NCER Assistance Agreement Annual Progress Report for Grant #83582401 - Assessment of Stormwater Harvesting via Manage Aquifer Recharge (MAR) to Develop New Water Supplies in the Arid West: The Salt Lake Valley Example

Period Covered by the Report: September 1, 2016 through August 31, 2017
Date of Report: November 13, 2017


Institution: Utah State University
Research Category: Human and Ecological Health Impacts Associated with Water Reuse and Conservation Practices

Project Period: September 1, 2015 through August 31, 2018
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The aims of the original proposed project remain the same, that is, to test the hypothesis that Managed Aquifer Recharge (MAR) for stormwater harvesting is a technically feasible, socially and environmentally acceptable, economically viable, and legally feasible option for developing new water supplies for arid Western urban ecosystems experiencing increasing population, and climate change pressures on existing water resources. The project is being carried out via three distinct but integrated components that include: 1) Monitoring of existing distributed MAR harvesting schemes involving a growing number of demonstration Green Infrastructure (GI) test sites; 2) Integrated stormwater/vadose zone/groundwater/ ecosystem services modeling; and 3) Social Science research assessing stakeholder attitudes, and solicitation of their collaboration, through a Stakeholder Advisory Committee (SAC), on feasible distributed MAR scenario development and subsequent analysis of scenario outcomes. Each of these components are discussed separately in the material presented below.

A. Project Summary
A. 1. MAR/GI system monitoring. Expansion of the system monitoring network on the Utah State University campus was carried out during Year 2 of the study to include a parking lot bioswale system collecting and infiltrating runoff from an approximately 1 acre parking area adjacent to an Early Education Building; a planter box system adjacent to a Distance Education building treating sidewalk and roof drainage from that building; and additional sampling wells below a previously monitored dry well system treating roof drainage from a large College of Engineering classroom building with a membrane roof. Additional sampling locations at the Green Meadows field demonstration site included the placement of paired suction cup soil pore water samplers at 6 and 9-inch depths in replicate plots vegetated with cattail, sedge, sunflower, and three newly planted grass species. Additional paired suction cup soil pore water samplers at 12 and 20-inch depths were installed and sampled at a curb cut/bioswale site located at 300 East in Logan, Utah, were installed to provide improved monitoring of metal contaminants moving through the treatment area. Finally, additional runoff samples were also collected from a metal roof and photovoltaic roof system during Year 2 to provide additional source data from various surfaces that could commonly be encountered by GI systems in our study area. Raw data from these various sites are located in Appendix A.

The most curb cut/bioswale GI system located in Logan, Utah, on 300 East along the block between 900 North and 1000 North is shown in Figure 1, along with newly placed suction cup lysimeter samplers (Prenart Equipment Aps, Denmark). The bioswale area is covered with turf grass, with small pear trees planted throughout the bioswales primarily for aesthetic value. The Prenart samplers were chosen based on reduced adsorption of Cu, Pb and Zn during sample collection of high iron content pore water, compared to conventional soil cup lysimeters initially placed at the site. These Prenart lysimeters have also been installed at the Green Meadows site, and will be used for pore water sampling at all other sites monitored in this study. Data presented
in Appendix A in Calendar Year 2017 reflect results using the new sample collection system. Roadway runoff as well as ponded and percolating stormwater have been monitored during four storm events occurring between September 2016 and September 2017, and are summarized as part of the data contained in Appendix A.

A second site, the Green Meadows Site, a 27-acre subdivision in the southwest corner of Logan, City, is the location of a field demonstration site used in previous research studies to evaluate the effectiveness of various vegetation types on the uptake of nutrients and metals from residential stormwater in vegetated bioretention stormwater management systems. Figure 2 shows vegetation growing at this site during the 2016-2017 growing season. Previous findings indicated that sedges provide optimal uptake and recovery potential for both nutrients (N and P) and metals from stormwater, compared to sunflower and cattail species used at the field demonstration site. Only limited data were collected from this site during the second year of the project period as presented in Appendix A, as three new plant species (Baltic rush (*Juncus balticus*), inland salt grass (*Distichlis spicata*), bunch grass (*Festuca idahoensis*)) that are common to stormwater bioretention systems in Utah have been incorporated into the study.

Figure 2. New vegetated treatment bays at the Green Meadows Field Stormwater Management Demonstration Site, Logan Utah.

design. Extensive monitoring of this site will take place during Year 3 of the project. A total of 48 Prenart suction cup pore water samplers were installed throughout the treatment bays during the
second year of the project to allow comparison of pollutant removal performance as a function of vegetation type across this field site compared to turf located at the 300 East site.

A third GI system monitored most extensively during the second year of this project was constructed as a field test site by the Salt Lake City Public Utilities to collect, treat, and infiltrate stormwater runoff from a 1-ac parking lot located at their headquarters facility in Salt Lake City. This field test site was constructed as per the drawing shown in Figure 3, with one half of the “bioretention” area being underlain by a washed gravel storage layer, while the other half is underlain by an expanded shale product marketed as UteLite Expanded Shale layer, selected for its metal and nutrient adsorption characteristics determined in laboratory scale studies by a related research team. This site provides an opportunity to evaluate the performance enhancement of the UteLite material over a standard gravel infiltration layer, and allows a comparison of pollutant removal characteristics of this engineered material compared to pollutant removal via vegetation contained at the Logan sites. Roadway runoff as well as samples of percolating stormwater collected in the sump wells have been monitored during 12 storm events occurring between September 2016 and September 2017, and are summarized as part of the data contained in Appendix A.

