Health as effective methods for defining wellhead protection areas.

Wrote and sold ground water modeling software based on analytical element methods titled CAPTURE and WELLCALC for determining well capture zones and well head protection areas. Also developed and sold software for evaluating slug test data and ground water mounding below infiltration basins. Software is currently being use throughout the United States, Canada, and Europe.

Selected Projects:

Shakopee, Minnesota – Modeled hydrogeologic impacts of different designs of a cluster septic system for a mobile home park. Modeling demonstrated that a long, narrow infiltration system would work with the site topography and would have the necessary infiltration capacity. Installed wells and performed aquifer tests to determine hydrogeologic parameters for the model.

Hutchinson, Minnesota – Modeled the potential for infiltration in low-permeability soils below existing septic systems and a proposed cluster system.

South Washington County, Minnesota – Developed models for evaluating infiltration of stormwater. Modeled infiltration and mounding below large and small landlocked basins. Evaluated the effect of infiltration structures such as infiltration tubes and trenches. Installed monitoring wells and performed aquifer tests to determine hydrogeologic parameters. Monitored infiltration rates during and after storm events.

Developed a MLAEM model of the South Washington Watershed District (Woodbury, Cottage Grove area). Model is the first in Minnesota to fully utilize GIS data generated by the Minnesota Geological Survey and the ARCVIEW/MLAEM interface tools created by the Minnesota Department of Health. Completed model will be used for wellhead protection planning, infiltration management, and pollution tracking.

Twin Cities Metropolitan Area, Minnesota. Evaluated areas for septic system suitability on behalf of the Metropolitan Council. Evaluation was based on soils and hydrogeologic conditions.

Eagan, Minnesota – Assisted in modeling and permitting associated with dewatering for construction of the Seneca Wastewater Treatment Plant. HDR Engineering played a key role in installing the first permitted injection well in Minnesota in order to protect a calcareous fen.

Ramsey, Anoka, Washington Counties, Minnesota – Produced a regional ground water flow model to be used by the Minnesota Department of Health for source water protection planning. Large data bases and modeling results were created and presented using ArcView GIS.

Woodbury and Afton, Minnesota – Created a MLAEM model to study ground water / surface water interactions in the area of Valley Creek. Model was part of a study of high nitrate levels in Valley Creek by the St. Croix Watershed Research Station. Model was later used to evaluate effects of proposed municipal pumping wells on the springs that feed the headwaters of Valley Creek, a designated trout stream.

Selected Publications

Grubb, S., 1993. "Analytical Model for Estimation of Steady-State Capture Zones of Pumping Wells in Confined and Unconfined Aquifers." Ground Water, Vol. 31, No. 1.

Grubb, S., J. Swenson (Olson), C. Correll, B. Emmons, J. Nieber. 1999. “Monitoring and Modeling of Infiltration in an Urbanizing Watershed, Washington County”. Midwest Groundwater Association Conference. St. Paul, Minnesota.

Grubb, S., and J. Swenson (Olson). 2000. “Integrating storm water modeling, GIS, and AEM Modeling”. International Analytic Element Method Conference. Brainerd, MN.

BIOGRAPHICAL SKETCH

Name: **Jennifer L. Olson**

Position/Title: **Hydrogeologist**

Address: Emmons & Olivier Resources, Inc.
651 Hale Avenue N.
Oakdale, MN 55128

Phone #: (651) 770-8448
FAX #: (651) 770-2552

Education

Institution and Location	Degree	Year	Field of Study
University of Minnesota, Duluth	B.S.	1997	Hydrogeology and Environmental Geology
University of Minnesota, St. Paul	B.S.	2002	Water Resources Science

Research and Professional Experience

Professional Endeavors

Emmons & Olivier Resources, Inc. (10/97 – present)

Relevant Experience

Ms. Olson is a hydrogeologist with experience in surface water-groundwater interactions, ground water modeling, surface and ground water monitoring, and watershed management.

- Master's degree thesis. Modeling of infiltration and mounding below a large stormwater infiltration basin. Numerical model developed to solve for mounding occurring below infiltration basins which includes a comparison of available groundwater mounding models and solutions. Model calibrated to event-based piezometer data. Model evaluates the impact of thin, low-permeability layers and the effectiveness of different shaped structures (trenches, tubes) installed to penetrate the layers. Visual MODFLOW results will be compared to FEMWATER (Finite Element Model) and MLAEM (Analytic Element Model) results for the same area.
- Completed ground water mounding analyses for rainwater gardens and small scale infiltration practices, implemented changes to design based on mounding analysis using Glover's solution.
- Completed groundwater mounding analysis for community septic system. Conducted soil borings on site, permeability tests, and modeling of infiltration potential.
- Conducted a review of a surface water infiltration project for the effects on the local and regional water table. Review included groundwater mounding analysis, additional soils data collection, and assisting with an alternative design for the project.

- Managed an infiltration monitoring program that included identifying local monitoring sites, surveying for basin morphology, researching equipment needs, developing site monitoring plans, and analysis of data. This program also included surface water sampling and ground water sampling.
- Participated on an Infiltration Management Study that analyzed the role that infiltration plays in a metro watershed. This project included the development of a monitoring program to characterize the current conditions of the watershed, analysis of infiltration rates, installation of monitoring wells, HydroCAD surface water modeling, and ground water modeling (MLAEM).
- Participated on Integrating Groundwater and Surface Water Resources Study that included colleting data on recharge and discharge functions of water bodies, developing criteria to rank recharge and discharge areas, and develop model management policies to protect sensitive areas in a 225 square mile project area.
- Collaborated with local watersheds to develop a ground water monitoring and sampling program, including identifying well networks, addressing landowner issues, and conducting field sampling.
- Completed an analysis of the Metropolitan Area geology and surficial geology that identified private and public drinking water sources susceptible to contamination by septic systems.
- Conducted geotechnical investigations for private developments, specifically for siting infiltration practices and identifying permeability of materials.
- Created maps of infiltration potential using geology, water table, soils, and landuse GIS coverages for several watershed districts.
- Developed and evaluated innovative Best Management Practices for storm water management based on infiltration and volume control.
- Assisted with the development of a MLAEM ground water model for a metropolitan watershed, including collecting data and analyzing geologic parameters. Use of GIS and data sets provided by the county, MGS, MDH and MPCA.
- Experienced with surface hydrologic and water quality modeling software including BASINS, HydroCAD, P8 and PondNET.
- Experienced in Geographic Information Systems including ArcView and Spatial Analyst.

Selected Publications

Grubb, S., J. Swenson (Olson), C. Correll, B. Emmons, J. Nieber. 1999. "Monitoring and Modeling of Infiltration in an Urbanizing Watershed, Washington County". Midwest Groundwater Association Conference. St. Paul, Minnesota.

Grubb, S., and J. Swenson (Olson). 2000. "Integrating storm water modeling, GIS, and AEM Modeling". International Analytic Element Method Conference. Brainerd, MN.

Emmons, B., C. Olivier, C. Correll, J. Olson, and J. Nieber. 2001. Landscape Role of Wetlands in Infiltration and Groundwater Recharge". Proceedings of the American Water Resources Association Conference. Albuquerque, New Mexico.

Oberts, G., B. Emmons, J. Olson, and C. Correll. 2002. Basinwide Infiltration as an Effective Cold Climate Urban Runoff Management Practice. Proceedings of the American Water Resources Summer Specialty Conference: Ground Water/Surface Water Interactions. Keystone, Colorado.