2009 Project Abstract
For the Period Ending June 30, 2011

I. PROJECT TITLE: Innovative Springshed Mapping for Trout Stream Management-Continuation

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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2009, Chap.[143], Sec.[2], Subd.3D.

APPROPRIATION AMOUNT: $250,000

Overall Project Outcome and Results

Springshed delineation provides critical information for the protection and management of the springs that form the coldwater streams of southeast Minnesota. Our primary tool is fluorescent dye tracing. During the two-year period of Phase II, the U of M in collaboration with the DNR conducted 26 traces in Fillmore, Houston, Winona and Wabasha counties that mapped over 12,000 acres. Each individual trace typically has involved two or more different tracers with up to five different tracers employed in one trace. These traces are expanding the tools available for the springshed mapping, while defining new springsheds and refining the boundaries of known springsheds. These traces have been conducted in the Galena, Prairie du Chien and St. Lawrence springshed areas

The Fillmore County traces were in the Galena Formation. We discovered three previously unmapped springsheds and expanded the boundaries of five known springsheds. The expanded boundary springsheds were in the Watson Creek and South Fork Root watersheds, target areas for the local, state and federal Root River Initiative. The new springsheds are in the Crystal Creek watershed. These traces enhanced MDA watershed research and education efforts.

The traces in Houston, Winona and Wabasha were in the St. Lawrence Formation. This work expanded the geographic range of St. Lawrence traces and demonstrated that conduit flow in the St. Lawrence (a confining unit in the state well code) is a regional phenomenon. Four new springsheds were located in the St. Lawrence. Two of the traces in Houston County were run from streams that do not disappear into the St. Lawrence but flow continually across it. Both of those traces were detected at springs and one was detected in a private well. This indicates that St. Lawrence groundwater across southeast Minnesota could be impacted by the surface water quality of streams crossing the formation in shallow conditions.

Solinst level-temperature-conductivity loggers were purchased in the second year of the project. The data from them has shown that Prairie du Chien formation springs can be monitored for minor temperature fluctuations. Detecting these fluctuations has allowed us to conclude that the monitored springs are affected by snowmelt runoff. This network has identified four distinct thermal patterns which are related to the types of flow systems connecting each spring with its surface recharge. Temperature monitoring can be applied to a large number of springshed faster and more economically than can be dye traced. The combination of temperature monitoring and dye tracing is providing more information than either can provide alone. Work progressed on theoretical and modeling efforts to extract more information from the data generated by the tracer measurements. Base flow spring flow measurements are being collected to define Normalized Base Flow (NBF) Curves that will allow quick estimates of the size of springsheds. This information will be used for spring assessment protocol development.

The availability of new, high resolution LiDAR data for seven of the counties provided an important new tool that is being utilized to locate sinkholes, sinking streams and spring as part of the springshed mapping effort. This information was tabulated in the Minnesota Karst Features Data Base (KFDB), which is being updated and modernized to facilitate public accessibility to the springshed maps.

MGS staff visited numerous springs and stream sinks to identify their stratigraphic position to allow for more accurate spring data interpretation and to enhance dye trace planning. New higher resolution structural contour maps, that resulted from their work have shown that the locations of about half of the Galena springs can be related to the structural features in the bedrock.

We coordinated our efforts with other LCCMR funded programs is SE Minnesota and with ongoing resource management efforts by the DNR, MPCA and Ag Department State agencies. Six of the dye traces were done in coordination with local governmental staff in order to support the Root River pilot project of the Mississippi River Basin Initiative (MRBI) in Minnesota. We are working with the MPCA's TMDL efforts in SE Minnesota.

