2014 Project Abstract
For the Period Ending June 30, 2017

PROJECT TITLE: Rain Water Reuse and Valuation Investigation
PROJECT MANAGER: Scott Alexander
AFFILIATION: University of Minnesota
MAILING ADDRESS: 310 Pillsbury Dr SE
CITY/STATE/ZIP: Minneapolis, MN 55455
PHONE: 612-626-4164
E-MAIL: alexa017@umn.edu
WEBSITE:
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2014, Chapter 226, Section 2, Subdivision 03l
M.L. 2016, Chapter 186, Section 2, Subdivision 18

APPROPRIATION AMOUNT: $300,000
AMOUNT SPENT: $ 139,944.55
AMOUNT REMAINING: $ 160,055.45

Overall Project Outcomes and Results

This project evaluated rain water as a source for evaporative chillers and process water. Rain water has low dissolved solids and is better suited as process feed water than groundwater derived waters. The project investigated the utility of capturing high purity water that would otherwise contribute to excessive runoff, localized flooding, and downstream nutrient and contaminant transport.

Harvested rain water was run through an evaporative concentrator simulating operation of commercial evaporative chiller systems. In contrast to conventional systems which required complete replacement of the system water after 3 to 4 cycles the rain water fed systems could run more than 30 cycles without replacement. After 30 cycles of evaporation the accumulated dissolved solids were still not precipitating minerals, especially calcite. In conventional systems mineral deposits must be prevented by the addition of chemicals and/or removed by acid washes in addition to frequent water replacement.

Based on the much smaller volume of feed water required with rain water, estimates of the seasonal chiller demand, roof area, rain fall rates, and storage volume can be made with a spreadsheet tool developed as part of this project. The required volume of water can be as little as 10% of the volume of ground water derived drinking water required for current systems. The costs of a roof water capture and treatment system is partially offset by savings on potable drinking water and to a larger extent by reducing the cost of other storm water retention and detention systems.

As part of a literature review other potential ways rain water can advantageously replace potable water were investigated ranging from toilet flushing, laundry, industrial processes, and anywhere the naturally dilute nature of rain water is an advantage. Traditional plumbing codes and definitions of gray water need to be updated to consider the relative cleanliness of roof run-off. In fact, many regions of the world where there is limited fresh water collect rain water as their sole drinking water source.

Unfortunately, a demonstration system designed for the UM campus could not be constructed within the project timelines, leaving a significant portion the grant funds unspent.

Project Results Use and Dissemination

Results were provided as a future addendum to the Minnesota Storm Water Manual in coordination with UM Extension Service. A journal article covering the potential for rain water reuse in commercial evaporative chiller systems is in review. We are working with local watershed districts, engineers, and architects to identify potential sites for rain water reuse systems in commercial settings. Presentations of this work have been made to the Mississippi Watershed Management Organization in Minneapolis and the Capital Region Watershed District in St. Paul.

Presently rain water is being used at the 17th Ave Residence Hall where roof runoff is stored for reuse in toilet flushing and at the Landcare Building where a cistern stores storm water for irrigation. Results from these systems show that rain water quality declines rapidly from pure rain water to roof runoff to street level runoff. Finding ways to capture the cleanest fractions of rain water for reuse this water instead of simply dumping it to the river is critical. Options for rain water reuse are particularly important where underground conditions limit infiltration of storm water and dense urban areas where there is no room for conventional storm water management systems.

We have been in discussion with local storm water professionals and consulting firms about the use of rain water. Of particular interest are retail settings, like large shopping centers, that produce detrimental amounts of storm runoff but are resistant to giving up parking space for storm water management. These same retail areas use large evaporative chillers systems that consume significant ground water resources. In addition, rain water has great potential as feed for industrial process water. In particular, rain water can be easily polished through filtration and reverse osmosis to produce high purity water.

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

Date of Report: November 10, 2017

Date of Next Status Update Report:

Date of Work Plan Approval: June 4, 2014

Project Completion Date: March 27, 2017

Does this submission include an amendment request? No

PROJECT TITLE: **Rain Water Reuse and Valuation Investigation**

Project Manager: Scott Alexander

Organization: University of Minnesota

Mailing Address: Dept. of Earth Sciences, 310 Pillsbury Dr SE

City/State/Zip Code: Minneapolis, MN 55455

Telephone Number: (612) 626-4164

Email Address: alexa017@umn.edu

Web Address: https://sites.google.com/a/umn.edu/um-chillers/

Location: Hennepin and Ramsey Counties

Total ENRTF Project Budget:

ENRTF Appropriation:	**$300,000**
Amount Spent:	**$139,944**
Balance:	**$160,055**

Legal Citation: M.L. 2014, Chapter 226, Section 2, Subdivision 03l
M.L. 2016, Chapter 186, Section 2, Subdivision 18

Appropriation Language:
$300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to design, install, and monitor a rainwater reuse system for use in evaporative chiller systems and identify other potential applications for rainwater reuse systems.
Carryforward: (a) The availability of the appropriations for the following projects are extended to June 30, 2017: (7) Laws 2014, chapter 226, section 2, subdivision 3, paragraph (l), Rainwater Reuse and Valuation Investigation;

I. PROJECT TITLE: Rain Water Reuse and Valuation Investigation

II. PROJECT STATEMENT:

This project aims to convert a liability, in the form of excess storm water runoff in urban environments, into a valued resource for chilled water production. Rain water reuse for evaporative chiller feed directly replaces potable drinking water typically supplied by ground water wells. Rain water has the advantage very low dissolved solids as it is naturally distilled by atmospheric processes.

Currently, most urban areas, and particularly commercial districts, produce large amounts of rainfall runoff creating localized flooding while washing nutrients and contaminants downstream. Conventional storm water systems to mitigate these problems are difficult to implement in densely urban areas with many pre-existing structures and dense underground utilities. Additionally, most urban properties, especially shopping centers, put a premium on maximizing parking area.

Coincidentally, evaporative chiller systems are widely used in commercial, retail, and educational settings. On the U of M Twin Cities campuses about 1/3 of the summer-time potable water usage goes to evaporative chiller systems (100 million gallons/year). Chilled water systems fed by ground water can only cycle water 3 to 4 times before it has to be replaced to prevent mineral build up. By its very dilute, naturally distilled character, rain water can by cycled many more times before disposal. Additionally, this distilled water should reduce chemicals and acids used in “blow-down” cycles where accumulated minerals are removed reducing waste discharge and extending equipment life.

The discharge from roofs is nearly pure distilled water, relatively free of contaminants, and requires only modest cleanup for reuse. In Minnesota, the annual average rainfall on a typical building can easily supply feed water to evaporative chillers cooling the same building and perhaps several surrounding buildings.