A range of roof runoff samples were collected again during Year 2 of the study from various roofs across the USU campus. These samples continue to be collected to quantify the potential pollutant loading generated from these impervious surfaces throughout the USU campus and across much of the arid southwest, that are directed into shallow or deep dry wells without additional treatment. The roof types that were monitored included conventional composite membrane coated roofs, standard metal roofs, and solar panel covered roofs. The membrane roof system is collected and conveyed to a dry well. Two sump wells (4 ft depth and 6 ft depth) identical to those at the Public Utilities site were installed in this dry well (Figure 4) to allow

Figure 3. Sketch of the layout of the field test site constructed at the Salt Lake City Public Utilities Headquarters, Salt Lake City, Utah, showing newly installed sump wells for system performance monitoring and site photo of bioretention vegetation and rock mulch.
monitoring of pollutant levels as this roof runoff moves through the dry well system. The raw data from six rainfall events for these roof surfaces and conveyance piping and sump wells for the membrane roof are also summarized in Appendix A.

Finally, two additional GI sites have been instrumented for monitoring using autosamplers and sump wells. These include a vegetated parking strip at the Early Education building (Figure 5) instrumented to collect parking area runoff samples and sump well samples 4 ft and 6 ft below the parking strip surface, as well as a planter (Figure 6) adjacent to the Distance Education LEED Silver building on the USU campus. The later planter system was taken out of service to be replanted in the Spring 2018 right after installation of the sump wells at that location, so samples were not collected during Year 2 of the study. Data from five storm events from the Early Education site are included in Appendix A.

A. 2. Integrated systems modeling. In order to evaluate the potential of large-scale implementation of MAR/GI techniques on groundwater resource availability and subsequent impacts to surface water ecosystem services, an integrated modeling approach is underway using the Red Butte watershed in Salt Lake Valley as a case study area. This study area is familiar to a number of the members of the project team through their affiliation with the iUTAH NSF program, and this watershed has a robust set of continuous water quality and flow data being collected through the iUTAH GAMUT data collection network that are readily available by the project team to use in model calibration and validation.

This project aims to quantify the relative effects of LID and GI on stormwater disposition upon surface water and groundwater resources for different weather and urban development scenarios. This requires adequate understanding of current water flows and volume balances. To allow the
broadest use of project results we are using several public domain models simultaneously to simulate the different flows (Figure 7). For accuracy during each simulation, we use a cyclical convergence process to ensure that the three-dimensional boundary flows of each hydraulically linked model (here termed a module) are in equivalent during each simulation. For example, the flow from Module A to Module B is equal and opposite in sign to an otherwise identical flow from Module B to Module A. Employed linked models (simulators) simulate: precipitation-runoff-deep percolation; surface water flow and quality; vadose zone flow and water quality; and groundwater flow and water quality. Surface water-groundwater seepage is a sample flow that should be cyclically determined for accuracy. Other flows that must be consistent between modules are runoff to surface water, infiltration, and deep percolation groundwater recharge.

Precipitation-runoff models include HEC-HMS (USACE, 2016.) and WINSLAMM (PV and Associates, 2014). WINSLAMM (PV and Associates. 2014) software is being used to model baseline runoff and water quality conditions, and changes in runoff volume and quality as a result of MAR/GI modifications within the modeled catchments. Literature review (Pitt and Voorhees, 2004) and model evaluation suggest that that WINSLAMM can adequately perform this function. WINSLAMM has an effective user interface that will facilitate calibration for the Red Butte area, and will promote subsequent use for prediction of the effectiveness of MAR/GI.
Figure 7. Employed simulation model components of the integrated simulation modeling approach for the Red Butte watershed area, Salt Lake Valley, Utah.

implementation on runoff and pollutant load reductions extrapolated to the larger Salt Lake Valley that is of increasing interest to the SAC.

Although emphasizing the Red Butte Watershed, Figure 8 also shows portions of the Salt Lake Valley (SLV) MODFLOW groundwater flow simulation model finite difference grid (Lambert, 1995). Each displayed square cell is about 1/3 mile by 1/3 mile in size. Figure 8 shows sub-watersheds addressed using the HEC-HMS model that simulates precipitation, runoff, infiltration, and deep percolation. That figure also shows the SLV model cell that will receive groundwater discharge from the alluvial aquifer around Red Butte Creek. Progress in simulating relevant water flows made during Year 2 of the project is described in the Results section below.

Various parties (e.g., iUtah, USGS, and Jordan River-Farmington Bay Water Quality Council) have been collecting water quantity and quality data in the Salt Lake Valley. Potential collaborations have been identified, and data sources for surface water quality constituents of interest for ecosystem services modeling in the Jordan River and Red Butte Creek have been identified. These data include flow, stream temperature, specific conductance, turbidity, nitrogen, phosphorous, dissolved oxygen, fluorescent dissolved organic matter (fDOM), and chlorophyll, and are connected to how ecosystem services are quantified as indicated in Table 1.
Figure 8. MODFLOW grid cell (red dashed border) that will receive simulated groundwater flowing from uppermost Red Butte Watershed sub-watersheds.

