March, 1994

LCMR FINAL STATUS REPORT - Summary - Research

I. AQUIFER ANALYSES IN SOUTHEAST MINNESOTA

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A. M.L. 91, Ch. 254, Art. no. 1, Sec. 14, Subd. 4 (g) Appropriation: $73,000
Balance: $ 0

Aquifer Analyses in Southeast Minnesota: This appropriation is to the commissioner of natural resources for a grant to Winona State University to perform aquifer tests in southeast Minnesota in order to determine aquifer characteristics, surface-subsurface ground-water interaction, and aquifer interaction.

B. ***Compatible Data:*** During the biennium ending June 30, 1993, the data collected by the projects funded under this section that have common value for natural resource planning and management must conform to information architecture as defined in guidelines and standards adopted by the information policy office. In addition, the data must be provided to and integrated with the Minnesota Land Management Information Center's geographic data bases with the integration costs borne by the activity receiving funding under this section.

C. ***Match Requirement.*** Not applicable.

II. NARRATIVE

A. ***Statement of problem.*** Preliminary analyses of available pump-test data from southeastern Minnesota show that much of the information cannot be utilized to accurately determine aquifer characteristics, or as reliable input in models. Information on pump tests is often incomplete. At this time, very few research studies in Southeast Minnesota have used systematic field tests to determine aquifer characteristics, especially the delineation of local versus regional properties. Preliminary analyses also shows that more information is needed on the interactions between ground-water systems, and the interactions between ground-water systems and surface waters -- that is, the physical setting. Thus, in some parts of the region, simulations and models are of limited use due to a deficiency of reliable aquifer data.

B. ***Importance.*** The purpose of aquifer testing is to determine hydraulic parameters such as hydraulic conductivity (K), transmissivity (T), and storage (S). Aquifer tests can also be used to determine aquifer interaction, aquifer boundaries, and boundary conditions. This information is needed for modeling variations of flow directions, flow velocities, and effects of stress on the aquifer such as pumping. Also, aquifer parameters are needed in water-resource studies, and contaminant studies. Preliminary analyses will show if efforts will be

concentrated in one area or in the examination of one aquifer system. It is realized that the project can only begin to supplement the data base that exists. Contamination has affected the shallow aquifers of the region, and is of concern for the deeper aquifers. In order to better prepare for legislated water-management plans and well codes, and supplement the studies dealing with ground-water quality, reliable data is needed for characterizing the aquifers and discerning aquifer interaction. Our understanding of the complex ground-water regime in the highly sensitive karst region can be advanced by additional, more detailed aquifer studies.

C. ***Extent of problem.*** There is a regional extent to the problem of lack of reliable field-derived data. Certain areas of the southeastern region of Minnesota will be targeted; these include areas with very little data and areas where reliable data is urgently needed. Well tests are often performed after construction of new wells, but, tests are often of short duration, adequate data is not recorded, or insufficient well or well-log information is not recorded or known. The best information is usually from large municipal wells, not residential wells. Additionally, several studies by regulatory agencies have included what is known as an aquifer, pump, or well test. But, these have been performed mostly at one site, to address a specific question or problem such as well interference.

III. OBJECTIVES

Objective A. ***Preliminary site work.***

A1. *Narrative:*

Preliminary work is divided into two sections; first, analyses of pre-existing data, and second, site reconnaissance. The analyses of pre-existing data includes compiling an inventory of all available data for southeastern Minnesota that is applicable to the project.

A2. *Procedures:*

Analyses of pre-existing data includes compilation of an inventory of the available hydrologic, geologic, and well data for the area. Sources of information include the Minnesota Geological Survey, the Minnesota Department of Health, the Minnesota Pollution Control Agency, the Department of Natural Resources, the US Geological Survey, research studies, well drillers, and the Winona and Olmsted County atlases. The information will then be analyzed for use as a data base for the project based predominantly on completeness and reliability. Preliminary examination of well logs and well tests show that incomplete information is a problem.

The analyses of data will be the basis upon which location of aquifer tests will be determined. Sites will be chosen according to several criteria which include: will test information supplement data base, use of existing well, scarcity of data in area, urgent need for additional information in a specific area, adequate information on the geology and on well construction, and access to well.

Once a location is chosen, a site reconnaissance is completed . This includes a field check of the geologic and hydrologic setting, surveying (if necessary) and mapping the site - including location of other wells, location of water source if needed for pump test, and location of

discharge area if needed. Before field reconnaissance, permission and permits are obtained if necessary.

