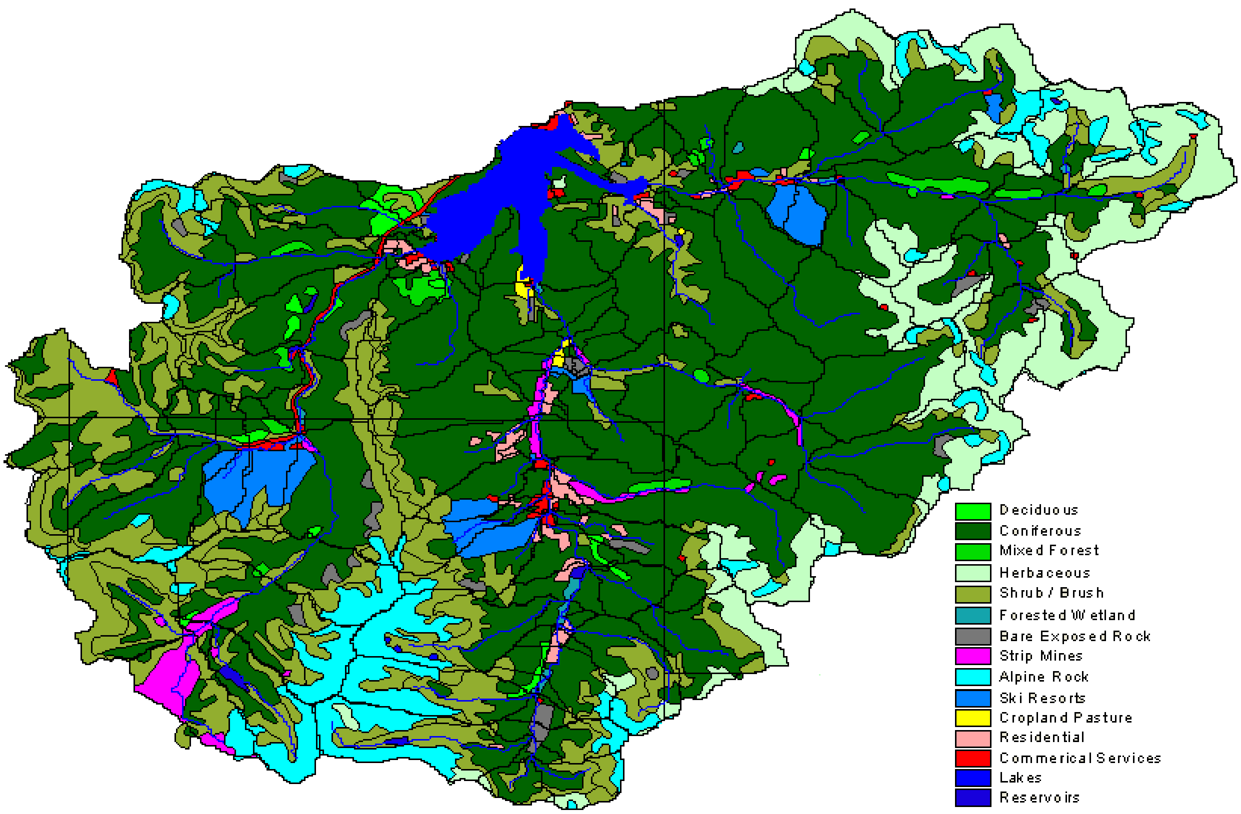
National Decentralized Water Resources Capacity Development Project

Executive Summary



Quantifying Site-Scale Processes and Watershed-Scale Cumulative Effects of Decentralized Wastewater Systems

Colorado School of Mines

January 2005

Quantifying Site-Scale Processes and Watershed-Scale Cumulative Effects of Decentralized Wastewater Systems

Submitted by the Colorado School of Mines

Golden, Colorado

NDWRCDP Project Number: WU-HT-00-27

National Decentralized Water Resources Capacity Development Project (NDWRCDP) Research Project

Final Report, January 2005

NDWRCDP, Washington University, Campus Box 1150
One Brookings Drive, Cupples 2, Rm. 11, St. Louis, MO 63130-4899

DISCLAIMER

This work was supported by the National Decentralized Water Resources Capacity Development Project (NDWRCDP) with funding provided by the U.S. Environmental Protection Agency through a Cooperative Agreement (EPA No. CR827881-01-0) with Washington University in St. Louis. This report has not been reviewed by the U.S. Environmental Protection Agency. This report has been reviewed by a panel of experts selected by the NDWRCDP. The contents of this report do not necessarily reflect the views and policies of the NDWRCDP, Washington University, or the U.S. Environmental Protection Agency, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

CITATIONS

This report is based on research completed by a team of investigators including:

Colorado School of Mines, Golden, CO
Dr. Robert L. Siegrist
Dr. John McCray
Ms. Kathryn Lowe, M.S.
Dr. Sheila Van Cuyk
Ms. Jennifer Bagdol, M.S.
Ms. Shiloh Kirkland, M.S.
Ms. Paula Jo Lemonds, M.S.
Ms. Heather Smith, M.S.

