Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2014 Work Plan

Date of Report: February 7, 2014

Date of Next Status Update Report: January 31, 2015

Date of Work Plan Approval:

Project Completion Date: June 30, 2016

Does this submission include an amendment request? _No_

PROJECT TITLE: Innovative Groundwater-Enhanced Geothermal Heat Pump Study

Project Manager: Martin Saar

Organization: University of Minnesota

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Location: Hennepin and Ramsey Counties, Minnesota

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$196,000**
	Amount Spent:	**$0**
	Balance:	**$196,000**

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08b

Appropriation Language:
$196,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to analyze and validate a new geothermal pump method and technology that will reduce heat pump costs and improve performance and predictability. This appropriation is subject to Minnesota Statutes, section 116P.10.

I. PROJECT TITLE: Innovative Groundwater-Enhanced Geothermal Heat Pump Study

II. PROJECT STATEMENT:

Space and water heating and cooling consume 48% of all energy used in an average US residence, and generally that energy is supplied by natural gas or fossil-fuel-derived electricity. Geothermal heat pumps (GHPs) can reduce energy requirements for heating/cooling by 75%. However, traditional GHPs are expensive, and their performance is difficult to predict before installation. We propose to analyze and validate a novel GHP method/ technology that is expected to substantially reduce GHP cost while improving performance and predictability.

GHPs can be used anywhere in the world because they use the shallow subsurface as a thermal capacitor, removing heat during winter months to provide space/water heating and returning heat during the summer to provide cooling. They function by boosting the temperature of heat extracted from the ground using compression. Traditional GHPs require considerable wells and/or excavation – their main cost – and are space-intensive. Thus, in the US, they have achieved minimal market penetration (3% of the heating, ventilation and air conditioning (HVAC) market). However, in areas with higher energy costs, such as Sweden and Switzerland, GHPs constitute up to 75% of the HVAC market, indicating there is significant room for growth in the US.

Conventional GHPs ignore groundwater flow and focus on heat exchange with subsurface rocks and sediments. However, groundwater carries heat much more effectively than rock and as such, our novel GHP system and technology specifically acknowledge groundwater flow. This groundwater-enhanced GHP takes advantage of the thermal transport properties of groundwater but in a closed-loop fashion so that no groundwater is used and no contaminants are introduced to the subsurface. Preliminary simulations suggest that our system is far more efficient, less space intensive and thus less costly than conventional systems.

The ultimate objective of this project is to determine the viability of groundwater-enhanced GHPs using numerical modeling and lab/field testing of a prototype. Early-stage modeling and validation of the novel technology/ approach have been completed. This project modifies existing GHP technology while incorporating established hydrogeologic practices and information; thus, we feel the new technology is well-position for success. The novel GHP would be smaller and cheaper than existing systems, permitting faster payback periods, more widespread GHP use, and helping GHPs become a significant renewable energy technology.

An Intellectual Property Disclosure has been filed with the Office for Technology Commercialization at the UMN. The UMN may pursue patent protection and as such, some information concerning this proposal is currently confidential. This proposal thus provides less detail than it would otherwise.

III. PROJECT STATUS UPDATES:

Project Status as of December 31, 2014:

Project Status as of June 30, 2015:

Project Status as of December 31, 2015:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Detailed numerical modeling of innovative GHP system.
Description: We will extensively expand upon existing models in order to study the new GHP system under a variety of configurations and geologic conditions relevant to Minnesota. This modeling will further examine the

efficacy of the novel method and determine optimal system design. The GHP subsurface component can be installed vertically, using wells, or horizontally in trenches or horizontal boreholes. The former is less space-intensive and, thus, well-suited for urban areas while the latter may be less costly and suited for rural or industrial spaces. The new GHP is anticipated to require far less space and require significantly fewer boreholes than conventional systems under either configuration. However, numerical modeling is needed to determine space needs and overall system design for varied geologic conditions.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 18,500**
Amount Spent: $ 0
Balance: $18,500

Activity Completion Date: Dec. 31, 2014

Outcome	Completion Date	Budget
1. Development and testing of base case GHP numerical models using Comsol simulator.	Dec. 31, 2014	$ 18,500