Pertinent references for hydrologic and geologic setting for southeastern Minnesota:

1. "Paleozoic lithostratigraphy of southeastern Minnesota", Austin, G. *in* Sims, P., and Morey, G., eds, Geology of Minnesota: A centennial volume: Minnesota Geological Survey, 1972.
2. Bedrock Geologic map of Garvin Brook watershed, Winona County, Minnesota, Mossler, J.H., and Book, P.R., 1982.
3. Geologic map of Minnesota, St. Paul Sheet: Minnesota Geological Survey, scale 1:250,000, Sloan, R.E., and Austin, G.S., 1966.
4. The geology and underground waters of southern Minnesota: Minnesota Geological Survey Bulletin 31, Thiel, G.A., 1944.
5. The geology of Winona COunty: Geological and Natural History Survey of Minnesota Final Report, v. 1, Winchell, N.H., 1884.
6. Minnesota's Geology, Ojakangas, R.W., and Matsch, C.L., 1982.
7. "Groundwater pollution prevention in southeast Minnesota, St. Ores, J., Alexander, E.C., and Halsey, C.F.,1982.
8. Water Quality Monitoring and Assessment in the Garvin Brook Rural Clean Water Project Area, Wall, D.B., McGuire, S.A., and Magner, J.A., Minnesota Pollution Control Agency, 1989.
9. Reports from the Minnesota Pollution Control Agency.
10. Olmsted County Geologic Atlas, Minnesota Geological Survey, 1984.
11. Winona County Geologic Atlas, Minnesota Geological Survey, 1988.

A3. *Budget:*

a. Amount budgeted: $5,000
b. Balance: $ 0

A4. *Timeline for tasks:*

	July 91	Jan 92	June 92	Jan 93	June30, 93
Research data	x------x				
Research previous studies	x------x				
Analyses of pre-existing data	x----------x				
Site reconnaissance	x------x		x-------x		
Obtain permits	x------x		x-------x		
Surveying	x-------x		x--------x		

A5. *Status:*

1/1/92

Progress: We have successfully completed the first two tasks under this objective. Data and previous studies have been collected, and analyses are almost finished. Site reconnaissance is about 50% completed.

Problems: The last two tasks which are to obtain permits and survey in the actual sites, have been delayed due to the late arrival of the grant monies. The project was delayed by two months because of this, and unfortunately all of that time was during the summer field season. Further delay was caused by the late arrival of the updated County Well Index from the Minnesota Geological Survey.

7/1/92

Progress: The tasks under this objective have been completed except for obtaining permits where needed for the pumping tests. Many sites that are under consideration do not need permits. For those sites where permits are needed, they will be obtained before the field experiment commences.

Problems: No problems at this time other than delay of the project due to winter weather.

1/1/93

Progress: The tasks under this objective are completed.

7/1/93

Progress: The tasks under this objective are completed.

3/1/94

Summary: Data from approximately two thousand well logs along with information from previous studies were collected and examined. One of the analyses of the data showed that many of the "short duration" pumping tests completed by well drillers for well development can be used for preliminary analyses of aquifer response. This data is often not used by researchers. However, analyses did show trends in aquifer transmissivity that were dependent on aquifer type and geographic location. Further analyses of the data along with surveys of other researchers, planners, and interested state and regional agencies, showed that there was an interest, and a need, for information on the hydrogeologic connectiveness of the Prarie du Chien Aquifer and the Jordan Aquifer. These units were chosen because they are used extensively for water supply, and are susceptible to contamination from surface activity . These units do not interact in the same manner throughout the region. Concurrent studies dealing with ground-water quality support this observation. We focused on examining the physical parameters of these two units. One of the significant results was not only the accumulation and interpretation of all of the data in one place, but we also updated the State's County Well Index for the region, constructed maps and cross-sections, and increased the data base by hundreds of well points. This "upgrade" of data continues to be used by others. For the future, we will continue to maintain the data repository which will eliminate time spent in future projects on data collection and analyses.

Results from site reconnaissance were significant to the study only in a site-specific sense. Maps of each site were constructed and were integrated into maps constructed for the regional analyses. All of these maps will be useful to anyone who proposes to conduct research in the region.

A6. *Benefits:*

Inventory and analyses of previous studies in conjunction with the site reconnaissance will provide necessary information on which the project design will be formulated. Analyses of pre-existing data will show if certain areas will be targeted, of if certain aquifers need to be targeted. The purpose of analyzing pre-existing data is to show where data is most lacking, and where information obtained by the project can best begin to supplement the data base. This project, at the present level of funding, cannot fulfill all data needs of the region, but can determine where data is most needed, and begin to obtain some of that data.

Objective B. ***Design and completion of pumping tests.***

B1. *Narrative:*

Information and data obtained from the preliminary site investigation is used in conjunction with other information to determine the systems design of the project. The purpose of the pumping tests is to obtain data on the aquifers of the region, either a specific area or a specific aquifer system. Areas with little data or known problems will be targeted. Pumping tests will be performed during the two summer field seasons. Information from early pump tests is used to further analyze the optimum location of subsequent test sites.

B2. *Procedures:*

In order to determine the best location of test sites, type of pumping test, number of tests, and if new well installation is necessary, the following information is analyzed: the data base that was compiled from preliminary work, geologic and hydrologic maps and data, well logs and well construction information, previous studies in the area, site reconnaissance, access to well site, and potential for successful completion of test at the site. Based on the analyses, the project will concentrate on either a certain area of southeastern MInnesota or target a particular aquifer/surface-water system.

The method used to determine aquifer characteristics is by controlled aquifer pumping tests. The type of pumping test that will be performed is either a constant-rate pumping test, or a slug injection/withdrawal test. The constant-rate pumping test can involve a single well, or have multiple observation wells. Data that are measured during a pump test include discharge/recharge rate, time, and drawdown. A mobile pump will be used, and the tests will be performed for a duration of approximately 40 to 100 hours, depending upon the physical constraints of the study area, and the analyses of early-time data.