Project Results Use and Dissemination

The dissemination of the results of this project proceeded at several levels. We provided interim results to local landowners and to local, county, regional and state agency staff and resource managers. MPCA staff, for example, routinely contact us with questions about karst features in SE Minn. We worked synergistically with other LCCMR funded research projects and with a range of resource management efforts. The generation and dissemination of the maps and written reports was part student educational projects – from local High School students through University students in classes and interns, graduate student theses, post Doctoral researchers and colleagues. We lead and participated in fieldtrips sponsored by LCCMR, the MGWA and other groups focused on protecting SE MN trout streams and water resources. We worked collaboratively with MPCA, DNR, Department of Agriculture and other agencies to expand and complement the LCCMR funded work. A dozen reports on the interim results of this project were presented at state and national scientific meetings.

Trust Fund 2009 Work Program

Date of Report: 31 January 2012
Date of Next Progress Report:
Date of Work Program Approval: 16 June 2009
Project Completion Date: 30 June 2011

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Web Site Address: http://www.geo.umn.edu/people/profs/ALEXANDER.html

Location: Dakota, Dodge, Goodhue, Houston, Fillmore, Mower, Olmsted, Winona, Wabasha, and Washington Counties.

Total Trust Fund Project Budget:	U of Mn	Mn DNR	**Total**
Trust Fund Appropriation	$ 250,000	$ 250,000	**$ 500,000**
Minus Amount Spent:	$ 187,421	$ _____	**$ _____**
Equal Balance:	$ 62,579		**$**

Legal Citation: M.L. 2009, Chp. 143, Sec. 2, Subd. 3d.

Appropriation Language: Springshed Mapping for Trout Stream Management. $500,000 is from the trust fund to continue to identify and delineate supply areas and springsheds for springs serving as coldwater sources for modern and historic trout streams and to assess the impacts from development and water appropriations. Of this appropriation, $250,000 is to the Board of Regents of the University of Minnesota and $250,000 is to the commissioner of natural resources.

II and III. FINAL PROJECT SUMMARY AND RESULTS: Springshed delineation provides critical information for the protection and management of the springs that form the coldwater streams of southeast Minnesota. Our primary tool is fluorescent dye tracing. During the two-year period of Phase II, the U of M in collaboration with the DNR conducted 26 traces in Fillmore, Houston, Winona and Wabasha counties that mapped over 12,000 acres. Each individual trace typically has involved two or more different tracers with up to five different tracers employed in one trace. These traces are expanding the tools available for the springshed mapping, while defining new springsheds and refining the boundaries of known springsheds. These traces

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We coordinated our efforts with other LCCMR funded programs is SE Minnesota and with ongoing resource management efforts by the DNR, MPCA and Ag Department State agencies. Six of the dye traces were done in coordination with local governmental staff in order to support the Root River pilot project of the

Mississippi River Basin Initiative (MRBI) in Minnesota. We are working with the MPCA's TMDL efforts in SE Minnesota.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Innovative Trout Springshed Maps and Reports

Description: Springsheds that feed source springs of trout streams will be delineated in the Galena, Prairie du Chien, and St. Lawrence karst lands. Dye tracing will be expanded in the Prairie du Chien and Galena karsts. We will also conduct dye traces in the St. Lawrence Formation as karst features are located in this newly recognized karst unit. Maps of the springsheds will be made available via a GIS-based website allowing regular updates. The temperature monitoring network will be maintained and expanded as equipment and sites become available. High resolution structural contour maps, fluorescence data on the dissolved organic compounds in the springs and stable isotope results will be included in the springshed maps and reports as they become available and useful.

Summary Budget Information for Result 1:

Trust Fund Budget:	U of Mn	Mn DNR	**Total**
Trust Fund Appropriation	$ 190,211	$ 250,000	**$ 440,211**
Minus Amount Spent:	$ 130,740	$ _____	**$** _____
Equal Balance:	$ 59,472	$	**$**

Deliverable	**Completion Date**	**Budget**
1. Innovative Trout Springshed Maps and Reports U of Mn. These reports and maps will present the results of the dye traces and other data that help to define the trout spring springsheds.	**30 June 2011**	**$ 190,211**

Final Results

Extensive GIS and field reconnaissance work identified many promising areas for dye tracing. These areas are in Fillmore, Houston, Wabasha and Winona, Dakota and Goodhue Counties. Twenty-six traces were conducted in Fillmore, Houston and Winona Counties. These traces typically involved two or more tracers and one recent trace involved five different tracers.