Activity Status as of: **December 31, 2014**

Final Report Summary:

ACTIVITY 2: Prototype subsurface unit modeling, design and construction.
Description: The groundwater-enhanced GHP incorporates a novel subsurface heat exchange unit, which is projected to decrease the GHP subsurface footprint, substantially reducing installation costs while making the system more serviceable than conventional GHPs. This activity will finalize the design of a prototype unit, test the unit in geologic models, and construct a small prototype.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 69,500**
Amount Spent: $ 0
Balance: $69,500

Activity Completion Date: Sept. 30, 2015

Outcome	Completion Date	Budget
1. Finalize design of the prototype subsurface heat exchange unit.	March 31, 2015	$ 24,500
2. Incorporate the subsurface heat exchange unit into geologic numerical models.	June 31, 2015	$ 5,000
3. Have prototype subsurface unit constructed at UM machining facilities.	Sept. 30, 2015	$ 40,000

Project Status as of December 31, 2014:

Project Status as of June 30, 2015:

Project Status as of December 31, 2015:

Final Report Summary:

ACTIVITY 3: Prototype laboratory testing, numerical verification.
Description: The prototype subsurface GHP unit will be tested in a lab setting. We will construct a tabletop-scale subsurface analogue consisting of a rectangular, open-topped Plexiglas box filled with sediment. It will be filled with water, and a pump will drive the water, simulating groundwater flow. The prototype will be installed in the subsurface analogue, and a heat transfer fluid will be circulated through the device. Heat will be added to or removed from the transfer fluid using a heat exchanger. The system will be used to determine the efficacy of heat transfer through the prototype, to ensure the analogue groundwater is isolated from the heat transfer

fluid, and to quantify heating and/or cooling of the analogue space. We will also compare lab models with numerical models. Note, we have previously constructed and successfully operated similar analogues for other studies.

Summary Budget Information for Activity 3: **ENRTF Budget: $ 55,500**
Amount Spent: $ 0
Balance: $55,500

Activity Completion Date: Jan. 31, 2016

Outcome	Completion Date	Budget
1. Subsurface analogue device construction.	Sept. 30, 2015	$ 42,500
2. Installation and operation of GHP prototype; comparison of lab and numerical results.	Jan. 31, 2016	$ 13,000

Activity Status as of December 31, 2015

Activity Status as of June 30, 2015:

Activity Status as of December 31, 2015:

Final Report Summary:

ACTIVITY 4: Prototype field testing.

Description: The prototype subsurface unit will be installed in a groundwater monitoring well – selected to be similar to wells used for commercial GHP operation – on the UM campus. Location will be found on Minneapolis or St. Paul Campus to allow easy access and monitoring by staff. Geophysical logging, in coordination with the Minnesota Geological Survey, will determine the hydrologic connectivity of the selected well. It will be connected to a conventional GHP surface unit, housed in a small enclosure, to test the prototype operation over a variety of operating conditions. We will install monitoring devices to facilitate analysis of GHP performance and subsurface impacts.

Summary Budget Information for Activity 4: **ENRTF Budget: $ 52,500**
Amount Spent: $ 0
Balance: $52,500

Activity Completion Date: June 30, 2016

Outcome	Completion Date	Budget
1. Install subsurface prototype in a well; construct surface facility.	March 31, 2016	$ 20,000
2. Operate and analyze prototype system.	June 30, 2016	$ 42,500

Activity Status as of December 31, 2015

Activity Status as of June 30, 2015:

Activity Status as of December 31, 2015:

Final Report Summary:

V. DISSEMINATION:

Description: Project results will be reported in peer reviewed publications and patent documents.