Calculations of storage volumes and treatment requirements, based on rainfall rates, urban roof water quality, and seasonal chiller demand, are needed to estimate project costs and space requirements. Once these baseline parameters and engineering/operational issues are defined, design and implementation of rain water reuse in an operational chiller system can commence. The cost of cistern systems compared to traditional storm water management can be offset by savings on potable water supply.

Supplemental work would include evaluation of rain water reuse compared to applications that have been traditionally supplied by treated, municipal potable water supplies. Current reuse programs are focused on lawn and turf grass irrigation where low cost treated city water is difficult to displace. New areas of reuse include water supply for toilet flushing, laundry, industrial process water, and anywhere the naturally dilute nature of rain water would be an advantage. Additionally, this study would investigate scaling up from individual chillers to district areas, identify policy issues, and analyze cost benefits associated with a high quality, non-potable water supply distinct from gray water and treated waste water.

III. PROJECT STATUS UPDATES:

Project Status as of December 31, 2014:
Rain water samples from 12 events over the late summer and fall of 2014 have been collected and are in the process of being analyzed. Samples were collected from traditional asphalt roofing, metal roofing, in addition to pure rain water. Additional samples from the cistern at the 17th St Residence Hall were collected as being representative of stored cistern water. These results will be used to design a feed water management plan for the proposed cistern/evaporative chiller system. Two students have been hired to conduct the analyses and compile results. In addition, these students will also assist in the rotary evaporation lab scale experiments.

Site selection for a cistern has been started in coordination with Facilities and Management staff. We are presently looking at three sites including one location adjacent to Northrup Auditorium which has a new chiller system that was installed with its recent renovation.

A series of batch experiments have been set up to determine the effects of storing water in a cement cistern versus a plastic cistern. Early results indicate that a cement cistern provides a significant amount of pH buffering that could enhance the performance within the chillers.

Project Status as of June 30, 2015:
After a relatively dry fall and winter period numerous rainfall events have been sampled since late April 2015. Rainwater chemistries have proven to be fairly consistent with some of the largest variation due to dry deposition of dust in between rain events. Longer dry periods lead to more dust on the sampling setup which is then washed into the collection vessel.

Batch experiments measuring the dissolution of cement and limestone in rain water have been completed. Results are being written up for journal submission in August. The results show a small, but significant dissolution of carbonate from the cement and limestone that adds to the buffering capacity of the cistern water.

The first results from the rotary evaporation system show that the buffered rainwaters do not go acidic with evaporative concentration. Interestingly the pure rain water samples appear to have enough natural CO_2 buffering to resist acidification under concentration as well. Geochemical modeling of the results is in progress.

A literature review of rainwater reuse is in progress with Co-PIs from the Department of Civil Engineering.

Site selection is still in progress with the large uncertainty the exact chemistries of Minnesota rain waters removed.

Project Status as of December 31, 2015:
Rainwater chemistries for a full year have been collected and analyzed. Results of isotopic analyses are pending.

Journal article on rainwater chemistry and effects of cistern storage has been submitted and is under review.

Literature review of rainwater reuse is in final phases, write up is now in progress.

Selection and implementation of test site on UM campus has proven to be complicated. We are working with Facilities and Management staff to finalize site selection.

Amendment Request (01/29/2016)
Working with Facilities and Management and the Capital Planning and Project Management departments to identify a site for cistern installation and connection to an existing evaporative chiller has been a long bureaucratic process. Questions from the Facilities engineers about rainwater chemistry and its impact on chiller equipment also delayed site selection. Given these delays there is little time under the current work plan to complete installation and conduct monitoring of the system before the June 30, 2016 end date. A one year extension of the grant would allow for full completion of the research.
Amendment Approved: 05/25/16

Project Status as of June 30, 2016:
With an additional year of time on the grant we are pushing forward with Capital Planning and Facilities engineers to construct a cistern to feed rain water to an evaporative chiller on campus. We now have a short list of potential sites with timelines amenable to completion of this research project. Our journal article on rain

water chemistry and potential for reuse has been submitted to a second journal after not be accepted by the first. Literature review on rain water reuse has been completed and is being submitted for publication.

Project Status as of December 31, 2016 (as of March 22, 2017): Capital Planning and Facilities engineers are still progressing to site a cistern on campus. Journal articles are in review. Literature review is complete and submitted for publication. Development of a spreadsheet tool to estimate cistern sizes given average seasonal rainfall and feed water needs is underway.

Project Status as of Mach 27, 2017: Due to lack of time before end of grant on June 30, 2017 to install an operating cistern the project was terminated.

Overall Project Outcomes and Results:

This project evaluated rain water as a source for evaporative chillers and process water. Rain water has low dissolved solids and is better suited as process feed water than groundwater derived waters. The project investigated the utility of capturing high purity water that would otherwise contribute to excessive runoff, localized flooding, and downstream nutrient and contaminant transport.

Harvested rain water was run through an evaporative concentrator simulating operation of commercial evaporative chiller systems. In contrast to conventional systems which required complete replacement of the system water after 3 to 4 cycles the rain water fed systems could run more than 30 cycles without replacement. After 30 cycles of evaporation the accumulated dissolved solids were still not precipitating minerals, especially calcite. In conventional systems mineral deposits must be prevented by the addition of chemicals and/or removed by acid washes in addition to frequent water replacement.

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As part of a literature review other potential ways rain water can advantageously replace potable water were investigated ranging from toilet flushing, laundry, industrial processes, and anywhere the naturally dilute nature of rain water is an advantage. Traditional plumbing codes and definitions of gray water need to be updated to consider the relative cleanliness of roof run-off. In fact, many regions of the world where there is limited fresh water collect rain water as their sole drinking water source.

Unfortunately, a demonstration system designed for the UM campus could not be constructed within the project timelines, leaving a significant portion the grant funds unspent.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Rain water quality and evaporative concentration

Description: We will collect representative samples of rain water from typical roof types representing seasonal, storm-to-storm, and single-storm variation. A variety of roof types will be utilized on the St. Paul and Minneapolis Campuses including red clay tile typical of historic buildings, flat tar roofs and galvanized steel common on commercial buildings, and asphalt shingles representative of residential roofs. Rain water itself varies in composition between individual storms and even with in single storms. In particular, the earliest parts of rain storms concentrate dust and particulates in the air while later rainfall has a much lower load of solids. Systems that bypass the first flush of rain water could be used to reduce sediment and contaminant load in the cistern water.

A representative selection of the collected rain waters and roof run off will be analyzed for constituents susceptible to concentration and mineralization in evaporative chiller systems. A laboratory scale concentration of sampled rainwater can be done with a bench top rotary evaporator. Some minerals, especially calcite, can easily precipitate clogging plumbing systems. Metals commonly found in roofing materials like copper and zinc can prevent, or poison, mineral precipitation. By conducting laboratory-scale evaporative concentration studies using pure rain water and roof run off water we can define the limits of rain water recycling in evaporative chiller systems. The results of the lab scale rotary evaporator will be used to define the initial operation of a full scale evaporative chiller in Activity 2.