In the Galena karst of Fillmore County the traces have been coordinated with the Root River pilot project of the Mississippi River Basin Initiative (MRBI) in Minnesota with the MPCA's TMDL work and with Department of Ag's ongoing research efforts. These traces have: 1) defined new springsheds, 2) refined the boundaries of previously mapped springsheds, 3) provided information on the relative responses of different tracers in the same systems, 4) provided calibration points for the NBF curve effort, and 5) involved local staff and citizens including High School Students

from Harmony and U of Mn students, interns and Post Docs in the trout stream protection effort. The traces in the well-developed karst of the Galena are typically through well-integrated conduit drainage systems and are relatively quick (days to weeks) and easy to conduct.

A successful quintuple trace at Freiheit Spring in the Galena karst of Fillmore County compared the behavior of a flow pulse, turbidity, fluorescent dye, salt conductivity, stable isotopes and heat as tracers. The differing responses of the traces yield significant new information on the geometry and behavior of the conduits through which the ground water flows to the trout springs. This is an important new tool in classifying the trout stream springs.

In the Prairie du Chien karst of Fillmore, Houston and Winona Counties many of the traces have also contributed to the Root River MRBI effort. Traces in the less well integrated Prairie du Chien karst were slower (weeks to months) and more expensive to conduct, but the Prairie du Chien hosts important trout streams and major trout hatcheries with significant environmental threats. We have had successful traces in some cases and frustrating "lost" traces in other cases.

Our discovery, in the previous biennium's project, that the St. Lawrence "aquitard" is actually a conduit karst aquifer north of Rushford, MN (northeastern Fillmore and southern Winona Counties) was confirmed by traces from sinking and losing streams in the St. Lawrence Formation to trout stream springs in five locations from the Kieffer Valley of northern Winona County to central Houston County. These traces have revealed a new type of tracer breakthrough curves – characterized by relatively quick (days to a week) initial breakthroughs followed by very long tails of tracers at the springs. These traces take up to a year or more to complete. These results have major implications for the management of the many trout streams with St. Lawrence source springs. These traces have dramatically changed our understanding of the hydrology of St. Lawrence springs and have demonstrated that these springs are significantly more vulnerable then we had previously believed. These traces emphasize that losing reaches of surface streams (which are much less obvious than stream sinks) are significant threats to trout springs.

In the previous biennium we demonstrated that temperature logging of trout springs could provide an economical screening tool to identify trout springs with rapid connections to their recharge areas. We maintained and expanded the temperature monitoring efforts. We started with a mixture of small, very economical Hobo temperature loggers and a collection of pre-existing, more expensive Campbell temperature/conductivity/water level loggers. The Hobos proved to provide a useful initial screening but lacked the temperature resolution of the Campbell systems. The conductivity and water level data provided by the Campbells provided critical additional information. During this project we have added five Solinst temperature/ conductivity/stage loggers to our temperature array. They proved to be effective complements to the Campbell loggers for temperature monitoring but yielded disappointing results for level and conductivity logging.

The results from the temperature monitoring array revealed four different temperature responses in trout springs. Spring in the well-integrated Galena karsts typically show numerous hour-to-day temperature events. These are produced by

individual recharge events. The winter and spring snow melt events are relatively cold water. The late spring, summer and early fall events are warm events. Springs fed by perennial sinking streams show large seasonal temperature variations that are in phase with the surface temperatures. We see a few springs whose temperature is constant. The fourth pattern, seen in some of the St. Lawrence springs are seasonal temperature variations (of up to a couple of degrees) that are four to eight months out of phase with the surface temperature. These springs have the property that they are warmer in the winter than they are in the summer. This phenomenon has not been reported previously and may have a very significant impact on trout ecology.