Table 1. Ecosystem Services, Metrics, and Constituents that are being Quantified with Green Infrastructure Surface Water Quality Model Alternatives

<table>
<thead>
<tr>
<th>Ecosystem Service</th>
<th>Metric (Units)</th>
<th>Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Summer Baseflow</td>
<td>Duration of Low Flow Conditions (days)</td>
<td>Streamflow</td>
</tr>
<tr>
<td>Flood Attenuation</td>
<td>Flood Magnitude ($m^3/s$), Duration (minutes), Rate of Change of Slope of Hydrograph</td>
<td>Streamflow</td>
</tr>
<tr>
<td>Water Purification</td>
<td>Pollutant Concentration (mg/L), Conductivity ($S/m$)</td>
<td>Specific Conductance, Turbidity, Nutrients (N &amp; P), Dissolved Oxygen, Chlorophyll, TSS</td>
</tr>
<tr>
<td>Climate Regulation</td>
<td>Maximum Weekly Average Temperature (°C) &amp; Maximum Daily Temperature (°C)</td>
<td>Stream Temperature</td>
</tr>
<tr>
<td>Aquatic Biodiversity</td>
<td>Habitat Suitability Curves and Conditions for Bonneville Cutthroat Trout and June Sucker</td>
<td>Species Presence/Absence</td>
</tr>
</tbody>
</table>

A. 3. Social science research. Much of the Year 2 activities in this project area were spent completing Key Informant interviews with a total of 31 key informants. The latter round of interviews completed during Year 2 expanded the sample population to include more home developers and engineering firms so that the Key Informant pool now includes the following: 16 Municipal Stormwater Managers; five County Stormwater Managers; four Engineering firms;
two State Regulatory Agency Staff; and four Developers. The interview recordings have been professionally transcribed and two coders have been employed to qualitatively code the interviews for key themes. Coding was done by multiple individuals and checked for intercoder reliability. Initial results of the interviews were presented at the spring stakeholder advisory committee meeting (April 2016). The Key Informant Interview Instrument is provided in Appendix C, and formal analysis of interview transcripts using NVIVO software to verify preliminary findings is ongoing.

An online survey was also developed in Year 2 in collaboration with the SAC and the leadership of the Utah Stormwater Advisory Coalition leadership. This survey is designed to solicit perceptions and experiences with green stormwater infrastructure from a larger and more representative sample of municipal stormwater management employees. The survey sample frame consists of contact persons for all permitted MS4 municipalities in Utah, supplemented with additional staff in these cities that are working on developing and implementing stormwater programs. The survey is awaiting final USU IRB and EPA Human Subjects Research Office approval and should be initiated by December, 2017.

Two Stakeholder Advisory Committee (SAC) meetings were held during Year 2 of the project, one in October 2016 in conjunction with a statewide American Public Works Association meeting, and another in April 2017 in conjunction with a Utah Storm Water Advisory Coalition meeting at the Utah DEQ. The October meeting was focused on initiating the SAC and familiarizing the SAC with the overall project and the role the SAC is being requested to play in providing input and reflection on GI approaches and identification of questions and barriers to implementing GI systems in Utah. The April 2017 meeting provided the SAC with an update on project accomplishments to date, solicited their help in broadening stakeholder involvement, requested input on the underlying design and structure of the landscape, surface water, groundwater, and ecosystem service models, and encouraged their support for the on-line survey described above. Two additional SAC meetings are planned for October 2017 (for final input to the modeling scenarios and the on-line survey) and May 2018 (a scenario modeling workshop).

A. Key Personnel
All Key Personnel at USU remain associated with the funded project. One change in Key Personnel that has been discussed with the EPA Project Officer is the move in August 2016, from USU to the Ohio State University by Dr. Douglas Jackson-Smith, the Co-PI responsible for the Social Science aspects of the funded work. Dr. Jackson-Smith remains an Affiliated Faculty at USU and will remain active on this project through its completion in 2018. Dr. Jackson-Smith’s graduate student (Ennea Fairchild) has shifted to another advisor at USU and is no longer actively working on the project (but remains interested in the analysis and writing related to the qualitative interviews). Dr. Jackson-Smith employed two undergraduate research assistants in the summer of 2017 (Karlee Peterson and Lia Francis) to conduct the formal coding of the qualitative interview transcripts in NVIVO. Dr. Jackson-Smith is recruiting a new graduate or undergraduate assistant to help with analysis of online survey data and to plan and implement the citizen focus groups in Spring and Summer 2018.

B. Expenditures to Date
Based on the original timeline proposed for the project, approximately 55% of the project tasks are complete compared to the originally planned 66% project completion by the end of Year 2 of the project. The social science component of the project, Component 3, has progressed at an
accelerated pace compared to the originally proposed timeline, while the ecosystem services and integrated modeling activities have been slightly delayed. A revised timeline for all proposed project activities is being developed to reevaluate sequencing of activities and reprioritize efforts to reach project completion by the end of the 3-year project period. This revised timeline will be submitted to the EPA Project Officer for his review by the end of Calendar Year 2017. Expenditures through the end of Year 2 of the project period were at 47% of funds originally requested through Year 2 of the project, and it is anticipated that the budget expenditure rate will rapidly increase during Year 3 of the project as task timeline revisions, activity reprioritization and final project tasks are completed by the project team.