Electric Power Research Institute, Palo Alto, CA
Dr. Robert Goldstein

Systech Engineering, Inc., San Ramon, CA
Dr. Carl Chen
Ms. Laura Weintraub, M.S.

Summit County Environmental Health, Frisco, CO
Mr. Jim Rada

The research described in this report was sponsored in large part by the National Decentralized Water Resources Capacity Development Project. Some elements of the research were enabled by supplementary funding provided through grants and student scholarships received from the National Science Foundation, Department of Education, Infiltrator Systems, Inc., and others.

The final report was edited and produced by ProWrite Inc., Reynoldsburg, OH.

This report is available online at www.ndwrcdp.org. This report is also available through the

National Small Flows Clearinghouse
P.O. Box 6064
Morgantown, WV 26506-6065
Tel: (800) 624-8301
WWCDRE45

This report should be cited in the following manner:

Siegrist, R. L., J. McCray, L. Weintraub, C. Chen, J. Bagdol, P. Lemonds, S. Van Cuyk, K. Lowe, R. Goldstein, and J. Rada. 2005. *Quantifying Site-Scale Processes and Watershed-Scale Cumulative Effects of Decentralized Wastewater Systems*. Project No. WU-HT-00-27. Prepared for the National Decentralized Water Resources Capacity Development Project, Washington University, St. Louis, MO, by the Colorado School of Mines, Golden, CO.

ACKNOWLEDGEMENTS

Appreciation is extended to the following individuals for assistance in the preparation of this report:

Colorado School of Mines
Robert L. Siegrist
John McCray
Jennifer Bagdol
Sheila Van Cuyk
Kathryn Lowe
Paula Jo Lemonds
Heather Smith

Electric Power Research Institute
Robert Goldstein

Systech Engineering, Inc.
Carl Chen
Laura Weintraub

Summit County Environmental Health Department
Jim Rada

Acknowledgments are given to Dr. Ron Harvey and his colleagues at the United States Geological Survey (USGS) in Boulder, CO for assistance with the experimentation regarding virus transport and fate.

Dr. Tissa Illangasekare, Colorado School of Mines, is acknowledged for coordination of the independent peer review, which was completed near the end of the project. The members of the peer review panel included: Drs. Arturo Keller, University of California-Santa Barbara, Dr. Jayantha Obeysekera, South Florida Water Management District, Dr. Robert Prucha, Integrated Hydro Systems, LLC, and Mr. Russell Clayshulte, RNC Consulting. Kent Glover, Colorado School of Mines is also acknowledged for his participation in the peer review and assistance with coordination of the peer review report.

Acknowledgements are given to Greg O'Neill and staff of the USGS District Office in Lakewood, Colorado and the USGS National Water Quality Laboratory in Arvada, Colorado for their collaboration on the water quality monitoring facets of the research described herein.

Mark Mumby and Kayenta Consulting, Inc. are acknowledged for their efforts during the drilling activities in support of subsurface exploration and monitoring well installation.

The University of Rhode Island is acknowledged for providing and supporting the watershed modeling using MANAGE.

The residents and owners of property in the Dillon Reservoir watershed who allowed site access in support of the environmental characterization are acknowledged for their cooperation and support of the project.

Appreciation is also expressed to the NDWRCDP for their support of this work:

Principal Investigator
Jay R. Turner, D.Sc., Washington University

Project Coordinator
Andrea L. Shephard, Ph.D.

NDWRCDP Project Steering Committee:

Coalition for Alternative Wastewater Treatment
Valerie I. Nelson, Ph.D.

Consortium of Institutes for Decentralized Wastewater Treatment
Ted L. Loudon, Ph.D., P.E.

Electric Power Research Institute
Raymond A. Ehrhard, P.E.
Tom E. Yeager, P.E.

National Onsite Wastewater Recycling Association
Jean Caudill, R.S.

National Rural Electric Cooperative Association
Steven P. Lindenberg
Scott Drake, P.E.

Water Environment Research Foundation
Jeff C. Moeller, P.E.