Summary Budget Information for Activity 1:		
	ENRTF Budget:	**$ 143,000**
	Amount Spent:	**$ 102,778**
	Balance:	**$ 40,222**

Activity Completion Date:

Outcome	Completion Date	Budget
1. Journal article on properties and quality of rain water from urban roof top environments.	June 30, 2015	$ 100,000
2. Journal article on potential impacts and improvements to chiller operation from rainwater reuse.	September 30, 2016	$ 43,000

Activity Status as of: **December 31, 2014**
Rainwater samples have been collected and are in the process of being analyzed. Early results indicate that the type of cistern may play a role in water quality which should lead to publishable results.

Activity Status as of June 30, 2015:
We have collected representative samples of rain water from more than a dozen rainfall events. Rain water chemistries have proven to be quite low in dissolved ions, as expected. The typical chemistries have proven to have enough natural dissolved carbonate ions to maintain near neutral pH ranging from 5 to about 6.5. At this pH range the samples are proving to resist acidification under evaporative concentration. This is a very encouraging result for HVAC operators who are very leery of acid solutions dissolving parts of expensive chiller systems.

A representative selection of collected rain waters have been analyzed for constituents susceptible to concentration and mineralization in evaporative chiller systems. Between the time of the grant proposal and the present the Buchi Company has come out with a new research grade rotary evaporative system that is simpler and less expensive than previous models. This simple, basic system is robust enough for our rain water experiments without the added features needed for more complex liquids. A laboratory scale concentration of one rain water and one cement buffered rain water have completed with a bench top rotary evaporator. Additional sample runs are being completed now that the rotary evaporation system is setup and operational. The results of the lab scale rotary evaporator will be used to define the initial operation of a full scale evaporative chiller in Activity 2.

Activity Status as of December 31, 2015:
Journal article on rain water chemistry and effects of storage in a cistern has been submitted for review. Article on implications of rainwater reuse in industrial, commercial, and residential systems is in progress.

Activity Status as of June 30, 2016:
Paper has been submitted to a second journal after being rejected by a first. Additional work on density and viscosity of dilute rain waters has been added, building on original chemistry work. This new material should make for a stronger paper to address reviewer's comments.

Activity Status as of March 22, 2017: No new activity in this time period.

Paper presently in review.

Final Report Summary:
Representative rain water samples were tested in a rotary evaporation system to simulate the evaporative process in commercial chiller systems. These results proved very positive in terms of potential for rain water reuse. In particular, natural bicarbonate buffers in the rain water kept acidity levels near a neutral pH. High acidity due to concentration of hydrogen ions by evaporation does not occur. Highly acid systems could potentially damage delicate surfaces in the chiller system. Further, any potential for acids to concentrate can be completely removed by using either a cement cistern or by adding a few block of limestone to a plastic cistern. By limiting the concentration of acids and by replenishing evaporated water with rain water far from mineral saturation the chiller systems can be operated through 20 to 30 cycles before the system has to be shutdown. During these shutdown, or blowdown cycles, the system water is completely replaced with fresh water and the existing water which as has accumulated dissolved ions is discharged. Compared to current systems that use ground water derived drinking water rain water systems require less frequent blowdown and require little additional treatment chemicals and acid washes during these cleaning cycles.

ACTIVITY 2: Design, installation, and monitoring of rain water reuse system.
Description: A specific site will be found on campus for the cistern system that is favorably located near an existing evaporative chiller system. A specific design will be produced that meets the needs of the site and takes advantage of current construction projects on campus. The cistern and treatment system will be connected to an existing evaporative chiller system.

Real time monitoring of water quality within the chiller system will allow adjustment, adaption, and optimization of operation. Direct determination of the number of operational cycles rain water can be reused through and the reduction in periodic descaling requirements are a key result. This real world experience can be applied to additional rain water reuse systems on campus and all around the state of Minnesota.

Summary Budget Information for Activity 2:	**ENRTF Budget:**	**$ 125,500**
	Amount Spent:	**$ 5,667**
	Balance:	**$ 119,833**

Activity Completion Date:

Outcome	Completion Date	Budget
1. Design rain water storage and reuse system.	July 31, 2015	$ 15,000
2. Install rain water reuse in evaporative chiller system.	March 1, 2016	$ 100,000
3. Journal article on monitoring and operation of rain water fed chiller system.	June 30, 2016	$ 10,500

Activity Status as of December 31, 2014
Discussions are in progress with Facilities Management and Capital Planning for location of cistern.

Activity Status as of June 30, 2015:
With real Minnesota rain water chemistries in hand, design and operational parameters of rainwater fed evaporative chiller systems is underway. Coordinating with Facilities and Management staff and Capital Planning to get cistern installation underway.

Activity Status as of December 31, 2015:
Finding a project with timelines amenable to addition a rain water cistern has proven difficult. Projects seem to be in either a pre-design phase where the architects are focused on the facility itself or in a ready to build phase where there is little room for add on like a cistern. We are coordinating with Facilities and Management staff and Capital Planning to find a place with in this design cycle.

Activity Status as of June 30, 2016:
Three potential project sites have been identified and we are progressing on integrating a rain water cistern in to one of these sites.

Activity Status as of December 31, 2016:
Capital Planning and Facilities staff are working to finalize a location.

Final Report Summary:
Several sites on the Twin Cities University of Minnesota campuses were investigated. The first site considered at Northrup Auditorium was already too late in the Northrup renovation process. Digging up freshly paved sidewalks to install a cistern was untenable. Additional sites along Church Street SE did not progress in time to meet the grant time lines. Two sites on the St. Paul Campus were also investigated but separate funding for the larger storm water project, of which the rain water cistern would be an add-on, did not proceed. Due to lack of progress in lining up a cistern site before the end of this project on June 30, 2017 the cistern demonstration was project was terminated on March 27, 2017.

ACTIVITY 3: Public Education and Outreach.
Description: Results will be provided in an addendum to the Minnesota Storm Water Manual in coordination with UM Extension Service. Journal articles covering the potential for rain water reuse in commercial evaporative chiller systems will be produced. Additional opportunities that take advantage of rain water properties for irrigation, non-potable supply to toilets, laundry, etc. will similarly be written up in for peer reviewed journals.

We are also already working with local engineers and architects to develop rain water reuse systems in the commercial market. Of particular interest are retail settings, like large shopping centers, that produce detrimental amounts of storm runoff but are resistant to giving up parking space for storm water management. These same retail areas use large evaporative chillers systems that consume significant ground water resources. Having an operational system on campus would allow open house tours demonstrating their operational requirements.