Tony Runkel and Julia Steinberg of the MGS used their contract time to assist both the U of M and DNR staff in determining the stratigraphic position of springs of interest. This work is vital as we are finding more and more evidence that there is a significant element of stratigraphic control on where the springs occur on the landscape. The characterization work is being used to plan dye traces, interpret temperature monitoring, and to develop a conceptual model of spring occurrence and vulnerability. This work is being used in conjunction with spring flow measurements to apply a methodology (originally developed in Kentucky) for determining springshed area by base flow measurements. The data are gathered at springsheds of known size and geology and then plotted to develop a regression equation that will give you basin size.

The number of well-defined springsheds has grown, allowing the area of those springsheds plotted against the base flow of the springs is yielding increasingly accurate NBF curves. These curves provide a rapid way of estimating the size – but not the shape or location) of a trout stream's springshed.

The unexpended balance on Result 1 was due to three changes that resulted in savings to the grant: 1) the largest savings was in salaries. The advanced graduate students who worked on this project have smaller fringe benefit costs than do the beginning graduate students on which the budget was based. The P.I. only drew one of the two months of salary budgeted. 2) The capital equipment budget of $20,000 was to purchase a piece of equipment whose cost had tripled to $60,000 by the time the LCCMR funds were available, leaving insufficient funds to purchase the equipment. 3) The travel expenses in state proved to be significantly cheaper that estimated at in the proposal.

Result 2 <u>Web Accessible Trout Springshed Maps and KFDB</u>

Description: The springshed maps as they are produced and updated will be useful to resource managers. They need to be accessible in a user-friendly web site. The MN Karst Features Data Base (KFDB) exists and is and will continue to be an integral part of the springshed mapping project. The KFDB will be updated, made more web accessible and user friendly. Web sites will be designed to facilitate user access to the springshed maps and the data in the KFDB. The most appropriate location for the long term web host for the Springshed Maps and web accessible KFDB is being investigated. Whatever

host is most appropriate, the site will be linked to the Mn DNR, MGS and U of Mn and any other relevant web pages.

Summary Budget Information for Result 2:

Trust Fund Budget:	U of Mn	Mn DNR	**Total**
Trust Fund Appropriation	$ 59,789	$ 000	**$ 59,789**
Minus Amount Spent:	$ 56,681	$ 000	**$ 56,681**
Equal Balance:	$ 3,108	$ 000	**$ 3,108**

Deliverable	**Completion Date**	**Budget**
1. Web site for user friendly posting of GIS based springshed maps & updated access to KFDB for on-line data entry & management.	**30 June 2011**	**$ 59,789**

Final Results

Bob Tipping of the MGS has been using his contract time to maintain the KFDB and to assist Yongli Gao modernize and update the systems. Yongli Gao, a contract worker, was in residence at the University of Minnesota from the summer of 2010 through May 2011. The data base has been significantly improved. Gao also worked on the web-based accessibility of the springshed maps. The availability of the 2008 high resolution LiDAR data for SE Minnesota were utilized at all levels in this project. Summer interns and graduate students have conducted initial photo interpretation of the LiDAR data sets from Houston, Winona, Wabasha and Fillmore Counties and those new data sets are being entered into the KFDB. A full integration of this important new data set is an important part of the effort to develop and demonstrate new springshed mapping tool.

A major challenge for the KFDB and associated web site is the where the data base and web site should be. Versions of the data base are accessible via the DNR Data Deli and the MGS web site. We currently hope that the data base will be maintained at the MGS and the resulting maps and data will be available on the DNR and MGS web sites.