Pertinent references for project design and pumping test analyses:

1. Ground Water Pumping Tests: Design and Analysis, Walton, W. C., 1989.

2. Analysis and Evaluation of Pumping Test Data, Kruseman, G., and de Ridder, 1970.
3. Ground Water Manual, US Department of the Interior, 1981.
4. Groundwater and Wells, Driscoll, F. G., 1986.
5. Groundwater, Freeze, R. A. and Cherry, J. A., 1979.
6. Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells, National Water Well Association, 1990.
7. Journals such as Ground Water, Ground Water Monitoring Review, Water Resources Research, and Hydrology.
8. Analysis and Design of Aquifer Tests - National Water Well Association Short Course, will be attended by project manager March 25-28, 1991.

If new well installation is deemed necessary, permission and a permit will be obtained. The well will be drilled, logged, constructed, and developed according to code. The Geology Department at Winona State University owns a small drill rig which can be used at cost if necessary. The project monies cannot cover large-scale well drilling and construction.

B3. *Budget:*

a. Amount budgeted:	$53,000
b. Balance:	$ 0

B4. *Timeline for tasks/products:*

	July 91	Jan 92	June 92	Jan 93	June30, 93
Analyze previous work	x------x				
Deter. of tests and sites	x------x		x---x		
Drilling, Aquifer testing	x----------x		x----------x		

B5. *Status:*

1/1/92

Progress: Analyses of previous work is 80% completed. Detailed maps, cross-sections, and fence diagrams, have been constructed, and completed interpretations will soon follow. Five sites have been chosen to this date.

Problems: The completion of the actual aquifer tests has been delayed by one field season due to the late arrival of the grant monies. However, there should be no problems in the coming field season, and we should have no trouble with completing all of the proposed tests.

7/1/92

Progress: Analyses of previous work is completed. Interpretations are approximately 75% complete, and continue to be an ongoing task. Most of the sites have been chosen and detailed geologic cross-sections of those areas will be completed.

Problems: Aquifer testing has not begun due to the late start of the project and the winter season.

1/1/93

Progress: A great deal of effort has been extended in order to coordinate this project with other research that has begun in the area. We are coordinating efforts with the two counties that are completing County Atlases. We hope to supplement the information that is being gathered by the DNR, MGS, and independent researchers. This project hopes to "extend" the information (especially flow paths and aquifer characteristics) beyond county lines. We are also working with the MPCA and the Zumbro/Root River Group (coalition of 9 southeast MN counties) which is conducting comprehensive water-quality analyses in the region. Many of the wells for their project were chosen based on the information obtained so far in this project. Several of the pumping tests will be performed on the same wells that are being sampled for chemical analyses, thus greatly supplementing the information that both projects can produce. In addition, we are working with individual counties that have submitted requests for possible consideration for aquifer tests because of areas of special concern such as contamination sites or aquifers that are being heavily developed.

Problems: Due to personnel difficulties and coordination efforts, the tasks under this objective have not been completed according to the proposed timeline. The project director is now on sabbatical with other responsibilities completed. The remainder of the sabbatical will now be focused almost entirely on this project. We feel that the project can be successfully completed by the original due date because a great deal of effort has been expended and the project will move very quickly from this point on.

7/1/93

Progress: Twelve controlled, long-term, pumping tests were performed on two of the major domestic water-supply aquifers in Southeast Minnesota. All tests were successfully completed. The research concentrated on the interaction of two aquifers -- the Prairie du Chien and the underlying Jordan Formation in a region from Rochester (Olmsted County) to Chatfield (Fillmore County) to Ridgeway (Winona County). After initial screening, wells were chosen based upon proper construction and accessibility. The data from these tests are being analyzed at this time and will be coordinated with information obtained from concurrent studies by the DNR, the MGS, and the MPCA.

Problems: Field work at several of the sites was delayed due to the unusually high amount of precipitation that fell in the region during spring and early summer. Mud became an enemy to the drill rigs and the equipment. We fit in tests when weather permitted, but the last portion of the research involving analyses was

delayed. Interpretations and analyses of the pumping tests are currently being completed.

3/1/9

Summary: The project focused on determining the interaction between the Prarie du Chien and Jordan Aquifers, and between those aquifers and surface flow as shown by need and interest during early investigations Analyses showed that there were possible changes in the interaction between the two aquifers in the region -- one in the vicinity of the Rochester area. Thus, we concentrated on two aquifers in a specific region. Test locations that met the proposed criteria were ultimately chosen based on accessibility and availability. Twelve pumping tests were conducted, all successfully, even after problems with driller availability, pump failure, and an abundance of mud during part of the project. Two well-drilling companies, one from Rochester, and, one from Chatfield were used to assist in the field set up and in conducting the pumping tests. The design of the test at each site was determined by the size and the construction of the well, and potential well yield. The size of the pump was chosen in order to produce the maximum discharge possible based on estimates of aquifer conductivity, and, in order to produce the maximum perturbation to the system. All the tests were of long duration (at least 30 hrs), followed proposed guidelines, and were monitored continually. The changes in water level were monitored with the use of pressure transducers and manual readings. At two of the test sites there was access to one observation well, and at four of the sites there were at least two observation wells. There really are no other "results" under this objective other than the successful completion of the pumping tests. Results of the pumping tests are discussed in the next section.