Spending on Component 3, Social Science, activities during Year 2 reflect a shift of funds from faculty summer salary to travel to facilitate Dr. Jackson-Smith’s travel back to Utah to complete fieldwork and engage with the SAC and project team members during Years 2 and 3 of the project as per revised budget and budget narrative submitted to the EPA Project Officer early in Year 2 of the project period.

C. Quality Assurance

D. 1. MAR/GI system monitoring. Standard analytical procedures, as indicated in the original project proposal, are being used for all samples collected in this project. Standard sample handling, labeling, chain of custody, and sample log in procedures are being utilized for all samples collected as part of this project. Sample holding times are verified and any samples exceeding the holding time were not analyzed, nor reported in data summaries contained in Appendix A. Control charts are being maintained and reviewed for all analyses conducted in the study. Examples of typical control charts are provided in Appendix B. Through weekly project laboratory meetings, issues related to blank and sample spiking have been identified and associated with laboratory techniques employed by a subset of the project analytical team. Corrective action has taken place through discussion, retraining, and intervention by the project QA/QC Officer, Joan McLean. Analytical techniques have improved and while this issue will be diligently monitored on an on-going basis, it is believed that all procedural and instrument errors have been corrected. All other QC samples, i.e., CCVs, blanks, replicate samples, etc., have passed QC checks for all data reported in Appendix A.

D. 2. Integrated systems modeling. The iUTAH EPSCoR project that began in 2013, continuously collects data at their RBC watershed sites. The USGS and iUTAH EPSCoR routinely quality control these continuously collected data and annotate QC issues that arise. The iUTAH EPSCoR data quality coordinator (Dave Eriksson), continues to rapidly respond to queries sent to him, and has quickly addressed any data quality issues that appear to impact the data sets being used for model calibration and verification. Data used for WinSLAMM calibration and validation efforts during Year 2 of the project period were generated through the Environmental Quality Laboratory at the Utah Water Research Laboratory, the same lab utilized for primary data generation in the project, and all laboratory QA/QC procedures described above for MAR/GI system monitoring above were used for data sets being utilized in WinSLAMM modeling activities.

D. 3. Social science research. Sampling of key informants for the interviews have proceeded along the lines outlined in the proposal and QA/QC plan using: (a) representative stormwater Program Managers and Public Works Directors from different sized municipalities across several counties; (b) County or Regional Planners; (c) State agency regulatory staff; (d) private sector
engineers; and (e) private developers with interest in stormwater management requirement that were all selected to participate in the interviews. Interviews continued through Summer 2017 until saturation was reached at a total of 31 key informants. To ensure scientific integrity and protection of research subjects, all social science research methods continue to be reviewed and approved by the USU Institutional Review Board and will continue to be subjected to EPA Human Subjects Research Office final review.

To ensure validity and reliability in the coding and analysis of the qualitative interviews, two students were tasked with using the NVIVO software schema described above to independently code the interview transcripts. A comparison of the two coding files suggested a very high rate of intercoder reliability (nearing 0.90), which boosts confidence in the reliability of the conclusions drawn from these interviews. In a separate effort, a complete sample of municipal stormwater managers from all MS4 permitted cities in the state was developed starting from a list of MS4 permits and contact persons provided under a Freedom of Information Act (FOIA) request to the state Department of Environmental Quality. This list was checked against websites and telephone calls with most cities were made to confirm apparent changes in personnel (and to identify any additional personnel who work on stormwater issues in these MS4 entities). The survey sample frame represents the best possible universe of potential respondents for this project and will be the basis for a systematic multi-mode survey implemented beginning December, 2017.

E. Results

E. 1. MAR/GI system monitoring. A major objective of Year 2, Component 1 activities was to continue to quantify stormwater pollutant concentrations generated in the Intermountain West from a variety of land use categories. To that end, stormwater quality samples from pavements in residential areas and parking lots (300 E, Early Childhood Education Building, and Salt Lake County Public Utilities sites), and roof drains, continued to be collected and analyzed for various rainfall events occurring during Year 2 of the project. Raw data for these sites are included in Appendix A. Table 2 shows summary data for pavement runoff pollutant concentrations from the 300 East and the Early Childhood Education sites in Logan, Utah, and the Salt Lake City Public Utilities site in Salt Lake City, Utah. All three sites are associated primarily with drainage from pavement surfaces, with the Public Utilities and Early Education sites exclusively used for day time parking of facility personnel, while the 300 East site is a side road in a residential area adjacent to lawn and landscaped single family lots of 1/4-acre size. As indicated in Table 2, there is a wide range of pollutant concentrations when data from a range of rainfall events are combined. As indicated in the planned activities for Year 3, disaggregation of these data will be carried out to evaluate relationships between pollutant concentrations and rainfall event return periods. Based on overlapping 95% Confidence Intervals, Year 2 sampling showed differences among sites for TN and Cr (Public Utilities and Early Ed being higher), TDN, TP and TDP (higher at the Early Ed site), and Cu and Pb (higher at the Public Utility site).

