1995 Project Abstract
For the Period Ending June 30, 1997
This project was supported by an appropriation from the Natural Resources Trust Fund, Legal Citation: ML 95, Chp. 220, Sec. 19, Subd. 8(g).

Project Title:	**Metropolitan Area Groundwater Model to Predict Contaminant Movement.**
Program Manager:	**Andrew Streitz**
Organization:	**Minnesota Pollution Control Agency**
Mail Address:	**Ground Water Unit, Program Development Section** **Ground Water & Solid Waste Division** **520 Lafayette Road** **St. Paul, Minnesota 55155**
Legal Citation:	**ML 95, Chp. 220, Sec. 19, Subd. 8(g).**
Appropriation Amount:	**$250,000**

(As reported in the Workprogram, a formal final report was not developed due to a scaling back of funding levels by LCMR. Alternately, the Summary from the Interim Progress Report (written in February 1997) is copied below. The complete Report itself is also included.)

Interim Progress Report- A Summary

This report summarizes the current development of the Twin Cities Metropolitan Groundwater Model (Metro Model), a computer model that simulates regional groundwater flow in the seven-county Twin Cities Metropolitan area. The model is being developed by staff from the Minnesota Pollution Control Agency (MPCA) and the University of Minnesota (UM). The computer model is based on the analytic element method and simulates multi-aquifer groundwater flow. It will be used as a management tool for groundwater resources by providing the background aquifer parameters for use in more detailed modeling of localized areas of concern. Although MPCA staff intend to apply it to problems of groundwater contamination, it is being developed with other objectives in mind, to ensure that it has the broadest utility to other governmental agencies, local governments, and private parties.

The purpose of this interim document is to inform interested parties of the approach and application of data and information in constructing the Metro Model. Part of the rationale for presenting this information is to make it available to others while the model is still under construction. More important to the quality of the Metro Model, however, is to receive critical feedback on the effort. Therefore, reviewers are invited to share feedback, ideas, and criticisms on any aspect of the project at *any* time. This document presents information used to produce the Metro Model as it now stands. Research into the hydrogeology of the hydrostratigraphic units that are already included in the Metro Model will continue, and the depth of knowledge of these layers will increase. Additionally, more information, representing regional variations in properties of the hydrostratigraphic units will also be incorporated into the model as the hydrogeologic conceptual model is refined. Consequently, the hydrogeologic conceptual model will change in response to increasing our knowledge base of the hydrogeology, resulting in changes to the Metro Model. Therefore, judicious use of the information contained in this document is necessary. Be aware that, because the regional hydrogeologic system is being considered, the information presented here is not intended to represent site-specific conditions for local sites. A follow-up report to be produced at the end of this year will supersede this Progress Report.

Description

The Metro Model is being developed using the Multi-Layer Analytic Element Model program (MLAEM) developed by Prof. Otto D.L. Strack of the Department of Civil Engineering of the University of Minnesota. Hydrostratigraphic units comprised of both bedrock and glacial drift units are included in the Metro Model. The model simulates three-dimensional groundwater movement.

The subsurface is divided into water-bearing units that may be used for groundwater exploration (aquifers). Aquifers are separated by leaky layers. The Metro Model simulates regional interactions between aquifers, and will be calibrated by comparison between measured and simulated heads and discharges.

The complete model will consist of five layers representing the following aquifers listed from the surface downward: glacial drift, St. Peter Sandstone, and the Prairie du Chien-Jordan, Ironton-Galesville, and Mt. Simon-Hinckley Aquifers. At the present time Layers 3, 4, and 5, representing the three lower aquifers, have been modeled. Development of Layer 2 is nearing completion. Layers 1 is under development.

The Metro Model will be available to groundwater scientists working in both the public and private sectors. It will provide the context of regional groundwater flow in the Metropolitan Area and can be used to aid in management decisions affecting groundwater. Additionally, users can add local detail to the model to conduct site-specific modeling for groundwater flow analysis.

1995 Project Abstract
For the Period Ending June 30, 1997
This project was supported by an appropriation from the Natural Resources Trust Fund, Legal Citation: ML 95, Chp. 220, Sec. 19, Subd. 8(g).

Project Title:	**Metropolitan Area Groundwater Model to Predict Contaminant Movement.**
Program Manager:	**Andrew Streitz**
Organization:	**Minnesota Pollution Control Agency**
Mail Address:	**Ground Water Unit, Program Development Section** **Ground Water & Solid Waste Division** **520 Lafayette Road** **St. Paul, Minnesota 55155**
Legal Citation:	**ML 95, Chp. 220, Sec. 19, Subd. 8(g).**
Appropriation Amount:	**$250,000**

(As reported in the Workprogram, a formal final report was not developed due to a scaling back of funding levels by LCMR. Alternately, the Summary from the Interim Progress Report (written in February 1997) is copied below. The complete Report itself is also included.)