If this procedure was to be done over again in the future, it would be made easier by the data analyses that has been completed. Projects that possibly involve pumping tests could be conducted in other areas in order to supplement the data base. The limitations of the testing encountered at each site would also be guidelines for future work (e.g. well yield vs. pump size in a well of a certain diameter and depth).

A hindsight view is somewhat dictated by wishing for the ideal set up. It would be great to have a field site dedicated to studies on determining the physical characteristics of the aquifers in the region. Then, one could construct wells and observation wells based on strict criteria that would reveal the most information. For example, it is most ideal to have wells that penetrate the entire thickness of the aquifer, are constructed correctly, and are large enough to produce the responses that one is testing for. And, in an area where flow is controlled by fractures in the bedrock (such as SE MN), the positions of the observation wells are very important. Finally, monitoring could be on a long term basis and it would not interfere with anyone's use of the well.

B6. *Benefits:*

Aquifer pumping tests can generate significant data and information on ground-water flow, aquifer parameters, aquifer boundaries, boundary conditions, and aquifer interaction. This data can be used in a models of flow direction, flow velocities, and aquifer response to stress. Reliable data can be used by scientists, modelers, and planners. Students and/or community members can be employed directly to perform tasks and be involved in a research project conducted in the region.

Objective C. *Undergraduate student internships and/or directed research.*

C1. *Narrative:*

One of the reasons for the modest cost of the this project is the access to student help and equipment at Winona State University. Students can be employed directly by the project or submit applications for internships or directed research.

A student internship involves a student performing tasks associated with the research project in order to gain practical experience. A report which summarizes the work performed and critiques the work experience is submitted to the work supervisor and faculty advisor. An internship is similar to an apprenticeship, that is, experience is the focus, interpretation and analyses of data are not necessarily a requirement. Student internships at Winona State University must be applied for by the student and approved by the Geology Department. Student research may be part of, or, supplemental to the faculty research project. This opportunity is designed to provide experience in the scientific process. In conjunction with a faculty advisor, the student designs and submits a research proposal which must be approved by the Geology Department. The student must perform the research, analyze the data, and present the results.

C2. *Procedures:*

Employ students/community members to assist in execution of aquifer tests. Project manager and faculty advisor will be responsible for successful completion of internships and directed research.

Student internships - student applies for internship status with the project according to regulations of Winona State University. Work is performed by student under the guidance of a faculty advisor and the project manager. Student submits final report to project manager. Internships are appropriate for the following tasks: research previous work, construct preliminary maps, and assist in execution of pumping tests.

Student directed research - student applies for directed research with the project according to the regulations of Winona State University. Student research is performed under the guidance of a faculty advisor and the project manager. The student is responsible for submitting a final report. Research topics appropriate for students which are part of the project include interpretation of previous hydrogeologic work in the area, computer modelling of data, and analyses of pumping tests. Examples of supplemental research projects include: analyses of type of pumping test (possible comparative study), analyses of water chemistry during pumping, and a geophysical study.

C3. *Budget:*

a. Amount budgeted: $7,000
b. Balance: $ 0

C4. *Timeline for tasks/products:*

	July 91	Jan 92	June 92	Jan 93	June30, 93
Student internships/ research (includes application, work performed, and report-writing)	x				x

C5. *Status:*

1/1/92

Progress: Two students have been involved with the project to date. Both have been actively involved in the project since September. Products that are completed include collecting previous work and existing data, plotting thousands of well data points, digitizing the data, and constructing maps and cross sections. Reports and a comprehensive display of the maps will be due at the end of the academic year in May 92.

Problems: There are no problems under this objective at this time.

7/1/92

Progress: Both students have completed their tasks successfully. One graduated in May, and the other will be continuing on the project during the next year. Their reports and maps have been completed and are an integral part of the research project. Student involvement will continue to be an important aspect of the research. It is estimated that two new students will be chosen for field work and computer work.

Problems: There are no problems under this objective at this time.

1/1/93

Progress: Three students are now actively involved in the research project. One of the major tasks that has been completed is the update of the County Well Index for this region. Thousands of data points have been checked, entered and digitized into a GIS system. In working with the all of the available data it became evident that our understanding of this area is not as clear as first proposed. There is controversy in interpretation of data and varying hypothesis. Therefore, we have spent a great deal of time in trying to understand the geology and the geologic settings. This is vital before hydrogeologic studies make any sense or are valid. We have constructed detailed three-dimensional maps that show the upper

surfaces of the major aquifers in this region, and have used geophysical data provided by the MN Geol. Survey in addition to well log information to construct paleo-structure and environment of deposition diagrams. We feel we have new information and interpretations that will be presented and which are the cornerstone of this study. For example, one of the students is working on a computer model of the interaction between the Jordan and Prairie du Chien aquifer systems, a connection that is not uniform throughout the region. We have identified new areas that will be the sites of pumping tests that were not first considered.