Results of this study will be combined with existing storm water quality monitoring on campus. We will explore additional opportunities for reuse of storm water runoff on campus as at the 17th Ave Residence Hall where roof runoff is stored for reuse in toilet flushing and at the Landcare Building where a cistern stores storm water for irrigation. While rain water quality declines from pure rain water to roof runoff to street level runoff finding ways to reuse this water instead of simply dumping it to the river at critical. New options for rain water reuse are particularly important where underground conditions limit infiltration of storm water and dense urban areas where there is no room for conventional storm water management systems.

Summary Budget Information for Activity 3:		
	ENRTF Budget:	**$ 31,500**
	Amount Spent:	**$ 29,404**
	Balance:	**$ 1,996**

Activity Completion Date:

Outcome	**Completion Date**	**Budget**
1. Addendum for Storm Water Manual.	June 30, 2016	$ 16,000
2. Peer reviewed journal articles on policy implications for storm water reuse.	June 30, 2016	$ 8,250
3. Peer reviewed journal articles on additional reuse opportunities.	June 30, 2016	$ 8,250

Activity Status as of December 31, 2014
Andy Erickson in Civil Engineering has been identified to assist with development of rain water reuse guidelines. He will begin literature reviews and start developing Storm Water Manual materials and will be a co-author on journal articles which are in very early stages of writing.

Activity Status as of June 30, 2015:
The initial literature review is underway with Andy Erickson and Scott Alexander collaborating. Co-PI Saar is proving an excellent contact for rain water reuse projects in Europe.

Co-PI Jain and PI Alexander are collaborating on a write up of the 17th Street Residence rain water reuse system. This system captures roof runoff and uses it for flushing toilets after treatment.

Activity Status as of December 31, 2015:
Andy Erickson is in final stages of writing up the literature review. Results will be added to the Minnesota Storm Water Manual.

A public presentation on rainwater reuse has been created. The initial presentation was made to the Mississippi Watershed Management Organization and a second presentation to the Capital Region Watershed District is planned. We are exploring additional audiences.

Activity Status as of June 30, 2016:
Literature review is complete and being readied for journal submission. Trade journal publication on rain water reuse for building engineers, in coordination with co-PI Jain is ready for submission.

Activity Status as of March 22, 2017:
Development of a spreadsheet tool to estimate cistern sizing given average seasonal rainfall and chiller cooling water requirements is nearly complete and is in a beta test stage.

Final Report Summary June 30, 2017:
Results were provided as a future addendum to the Minnesota Storm Water Manual in coordination with UM Extension Service. A journal article covering the potential for rain water reuse in commercial evaporative chiller systems is in review. We are working with local watershed districts, engineers, and architects to identify potential sites for rain water reuse systems in commercial settings. Presentations of this work have been made to the Mississippi Watershed Management Organization in Minneapolis and the Capital Region Watershed District in St. Paul.

Presently rain water is being used at the 17th Ave Residence Hall where roof runoff is stored for reuse in toilet flushing and at the Landcare Building where a cistern stores storm water for irrigation. Results from these systems show that rain water quality declines rapidly from pure rain water to roof runoff to street level runoff. Finding ways to capture the cleanest fractions of rain water for reuse this water instead of simply dumping it to the river is critical. Options for rain water reuse are particularly important where underground conditions limit infiltration of storm water and dense urban areas where there is no room for conventional storm water management systems.

We have been in discussion with local storm water professionals and consulting firms about the use of rain water. Of particular interest are retail settings, like large shopping centers, that produce detrimental amounts of storm runoff but are resistant to giving up parking space for storm water management. These same retail areas use large evaporative chillers systems that consume significant ground water resources. In addition, rain water has great potential as feed for industrial process water. In particular, rain water can be easily polished through filtration and reverse osmosis to produce high purity water.

V. DISSEMINATION:

Description: Project results will be reported in an addendum to the Minnesota Storm Water Manual, several peer reviewed journal articles, and in semi-annual reports to the LCCMR.

Status as of December 31, 2014:
No published results to date. No other public outreach or dissemination to date.

Status as of June 30, 2015:
No published results to date. No other public outreach or dissemination to date.

Status as of December 31, 2015:
Journal article submitted for review. Public presentation on rainwater reuse created.

Status as of June 30, 2016:
Presentations at several local watershed districts. Two papers in re-written to address reviewers concerns and resubmitted for review.

Status as of December 31, 2016:
Papers still in review.

Final Report Summary: July 31, 2017
Results were provided as a future addendum to the Minnesota Storm Water Manual in coordination with UM Extension Service. A journal article covering the potential for rain water reuse in commercial evaporative chiller systems is in review. We are working with local watershed districts, engineers, and architects to identify potential sites for rain water reuse systems in commercial settings. Presentations of this work have been made to the Mississippi Watershed Management Organization in Minneapolis and the Capital Region Watershed District in St. Paul.

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We have been in discussion with local storm water professionals and consulting firms about the use of rain water. Of particular interest are retail settings, like large shopping centers, that produce detrimental amounts of storm runoff but are resistant to giving up parking space for storm water management. These same retail areas use large evaporative chillers systems that consume significant ground water resources. In addition, rain water has great potential as feed for industrial process water. In particular, rain water can be easily polished through filtration and reverse osmosis to produce high purity water.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 131,726	Research Scientist (S. Alexander) 72% salary, 28% benefits, 2 years, 40% time position; Graduate Students in Earth Sciences and Mechanical/Civil Engineering 52% salary, 48% benefits (includes tuition), 2 years, 2 - 1/4 time positions
Equipment/Tools/Supplies:	$ 60,274	Water chemistry and stable isotope analysis of rain water and evaporative concentrates 300

		analyses at $110 per analysis and water treatment and monitoring supplies for pilot cistern system.
Capital Expenditures over $5,000:	$ 100,000	Pilot scale cistern components and installation.
Capital Expenditures over $5,000:	$ 8,000	Roto-Evaporator for evaporation of rain water research.
TOTAL ENRTF BUDGET:	**$ 300,000**	

Explanation of Use of Classified Staff:
N/A

Explanation of Capital Expenditures Greater Than $5,000:
Roto-evaporator will be used to simulate evaporation of rain water in the laboratory allowing investigation of geochemical processes and mineral equilibria as they will evolve in the full scale evaporative chiller. The roto-evaporator will continue to be used in follow-on rain water reuse studies at the University of Minnesota.