Pollutant generation from various roof materials is summarized in Table 3 (raw data in Appendix A), and includes a commercial membrane roof on the Engineering building, runoff from a PV array, and runoff from an associated metal roof. Only one sample was collected during Year 2 of the project from the metal and PV roofs, and additional sampling is planned for Year 3 of the project to expand the data set for these roofing materials. Based on the available data set and comparison of overlapping confidence interval values indicates both the PV and metal roofs continue to generate pH values higher than the membrane roof. Once again, lead concentrations in
Table 2. Stormwater Runoff Pollutant Concentrations from the 300 East site and Early Education Building, Logan, and Salt Lake Public Utilities GI Monitoring Sites, Collected during Year 2 of the Project*

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Units</th>
<th>MDL</th>
<th>300 East, Logan</th>
<th>Salt Lake City Public Utilities</th>
<th>Early Childhood Education Parking Area</th>
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<tr>
<td></td>
<td></td>
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<td>Average</td>
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<tr>
<td>TN</td>
<td>mg/L</td>
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<td>NO3-N</td>
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<td>0.11</td>
<td>13</td>
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<td>NH3-N</td>
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<td>0.19</td>
<td>0.06</td>
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<tr>
<td>Cr</td>
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<td>Fe</td>
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* Note, these results were generated by assigning <MDL values from Appendix A a value of ½ the posted MDL for a given analyte. NA indicates no value is available due to limited data for that parameter.
increases in EC and mobilization of Cr, Fe, Cu, and Pb.

2017. Here, removal efficiency is based on influent concentr

1,000%) in EC values indicating dissolution of salts. N and P and Total

the soil. The pollutants actually released from the bioswale system to soil pore water included Total

Figure 9. As was indicated in previous sampling events from Year 1, for a large number of

adjacent dry wells.

Further analysis of these concentrations in the roof drains will be carried out

during Year 3, with samples on the membrane roof itself collected to investigate potential sources

of lead and aluminum in the roof drain piping used to convey membrane roof drainage into

adjacent dry wells.

The curb cut bioswale MAR/GI system at 300 East in Logan was not sampled as frequently during

Year 2 of the project due to issues related to potential metal sorption to the original lysimeters

installed at the site. Estimated non-metal pollutant removal through this GI system based on

bioswale input (bay ponding and pavement runoff samples, Appendix A) versus 24-inch lysimeters

concentration data measured during the fall (October 2016) of Year 2 of the project are shown in

Figure 9. As was indicated in previous sampling events from Year 1, for a large number of pollutants, concentrations actually increased from the pavement runoff values to a 24-inch depth in the soil. The pollutants actually released from the bioswale system to soil pore water included Total N and P and Total Dissolved N and P, and EC. Of continuing concern are significant increases (> 1,000%) in EC values indicating dissolution of salts. Figure 10 displays pollutant removal efficiency as sampled using newly installed, non-metal sorbing Prenart suction cup lysimeters in 2017. Here, removal efficiency is based on influent concentrations compared to 20-inch depth Prenart lysimeters. Figure 10 indicates 30 to 84% removal of TN and NO3-N, and the metals Al, Cr, Fe, Cu, and Pb. Phosphorous removal remains low at this site, and once again significant increases in EC and mobilization of arsenic (>600% increase from bay influent As concentrations)

<table>
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<th>Analyte</th>
<th>Units</th>
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<th>StDev</th>
<th>95% CI</th>
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<th>StDev</th>
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<th>Average</th>
<th>StDev</th>
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<tr>
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* Note, these results were generated by assigning <MDL values from Appendix A a value of ½ the posted MDL for a given analyte. Values tagged as ELH in Appendix A were assigned the stated value to allow as estimate of mean concentrations for a given analyte. NA indicates no value is available due to limited data for that parameter.

Table 3. Pollutant Concentrations from Various Roof Samples Collected throughout USU Campus during Year 2 of the Project*
are evident below this bioretention area, although the pore water arsenic concentration (2.7 µg/L) is significantly below its drinking water standard of 10 µg/L. Monitoring of this bioswale system, along with the monitoring of the parking strip bioswale at USU’s Early Education building, the demonstration bioretention site as Green Meadows in Logan, and a test bioretention system constructed at the University of Utah, will continue through Year 3 of the project to specifically focus on overall pollutant removal from these systems with varying vegetative cover, as well as DOC loading, arsenic mobilization, and to identify baseline soil conditions (total arsenic, labile arsenic, etc.) that might significantly contribute to arsenic release potential in MAR/GI stormwater management systems in Utah.

The MAR/GI site that was sampled extensively during Year 2 of the project was the bioretention system treating parking lot runoff at the Public Utilities office complex in Salt Lake City. Samples were collected from a total of 12 individual rain events during Year 2, and all data are summarized in Appendix A. Pollutant removal provided by the two media filter layers are show in Figure 11, and as was seen for the 300 East bioswale site in Logan, both media layers at the Public Utility site appear to be a significant source of a number of pollutants including nitrate, EC, Al, Cr, Ni, As, and Cd. The UteLite Expanded Shale generally performs better than the construction pea gravel, but does not provide metal and nutrient uptake that is claimed by the supplier. Arsenic remains a contaminant of concern and further analysis of these media and soils from the Public Utility site are being analyzed to determine characteristics of these materials that are contributing to arsenic mobilization.

![Figure 9. Pollutant removal efficiency through the 300 East bioswale GI system, Logan, Utah. Data collected using original lysimeters at 6-inch and 24-inch depth, October 2016.](image-url)
Figure 10. Pollutant removal efficiency through the 300 East bioswale GI system, Logan, Utah. Data collected using Prenart lysimeters at 12-inch and 20-inch depth, October 2016.