Interim Progress Report- A Summary

This report summarizes the current development of the Twin Cities Metropolitan Groundwater Model (Metro Model), a computer model that simulates regional groundwater flow in the seven-county Twin Cities Metropolitan area. The model is being developed by staff from the Minnesota Pollution Control Agency (MPCA) and the University of Minnesota (UM). The computer model is based on the analytic element method and simulates multi-aquifer groundwater flow. It will be used as a management tool for groundwater resources by providing the background aquifer parameters for use in more detailed modeling of localized areas of concern. Although MPCA staff intend to apply it to problems of groundwater contamination, it is being developed with other objectives in mind, to ensure that it has the broadest utility to other governmental agencies, local governments, and private parties.

The purpose of this interim document is to inform interested parties of the approach and application of data and information in constructing the Metro Model. Part of the rationale for presenting this information is to make it available to others while the model is still under construction. More important to the quality of the Metro Model, however, is to receive critical feedback on the effort. Therefore, reviewers are invited to share feedback, ideas, and criticisms on any aspect of the project at *any* time. This document presents information used to produce the Metro Model as it now stands. Research into the hydrogeology of the hydrostratigraphic units that are already included in the Metro Model will continue, and the depth of knowledge of these layers will increase. Additionally, more information, representing regional variations in properties of the hydrostratigraphic units will also be incorporated into the model as the hydrogeologic conceptual model is refined. Consequently, the hydrogeologic conceptual model will change in response to increasing our knowledge base of the hydrogeology, resulting in changes to the Metro Model. Therefore, judicious use of the information contained in this document is necessary. Be aware that, because the regional hydrogeologic system is being considered, the information presented here is not intended to represent site-specific conditions for local sites. A follow-up report to be produced at the end of this year will supersede this Progress Report.

Description

The Metro Model is being developed using the Multi-Layer Analytic Element Model program (MLAEM) developed by Prof. Otto D.L. Strack of the Department of Civil Engineering of the University of Minnesota. Hydrostratigraphic units comprised of both bedrock and glacial drift units are included in the Metro Model. The model simulates three-dimensional groundwater movement.

The subsurface is divided into water-bearing units that may be used for groundwater exploration (aquifers). Aquifers are separated by leaky layers. The Metro Model simulates regional interactions between aquifers, and will be calibrated by comparison between measured and simulated heads and discharges.

The complete model will consist of five layers representing the following aquifers listed from the surface downward: glacial drift, St. Peter Sandstone, and the Prairie du Chien-Jordan, Ironton-Galesville, and Mt. Simon-Hinckley Aquifers. At the present time Layers 3, 4, and 5, representing the three lower aquifers, have been modeled. Development of Layer 2 is nearing completion. Layers 1 is under development.

The Metro Model will be available to groundwater scientists working in both the public and private sectors. It will provide the context of regional groundwater flow in the Metropolitan Area and can be used to aid in management decisions affecting groundwater. Additionally, users can add local detail to the model to conduct site-specific modeling for groundwater flow analysis.

Date of Report: July 1, 1997.

LCMR Final Work Program Update Report: 1995

I. Project Title and Project Number: Metropolitan Area Groundwater Model to Predict Contaminant Movement. J4

Program Manager:	Andrew Streitz
Agency Affiliation:	Minnesota Pollution Control Agency
Mail Address:	Ground Water Unit, Program Development Section
	Ground Water & Solid Waste Division
	520 Lafayette Road
	St. Paul, Minnesota 55155
Phone:	(612) 296-7791
Fax :	(612) 296-9707
E-mail:	andrew.streitz@pca.state.mn.us

A. Legal Citation: ML 95, Chp. 220, Sec. 19, Subd. 8(g).

Total biennial LCMR appropriation:	$250,000
Obligated: University Contract	$26,000
Liquidated: University Contract	$100,000
Obligated: Salary	$2,815
Liquidated: Salary	$98,721
Obligated: Non-salary	$3,481
Liquidated: Non-salary	$13,868
Balance:	$5115

Appropriation Language: This appropriation is from the trust fund to the commissioner of the pollution control agency to develop and apply a tool to improve prediction of contaminant movement in groundwater at contamination sites in the metropolitan area using a flexible regional groundwater flow model. Data compatibility requirements in subdivision 14 apply to this appropriation.

B. Status of Match Requirement:	**N/A**
Match Required:	**N/A**
Amount Committed to Date:	**N/A**
Match Spent to Date:	**N/A**

II. Project Summary: Groundwater flow systems in the seven county metropolitan area were evaluated using the latest information on soil, hydrogeology, surface-groundwater interactions, and water use. This information was used to develop the datasets for the model that provided the computer simulation of groundwater flow. This effort was built on previous efforts, and incorporated data from geologic atlases, the Ground Water Clearinghouse, and the Minnesota and U.S. Geological Surveys. The effort relied on Geographic Information Systems (GIS) for organization of the datasets. The computer model was calibrated and verified to ensure that it properly simulates the regional groundwater flow.

At every stage, assumptions and results were shared with an advisory workgroup made up of government scientists, university researchers and private consultants. Their suggestions were incorporated into the model design.