V. TOTAL TRUST FUND PROJECT BUDGET:

	U of Mn	Mn DNR	**Total**
Personnel:	$ 171,291	$ 202,500	**$ 373,791**
Contracts:	$ 28,000	$ 000	**$ 28,000**
Equipment/Tools/Supplies:	$ 30,000	$ 16,000	**$ 46,000**
Travel:	$ 20,709	$ 29,000	**$ 49,709**
Other:	$ 000	$ 2,500	**$ 2,500**

(See explanation of the capitol equipment, equipment/tools/supplies and the in- and out of state travel below.)

TOTAL TRUST FUND PROJECT BUDGET: $ 500,000

Explanation of Capital Expenditures Greater Than $3,500:
The $20,000 Capital Equipment item in the U of Mn portion of this project is to purchase a new, fast, high capacity Laser Cavity Liquid Water Isotope Analyzer to measure the stable isotope composition of oxygen and hydrogen in water. The $20,000 from the LCCMR will be matched by funds from other sources to purchase an Analysis System that will cost about $40,000. The current high cost of mass spectrometric water isotope measurements limits the application of isotope measurements to Trout Springshed mapping. This new technology decreases the cost by a factor of 10.

Of the remaining $10,000 of the U of Mn Equipment/Tool/Supplies budget, $2,000 will be spent purchasing non-capital equipment and tools such as field meters, electrodes for field meters, sensors, and replacement parts for existing equipment. $8,000 will be spent on expendable supplies such as fluorescent dye, charcoal, labels, bottles, lab supplies, etc.

Explanation of Travel Costs:
The U of Mn's $17,709 item for instate travel is to cover the cost of the extensive field work involved in this project. Most of that will cover the mileage costs of the field vehicles. A few overnight trips will include lodging and food charges for the project partners.

The $3,000 item for travel outside of Minnesota is to partially defray the costs of the Project Manager, Scientist and Graduate Research Assistant to attend to learn from colleagues in other states who are working on karst hydrogeology. Possible meetings include the 12th Sinkhole Conference in 2010 or the Annual Geological Society of America Meetings.

VI. PROJECT STRATEGY:

A. Project Partners:

Dr. E. Calvin Alexander, Jr. will be the project manager of the overall Trout Springshed Mapping Project and the manager of the U of MN portion of the project. He is a tenured Professor in the Geology & Geophysics Department at the University of Minnesota

Jeff Green will be project manager of the DNR portion of this project and will be responsible for carrying out the DNR share of project activities. He is a classified state employee. His current position of Ground Water Specialist will be backfilled.

Dr. Yongli Gao will be a contractor who was responsible for developing the GIS based web site for public access to the springshed maps and updating the KFDB to make it more user friendly and accessible. Gao designed and implemented the current MN KFDB and is currently working with the USGS on a National Karst Features Data System. He is an Assistant Professor at East Tennessee State University in Johnson City, TN.

Dr. Anthony C. Runkel will be contributing stratigraphic information to Results 1 of this project. Tony is the Minnesota State Geologist with the Minnesota Geological

Survey. He has done extensive work on the karst hydrostratigraphy of southeastern Minnesota.
Robert G. Tipping is a Senior Scientist with the Minnesota Geological Survey. Bob currently maintains the MN KFDB. He has also done pioneering work on the karst hydrostratigraphy of southeastern Minnesota.

B. Project Impact and Long-term Strategy: By delineating springsheds and making web-based maps available, this project will provide critical information for the protection and management of the springs that form the coldwater streams of southeast Minnesota. This information is critical for Total Maximum Daily Load (TMDL) implementation strategies, impaired waters remediation, ground water protection and allocation issues, and local land and water management decisions.