Figure 11. Pollutant removal efficiency through the media filter layer below the bioretention cells at the Public Utilities building, Salt Lake City Utah.
Finally, sampling was initiated during Year 2 to quantify pollutant removal through a dry well used to infiltrate roof drainage from the Engineering Building, as well as to evaluate pollutant removal through the vegetated parking strip at the Early Childhood Education Building on the USU campus. Figure 12 presents pollutant removal results for the Engineering Building Dry Well based on roof drain pollutant concentrations compared to concentrations measured in a sump well sampling 6-ft below the gravel dry well from three rainfall events. Significant removal of both nutrients and metals were observed through this GI system despite no pre-treatment of roof drainage prior to infiltration in the dry well. This is the highest performance observed of any GI systems monitored as part of this MAR study, and monitoring of this dry well will continue through Year 3 of the study to increase the size of the data set to verify this high pollutant removal performance.

![Analyte % Removal](image)

Figure 12. Pollutant removal efficiency through a dry well at the Engineering Building on USU Campus, based on roof drain and 6-ft deep sump well samples.

Pollutant removal efficiency data for the vegetated parking strip at the Early Childhood Education Building are summarized in Figure 13. These data, collected during three rainfall events, indicate a generally increasing pollutant removal with depth for most nutrients, DOC, and many metals. The notable exceptions were ammonia and Al, Fe, and Ni, which all showed increasing concentration with depth. Monitoring will continue at this site as with others during Year 3 of the project to capture system response over a wider range of rainfall and runoff conditions and to verify all of the system’s steady-state performance for input to the integrated modeling activities taking place in parallel to the MAR/GI system monitoring effort.
Figure 13. Pollutant removal efficiency via a vegetated parking strip at the Early Childhood Education Building, USU Campus, based on gutter flow and 4-ft and 6-ft deep sump well samples.

E. 2. Integrated systems modeling. Precipitation-runoff-deep percolation modeling progress. The HEC-HMS precipitation-runoff model simulates hydrologic response to precipitation falling as water and as snow. When using HEC-HMS, the following approaches and assumptions are made: the Temperature Index method is employed to simulate snowmelt; initial capture parameters are assumed and the Priestley Taylor method is used to simulate evapotranspiration; infiltration parameters and limits are assumed and the Soil Moisture Accounting method is used to simulate infiltration; the Linear Reservoir method is used to represent subsurface flow to a stream; and parameters are assumed to enable computing deep percolation to an aquifer.

HEC-HMS calibration was begun at the uppermost portion of the Red Butte Creek Watershed-the Lower Knowlton Fork (LKF) sub-watershed. Calibration employed weather data from the Innovative Urban Transitions and Arid Region Hydro-sustainability (iUTAH) Knowlton Fork Climate Station, flow data from iUTAH Lower Knowlton Fork (LKF) Aquatic Station, and local SNOTEL data. For Water Year 2016, Figure 14 shows LKF sub-watershed precipitation (as water) and the resulting observed stream discharge. The discharge hydrograph does not show appreciable, immediate response to preceding precipitation. Figure 15 shows observed and simulated flow time series at the LKF watershed discharge location. This simulation provides the best match with observed flows to date. However, initial simulated baseflow is too high and final simulated baseflow is too low, and further calibration is necessary to improve simulation results.
Figure 14. LKF sub-watershed precipitation (as water) and measured stream discharge.

Figure 15. Water Year 2016 Observed versus Simulated LKF Watershed discharge.

Table 4 shows the Water Year 2016 volume balance computed for the Figure 15 simulation. These results suggest that virtually no direct runoff reaches the stream. Applying the Local Minimum Method of flow separation to observed LKF flows also indicates that there was virtually no direct runoff (Figure 16). In addition, an eye-witness stated that “… based on what I’ve seen up there I think that's reasonable. That creek goes up in the spring and down in the winter/summer/fall and doesn't seem to respond much at all to rainfall events.” Farther downstream, the Local Minimum Method estimates that less than 10% of the Red Butte Creek water entering Red Butte Reservoir is direct runoff. Purdue’s Web-based Hydrograph Analysis Tool (WHAT) was used to apply the Local Minimum Method.

Although the current HEC-HMS model generally matched observed Water Year 2016 flows, inappropriate simulated flow trends at the beginning and end of the water year must be corrected. To do this, assumptions affecting water infiltration, subsurface storage, and base flow will be improved. Calibration will continue to better match observed flows.

**Surface water baseflow and direct runoff modeling progress.** For alternative weather and GI-LID implementation scenarios, this project will predict the resulting change in surface water and
groundwater flows within Salt Lake Valley. Predicting the relative impacts on such flows requires the ability to predict how surface water and groundwater flows will change for different weather scenarios even without the GI-LID changes.

To aid future HEC-HMS application to all of Red Butte Watershed upstream of Red Butte Reservoir, historic flows entering the reservoir via Red Butte Creek were analyzed. Analysis of 52 years of USGS data near the entrance location provided the average monthly total flow, baseflow, and direct runoff rates shown in Figure 17. Flow separation was provided by the Local Minimum Method using WHAT.
Evaluation of the 5-year moving average of total annual flow entering the reservoir provided the downward linear trend line seen in Figure 18. Nevertheless, applying the Mann-Kendall method suggests that the decrease is not significant at the 95% confidence level. Linear trends in annual baseflow and direct runoff are similarly not significant (Figures 19 and 20, respectively). Further countering the notion that might be a significant downward trend, Figure 21 shows that flow can vary greatly between decades.