Members-At-Large:
James F. Kreissl
Richard J. Otis, Ph.D., P.E.
Jerry Stonebridge

EXECUTIVE SUMMARY

Wastewater management in the US includes millions of individual onsite wastewater systems (OWS), which are relied on to effectively treat and dispose of wastewater generated by 25% of the country's population. In the past, OWS have often been viewed as a temporary approach to wastewater management and acceptable for use only until a centralized approach could be implemented. Yet there are many situations within the US (and more so in developing countries) where centralized systems are neither cost-effective nor sustainable due to a variety of factors (such as low-density development, rugged topography, limited water and energy supplies, and lack of skilled labor).

Onsite and decentralized systems are characterized by collection distances that are short or negligible, with tank-based pretreatment followed by soil absorption to provide advanced treatment as the water percolates toward groundwater. These wastewater soil absorption systems can function as porous media biofilters. Soil porous media biofilters have the potential to achieve high treatment efficiencies over a long service life at low cost, and be protective of public health and environmental quality. These facts have been well-established (US EPA 1978; Jenssen and Siegrist 1990; Siegrist *et al.* 2001; and US EPA 2002).

Favorable results from lab and field studies as well as an absence of documented adverse effects are consistent with an assessment that the performance of common OWS serving individual households is generally satisfactory. However, the quantitative understanding of and ability to predict the performance of household OWS as a function of design, installation/operation, and environmental factors have not been fully elucidated (Siegrist 2001; Siegrist *et al.* 2001). These gaps in knowledge are present for some facets of design and performance for OWS serving individual homes in low-density applications (for example, one OWS per hectare), while the knowledge gaps are even greater for OWS serving nonresidential establishments (such as fast-food restaurants, nursing homes, or veterinarian clinics). As a result, the current state of knowledge and standard-of-practice have gaps that can preclude rational design of individual OWS to predictably and reliably achieve performance goals for a specific OWS application. Moreover, for higher density applications of OWS (for example, five OWS per hectare) or applications of large numbers of individual OWS within a watershed-scale framework, the quantitative analysis of long-term treatment efficacy, including assessment of cumulative effects and establishment of total maximum daily loads (TMDLs), is quite difficult.

The goal of this National Decentralized Water Resources Capacity Development Project (NDWRCDP) project, (*Quantifying Site-Scale Processes and Watershed-Scale Cumulative Effects of Decentralized Wastewater Systems*) was to develop understanding and modeling tools that can help quantify site-scale system processes and watershed-scale cumulative effects of OWS. A second major goal was to enhance the understanding of the potential watershed-scale effects of a broad-scale application of OWS, incorporating project results on the dynamic quantification of site-scale processes during the refinement, application, and evaluation of watershed modeling tools. To accomplish these goals, the project was designed and carried out by a collaborative team involving the Colorado School of Mines (CSM), Electric Power Research Institute (EPRI), Systech Engineering, Inc., United States Geological Survey (USGS), and the Summit County Environmental Health Department. The project scope included:

- Literature review and analysis
- Laboratory and field experimentation
- Development and refinement of mathematical models
- Completion of site-scale and watershed-scale model simulations
- Field monitoring in a study watershed

An independent peer review of the research was completed near the end of the project period.

For the common soil-based OWS at the single-system scale, quantitative understanding of hydraulic and purification processes has been improved and site-scale models and decision-support tools have been developed and tested in this project. Based on literature data, cumulative frequency distributions were developed for concentrations of key characteristics of domestic septic tank effluent (STE) and for the transport/fate parameters that describe the treatment of nutrients in soil and groundwater systems (Kirkland 2001 and McCray *et al.* 2005). Experimental studies were completed involving STE treatment in a soil-based OWS to test a new experimental design methodology based on life-cycle acceleration and to provide a dataset for site-scale modeling (Siegrist *et al.* 2002). Through a series of experimental studies, fundamental understanding of bacteria and virus transport/fate in soil-based OWS was enhanced (Van Cuyk 2003). At the Mines Park Test Site on the CSM campus, test cells representing a segment of an in situ porous media biofilter were established to examine hydraulic and purification processes as affected by hydraulic loading rate and infiltrative surface architecture in sandy-loam soils (Lowe and Siegrist 2002 and Tackett *et al.* 2004). An existing numerical model, HYDRUS 2-D, was set up to simulate a soil-based OWS and enable site-scale scenario analyses regarding hydraulic and purification performance (Beach and McCray 2003). A new site-scale model, referred to as the Biozone Algorithm, was formulated by Systech Engineering to describe the biozone development in a soil-based OWS and the hydraulic and purification performance of that OWS (Weintraub *et al.* 2002). This biozone model was tested against CSM experimental datasets.