Karst ground water flow is the most complex hydrogeologic environment in Minnesota. Springs are the natural features that return groundwater to surface waters. Karst springs respond much faster to surface recharge than is expected from conventional hydrology theory. Karst springs exhibit a wide range of rapid responses to recharge events. Springs integrate all of the natural and anthropogenic processes that occur in their recharge areas – in their individual springsheds. Springshed mapping is critical component of karst aquifer characterization. Long-term resources are needed to gather and maintain the parameters necessary to realistically, effectively manage karst springs in Minnesota and to train staff and resource managers in the use of the available karst data. LCMR and LCCMR have played a leading role in the effort to understand and manage Minnesota's karst springs

The availability of high-resolution LiDAR maps, beginning July 2009, produced a flood of new information showing the locations of karst features. That new information has had a major impact on the springshed mapping project.

C. Other Funds Proposed to be Spent during the Project Period:

A NSF Summer Intern in both the summers of 2009, 2010 and 2011 worked on projects contributing directly to this project. Their $4,700 summer stipends, each paid by the NSF, contributed significant information this effort.

Two University of Minnesota Undergraduate Research Opportunity Projects (UROP) students have conducted dye traces in SE Minn which contribute directly and significantly to this project. They each received $1,400 from University of Minnesota funds.

Dr. Matt Covington, on a NSF Post-Doctoral Fellowship, made major theoretical and experimental contributions to this project – at no cost to the LCCMR – estimated $25,000.

D. Spending HIstory*:* $ 250,000 from the trust fund to a joint project between the U of MN and the DNR, 1 July 2007 to 30 June 2009.

VII. DISSEMINATION: GIS based maps and written reports of the springsheds will be prepared and disseminated to the LCCMR and interested residents and to local,

regional and state resource managers and regulators interested in specific targeted areas. Interim dye trace results will be available as GIS shape files and derived products on a dye trace by dye trace basis. Data tables of discharge and chemistry will be available as developed.

Final

The dissemination of the results of this project proceeded at several levels. We provided interim results to local landowners and to local, county, regional and state agency staff and resource managers. MPCA staff, for example, routinely contact us with questions about karst features in SE Minn. We worked synergistically with other LCCMR funded research projects and with a range of resource management efforts. The generation and dissemination of the maps and written reports was part student educational projects – from local High School students through University students in classes and interns, graduate student theses, post Doctoral researchers and colleagues. We lead and participated in fieldtrips sponsored by LCCMR, the MGWA and other groups focused on protecting SE MN trout streams and water resources. We worked collaboratively with MPCA, DNR, Department of Agriculture and other agencies to expand and complement the LCCMR funded work. A dozen reports on the interim results of this project were presented at state and national scientific meetings.

Formal Publications:

Luhmann, Andrew J., Matthew D. Covington, Scott C. Alexander, Su Yi Chai, Benjamin F. Schwartz, Joel T. Groten and E. Calvin Alexander, Jr. (2012) Comparing Conservative and Nonconservative Tracers and Using Them to Estimate Flow Path Geometry. In review, Journal of Hydrology.

Alexander, E. Calvin, Jr., Jeffrey A. Green, Anthony Runkel and Katherine J. Logan (2011) Southeastern Minnesota karst hydrogeology: New insights from data loggers, tracing, LiDAR and hydrophysics. *in* Miller, J.D., Jr., Hudak, G.J., Wittkop, C. and McLoughlin, P.I. eds., Archean to Anthropocene: Field Guides to the Geology of the MidContinent of North America: Geological Society of America Field Guide 24, p. 243-257.

Tipping, R., Alexander, Scott C. Alexander and E.C. Alexander Jr. (2011) Groundwater Policy at State and Local Levels: The Science-Policy Linkage, (K. William Easter and Jim Perry, *eds.*) **Water Policy in Minnesota Issues, Incentives, and Action**. RFF Press, Earthscan, London, p. 122-133. ISBN: 978-1-61726-086-5.

Andrew J. Luhmann, Matthew D. Covington, Andrew J. Peters, Scott C. Alexander, Cale T. Anger, Jeffrey A. Green, Anthony C. Runkel and E. Calvin Alexander, Jr. (2011) Classification of Thermal Patterns at Karst Springs and Cave Streams, Ground Water, Vol 49, no.3, p 324-334.