During the project period, the model was used on a provisional basis at individual sites. Initially, the project hoped to 1) design and evaluate remedial groundwater actions, 2) predict the movement of contaminant plumes, 3) identify contamination sources, 4) help target regional sampling locations for the MPCA Ground Water Monitoring and Assessment Program, and 5) determine capture zones of pumping wells. Upon notification of the continuation of funding for the next biennium, extra development was put into the completion of the uppermost Layer of the Metro Model to benefit actual site work. Discussions with technical staff from several Agency groundwater contamination sites convinced the team to finish certain features of the Metro Model before beginning site work. Site work will begin by this winter and will also include training to MPCA staff in the operation of the Metro Model.

The modeling inputs, results, and applications have been summarized in a progress report, completed this spring. This report will be updated this coming winter, including all progress made through the end of this biennium and the beginning of the 1997 LCMR Project in Fiscal Year 1998. The original proposal for the 1995 workprogram included money for the development of a report at the end of the biennium. However, the report was scaled back and incorporated into the regular release of progress reports due to the initial funding reduction.

III. Six Month Work Program Update Summary:

The geologic conceptual model has continued to undergo improvement over the last six months. The Metro Model consists of five separate aquifer layers that are separated by leaky beds. Most recently, a large portion of the groundwater model development has focused on analyzing, conceptualizing, and modeling the near-surface Quaternary material, which is composed of unconsolidated glacial sand and clay. In particular, the top layer was characterized through the automated manipulation of databases, geostatistical analyses, and the application of GIS displays. These analyses have enabled the team to develop a technically-based conceptual model that accounts for differences in infiltration and hydraulic properties of the glacial material on a regional scale. The glacial material was deposited and reworked by different glacial events and is therefore much more heterogeneous in composition and extent than the bedrock aquifers that underlie it. Through close cooperation with geologists, engineers, researchers, and groundwater modelers throughout the metropolitan area, the team has developed a workable glacial drift flow model for the area comprised of Hennepin and Carver Counties, and has built the necessary framework to sufficiently complete this layer in the Metro Model for the remainder of the Metropolitan area counties in the very near future. Besides being the most geologically complicated unit, the top layer is also the most important to the study of groundwater contamination, which is the main focus of groundwater modeling for the MPCA.

The Project team has also made progress on scaling the regional model down to the site level, adding detail to the conceptual model and supporting databases in the area of two Agency Superfund sites. Work on the conceptual model for the Baytown site in Washington County is essentially complete, while work on a site in Hennepin county will begin shortly into the next biennium..

The project has benefited tremendously from the active participation of a group of 30 scientists from government and private sectors. These interested parties have been involved in the Metro Model's development both because they have the expertise to guide its development and because they will be using the Metro Model to solve a variety of groundwater management problems encountered by the various parties.

Timeline for Completion of Objectives:

	7/95	1/96	6/96	1/97	6/97
Objective A. Develop a model of the metropolitan area	xxxxxxxxxxxxxxxxxxxxxxxxxxxxx				
Objective B. Apply model to groundwater contamination problems in the metropolitan area			xxxxxxxxxxxxxx		
Objective C. Summarize results and evaluate the potential to expand the effort				xxxxxxxxxx	

V. Objectives/Outcome:

A. Title of Objective/Outcome: Develop a model of the metropolitan area.

A.1 Activity: Model development

A.1.a. Context within the project: This activity represents the core of the metro model project, the actual construction of the working groundwater model.

A.1.b. Methods: Available hydrogeologic data was used to develop the conceptual model, which forms the basis for constructing the computer flow model. The conceptual model was also used to determine information and data needed to enhance the Metro Model. Datasets containing geologic information and groundwater elevations were analyzed within various software packages, including GIS applications, to investigate geologic and hydrogeologic relationships. Analysis was conducted using geostatistics and three-dimensional visualization software packages. Upon interpretation and export of the datasets to the groundwater model (MLAEM), they were further manipulated graphically to test assumptions and run scenarios.

A.1.c. Materials: Total equipment costs for the Project were $11,000, to provide the purchase of two personal computers and necessary peripherals. The first computer is located at the University of Minnesota in the office of the Project cooperator, Dr. Otto Strack. It will remain there until the University of Minnesota personnel are no longer actively working on the project, at which point all equipment will be turned over to the MPCA. The second computer is being used at the Agency for model development. Both computers will eventually be connected to the Agency network to allow for distribution of the completed groundwater simulation to Agency technical staff and all other interested parties. All equipment purchased with this appropriation will continue to be used for the same program through its useful life and if that use changes, monies will be paid back to the appropriate Fund at a level negotiated with the Director. Equipment needs not specifically covered here will be provided from other funding sources.

A.1.d. Budget

Total Biennial LCMR Budget:	$175,000
LCMR Balance:	$978
MATCH: $	NA
MATCH BALANCE:	NA

A.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1 Collect geologic and hydrologic data of model area and previous model efforts	xxxxxxx				
Product #2 Incorporate data into GIS structure	xxxxxxxxxxxxxxxxxxxx				
Product #3 Build model		xxxxxxxxxxxxxxxxxxxxxxxx			

A.1.f. Workprogram Update: The project has incorporated new geologic GIS coverages of the model area into the geologic conceptual model. A functional regional groundwater model exists for the bottom four layers, representing the four major bedrock aquifers of the St. Peter, Prairie du Chien-Jordan, the Ironton-Galesville, and the Mt. Simon-Hinckley for the entire metropolitan area. Additionally, the model for the top glacial material layer in Hennepin and Carver Counties is essentially complete. Implementation of the approach developed for handling the glacial aquifer layer has already begun for the remainder of the metropolitan area.