Status as of December 31, 2014:

Status as of June 30, 2015:

Status as of December 31, 2015:

Final Report Summary: July 31, 2016

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 111,216	Dr. Martin O Saar (PI, associate professor 1.5 % time per year for two years, salary 83.4% of cost, fringe benefits 16.6% of cost), Dr. Jimmy B Randolph (co-PI, research assistant, 4% time per year for two years, salary 74.1% of cost, fringe benefits 25.9% of cost), Scott Alexander (co-PI, Research Scientist 72% salary, 28% benefits, 2 years, 35% time position, Graduate Research Assistant 50% time per year for three semesters or 1.5 years and 1/8 summer, salary 52% of cost, fringe benefits 48% of cost.
Equipment/Tools/Supplies:	$ 35,000	Supplies for developing, monitoring, and analyzing performance of lab and field scale prototypes.
Capital Expenditures over $5,000:	$ 42,000	Prototype Geothermal Heat Pump Subsurface Interface, including design, machining, and ancillary supplies; and Geothermal Heat Pump surface unit with related automated controls and surface heat exchanger.
Other:	$ 7,784	Repairs and maintenance of GHP prototype system and surface components by UM machine shops ($2,284), and downhole geophysical logging of the geologic formation in which the prototype unit will be tested, for analysis for prototype performance, to determine hydrologic flow conditions and measure subsurface impacts ($5,500). Logging will be done in coordination with the Minnesota Geologic Survey using MGS and rented equipment.
TOTAL ENRTF BUDGET:	**$ 196,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: The field scale Geothermal Heat Pump will require custom design, machining, and assembly of a functional prototype (estimated cost $32,500) as part of Activity 2, Field Scale testing in Activity 4 will require that the prototype GHP be connected to an off the shelf GHP surface unit ($9,500) with related controllers. Equipment will continue to be used for on-going research at UM through its useful life. If the use changes UM would pay back the Environment and Natural Resources Trust Fund an amount equal to either the cash value received or a residual value approved by the LCCMR director if it is sold.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 1.8 FTE

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: N/A

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
Saar Departmental Start Up funding	$ 40,000	$ 40,000	Existing computational hardware (computer workstations, linux cluster) and software licenses (Comsol Multiphysics and TOUGH2).
UM Facilities and Mgmt	$ 20,000	0	Monitoring well on UM campus.
State			
	$ 0	$ 0	
TOTAL OTHER FUNDS:	**$ 60,000**	**$ 40,000**	

VII. PROJECT STRATEGY:

A. Project Partners: UMN Facilities and UMN Office for Technology and Commercialization.

B. Project Impact and Long-term Strategy:

A successful prototype-scale demonstration of the novel GHP system would be followed by a full-scale system design. Thereafter, we will approach the UMN facilities division to investigate installing a full system on campus to heat/cool the to-be-renovated Tate Hall or the Biomedical Discovery District. Soon, the UMN will require additional heating infrastructure, which could be supplied renewably with the new GHP technology/approach rather than with natural gas, which dominates the current heating system. In addition, we anticipate approaching, with the assistance of the UMN Office for Technology Commercialization, a commercial entity to pursue statewide implementation of the novel GHP technology. GHPs that are less costly, more predictable, and more serviceable – such as what we propose – could reduce Minnesota's fossil fuel requirements for heating and cooling by 50%, substantially reducing the state's greenhouse gas emissions and providing massive environmental benefits.

Non-confidential results of all studies will be published in peer-reviewed journals, such as the Hydrogeology Journal, and presented at conferences including the Midwest Groundwater Conference.

C. Spending History:

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13	M.L. 2013 or FY14
UM Earth Sciences – computer modeling of GHP systems.			$35,000	$35,000	

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. VISUAL ELEMENT or MAP(S): See attached visual element.

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: N/A

XI. RESEARCH ADDENDUM: N/A

XII. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 31, 2015; July 31, 2015; and January 31, 2016. A final report and associated products will be submitted between June 30 and August 15, 2016.