Problems: There are no problems at this time in regards to the tasks under this objective.

7/1/93

Progress: A total of six students have had the opportunity to be involved with this research project. Several others have assisted with field and laboratory work. There are three completed internships, and one in progress related to the final stages of analyses of the data. The completed student research projects are as follows: Interpretation of geophysical logs of the Prairie du Chien Group and the Jordan Formation in Southeast Minnesota; the Hydrogeologic Connectivity between the Jordan Formation and the Prairie du Chien Group in the Prairie du Chien/Jordan Aquifer System; and sedimentological analyses of the Prairie du Chien and Jordan Aquifers in Southeast Minnesota. The student research will be incorporated into the final scientific report, but will also be available as individual reports.

Problems: A delay in completion time for the last student research project is directly related to the delay in completing the pumping tests. Unusual high precipitation forced us to wait for accessibility at many of the field sites. All field work is now completed, and analyses of the pumping tests is currently in progress.

3/1/94

Summary: Winona State University students had the opportunity to be involved with the research project at all stages. This involvement in research was an unique opportunity at the undergraduate level and provided invaluable experience. Nine students had varying degrees of responsibility in the project. There were three students and three community members that assisted with field work, and three students that assisted with laboratory work. Two of the students applied for directed research, and two other students applied for student internships. In both the directed research and internship courses the students receive credit and are required to complete a project that was a substudy of the main project. The results or data from these projects will be available froThese projects are as follows:

•An investigation of the information as revealed in geophysical logs from the region was conducted. The student correlated the geophysical logs from different locations in the study area. Observations were made on the changes in lithology as seen in the logs. Analyses then involved determining if these changes related to location within the basin structure found in SE Minnesota.

•A study of the hydraulic interaction between the Prarie du Chien and Jordan units. The student prepared maps and cross-sections of the potentiometric surfaces for both of the units. A comparison of the surfaces was conducted along with observations on the change in lithology, aquifer setting (confined vs. unconfined), and topographic controls such as proximity to a stream valley.

•A comparison of the lithology determined from the geophysical logs with the sediment analyses determined from samples obtained from well drilling and outcrops. In this investigation the student conducted a detailed study, over small intervals, of the changes in sediment size and mineralogy, to changes shown in the geophysical log.

•An analyses of the data from the pumping tests and from other related studies. For each of the tests the transmissivity and storativity of the aquifer was determined. The student had to learn how to choose the correct method and include all the necessary limitations such as partial penetration of the well and location of hydrologic boundaries. Analyses were conducted by computer programs and manual methods.

Another result from this objective includes the students being involved in a cooperative project. It is hard to describe this result. What I observed is that the students were afforded the opportunity by this project to learn in ways I cannot teach in the classroom. Most of the students were from Minnesota, and they were very interested, and very proud, to be working in their "backyard".

It is very difficult to go out and find a well to conduct a long-term test on. Many people and agencies were instrumental in providing information and access to wells. (WInona School District, Rochester School District, Rochester Solid Waste Department, Chatfield Fish and Game Club, Fillmore County Road Department, MN Geological Survey, MN Pollution Control Agency, MN Department of Natural Resources, and private home owners). Students had a chance to be a part of a cooperative project and to see first hand the interrelationship between the science they are taught how it applies to conducting field work. This experience was also enhanced with learning about well codes, drilling regulations, environmental impacts, politics crisis management, mud, economics, and human relations.

C6. *Benefits:*

Students have an opportunity to be involved in a faculty research project through internships and directed research programs in conjunction with their university studies. This project will provide an excellent opportunity for students to gain experience in the process of a scientific investigation. Students will obtain practical work skills in the field of hydrogeology which cannot be offered in the classroom setting. Independent studies by the students can augment the results of the research project. It is expected that much of the field assistance will be provided by students from Winona State University who have been accepted for internships or directed research. Therefore, the student internships and research projects help moderate the cost of the project.

Objective D. *Interpretation of data, simulation of ground-water flow, and presentation of results.*

D1. *Narrative:*

Analyses and interpretation of the results from pumping-tests will be completed with the aid of computer programs. The final stage involves interpretation of the data, integration of new and old data, and the construction of a hydrogeologic map of the selected region. The map is a model, or simulation, of the ground-water regime, and will delineate ground-water flow direction and velocities, possible aquifer interactions, ground-water flow boundaries, and boundary conditions. The map will be produced with the aid of an appropriate computer model(s). The actual modeling of the data is a supplementary aspect of this project; the main objective is to obtain data where needed.

D2. *Procedures:*

Preliminary graphical analyses of the data is performed during field testing. This aids in determining the reliability of the pumping test during early-time. Computer programs will be used to further analyze the complete data set. Various analyses of the data is necessary for the best interpretation of the pumping-test results.

The new data is added to the pre-existing data base. Next, analyses and interpretations which are based on the new and pre-existing data, together with the hydrogeologic information for the area, are used to choose the most appropriate computer model available. Formulation of a model is not an objective of this project--the most appropriate "packaged" model will be chosen. The computer model is used to simulate the flow regime in the selected region, and will aid in revealing where further information is needed.