A.2 Activity: Model calibration and verification

A.2.a. Context within the project: This step provides a check on the accuracy of the model, identifying areas requiring further work, resulting in improvement of the model's interpretation of groundwater behavior.

A.2.b. Methods: This has been accomplished by comparison of both observed surface water flow to model output and groundwater elevations against predicted values.

A.2.c. Materials: No additional equipment purchases are planned for this activity.

A.2.d. Budget

Total Biennial LCMR Budget:	$35,000
LCMR Balance:	$1,600
MATCH:	NA
MATCH BALANCE:	NA

A.2.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1 Calibration and verification	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				

A.2.f. Workprogram Update: Initial calibration of the deepest four aquifers was completed primarily using the County Well Index database. Model elements of Layer 1 are being calibrated separately and combined with the larger model as they are completed. The Metro Model team also coordinated the collection of synchronous water level measurements across the metropolitan area twice yearly. Participants included technical and planning staff from the seven metropolitan counties and the Department of Natural Resources, Division of Waters. This information was used in calibration of the model.

B. Title of Objective/Outcome: Apply model to groundwater contamination problems in the metropolitan area.

B.1 Activity: Model applications

B.1.a. Context within the project: Application of the model to groundwater contamination problems is the chief reason for the development of this tool. These applications will also be used to further test the validity and ease of use of the model by MPCA staff.

B.1.b. Methods: With the completion of the Metro Model, MPCA staff in site cleanup are being trained in its use for site work in the identification of groundwater contamination sources, design of monitoring well networks, and selection of a remedial action.

B.1.c. Materials: No equipment purchases are planned for this activity.

B.1.d. Budget

Total Biennial LCMR Budget:	$35,000
LCMR Balance:	$2,200
MATCH:	NA
MATCH BALANCE:	NA

B.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1 Use model to design and evaluate remedial actions for groundwater at hazardous waste sites			xxxxxxxxxxxxxxxxxxx		
Product #2 Predict the movement and extent of contamination plumes in groundwater		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Product #3 Help identify contamination sources		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Product #4 Target sampling locations for GWMAP				xxxxxxxxxxxxx	
Product #5 Determine capture zones of pumping wells			xxxxxxxxxxxxxxxxxxx		
Product #6 Train and assist MPCA staff			xxxxxxxxxxxxxxxxxxxxxxx		

B.1.f. Workprogram Update: The Project team has begun working with Agency site teams to investigate groundwater contamination. Work has begun on several sites to produce local scale testing of the larger regional Metro Model. Work on the conceptual model of the Baytown site is almost complete, with GIS coverages and calibration datasets already developed. Work on a second Superfund site has begun, and GIS and hydrogeologic support for other Agency sites has been performed throughout the biennium.

C. Title of Objective/Outcome: Summarize results and evaluate the potential to expand the effort.

C.1 Activity: Prepare report

C.1.a. Context within the project: An interim progress report was completed and sent to interested parties in February 1997. A second comprehensive report will be prepared and sent out following completion and documentation of the full initial phase of model development. The anticipated completion time for this report is expected to be before the end of 1997. Final presentation of the results of the project will be provided in that comprehensive report. For purposes of reporting at the end of the current biennium, the reporting requirements were scaled back substantially due to the reduction in funding from the original Project proposal. This workprogram is intended to fulfill the reporting needs for the end of the biennium.

C.1.b. Methods: The comprehensive report on the initial modeling phase will include a description of the documentation of dataset development, an explanation of all major geologic assumptions made by the project team, and a straightforward presentation of steps taken to build the model. This will be critical to the acceptance of this model by the larger hydrogeologic community.

C.1.c. Materials: The computer and related equipment purchased for this project are being used to house and distribute the completed groundwater simulation at the MPCA. In this way the simulation is available to all Agency technical staff. This equipment will continue to be used for the same program through its useful life and if that use changes, monies will be paid back to the appropriate Fund at a level negotiated with the Director.

C.1.d. Budget

Total Biennial LCMR Budget:	$5,000
LCMR Balance:	$337
MATCH:	NA
MATCH BALANCE:	NA

C.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1					xxxxxxxxxx
Prepare report					
Product #2					xxxxxxxxxx
Evaluate the potential for expanding model to Greater Minnesota					

VI. Evaluation: The project may be termed a success if three goals are met: 1) the completed model accurately predicts the movement of groundwater in the metro area, 2) the model is available to, and is used by Agency technical staff, and 3) is accepted and used by the larger hydrogeologic community including other state agencies, government units and private consultants. The project team continues to gather information to help evaluate how accurately the model predicts groundwater movement. Much of this will actually occur during site-specific applications of the model. The team is currently working with interested MPCA staff to apply the model to specific sites. Additionally, the project team is working with county-level government scientists to apply the model to specific groundwater management problems.