The prototype cistern is required to store several thousand gallons of rain water for reuse in a nearby existing evaporative chiller system. The cistern system will be permanently installed in an underground vault or basement area and will continue to be used for feed water to an evaporative chiller system.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 1.3 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			
In-kind salary	$ 20,000	$ 0	Time for UMN Facilities Co-PIs to work on project.
State			
TOTAL OTHER FUNDS:	**$ 20,000**	**$ 0**	

VII. PROJECT STRATEGY:

A. Project Partners: UMN Facilities

B. Project Impact and Long-term Strategy: This project aims to reduce the demands on municipal water supplies and the aquifers by chiller systems while reducing storm water runoff. Storage cisterns can help cities meet increasingly stringent MS-4 storm water rules while reducing the load on existing storm water conveyances. The reduction in ground water demand can help preserve this precious resource for human consumption. The cisterns can be placed underground at commercial sites and then paved over to retain parking.

By realizing the value of rain water compared to potable drinking water we can reduce the need for additional wells and water treatment systems in a given municipality. A direct by-product is the more efficient operation of evaporative chiller systems. Current evaporative chiller systems are fed by municipal drinking water which has a significant load of dissolved minerals. These minerals concentrate in the chiller waters and must be disposed to the municipal waste water treatment system after 3 to 8 cycles in the chiller. In addition, harsh chemicals are used remove any built up mineral scale on a semi-annual basis. The discharge of these chemical de-scalers requires additional permits and fees. This is better than the old, now illegal, systems that used ground water in a once through process but is not a lot better. The low concentration of dissolved solids in rain water may allow more than 20 operational cycles of use before disposal.

Rain water reuse in chiller systems will reduce demands on storm water systems, municipal water supplies, and chiller operation. The costs of cistern installation and operation can be offset reduced costs for storm water management and drinking water supply allowing wide-spread adoption.

Chiller systems actually mimic the natural system where evapo-transpiration of rain water dominates the hydrologic cycle in Minnesota. The chiller reuse systems will never replace prairies and woodlands but do preserve their function in the hydrologic cycle.

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 Facilities – for rain water cisterns at Landcare Building for irrigation water.		$25,000			
UM CPPM – for rain water cisterns at 17th Ave Residence Hall to flush toilets.				$100,000	
UM DEHS – storm water quality monitoring on campus.	$7,000	$5,000	$5,000	$10,000	

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; January 31, 2016; July 31, 2016; and January 31, 2017. A final report and associated products will be submitted between June 30 and August 15, 2017.

Sample Name	Distilled Water	Rainwater Composite 2014	17th Ave Res Cistern	WoodenRain Barrel	Condensate 101	
UTM E (NAD83)						
UTM N (NAD83)						
Sample Date						
Field Parameters						
Temp (ºC)						
pH	5.45	5.30	5.50	5.60	4.67	
Cond (mS/cm)						
DO (ppm)						
Cations (in ppm)						
Ca	0.0068	0.8	8.52	6.20	0.06	
Mg	0.002	0.204	1.219	1.146	0	
Na	0	0.2066	1.19	1.02	0	
K	0	0.74	1.51	1.54	0.02	
Al	0.004	0.009	0.02	0.05	3.06	
Fe	0.004	0.01	0.02	0.83	0.11	
Mn	0.0003	0.0186	0.00	0.05	0.01	
Sr	0	0.002	0.01	0.01	0.00	
Ba	0.0005	0.004	0.008	0.009	0.004	
Si	0.1	0.0	0.85	0.54	0.21	
Anions (in ppm)						
Alk. (as $CaCO_3$)	0.17	*3.5*	23	21	12	
Cl	0.0	0	0.7	1.9	0.3	
Br	*0*	*0*	0.006	*0*	0.117	
NO_3-N	*0*	0.007	0.837	0.003	0.107	
NO_2-N	*0*	*0*	*0*	*0*	0.134	
SO_4	*0*	0.583	3.118	0.764	0.146	
PO_4-P	*0*	0.034	*0*	*0*	*<0.005*	
Total P	0.001	0.061	0.034	0.052	0.003	
F	*0*	*0*	0.025	0.017	0	
CH_3CO_2-	*0*	*0*	*0*	*0*	32.729	
HCO_2-	*0*	*0*	*0*	*0*	21.468	
Calculated Data						
Charge Balance						
Cations (meq/kg)	0.0040	0.092	0.620	0.490	0.025	
Anions (meq/kg)	0.0040	0.087	0.607	0.491	1.290	

% difference	**0.55**	**2.34**	**1.07**	**-0.11**	**-96.21**	

Rainwater 150503	Rainwater 150507	Rainwater 150511	Rainwater 150513	Rainwater 150515	Rainwater 150526	Rainwater 150527
5.76	5.87	6.36	6.38	6.43	6.28	6.13
1.49	1.99	2.66	3.66	3.06	1.26	0.98
0.41	0.27	0.32	0.46	0.46	0.20	0.15
0.97	0.72	0.62	1.09	0.47	0.75	0.39
0.46	0.47	0.34	0.71	0.31	0.27	0.17
0.033	0.032	0.011	0.013	0.019	0.005	0.008
0.034	0.038	0.009	0.009	0.022	0.008	0.005
0.006	0.009	0.003	0.005	0.006	0.002	0.001
0.007	0.104	0.118	0.002	0.006	<0.001	<0.001
0.004	0.004	0.004	0.006	0.004	0.002	0.003
0.102	0.104	0.118	0.187	0.168	0.080	0.085
6.8	6.0	8.2	9.5	9.4	4.5	3.5
0.81	0.39	0.28	1.04	0.27	0.14	0.14
<0.005	*<0.005*	*<0.005*	*<0.005*	*<0.005*	*<0.005*	*<0.005*
0.039	0.319	0.203	0.286	0.153	0.243	0.100
0.004	0.013	0.013	0.059	0.016	0.019	0.027
0.22	0.94	0.67	1.06	0.48	0.59	0.27
<0.005	0.037	0.008	*<0.005*	*<0.005*	*<0.005*	*<0.005*
0.012	0.044	0.016	0.018	0.019	0.009	0.007
0.023	<0.005	<0.005	0.015	*<0.005*	*<0.005*	*<0.005*
<0.005	*<0.005*	*<0.005*	*<0.005*	*<0.005*	*<0.005*	*<0.005*
<0.005	*<0.005*	*<0.005*	*<0.005*	*<0.005*	*<0.005*	*<0.005*
0.164	0.169	0.198	0.287	0.219	0.119	0.083
0.168	0.174	0.201	0.267	0.218	0.125	0.089

-1.08	**-1.62**	**-0.81**	**3.60**	**0.45**	**-2.48**	**-3.05**

Rainwater 150530	**Average Rainwater 2015**
6.03	**6.16**
1.09	**2.02**
0.08	**0.29**
0.02	**0.63**
0.14	**0.36**
0.007	**0.02**
0.007	**0.02**
0.002	**0.00**
<0.001	**0.05**
0.002	**0.00**
0.033	**0.11**
2.2	**6.26**
0.13	**0.40**
<0.005	
0.153	**0.19**
0.006	**0.02**
0.57	**0.60**
<0.005	**0.02**
0.009	**0.02**
<0.005	**0.02**
<0.005	
<0.005	
0.066	**0.16**
0.071	**0.16**

-3.25

Rainwater samples collected at Pillsbury Hall

Cations analyzed by ICP-OES
Anions analyzed by I.C.
Alkalinity titrations by Gran titration with 0.16N H_2SO_4

Reusing Rainwater for Commercial Cooling

Andrew J. Erickson[1], Scott Alexander[2], John S. Gulliver[1], Tyler Olsen[1], Seth Strelow[3], and Raphael Martins Carvalho[4]

[1] St. Anthony Falls Laboratory and Department of Civil, Environmental, and Geo-Engineering, University of Minnesota.