To facilitate applying confidence intervals to predictions, probability density functions for annual, monthly, and daily total flow, baseflow, and direct runoff were developed. For example, Figure 22 shows the lognormal probability density function of direct runoff in May developed using 53 years of data.

**Unsaturated zone and deep percolation aquifer recharge modeling progress.** The project team has evaluated using storm water to recharge the unconfined aquifer near the University of Utah. Figure 23 shows two locations selected for simulating assumed infiltration through the bottom of a grassed retention basin, and subsequent recharge of the aquifer due to deep percolation. MODFLOW and its Unsaturated Zone Flow (UZF) package were used to simulate the infiltration, deep percolation, and recharge under this scenario.

Figure 24 shows a MODFLOW-grid overlaid over the areas Unsaturated Sites 1 and 2 in Figure 23. Within the black-dash-outlined area of Figure 24, the top right cell is the same as the red-dash-outlined cell in Figure 8. Figure 24 also shows the two cells (Row 33, Column 56; and Row 34, Column 55) containing the unsaturated sites. Within these cells, large-font numbers show the smallest simulated depth to groundwater from 2009 through 2014. At Unsaturated Site 1 in Cell (33, 56) that smallest distance from the ground surface to the water table was 429.4 feet. At Unsaturated Site 2 in Cell (34, 55), the smallest distance was 305.2 feet.

The UZF package requires a uniform soil profile and uniform vertical hydraulic conductivity among other parameters. Assumed parameters were: 6.697 ft/day horizontal hydraulic conductivity, 0.6697 ft/day vertical hydraulic conductivity, 0.3 porosity, 0.25 saturated water content, 0.05 initial water content, 0.05 residual water content, 0.1 evapotranspiration extension water content, and 15 ft evapotranspiration extension depth. With these input parameters, the UZF simulations predicted
Figure 18. Variation in annual average of total Red Butte Creek flow entering Red Butte Reservoir (cfs).

Figure 19. Variation in annual Red Butte Creek baseflow entering Red Butte Reservoir (cfs).
Figure 20. Variation in annual Red Butte Creek direct runoff entering Red Butte Reservoir (cfs).

Figure 21. Variation in mean daily flow by decade (cfs).
Figure 22. Lognormal probability density function of May direct runoff contribution to Red Butte Creek flow entering Red Butte Reservoir.

Figure 23. Unsaturated Sites 1 and 2 west of the mouth of Red Butte Canyon.
that it would require a large steady infiltration rate for the aquifer to receive recharge within months of beginning injection. At Unsaturated Site 2, unrealistically assuming the soil could continually accept infiltration equaling its vertical hydraulic conductivity rate (0.67 ft/day), in a 251.4 ft. x 251.4 ft. grassed basin, it would take 94 days before deep percolation would reach the water table. Figure 25 shows top and side views of water table changes resulting from such steady infiltration for 120 days.

Discussion with the project SAC has indicated that only MAR for the shallow unconfined aquifer that lies primarily in the central part of Salt Lake Valley should be considered. That aquifer (termed aquifer Layer 1 in the MODFLOW implementation) is not used for a potable water supply. Conceptually and physically, one can readily recover intentional recharge to that aquifer for secondary water applications.

The next MAR simulations will occur in aquifer Layer 1 cells where the water table is relatively close to the ground surface. Yellow dashed lines surround such sample recharge cells in Figure 24. It appears that the negative depths to water shown in Cells (35, 53) and (36, 53) are artifacts of the coarse MODFLOW discretization and abrupt ground surface elevation changes in that area. Per cell, MODFLOW only has one ground surface elevation as input and computes only one groundwater elevation. When the MODFLOW grid is refined to use smaller cell sizes the abnormality should disappear. It has been noted that the MODFLOW implementation, as calibrated by the USGS, computed water table heads that were above the ground surface in eastern and northeastern parts of the Salt Lake Valley. Additional and potentially more favorable candidate unconfined aquifer recharge sites exist in the more central portion of the valley. Hydrogeologically,
the best sites would have sufficient unsaturated zone thickness to permit needed recharge mounding, and would have sufficiently low background groundwater flow velocity so that a high percentage of the harvested stormwater could be extracted for secondary water use. Final simulations in these areas will utilize stormwater capture/shallow aquifer recharge volumes and pollutant loadings from Utah calibrated WinSLAMM output as described in more detail below.

A final input from the project SAC related to stormwater harvesting and recovery for secondary water use was a general uncertainty regarding the legal right to the recharged water by municipal entities in the State of Utah. Early in Year 3 of the project, the Project PIs will meet with the Utah State Engineer’s Office personnel responsible for Utah Water Rights to determine the legal feasibility of intentional recharge and recovery from shallow aquifers, and the conditions (recovery within a specified time period, recovery of a specified percentage of water recharged, etc.) under which such recharge and recovery systems must legally operate.

*Groundwater flow modeling progress*. During Year 2 of the project, the SLV MODFLOW model discretization was refined in several locations to yield adequate accuracy for modeling individual recharge or injection mechanisms. Figure 26 shows a grid refinement (i.e., subdivision of original MODFLOW cells into smaller cells), that yielded 38.5 ft. x 38.5 ft. cell size. The refined grid was used as a basis for the small subsystem modeled in the previous section on vadose zone simulation.
Figure 26. Original MODFLOW cells and refined grid at the mouth of Red Butte Canyon.