Environment and Natural Resources Trust Fund
M.L. 2014 Project Budget

Project Title: *Innovative Groundwater-Enhanced Geothermal Heat Pump Study*
Legal Citation: *M.L. 2014, Chp. 226, Sec. 2, Subd. 08b*
Project Manager: *Martin Saar*
Organization: *University of Minnesota*
M.L. 2014 ENRTF Appropriation: $ *196,000*
Project Length and Completion Date: *2 Years, June 30, 2016*
Date of Report: *01/07/2014*

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	Activity 4 Budget	Amount Spent	Activity 4 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	*Detailed numerical modeling 18,500*			*Prototype design & construction 69,500*			*Prototype lab scale testing & verification 55,500*			*Prototype field testing 52,500*				
Personnel (Wages and Benefits)	**$18,500**	**$0**	**$18,500**	**$37,000**	**$0**	**$37,000**	**$31,500**	**$0**	**$31,500**	**$24,216**	**$0**	**$24,216**	**$111,216**	**$111,216**
Dr. Martin O Saar - PI, associate professor 1.5 % time per year for two years, salary 83.4% of cost, fringe benefits 16.6% of cost (~$4,187).														
Dr. Jimmy B Randolph - co-PI, research assistant, 4% time per year for two years, salary 74.1% of cost, fringe benefits 25.9% of cost (~$4,606)														
Scott Alexander - co-PI, Research Scientist, 35% time per year for two years, 72% salary, 28% benefits ($47,423)														
Graduate Research Assistant 50% time per year for three semesters or 1.5 years and 1/8 summer, salary 52% of cost, fringe benefits 48% of cost($55,000).														
Equipment/Tools/Supplies														
Supplies: Outdoor enclosure, electrical connections, and heat pump-to-well connections for prototype operation.	$0	$0	$0	$0	$0	$0	$0	$0	$0	$3,500	$0	$3,500	$3,500	**$3,500**
Supplies: Monitoring supplies to measure subsurface and surface conditions during geothermal heat pump prototype testing.	$0	$0	$0	$0	$0	$0	$0	$0	$0	$7,500	$0	$7,500	$7,500	**$7,500**
Supplies: Laboratory supplies - including monitoring tools, heater, water pumps, tubing, and benchtop-scale simplified subsrface replica to allow testing of prototype geothermal heat exhanger prior to installation.	$0	$0	$0	$0	$0	$0	$24,000	$0	$24,000	$0	$0	$0	$24,000	**$24,000**
Capital Expenditures Over $5,000														
Equipment: Prototype Geothermal Heat Pump Subsurface Interface, including design, machining, and ancillary supplies.	$0	$0	$0	$32,500	$0	$32,500	$0	$0	$0	$0	$0	$0	$32,500	**$32,500**
Equipment: Geothermal heat pump surface unit with related automated controls and surface heat exchanger.	$0	$0	$0	$0	$0	$0	$0	$0	$0	$9,500	$0	$9,500	$9,500	**$9,500**
Other														
Repair and Maintenance: of GHP prototype system and surface components by UM machine shops	$0	$0	$0	$0	$0	$0	$0	$0	$0	$2,284	$0	$2,284	$2,284	**$2,284**
Geophysical Logging Services: Downhole geophysical surveys of the geologic formation in which the prototype unit will be tested, for analysis for prototype performance, to determine hydrologic flow conditions and measure subsurface impacts. Logging will be done in coordination with the Minnesota Geologic Survey using MGS and rented equipment.	$0	$0	$0	$0	$0	$0	$0	$0	$0	$5,500	$0	$5,500	$5,500	**$5,500**
COLUMN TOTAL	**$18,500**	**$0**	**$18,500**	**$69,500**	**$0**	**$69,500**	**$55,500**	**$0**	**$55,500**	**$52,500**	**$0**	**$52,500**	**$196,000**	**$196,000**

Conventional Geothermal Heat Pump

The figure shows a conventional geothermal heat pump, this one employing vertical well-based subsurface heat exchange loops. Note the use of multiple vertical loops/wells and the lack of reference to groundwater. The novel groundwater-enhanced geothermal heat pump technology, to be investigated in the proposed study, specifically acknowledges groundwater flow and is designed to decrease the required number of wells, thereby reducing costs and improving predictability. Also note that the wells in the figure are fully buried, whereas the novel technology in this proposal is designed with wells that reach the surface and subsurface equipment that can be serviced without excavation, improving long-term system performance. Figure retrieved 2013 from www.geoexchange.org .