VII. Context within field: Though the techniques to be used in this project have been used to model individual sites, this project represents the first time this level of effort has been applied to the development of a regional multi-layer analytical groundwater model in the United States. Locally, several counties are actively working on groundwater models. The goal of the Metro Model project is to provide the framework for future investigations without the duplication of effort that would otherwise be necessary. The advisory workgroup working with the project team will draw participants from the ranks of government and private sector modelers.

VIII.Budget context: For the two-year period ending June 30, 1995, a MPCA employee, Andrew Streitz (LCMR project manager) worked more than half-time to prepare for the project start on July 1, 1995. Additional, Mr. Streitz and Hsu Yuan-Ming worked on the project during fiscal years 1996-97 using other state funds, full and half-time respectively.

IX. Dissemination: During the project period, many meetings with project cooperators, fellow modelers and interested parties are planned to ensure the widest possible dissemination of the projects goals and conclusions. Presentations at professional gatherings, government forums and academic seminars are expected. In addition to making information available to interested parties in the Twin Cities area, the project team has presented technical papers (attached) at an international conference on groundwater modeling, for which they received partial funding to attend from the Dutch government.

X. Time: Funding reductions effectively cut the project back to 20 months. With the end of the 1995 Project, the model will be further refined by the MPCA during the 1998-99 LCMR Project Biennium, according to a strategy developed by the Project team and the advisory workgroup of interested scientists, engineers and groundwater modelers.

XI. Cooperation: The project team includes Dr. Otto Strack, University of Minnesota, Civil Engineering, as well as his graduate students. Dr. Strack provided expert guidance in the use of the newest version of his analytical software to the groundwater modeling of the metropolitan area. The advisory workgroup includes technical staff from the Minnesota Department of Health, Minnesota Department of Natural Resources, United States Geological Survey, Minnesota Geological Survey, Hennepin Conservation District, Dakota County and private consulting firms.

XII. Reporting Requirements:
Semiannual six-month workprogram update reports will be submitted not later than January 1, 1996, July 1, 1996, January 1, 1997, and a final six-month workprogram update and final report by June 30, 1997.

XIII. REQUIRED ATTACHMENT:

1.	**Qualifications:**	**Attached**
2.	**Project Staffing Summary:**	**Attached**

XIII. REQUIRED ATTACHMENT:
1. Qualifications: CVs of Project Participants

A. Project Manager: Andrew Streitz

Employment
Senior Hydrologist. March 1990 to Present. Minnesota Pollution Control Agency, Division of Ground Water and Solid Waste, Program Development Section, Ground Water Unit.

Hydrologist. March 1985 to 1990. MN Department of Natural Resources, Division of Waters, Ground Water Unit.

Education
Masters Degree. Degree Awarded: 1989. University of Minnesota, Minneapolis, Dept. of Geology and Geophysics.

Bachelor's Degree. Degree Awarded: 1980. St. Olaf College, Northfield, MN. Liberal Arts (BA).

B. Chief Professional Cooperator: Dr. Otto Strack

Employment
Professor. 1985 - present. Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, MN.

Associate Professor. 1979 - 1985. Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, MN.

Assistant Professor. 1974 - 1979. Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, MN.

Education
Doctor of Philosophy. Degree Awarded: 1973. Delft University of Technology, The Netherlands.

Masters Degree (Ingenieurs). Degree Awarded: 1969. Delft University of Technology, The Netherlands.

Selected Publications
Strack, O.D.L. 1989. The Analytic Element Method; an Overview. *Hydrolo. Science and Technol.; Short Papers*, 4, (1-4), pp. 377-379.

Strack, O.D.L. 1992. A mathematical Model for Dispersion with a Moving Front in Groundwater. *Water Resour. Res.*, 28, (11), pp. 2973-2980.

Strack, O.D.L. 1994. A Dupuit-Forchheimer Model for Three-Dimensional Flow with Variable Density. Submitted to *Water Resour. Res.*

Textbooks:
Strack, O.D.L. 1989. *Groundwater Mechanics* (732 pp.), Prentice Hall, Englewood Cliffs, NJ.

Date of Report: July 1, 1997.

LCMR Final Work Program Update Report: 1995

I. Project Title and Project Number: Metropolitan Area Groundwater Model to Predict Contaminant Movement. J4

Program Manager: Andrew Streitz
Agency Affiliation: Minnesota Pollution Control Agency
Mail Address: Ground Water Unit, Program Development Section
Ground Water & Solid Waste Division
520 Lafayette Road
St. Paul, Minnesota 55155
Phone: (612) 296-7791
Fax : (612) 296-9707
E-mail: andrew.streitz@pca.state.mn.us

A. Legal Citation: ML 95, Chp. 220, Sec. 19, Subd. 8(g).

Total biennial LCMR appropriation:	$250,000
Obligated: University Contract	$26,000
Liquidated: University Contract	$100,000
Obligated: Salary	$2,815
Liquidated: Salary	$98,721
Obligated: Non-salary	$3,481
Liquidated: Non-salary	$13,868
Balance:	$5115

Appropriation Language: This appropriation is from the trust fund to the commissioner of the pollution control agency to develop and apply a tool to improve prediction of contaminant movement in groundwater at contamination sites in the metropolitan area using a flexible regional groundwater flow model. Data compatibility requirements in subdivision 14 apply to this appropriation.