[2] Department of Earth Sciences, University of Minnesota

[3] Department of Civil Engineering, Valparaiso University

[4] Institute of Science, Engineering and Technology. Universidade Federal dos Vales do Jequitinhonha e Mucuri.

Rainwater and Roof Runoff Water Quality

Capturing, storing, and reusing rainwater can restore and preserve natural hydrology in urban watersheds that create large impervious areas. Rainwater reuse systems have shown 23% to 100% reduction of stormwater runoff (Askarizadeh et al. 2015), but there are still some significant restrictions to wide-spread use: low potable water prices create little incentive for reuse; plumbing and construction codes lack guidance for incorporating reuse systems; local, state, and federal regulations are sparse, varied, and sometimes conflict; local regulations and water law in arid regions may prevent reuse; and hesitation due to public health concerns and lost water treatment revenue (Azkarizadeh et al. 2015).

Some studies have shown roof harvested rainwater posed no risk compared to reticulated supplies (Azkarizadeh et al. 2015). Non-potable uses of harvested rainwater include toilet or urinal flushing, wall spigots, or irrigation (Garrison 2011). However, few institutions define standards for using rainwater in non-potable applications, especially indoors with more potential human exposure.

In one study (Krishna, 2005), pure rainwater was found to have 2ppm TDS, little sodium content, but a low pH (approximately 5.7) compared to standard potable and non-potable treated water. Rainwater collected from rooftops often requires treatment to meet both primary and secondary USEPA drinking water requirements and water reuse requirements (Mendez et al. 2011). Rainwater quality can vary depending on the roof from which it was collected. Water quality parameters in runoff from five different roof types (shingle, metal, tile, cool, and green), including pH, conductivity, TC, FC, turbidity, TSS, nitrate/nitrite, DOC, and six metal cations have been compared (Mendez et al. 2011), as shown in Figures [3], [4], [5], [6], [8], and [9] below.

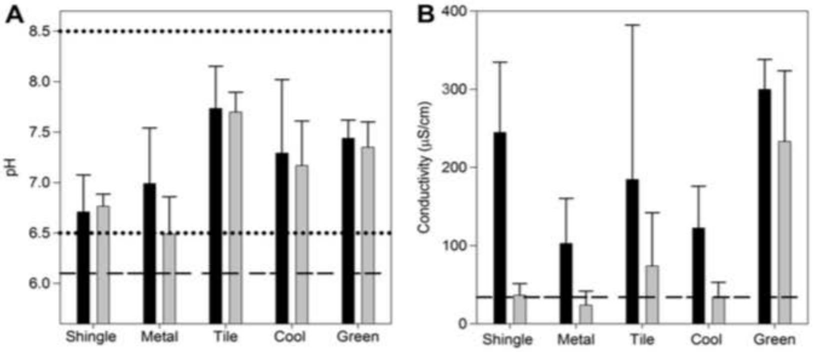

Fig. 3 – Average pH (panel A) and conductivity (panel B) for the pilot-scale events: (■) Quality of the first-flush, (▨) Quality after the first-flush (average of tank 1 and tank 2), ••• USEPA secondary drinking water standard range for pH (6.5–8.5), - - - Ambient sampler. One standard deviation is shown.

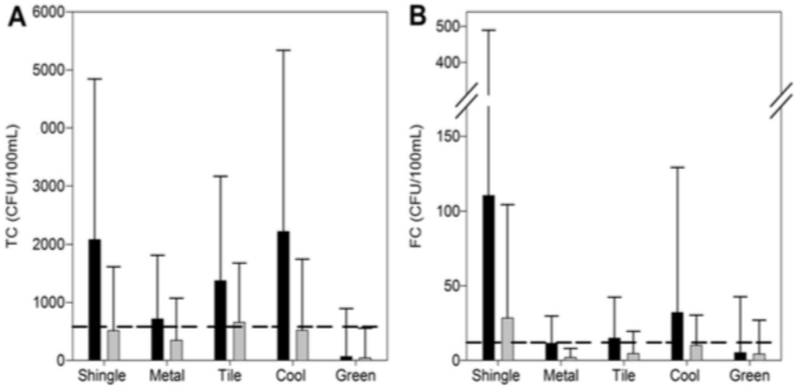

Fig. 4 – Geometric mean of TC (panel A) and FC (panel B) for the pilot-scale events: (■) Quality of the first-flush, (▨) Quality after the first-flush (average of tank 1 and tank 2), - - - Ambient sampler. One geometric standard deviation is shown.

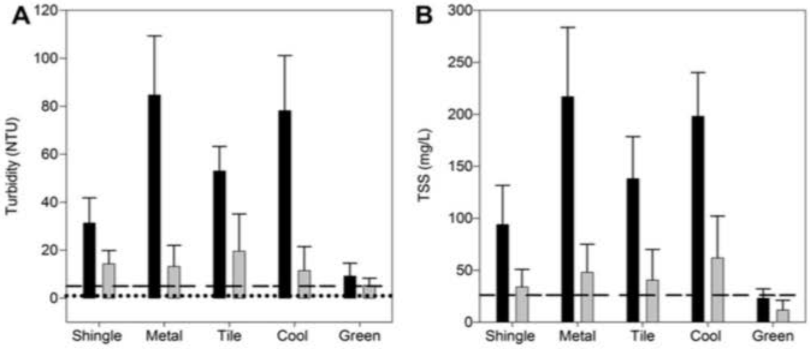

Fig. 5 – Average turbidity (panel A) and TSS concentrations (panel B) for the pilot-scale events: (■) Quality of the first-flush, (□) Quality after the first-flush (average of tank 1 and tank 2), ••• USEPA filtered system guideline (1 NTU), - - - Ambient sampler. One standard deviation is shown.