Pertinent references for data analyses and computer modelling:

1. Ground Water Pumping Tests: Design and Analysis, Walton, W. C., 1989.
2. Analysis and Evaluation of Pumping Test Data, Kruseman, G., and de Ridder, 1970.
3. Ground Water Manual, US Department of the Interior, 1981.
4. Groundwater and Wells, Driscoll, F. G., 1986.
5. Groundwater, Freeze, R. A. and Cherry, J. A., 1979.
6. Ground-water Hydrology and Hydraulics, McWhorter, D., and Sunada, D.K., 1977.

7. Groundwater Management: the use of numerical models, van der Heijde, P., and others, 1985.
8. Practical Aspects of Ground Water Modeling, Walton, W.C., 1984.
9. Physical and Chemical hydrogeology, Domenico, P.A., and Schwartz, F.W., 1990.
10. Groundwater Transport: Handbook of Mathematical Models, Javandel, I., Doughty, C., and Tsang, C., 1984.
11. Journals such as Ground Water, Ground Water Monitoring Review, Water Resources Research, and Hydrology.
12. "Analysis and Design of Aquifer Tests" - A National Water Well Association Short Course, will be attended by project manager March 25-28, 1991.

The data and results will be available to local and state agencies, and other interested groups or individuals, and will be reported in a compatible form as stated in I.B of this work plan.

D3. *Budget:*

a. Amount budgeted:	$8,000
b. Balance:	$ 0

D4. *Timeline for product/tasks:*

	July 91	Jan 92	June 92	Jan 93	June30, 93
Analy. and interpretation	x----------x				
Computer modeling			x----------x		
Semi-annual reports		x	x	x	x
Result reporting					x--------->

D5. *Status:*

1/1/92

Progress: The first semi-annual report is completed.

Problems: The analyses and interpretation of aquifer test data has been delayed due to the late arrival of the grant monies, and the loss of 2 months of the field season.

7/1/92

Progress: The second semi-annual report is completed.

Problems: Analyses and interpretation of test data will be completed when the pumping tests are performed which are delayed at this time.

1/1/93

Progress: The third semi-annual report is completed. A computer model has been chosen which will analyze previous and new data and produce potentiometric maps for the aquifers of interest.

Problems: Pumping tests have not been performed as yet as explained above. Analyses, interpretations, and reports will be completed within the next 1/2 year which is within the proposed timeline.

7/1/93

Progress: Water levels from hundreds of wells were plotted for the aquifers of interest and a computer program was used to simulate the water-level surface. Flow regimes have been determined, and the connectivity between the aquifers is currently being interpreted in conjunction with results from associated research in the area.

Problems: There are no problems with completing the final analyses and preparing the various reports. However, they will be delayed for two reasons, one, the weather for early spring and summer prohibited timely completion of several of the pumping tests, and two, in order to coordinate the results of this study with concurrent research in the region we are waiting for some of the chemical analyses from approximately 150 wells that were sampled in the region.

3/1/94

Summary: The results from the twelve long-term pumping tests have been analyzed. The new information has been integrated with the pre-existing data base and the new data that was derived from the analyses of about two thousand short-term well tests as found in the County Well Index. Several maps and graphs have been constructed to more easily depict the results of the analyses. The following is a summary of other results to date:

- Flow patterns in the upper aquifers in the region are locally controlled by barriers such as streams, fracture systems, and water use. These are not new interpretations, but this project greatly added to the data base, and in the maps that were constructed, we were able to show more detail. This information will be useful for other researchers, and local government agencies such as County Planners.

- Information derived from geophysical logs, sediment analyses, and other sedimentological studies, show that there is a change in lithology at the base of the Prarie du Chien and at the top the Jordan that possibly influences the hydraulic connection between the two units.

- Results from the pumping tests completed for this project, along with geochemical data from studies being conducted concurrently in the region, support the conclusion that the Prarie du Chien Group and the Jordan Sandstone should not be consistently be grouped as a single hydrogeologic unit throughout the region.

The significance of these results is that the hydraulic connection between the Prarie du Chien Group and the Jordan Sandstone should be well understood for planning and assessment purposes. Further field tests in areas of interest should be conducted in order to better understand the connection which is important for making decisions about activities that either use the water from these units, or impacts the quality of the ground water. In addition, information such as that obtained during this project aids in understanding the hydrogeologic setting of the units found in SE Minnesota. This data helps in our basic understanding of the environment of deposition of the bedrock units, the local and regional flow, and the age of the ground water, and ultimately supplements our understanding of the sensitivity of the units.

Results from this project will be disseminated in two ways. First, a paper will be submitted for presentation at a state and/or regional conference or workshop. Second, the final report and data will be available to the public through the regular State Agency routes, and will also be accessible at the Water Resource Center at Winona State University.

In hindsight, I feel that the project was successful at the funding level that was approved. If I had to do the project over, I would have proposed to conduct many more pumping tests at large wells, which unfortunately are often water supply wells, and not available to be shut off for three or four days at a time. Thus, I believe one is limited to the availability and location of wells that are not used constantly. Ideally, the well location should be based on hydrogeologic setting, not logistical parameters. Additionally, I would have proposed more money to install a larger system of monitoring wells at each site.