B. Status of Match Requirement:	**N/A**
Match Required:	**N/A**
Amount Committed to Date:	**N/A**
Match Spent to Date:	**N/A**

II. Project Summary: Groundwater flow systems in the seven county metropolitan area were evaluated using the latest information on soil, hydrogeology, surface-groundwater interactions, and water use. This information was used to develop the datasets for the model that provided the computer simulation of groundwater flow. This effort was built on previous efforts, and incorporated data from geologic atlases, the Ground Water Clearinghouse, and the Minnesota and U.S. Geological Surveys. The effort relied on Geographic Information Systems (GIS) for organization of the datasets. The computer model was calibrated and verified to ensure that it properly simulates the regional groundwater flow.

At every stage, assumptions and results were shared with an advisory workgroup made up of government scientists, university researchers and private consultants. Their suggestions were incorporated into the model design.

During the project period, the model was used on a provisional basis at individual sites. Initially, the project hoped to 1) design and evaluate remedial groundwater actions, 2) predict the movement of contaminant plumes, 3) identify contamination sources, 4) help target regional sampling locations for the MPCA Ground Water Monitoring and Assessment Program, and 5) determine capture zones of pumping wells. Upon notification of the continuation of funding for the next biennium, extra development was put into the completion of the uppermost Layer of the Metro Model to benefit actual site work. Discussions with technical staff from several Agency groundwater contamination sites convinced the team to finish certain features of the Metro Model before beginning site work. Site work will begin by this winter and will also include training to MPCA staff in the operation of the Metro Model.

The modeling inputs, results, and applications have been summarized in a progress report, completed this spring. This report will be updated this coming winter, including all progress made through the end of this biennium and the beginning of the 1997 LCMR Project in Fiscal Year 1998. The original proposal for the 1995 workprogram included money for the development of a report at the end of the biennium. However, the report was scaled back and incorporated into the regular release of progress reports due to the initial funding reduction.

III. Six Month Work Program Update Summary:

The geologic conceptual model has continued to undergo improvement over the last six months. The Metro Model consists of five separate aquifer layers that are separated by leaky beds. Most recently, a large portion of the groundwater model development has focused on analyzing, conceptualizing, and modeling the near-surface Quaternary material, which is composed of unconsolidated glacial sand and clay. In particular, the top layer was characterized through the automated manipulation of databases, geostatistical analyses, and the application of GIS displays. These analyses have enabled the team to develop a technically-based conceptual model that accounts for differences in infiltration and hydraulic properties of the glacial material on a regional scale. The glacial material was deposited and reworked by different glacial events and is therefore much more heterogeneous in composition and extent than the bedrock aquifers that underlie it. Through close cooperation with geologists, engineers, researchers, and groundwater modelers throughout the metropolitan area, the team has developed a workable glacial drift flow model for the area comprised of Hennepin and Carver Counties, and has built the necessary framework to sufficiently complete this layer in the Metro Model for the remainder of the Metropolitan area counties in the very near future. Besides being the most geologically complicated unit, the top layer is also the most important to the study of groundwater contamination, which is the main focus of groundwater modeling for the MPCA.

The Project team has also made progress on scaling the regional model down to the site level, adding detail to the conceptual model and supporting databases in the area of two Agency Superfund sites. Work on the conceptual model for the Baytown site in Washington County is essentially complete, while work on a site in Hennepin county will begin shortly into the next biennium..

The project has benefited tremendously from the active participation of a group of 30 scientists from government and private sectors. These interested parties have been involved in the Metro Model's development both because they have the expertise to guide its development and because they will be using the Metro Model to solve a variety of groundwater management problems encountered by the various parties.

Timeline for Completion of Objectives:

	7/95	1/96	6/96	1/97	6/97
Objective A. Develop a model of the metropolitan area	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				
Objective B. Apply model to groundwater contamination problems in the metropolitan area			xxxxxxxxxxxxxx		
Objective C. Summarize results and evaluate the potential to expand the effort				xxxxxxxxxx	

V. Objectives/Outcome:

A. Title of Objective/Outcome: Develop a model of the metropolitan area.

A.1 Activity: Model development

A.1.a. Context within the project: This activity represents the core of the metro model project, the actual construction of the working groundwater model.

A.1.b. Methods: Available hydrogeologic data was used to develop the conceptual model, which forms the basis for constructing the computer flow model. The conceptual model was also used to determine information and data needed to enhance the Metro Model. Datasets containing geologic information and groundwater elevations were analyzed within various software packages, including GIS applications, to investigate geologic and hydrogeologic relationships. Analysis was conducted using geostatistics and three-dimensional visualization software packages. Upon interpretation and export of the datasets to the groundwater model (MLAEM), they were further manipulated graphically to test assumptions and run scenarios.