Alexander, E. Calvin, Jr., Greg A. Brick, Arthur N. Palmer (2009) Ch. 4: Glaciated Central Lowlands, Minnesota, p. 146-150. *In:* Palmer, Arthur N., and Palmer, Margaret V., 2009, Caves and Karst of the USA: Huntsville, AL., National Speleological Society, 446 p. ISBN 9781879961289.

Anderson, Julia, Runkel, Anthony, Tipping, Robert G., Barr, Kelton D., and Alexander, E. Calvin, Jr. (2011) Hydrostratigraphy of a fractured, urban aquitards. Abstract 110-4, 2011 Geological Society of America Meeting, *Abstracts with Programs*, Vol. 43, No. 5.

Brick, Greg, Alexander, E. Calvin, Jr., Watkins, Justin and Lundy, James R. (2011) Surface and groundwater nitrate databases for southeastern Minnesota, USA. Poster 108-3, 2011 Geological Society of America Meeting, *Abstracts with Programs*, Vol. 43, No. 5.

Ladd, Bethany S., and Alexander, E. Calvin, Jr. (2011) Dye tracing in the Jordan Sandstone near the Crystal Springs State Fish Hatchery, Winona County, Minnesota. Poster 108-4, 2011 Geological Society of America Meeting, *Abstracts with Programs*, Vol. 43, No. 5.

Luhmann, Andrew J., Covington, Matthew D., and Alexander, E. Calvin, Jr. (2011) Using a multi-tracer experiment to estimate flow path geometry. Abstract 135-7, 2011 Geological Society of America Meeting, *Abstracts with Programs*, Vol. 43, No. 5.

Green, Jeffrey A., and Alexander, E. Calvin, Jr. (2011) Dye tracing observations from the Prairie du Chien Group in Minnesota, Abstract 60-11, 2011 Geological Society of America Meeting, *Abstracts with Programs*, Vol. 43, No. 5.

Talbot, Michael T. and Alexander, E. Calvin, Jr. (2011) The impact of karst on agriculture. (*eds.: Engel, Annette Summers, Engel, Scott, Moore, Paul J., DuChene, Harvey)* Carbonate Geochemistry: Reactions and Processes in Aquifers and Reservoirs, Billing, MT, 6-9 August 2011, Karst Waters Institute Special Publication 16, KWI, P.O. Box 1442, Leesburg, VA 20177, p. 69.

Rahimi, Mina and Alexander, E. Calvin Alexander, Jr. (2011) Three decades of sinkhole mapping in Winona County, MN, Poster presented at The 12th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst 10-14 January 2011, St. Louis, MO.

Anger, Cale T. and Alexander, E. Calvin, Jr. (2011) Bench scale models of dye breakthrough curves. Poster presented at The 12th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Program with Abstracts, 10-14 January 2011, St. Louis, MO, p 36.

Green, Jeffrey A., Runkel, Anthony C. and Alexander, E. Calvin, Jr. (2011) Karst conduit flow in the Cambrian St. Lawrence confining unit, southeast Minnesota, U.S.A. Abstract presented at The 12th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Program with Abstracts, 10-14 January 2011, St. Louis, MO, p 36.

Luhmann, Andrew J., Covington, Matthew D., Alexander, Scott C., Chai, Su Yi and Alexander, E. Calvin, Jr. (2011) Comparison of discharge, conductivity, temperature, dye, deuterium and turbidity responses from a multiple tracer test in karst. Abstract presented at The 12th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Program with Abstracts, 10-14 January 2011, St. Louis, MO, p 34.

Luhmann, Andrew J., Covington, Matthew D. and Alexander, E. C., Jr. (2010) Thermograph Recessions, Abstract 129-7, GSA 2010 Abstracts with Programs, Annual Meeting, Denver, CO, Vol. 42, No. 5, p. 329.