D6. *Benefits:*

Analyses and interpretation of the pump tests by computer helps determine the reliability of the data. Modeling is not the main focus of this project, but the benefits realized from modeling attempts can be valuable. The analyses, interpretation and model will provide not only scientific data, but necessary information needed by local and regional entities for water resource management and planning. Modeling will reveal the areas where more information is needed. The model can also be used to predict future effects of stress on the aquifer system. Finally, the model will supplement the numerous studies conducted on ground-water quality. The data reported by this project will have a common value for natural resource planning and management and will be available in a compatible form as defined by guidelines and standards.

IV. EVALUATION

The research project can be evaluated by the following: adherence to the work plan and proposed timeline for tasks and products. The products, or results, can be evaluated based on successful completion of the aquifer pumping tests and analyses which will provide reliable data on aquifer characteristics. Further evaluation can be based on the successful completion of the computer model which will provide a simulation of regional flow, and also indicate where further testing and data are needed.

V. CONTEXT: RELATED CURRENT AND PREVIOUS WORK

A. ***Inadequacy of previous work for future needs.*** Data for southeastern Minnesota is available from the Minnesota Geological Survey, Minnesota Department of Health, Department of Natural Resources, Minnesota Pollution Control Agency, well-drillers, Winona and Olmsted county atlases, and the US Geological Survey. Preliminary analyses of the aquifer data available for the study area shows that the information (other than static water level) from residential wells is often incomplete and therefore not reliable, especially as data input in simulation models of the ground-water regime. Examination of about two hundred residential well-logs throughout nine counties reveals that geologic logs were not completed or are missing, pump tests were run only for a short duration of time, pump test data is incomplete, and well construction information is missing or incomplete. There are very few research projects in the area that have run controlled aquifer pump tests. Many of the pump tests that have been performed were by regulatory agencies in response to a special request, or problem, at a well. Thus, the location of the tests are frequently controlled by need. Often the tests were performed only long enough to answer the problem, not to scientifically determine the properties of the aquifer. Much of the pre-existing data lacks the detailed information that is needed in order for to be used to reliably to delineate aquifer characteristics, aquifer interactions, ground-water flow boundaries, and boundary conditions in southeastern Minnesota. Reliable data and information on ground-water and aquifer parameters is needed now, and in the future. This information is vital for planning present and future wise stewardship of our water resources. Present and future studies dealing with ground-water quality will also need reliable information on aquifer characteristics.

B. ***Supplementary aspect.*** Most studies in the area dealing with water have concentrated on the water quality of surface water, runoff, and soil water. Subsurface studies have included tracer tests and pumping tests. The pumping tests were performed at municipal well sites or in order to resolve a well interference dispute. The proposed research will provide new data on the subsurface ground-water regime which will supplement the previous studies. The results and interpretations from the controlled aquifer pumping tests will greatly augment interpretations and analyses derived from other studies. New information will continue to enhance our general understanding of the subsurface. This type of research is also an excellent source of a reliable data base for future related studies. Furthermore, analyses from the ground-water model has the potential to be extremely useful to many entities such as the Department of Natural Resources, Minnesota Geological Survey, Minnesota Department of Health, Minnesota Pollution Control Agency, local planning agencies and environmental groups, environmental consulting firms, and future researchers.

C. ***Accomplishments.*** The aquifer pumping tests that have been performed in the area have not been funded by LCMR. Aquifer pumping tests that have been performed are mostly by regulatory agencies, or local governments at municipal water-supply wells.
Future accomplishments. It is anticipated that the results of this research project will identify areas that lack sufficient data, or where refinement of analyses are needed. Future support from LCMR will be sought, not only for further pumping test, but for supplementary studies of water quality in the saturated and unsaturated zone.

D. Not applicable.

E. Department of Geology, College of Science and Engineering, Winona State University.

VI. QUALIFICATIONS

1. Project Manager:

a. Dr. Nancy Olga Jannik
Hydrogeologist by training
Ph.D. , specialty in Hydrology, New Mexico Institute of Mining and Technology

b. Winona State University
Associate Professor of Geology
Specialty -- Hydrogeology, Land-use planning, Geochemistry

c. Work related to proposal: Dr. Jannik has been involved with the Zumbro/Root River Water Resources Advisory Committee for the past four years. The Advisory Committee is a coalition of nine southeast Minnesota counties which have joined together for legislated water-resource planning. Dr. Jannik's role has been as consultant, and as supervisor of student workers. Much of the work involves analyzing well logs and interpreting subsurface information. This work is ongoing, and results have not been published as yet.

Previous experience includes field and lab determination of porous media properties.

2. Major Cooperators

The following is a list of cooperators who will not be directly involved in the performing of aquifer tests or computer analyses, but will be vital links to sources of information that will aid in the search and analyses of previous studies. The cooperators will also aid in the location of the best test sites.

a. James Cooper, P.E., Regional Hydrologist
Department of Natural Resources - Region 5
Rochester, MN

Mr. Cooper is a resource for information from pump tests performed by the Department of Natural Resources.

b. Roman Kanivsky, Hydrologist
Minnesota Geological Survey
St. Paul, MN

Mr. Kanivsky is a hydrologist with the Minnesota Geological Survey. He was involved in the completion of the hydrologic sections of the Winona and Olmsted County Geologic Atlases.