A major facet of this project involved the refinement, application, and testing of an existing watershed-scale model, Watershed Analysis Risk Management Framework (WARMF) for the Dillon Reservoir watershed in Summit County, Colorado. There are about 1,500 OWS in this watershed as well as other nonpoint and point sources of pollution, and more than 600 onsite drinking water wells along with community wells and surface water supplies. In addition, Dillon Reservoir provides 25% of the drinking water supply for the City of Denver. In this project, WARMF has been modified to include explicit representation of OWS of different performance features, an integrated Biozone Algorithm, and cumulative frequency distribution curves for source concentrations and transport/fate parameters. As demonstrated in this project for the Blue River basin of the Dillon Reservoir watershed, the water quality effects of OWS were simulated using WARMF and compared to a water quality dataset generated during the project. Simulations were also completed to assess realistic decision-making scenarios concerning wastewater infrastructure in the watershed and to determine the comparative effects on water quality.

WARMF as well as two other models, the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)/Soil and Water Assessment Tool (SWAT) and Method for Assessment, Nutrient-loading, and Geographic Evaluation (MANAGE) models, were set up, calibrated, and applied to the Dillon Reservoir watershed. Compared to WARMF, the BASINS/SWAT model does not explicitly account for OWS, is less efficient in running scenario analyses, and does not include modules for TMDL analysis and stakeholder consensus building. In terms of setup and application to a given watershed, both models will require considerable resources either in the form of the upfront purchase price for a setup and calibrated model (such as WARMF) or for the consultant or in-house labor costs to setup, calibrate, and run a public-domain model (such as BASINS/SWAT). MANAGE is a comparatively simple geographic information system (GIS)-based vulnerability mapping tool to identify potential hotspots and is similar in many respects to mass balance calculation approaches that could be formulated and applied to a particular potential problem area. After setup and calibration, model simulations were completed to examine current wastewater management scenarios and the simulation results were compared to field monitoring data. Examination of future wastewater management scenarios was also completed through watershed-scale model simulations (such as simulation of the abandonment of OWS and connection of homes to a centralized wastewater treatment plant [WWTP]).

The environmental monitoring and subsurface characterization efforts of this project were focused on developing sufficient understanding of the Dillon Reservoir watershed to enable model setup and initial calibration. The water quality monitoring was focused on surface water flow and quality at up to 20 monitoring locations in the watershed. Quality data include routine water quality parameters, wastewater-related pollutants, and some chemical and biological tracers. In performing the characterization work an attempt was made to use limited and potentially uncertain data and to assess the reliability of that approach. At the watershed-scale in the Dillon Reservoir watershed, compared to urbanized development and WWTP discharges, OWS are not a principal source of water pollutants as evidenced by source load mass balance calculations, WARMF and BASINS/SWAT model simulation results, and water quality monitoring and analysis of spatial and temporal trends.

Application of a watershed-scale decision-support tool such as WARMF can enable analysis of wastewater management scenarios and provide critical insight into the water quality benefits of one management option compared to another. Based on WARMF simulations of different wastewater management scenarios in the Blue River basin, extending central sewers and conversion of OWS to a central WWTP appears to offer little or no benefit in terms of surface water quality protection, and in some cases may lead to surface water quality degradation.

While the research completed during this project has advanced the science and engineering of OWS, there are still some gaps in understanding that further research should attempt to fill. In general, there continues to be a need for quantitative understanding to enable proper OWS design to yield a desired performance level. Such understanding also enables the design and implementation of monitoring devices and methodologies for process control and performance assurance.

The methodology and tools developed in this project are recommended for application in support of decision-making in Summit County, Colorado, and the benefits gained from this decision support should be documented and used to assess the benefit/cost of quantitative decision support such as reported herein. In addition, the methods and tools developed in this project should be applied and tested for other situations and environmental conditions to determine the extent of extrapolation possible. Considering the scope of the research completed in this project, those components of the work that would be most valuable to enabling application to another geographic region of the US for watershed-scale management would include WARMF (and a comparative model) model refinement, setup, calibration, and simulations along with necessary and appropriate environmental characterization and watershed monitoring. Depending on the goals of the research during a similar project in another region of the US, additional site-scale testing and experimentation (to generate site-specific input data and algorithms for modeling) might also be warranted.

Printed on recycled paper in the United States of America.

WU-HT-00-27

NDWRCDP
Washington University, Campus Box 1150, One Brookings Drive, Cupples 2, Rm. 11, St. Louis, Missouri 63130-4899 • USA

This report is available online at www.ndwrcdp.org. This report is also available through the
National Small Flows Clearinghouse • West Virginia University/NRCCE, P.O. Box 6064, Morgantown, WV 26506-6064 • USA
Tel: (800) 624-8301 • WWCDRE45