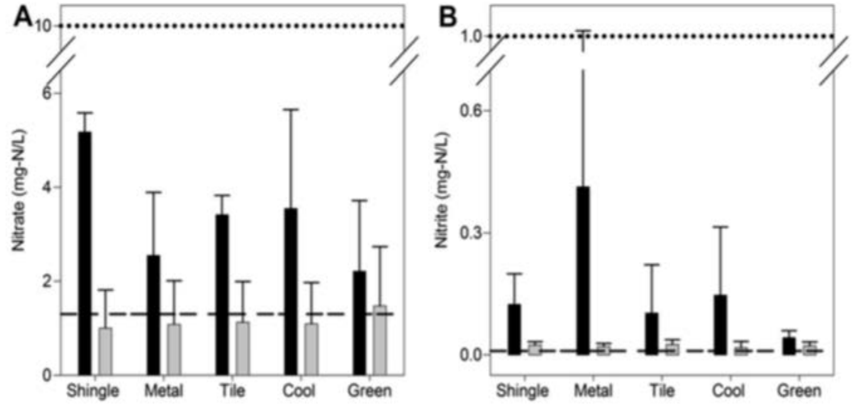

Fig. 6 – Average nitrate (panel A) and nitrite (panel B) concentrations for the pilot-scale events: (■) Quality of the first-flush, (□) Quality after the first-flush (average of tank 1 and tank 2), ••• USEPA MCLs for nitrate (10 mg-N/L) and nitrite (1 mg-N/L), - - - Ambient sampler. One standard deviation is shown.

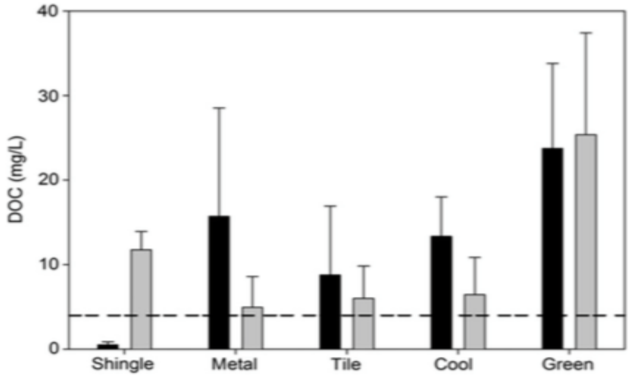

Fig. 8 – Average DOC concentrations for the pilot-scale events: (■) Quality of the first-flush, (□) Quality after the first-flush (average of tank 1 and tank 2), - - - Ambient sampler. One standard deviation is shown.

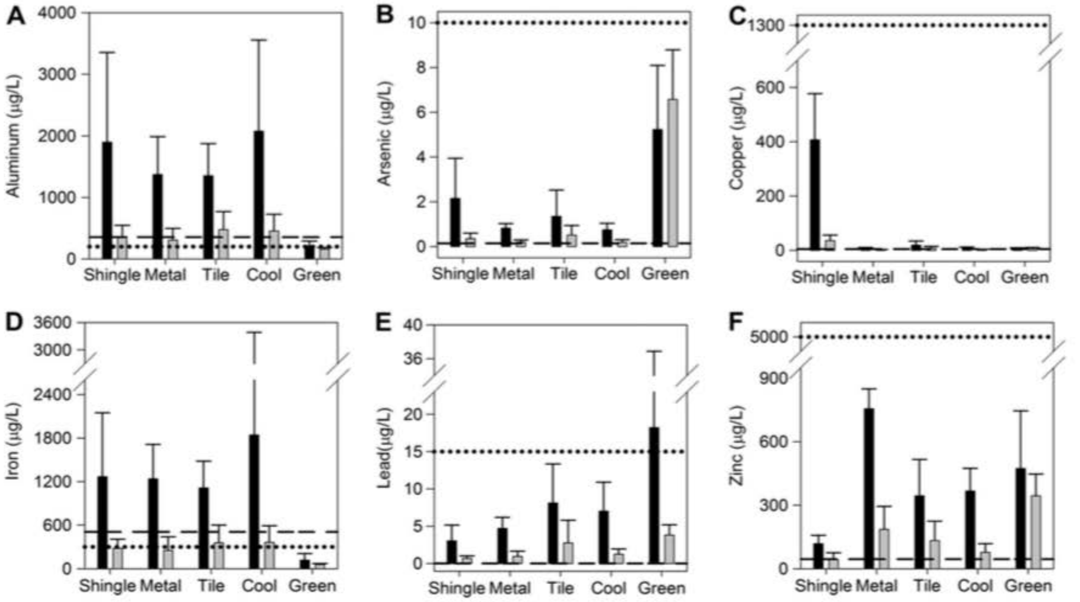

Fig. 9 – Average total aluminum (panel A), arsenic (panel B), copper (panel C), iron (panel D), lead (panel E), and zinc (panel F) concentrations for the pilot-scale events: (■) Quality of the first-flush, (▨) Quality after the first-flush (average of tank 1 and tank 2), ••• USEPA primary or secondary drinking water standards or action levels: aluminum (200 μg/L), arsenic (10 μg/L), copper (1300 μg/L), iron (300 μg/L), lead (15 μg/L), and zinc (5000 μg/L). - - - Ambient sampler. One standard deviation is shown.

Preliminary treatment options of rainwater can include conversion of shingle, metal, or tile roofing material to green roofs. Overall, rainwater collected from green roofs had low contaminant concentrations and parameter measurements compared to other roof types (see Figures [3], [4], [5], [6], [8], and [9]). Only pH, conductivity, and DOC were found to be high in green roof rainwater. Shingled roofs were shown to have high contaminant and parameter measurements when compared to most roof types, excluding lead and zinc concentrations (Mendez et al. 2011).

Lye (2009) also compared the quality of rainwater collected from each of several different roof types including wood, aluminum, galvanized steel, and a composite material (see Tables [2] & [4]). Specifically, the percent of metal ion concentrations that exceed USEPA freshwater quality standards is calculated for aluminum, magnesium, copper, lead and zinc, as shown in Table [2]. For some pollutants (e.g., Cu & Zn), rainwater exceeded USEPA standards most of the time. Additionally, the prevalence of certain pathogens in rainwater samples are also analyzed and averaged over a variety of roof types, as shown in Table [4].