A.1.c. Materials: Total equipment costs for the Project were $11,000, to provide the purchase of two personal computers and necessary peripherals. The first computer is located at the University of Minnesota in the office of the Project cooperator, Dr. Otto Strack. It will remain there until the University of Minnesota personnel are no longer actively working on the project, at which point all equipment will be turned over to the MPCA. The second computer is being used at the Agency for model development. Both computers will eventually be connected to the Agency network to allow for distribution of the completed groundwater simulation to Agency technical staff and all other interested parties. All equipment purchased with this appropriation will continue to be used for the same program through its useful life and if that use changes, monies will be paid back to the appropriate Fund at a level negotiated with the Director. Equipment needs not specifically covered here will be provided from other funding sources.

A.1.d. Budget

Total Biennial LCMR Budget:	$175,000
LCMR Balance:	$978
MATCH: $	NA
MATCH BALANCE:	NA

A.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1	xxxxxxx				
Collect geologic and hydrologic data of model area and previous model efforts					
Product #2	xxxxxxxxxxxxxxxxxxx				
Incorporate data into GIS structure					
Product #3		xxxxxxxxxxxxxxxxxxxxxxx			
Build model					

A.1.f. Workprogram Update: The project has incorporated new geologic GIS coverages of the model area into the geologic conceptual model. A functional regional groundwater model exists for the bottom four layers, representing the four major bedrock aquifers of the St. Peter, Prairie du Chien-Jordan, the Ironton-Galesville, and the Mt. Simon-Hinckley for the entire metropolitan area. Additionally, the model for the top glacial material layer in Hennepin and Carver Counties is essentially complete. Implementation of the approach developed for handling the glacial aquifer layer has already begun for the remainder of the metropolitan area.

A.2 Activity: Model calibration and verification

A.2.a. Context within the project: This step provides a check on the accuracy of the model, identifying areas requiring further work, resulting in improvement of the model's interpretation of groundwater behavior.

A.2.b. Methods: This has been accomplished by comparison of both observed surface water flow to model output and groundwater elevations against predicted values.

A.2.c. Materials: No additional equipment purchases are planned for this activity.

A.2.d. Budget

Total Biennial LCMR Budget:	$35,000
LCMR Balance:	$1,600
MATCH:	NA
MATCH BALANCE:	NA

A.2.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1 Calibration and verification	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				

A.2.f. Workprogram Update: Initial calibration of the deepest four aquifers was completed primarily using the County Well Index database. Model elements of Layer 1 are being calibrated separately and combined with the larger model as they are completed. The Metro Model team also coordinated the collection of synchronous water level measurements across the metropolitan area twice yearly. Participants included technical and planning staff from the seven metropolitan counties and the Department of Natural Resources, Division of Waters. This information was used in calibration of the model.

B. Title of Objective/Outcome: Apply model to groundwater contamination problems in the metropolitan area.

B.1 Activity: Model applications

B.1.a. Context within the project: Application of the model to groundwater contamination problems is the chief reason for the development of this tool. These applications will also be used to further test the validity and ease of use of the model by MPCA staff.

B.1.b. Methods: With the completion of the Metro Model, MPCA staff in site cleanup are being trained in its use for site work in the identification of groundwater contamination sources, design of monitoring well networks, and selection of a remedial action.

B.1.c. Materials: No equipment purchases are planned for this activity.

B.1.d. Budget

Total Biennial LCMR Budget:	$35,000
LCMR Balance:	$2,200
MATCH:	NA
MATCH BALANCE:	NA

B.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1 Use model to design and evaluate remedial actions for groundwater at hazardous waste sites			xxxxxxxxxxxxxxxxxxx		
Product #2 Predict the movement and extent of contamination plumes in groundwater		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Product #3 Help identify contamination sources		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Product #4 Target sampling locations for GWMAP				xxxxxxxxxxxxx	
Product #5 Determine capture zones of pumping wells			xxxxxxxxxxxxxxxxxxx		
Product #6 Train and assist MPCA staff			xxxxxxxxxxxxxxxxxxxxxxx		

B.1.f. Workprogram Update: The Project team has begun working with Agency site teams to investigate groundwater contamination. Work has begun on several sites to produce local scale testing of the larger regional Metro Model. Work on the conceptual model of the Baytown site is almost complete, with GIS coverages and calibration datasets already developed. Work on a second Superfund site has begun, and GIS and hydrogeologic support for other Agency sites has been performed throughout the biennium.

C. Title of Objective/Outcome: Summarize results and evaluate the potential to expand the effort.

C.1 Activity: Prepare report

C.1.a. Context within the project: An interim progress report was completed and sent to interested parties in February 1997. A second comprehensive report will be prepared and sent out following completion and documentation of the full initial phase of model development. The anticipated completion time for this report is expected to be before the end of 1997. Final presentation of the results of the project will be provided in that comprehensive report. For purposes of reporting at the end of the current biennium, the reporting requirements were scaled back substantially due to the reduction in funding from the original Project proposal. This workprogram is intended to fulfill the reporting needs for the end of the biennium.

C.1.b. Methods: The comprehensive report on the initial modeling phase will include a description of the documentation of dataset development, an explanation of all major geologic assumptions made by the project team, and a straightforward presentation of steps taken to build the model. This will be critical to the acceptance of this model by the larger hydrogeologic community.