Mina Rahimi Kazerooni, Scott C. Alexander and E. Calvin Alexander, Jr. (2010) LiDAR Mapping of Sinkholes: Winona County, MN (poster). Abstract 47-3, GSA 2010 Abstracts with Programs, Joint Meeting North-Central/South-Central Sections, Vol. 42, No. 2, p. 107-108.

Cale T. Anger and E. Calvin Alexander, Jr. (2010) Bench-Scale Models of Dye Breakthrough Curves. Abstract 40-3, GSA 2010 Abstracts with Programs, Joint Meeting North-Central/South-Central Sections, Vol. 42, No. 2, p. 98.

Andrew J. Luhmann, Cale T. Anger, Julie Greene, Erik B. Larson, Scott C. Alexander, Matthew D. Covington, Jeffrey A. Green and E. Calvin Alexander, Jr. (2010) Simultaneous Fluorescent Dye, Conductivity and Thermal Traces in a Karst Springshed. Abstract 26-5, GSA 2010 Abstracts with Programs, Joint Meeting North-Central/South-Central Sections, Vol. 42, No. 2, p. 77.

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Andrew J. Luhmann, Matthew D. Covington, Andrew J. Peters, Scott C. Alexander Cale T. Anger, Jeffery A. Green and E. Calvin Alexander, Jr. (2009) Thermal Patterns of Karst Springs and Cave Streams in Southeastern Minnesota. Abstract 127-6, Geological Society of America *Abstracts with Programs*, Vol. 41, No. 7, p. 346.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than 31December 2009, 30 June 2010, 31 December 2010. A final work program report and associated products will be submitted between June 30 and August 1, 2011 as requested by the LCCMR.

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2009 Projects - Summary and a Budget page for each partner (if applicable)								
Project Title: Innovative Springshed Mapping for Trout Stream Management-Continuation								
Project Manager Name: E. Calvin Alexander, Jr.								
Trust Fund Appropriation: $ 250,000								
2009 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Innovative Trout Springshed Maps and Reports	*1/31/2012*	*1/31/2012*	*Web Accessable Trout Springsheds and KFDB*	*1/31/2012*	*1/31/2012*		
BUDGET ITEM								
PERSONNEL: wages and benefits (Total)	**139,502**	**116,625**	**22,877**	**31,789**	**28,681**	**3,108**	**171,291**	**25,985**
UM Prof. E. Calvin Alexander, Jr. (1 month/yr - 8% FTE - $23,884)		4,829						
UM Scientist Scott Alexander (50% FTE - $59,540)		47,588						
UM Graduate Research Assistant (50% FTE - $53,300)		60,617			13,850			
MGS Scientist Anthony Runkel (1 month/yr - 8% FTE - $14,444)					11,741			
MGS Scientist Robert Tipping (1 month/yr - 8% FTE - $13,787) + Julia Steenberg					3,091			
UM Undergrad Res. Assist. (8 hr/wk, 9 m/yr - 15% FTE - $6,336)		3,591						
Contracts								
Professional/technical								
Yongli Gao (Web page & Data Base design)				28,000	28,000	0	28,000	0
Non-capital Equipment / Tools								
meters, electrodes, sensors, etc.	2,000	1,030	970				2,000	970
Capital equipment over $3,500								
Equipment such as Los Gatos Research Liquid Water Isotope Analyzer	20,000	0	20,000				20,000	20,000
Supplies								
Fluorescent dye, charcoal, labels, bottles, etc.	8,000	3,696	4,304				8,000	4,304
Travel expenses in Minnesota								
(see explanation in section V of work plan)	17,709	6,775	10,934				17,709	10,934
Travel outside Minnesota								
(see explanation in section V or work plan)	3,000	2,613	387				3,000	387
COLUMN TOTAL	**$190,211**	**$130,740**	**$59,472**	**$59,789**	**$56,681**	**$3,108**	**$250,000**	**$62,579**