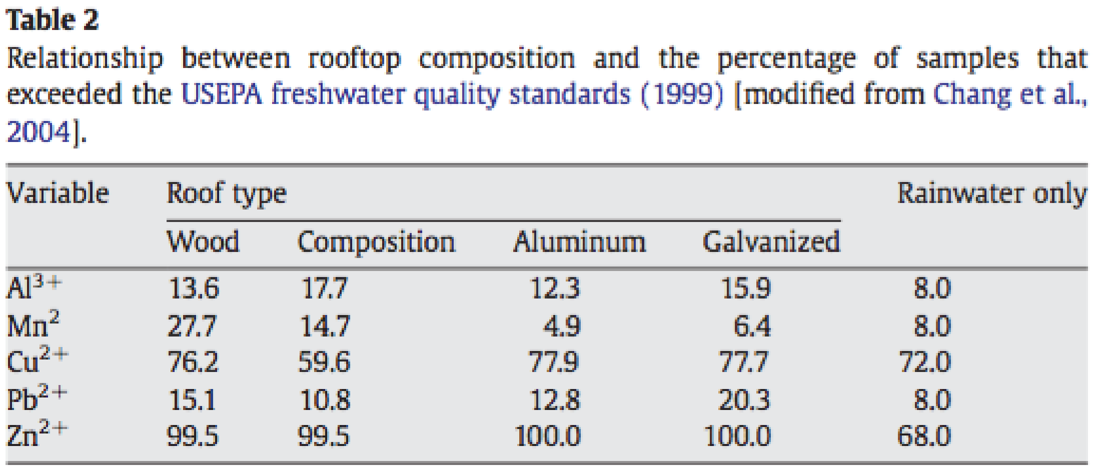

Table 2

Relationship between rooftop composition and the percentage of samples that exceeded the USEPA freshwater quality standards (1999) [modified from Chang et al., 2004].

Variable	Roof type				Rainwater only
	Wood	Composition	Aluminum	Galvanized	
Al^{3+}	13.6	17.7	12.3	15.9	8.0
Mn^2	27.7	14.7	4.9	6.4	8.0
Cu^{2+}	76.2	59.6	77.9	77.7	72.0
Pb^{2+}	15.1	10.8	12.8	20.3	8.0
Zn^{2+}	99.5	99.5	100.0	100.0	68.0

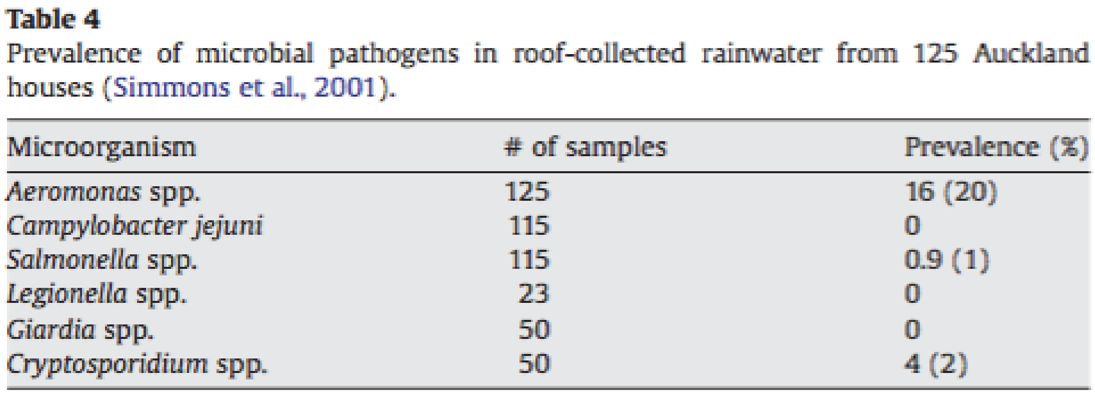

Table 4

Prevalence of microbial pathogens in roof-collected rainwater from 125 Auckland houses (Simmons et al., 2001).

Microorganism	# of samples	Prevalence (%)
Aeromonas spp.	125	16 (20)
Campylobacter jejuni	115	0
Salmonella spp.	115	0.9 (1)
Legionella spp.	23	0
Giardia spp.	50	0
Cryptosporidium spp.	50	4 (2)

Mendez (2011) also analyzed the effect of using a first flush system to treat collected rainwater before storage for reuse. The first flush system diverts the initial roof runoff and associated contaminants away from the collection tank. For all roof types, the presence of a first flush system decreased the concentration for most parameters in the collected rainwater, as shown in Table [1]. Only pH and DOC were seemingly unaffected by the first flush system, while DOC increased for shingled and green roofs with a first flush system present.

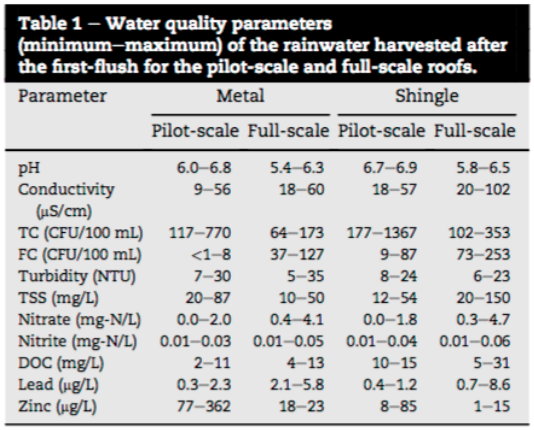

Table 1 – Water quality parameters (minimum–maximum) of the rainwater harvested after the first-flush for the pilot-scale and full-scale roofs.

Parameter	Metal		Shingle	
	Pilot-scale	Full-scale	Pilot-scale	Full-scale
pH	6.0–6.8	5.4–6.3	6.7–6.9	5.8–6.5
Conductivity (μS/cm)	9–56	18–60	18–57	20–102
TC (CFU/100 mL)	117–770	64–173	177–1367	102–353
FC (CFU/100 mL)	<1–8	37–127	9–87	73–253
Turbidity (NTU)	7–30	5–35	8–24	6–23
TSS (mg/L)	20–87	10–50	12–54	20–150
Nitrate (mg-N/L)	0.0–2.0	0.4–4.1	0.0–1.8	0.3–4.7
Nitrite (mg-N/L)	0.01–0.03	0.01–0.05	0.01–0.04	0.01–0.06
DOC (mg/L)	2–11	4–13	10–15	5–31
Lead (μg/L)	0.3–2.3	2.1–5.8	0.4–1.2	0.7–8.6
Zinc (μg/L)	77–362	18–23	8–85	1–15

References

Askarizadeh et al. (2015) “From Rain Tanks to Catchments: Use of Low-Impact Development To Address Hydrologic Symptoms of the Urban Stream Syndrome.” Environmental Science & Technology 49, 11264-11280.

Garrison et al. (2011) “Capturing Rainwater from Rooftops: An Efficient Water Resource Management Strategy that Increases Supply and Reduces Pollution.” National Resources Defense Council

Krishna, Hari J., “The Texas Manual on Rainwater Harvesting, Third Edition.” Texas Water Development Board (2005).

Lye, Dennis J. (2009) “Rooftop runoff as a source of contamination: A review.” Science of the Total Environment 407 5429-5434.

Mendez, Carolina B., J. Brandon Klenzendorf, Brigit R. Afshar, Mark T. Simmons, Michael E. Barrett, Kerry A. Kinney, Mary Jo Kirisits. (2011) “The effect of roofing material on the quality of harvested rainwater.” Water Research 45 2049-2059.