C.1.c. Materials: The computer and related equipment purchased for this project are being used to house and distribute the completed groundwater simulation at the MPCA. In this way the simulation is available to all Agency technical staff. This equipment will continue to be used for the same program through its useful life and if that use changes, monies will be paid back to the appropriate Fund at a level negotiated with the Director.

C.1.d. Budget

Total Biennial LCMR Budget:	$5,000
LCMR Balance:	$337
MATCH:	NA
MATCH BALANCE:	NA

C.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Product #1 Prepare report					xxxxxxxxxx
Product #2 Evaluate the potential for expanding model to Greater Minnesota					xxxxxxxxxx

VI. Evaluation: The project may be termed a success if three goals are met: 1) the completed model accurately predicts the movement of groundwater in the metro area, 2) the model is available to, and is used by Agency technical staff, and 3) is accepted and used by the larger hydrogeologic community including other state agencies, government units and private consultants. The project team continues to gather information to help evaluate how accurately the model predicts groundwater movement. Much of this will actually occur during site-specific applications of the model. The team is currently working with interested MPCA staff to apply the model to specific sites. Additionally, the project team is working with county-level government scientists to apply the model to specific groundwater management problems.

VII. Context within field: Though the techniques to be used in this project have been used to model individual sites, this project represents the first time this level of effort has been applied to the development of a regional multi-layer analytical groundwater model in the United States. Locally, several counties are actively working on groundwater models. The goal of the Metro Model project is to provide the framework for future investigations without the duplication of effort that would otherwise be necessary. The advisory workgroup working with the project team will draw participants from the ranks of government and private sector modelers.

VIII.Budget context: For the two-year period ending June 30, 1995, a MPCA employee, Andrew Streitz (LCMR project manager) worked more than half-time to prepare for the project start on July 1, 1995. Additional, Mr. Streitz and Hsu Yuan-Ming worked on the project during fiscal years 1996-97 using other state funds, full and half-time respectively.

IX. Dissemination: During the project period, many meetings with project cooperators, fellow modelers and interested parties are planned to ensure the widest possible dissemination of the projects goals and conclusions. Presentations at professional gatherings, government forums and academic seminars are expected. In addition to making information available to interested parties in the Twin Cities area, the project team has presented technical papers (attached) at an international conference on groundwater modeling, for which they received partial funding to attend from the Dutch government.

X. Time: Funding reductions effectively cut the project back to 20 months. With the end of the 1995 Project, the model will be further refined by the MPCA during the 1998-99 LCMR Project Biennium, according to a strategy developed by the Project team and the advisory workgroup of interested scientists, engineers and groundwater modelers.

XI. Cooperation: The project team includes Dr. Otto Strack, University of Minnesota, Civil Engineering, as well as his graduate students. Dr. Strack provided expert guidance in the use of the newest version of his analytical software to the groundwater modeling of the metropolitan area. The advisory workgroup includes technical staff from the Minnesota Department of Health, Minnesota Department of Natural Resources, United States Geological Survey, Minnesota Geological Survey, Hennepin Conservation District, Dakota County and private consulting firms.

XII. Reporting Requirements:
Semiannual six-month workprogram update reports will be submitted not later than January 1, 1996, July 1, 1996, January 1, 1997, and a final six-month workprogram update and final report by June 30, 1997.

XIII. REQUIRED ATTACHMENT:

1. **Qualifications:** **Attached**

2. **Project Staffing Summary:** **Attached**

XIII. REQUIRED ATTACHMENT:
1. Qualifications: CVs of Project Participants

A. Project Manager: Andrew Streitz

Employment
Senior Hydrologist. March 1990 to Present. Minnesota Pollution Control Agency, Division of Ground Water and Solid Waste, Program Development Section, Ground Water Unit.

Hydrologist. March 1985 to 1990. MN Department of Natural Resources, Division of Waters, Ground Water Unit.

Education
Masters Degree. Degree Awarded: 1989. University of Minnesota, Minneapolis, Dept. of Geology and Geophysics.

Bachelor's Degree. Degree Awarded: 1980. St. Olaf College, Northfield, MN. Liberal Arts (BA).

B. Chief Professional Cooperator: Dr. Otto Strack

Employment
Professor. 1985 - present. Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, MN.

Associate Professor. 1979 - 1985. Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, MN.

Assistant Professor. 1974 - 1979. Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, MN.

Education
Doctor of Philosophy. Degree Awarded: 1973. Delft University of Technology, The Netherlands.

Masters Degree (Ingenieurs). Degree Awarded: 1969. Delft University of Technology, The Netherlands.

Selected Publications
Strack, O.D.L. 1989. The Analytic Element Method; an Overview. *Hydrolo. Science and Technol.; Short Papers*, 4, (1-4), pp. 377-379.

Strack, O.D.L. 1992. A mathematical Model for Dispersion with a Moving Front in Groundwater. *Water Resour. Res.*, 28, (11), pp. 2973-2980.

Strack, O.D.L. 1994. A Dupuit-Forchheimer Model for Three-Dimensional Flow with Variable Density. Submitted to *Water Resour. Res.*

Textbooks:
Strack, O.D.L. 1989. *Groundwater Mechanics* (732 pp.), Prentice Hall, Englewood Cliffs, NJ.