Kanivetsky, R., 1984, Bedrock Hydrogeology, Plate 4, *in* Geological Atlas of Winona County, Minnesota, County Atlas Series, Atlas C-2, Balaban, N., and Olsen, B., eds., Minnesota Geological Survey, University of Minnesota, St. Paul .
Kanivetsky, R., 1988, Bedrock Hydrogeology, Plate 5, *in* Geological Atlas of Olmsted County, Minnesota, County Atlas Series, Atlas C-3, Balaban, N., ed., Minnesota Geological Survey, University of Minnesota, St. Paul.

c. Pamela K. B. Hunt, Director
Zumbro/Root River Water Resources Advisory Committee
Rochester, MN

Ms. Hunt coordinates and directs the activities of nine southeast MInnesota counties that are involved in designing and implementing water-resource management plans. The Advisory Committee and Winona State University have most recently worked together to produce a ground-water susceptibility map for the region. These efforts are ongoing and the report is pending. The data used were compiled and interpreted by Winona State University, and thus are directly available to the project.

d. Bruce Olsen
MN Department of Health
St. Paul, MN

Mr. Olsen was a geologist for the Minnesota Geological Survey. He was involved in mapping for both the Winona and Olmsted County Atlases. He was also involved in the project of interpretation of drillers logs for wells in the region.

Olsen, B., 1984, Data Base Map, Plate 1, *in* Geological Atlas of Winona County, ,Minnesota, County Atlas Series, Atlas C-2, Balaban, N., and Olsen, B., eds., Minnesota Geological Survey, University of Minnesota, St. Paul.
Olsen, B., 1984, Geology and well construction, Plate 1, *in* Geological Atlas of Winona County, ,Minnesota, County Atlas Series, Atlas C-2, Balaban, N., and Olsen, B., eds., Minnesota Geological Survey, University of Minnesota, St. Paul.
Hobbs, H., Olsen, B., and Wahl, T., 1988, Data Base Map Plate 1, *in* Geological Atlas of Olmsted County, Minnesota, County Atlas Series, Atlas C-3, Balaban, N., ed., Minnesota Geological Survey, University of Minnesota, St. Paul.
Olsen, B., 1988, Bedrock Geology, Plate 2, *in* Geological Atlas of Olmsted County, Minnesota, County Atlas Series, Atlas C-3, Balaban, N., ed., Minnesota Geological Survey, University of Minnesota, St. Paul.
Olsen, B., and Hobbs, H.,1988, Sensitivity of the Ground-Water System to Pollution, Plate 6 *in* Geological Atlas of Olmsted County, Minnesota, County Atlas Series, Atlas C-3, Balaban, N., ed., Minnesota Geological Survey, University of Minnesota, St. Paul.

Olsen, B., 1988, Geology and Well Construction, Plate 8, *in* Geological Atlas of Olmsted County, Minnesota, County Atlas Series, Atlas C-3, Balaban, N., ed., Minnesota Geological Survey, University of Minnesota, St. Paul.

e. Dr. E. C. Alexander
Professor of Geology
Department of Geology and Geophysics
University of Minnesota

Dr. Alexander has worked in southeast Minnesota as researcher, research advisor, and consultant. Studies have focused on using tracers in the carbonate units of the region in order to delineate flow patterns, and using ^{14}C to date ground-water in order to determine residence time and flow patterns.

Ores, J., Alexander, E.C., and Halsey, C., 1982, Groundwater Pollution Prevention in Southeast Minnesota's Karst Region, Extension Bulletin 465, Agricultural Extension Service, University of Minnesota, St. Paul.
Dalgleish, J., and Alexander, E. C., 1984, Sinkholes and Sinkhole Probability, Plate 5, *in* Geological Atlas of Winona County, ,Minnesota, County Atlas Series, Atlas C-2, Balaban, N., and Olsen, B., eds., Minnesota Geological Survey, University of Minnesota, St. Paul.
Alexander, E. C., and Maki, G., 1988, Sinkholes and Sinkhole Probability, Plate 7, *in* Geological Atlas of Olmsted County, Minnesota, County Atlas Series, Atlas C-3, Balaban, N., ed., Minnesota Geological Survey, University of Minnesota, St. Paul.
Alexander, E. C., and Book, P., 1984, Altura , Minnesota lagoon collapses, *in* Beck, B., ed., Sinkholes: Their geology, engineering, and environmental impact, Rotterdam, A.A. Balkema.
Alexander, S., and Alexander, E. C., 1987, A chemical and isotopic survey of the age or residence times of ground waters in Minnesota, Completion Report for the Minnesota Pollution Control Agency, Contract MN PCA-831412.
Alexander, S., and Alexander, E. C., 1989, A chemical and isotopic survey of the age or residence times of ground waters in Minnesota, Completion Report for the Minnesota Pollution Control Agency, Contract MN PCA-831412.

VII. REPORTING REQUIREMENTS

Semiannual status reports will be submitted not later than January 1, 1992, July 1, 1992, January 1, 1993, and a final status report by June 30, 1993.