A portion of the MAR extraction and injection process used in a previous project for surplus treated water (Forghani and Peralta, 2017) will be emulated for lot scale GI infiltration systems in this project. That project modeled the injection of surplus treated domestic water into an aquifer during the springtime period of high surface water flow, and extraction either immediately afterward or after 1 year of storage in the aquifer. The process of injecting stormwater when available during the springtime, and extracting it when needed during the following summer will be modeled using this Forghani and Peralta (2017) approach.

**WinSLAMM Utah site specific calibration progress.** WinSLAMM stands for the Source Loading and Management Model for Windows. It is a water quality model developed in Visual Basic for estimating runoff volume and pollutant loads at a discharge point. The model is based on small storm hydrology and particulate wash-off from several source areas. Its most remarkable characteristics are the ability of considering several stormwater control practices and, to accurately describe the drainage area. WinSLAMM can estimate the pollutant loads and runoff flow volumes for a range of land uses and source areas. This model has been widely used for planning purposes in many areas of North America and it has proven to be accurate in the prediction of flows and pollutant loads. It is important to note that appropriate calibration with local conditions and validation are necessary to ensure accurate results (Pitt, 2003).

Samples from different source areas and land uses from all over the U.S. and some locations in Canada were used to develop pollutant calibration files in WinSLAMM. The map shown in Figure
indicates, however, that most of the data were collected in the East Coast and the Great Lakes area, and none were generated in locations hydrologically similar to the Salt Lake City region.

Figure 27. Sampling locations for data contained in the National Stormwater Quality Database showing EPA Rain Zones and general calibration set regions for WinSLAMM (Pitt, 2003).

WinSLAMM calculates the runoff volume and the particulate concentration for each source area and for each rain event. From there it calculates suspended and dissolved pollutant concentrations. After calculating the parameters for each source and rain event, the program combines the result to determine the loadings at the outfall of the system (Pitt, 2003). To deal with uncertainty in the calculations, the model uses Monte Carlo simulation to express the output in probabilistic terms and generates a distribution of pollutant concentrations (Pitt, 2003). To generate runoff volumes and pollutant loading estimates, WinSLAMM utilizes regionally specific (Figure 27) parameter inputs that include pollutant probability distributions, particulate solids loadings, and runoff coefficients. The pollutant probability distribution file is used as to calculate pollutant loadings. The runoff coefficient file is used to calculate the volume of runoff. Particulate solids concentration files are used in conjunction with the runoff coefficient to determine solids concentrations for each rain event in each source area. The files compiled from regional locations shown in Figure 27 can be used if it is known that they work in the study area. If not, new files can be created to adjust the values to the characteristics of the site (PV & Associates, 2014). The calibration and validation process that took place in Year 2 of this study is generating these parameter files for use in Northern Utah site simulations.

To carry out this WinSLAMM calibration and validation, it was necessary to collect data for each of the target pollutants. TSS, TP, TDP, flow and precipitation data were collected for each of three sites being used for calibration and validation purposes (Figure 28). To better represent the variability in site area and land use, three calibration sites with areas ranging from 14 acres to 100 acres and different combinations of mixed commercial and residential land uses are being studied.
The first parameter to be calibrated is runoff coefficient because it influences every other parameter estimated by the model (i.e., runoff volume, suspended solids and phosphorus loadings). After calibrating this parameter, suspended solids calibration is next, followed by total dissolved and total suspended phosphorus loadings. The calibration of the model is an iterative process where simulated parameters are modified until all the values fall within the appropriate model performance ratings.

Figure 29 shows details of the delineation of the catchment areas that contribute to the stormwater sewer system discharging in the Northwest Field Canal that runs through Logan, UT. The area delimited with a green line in Figure 29 corresponds to a Sam’s Club and a gas station (100% commercial use). The second area, delineated in pink, has mixed land uses (22% residential, 78% commercial). These areas were defined using stormwater sewer and elevation contour information provided by the Public Works department of Logan City and analyzed using ArcGIS.
A Preliminary WinSLAMM model was developed for the 100% commercial site, Area #1 in Figure 28, the green boundary area in Figure 29. The runoff volume predicted was compared to flow data from the monitoring station at the outfall and it was observed that the simulated values were consistently lower than the observed data (Figure 30). This lead to a reevaluation of the model runoff coefficient, $R_v$, values. Currently, the revised model is being develop to continue the calibration process using revised runoff coefficients for commercial applied to modeling of the mixed land use Area #2.

Besides working on model calibration, collection of samples for TSS analysis at the 1300 South outfall of Red Butte Creek into the Jordan River has been done since November, 2016, and will continue through November, 2017. At this location, there is also an iUTAH continuous monitoring station from which turbidity values are being collected. These data are being used to develop a correlation between turbidity and suspended solids at this site, which will be used as an additional WinSLAMM model validation point for TSS and pollutant discharge from a large mixed use residential/commercial area in Salt Lake City, and as an input water quality parameter for the Jordan River surface water quality model. Preliminary data for this TSS/Turbidity correlation are shown in Figure 31 for both the Logan catchments and this Jordan River outfall site.

**Ecosystem services modeling progress.** Progress to date in the ecosystems services modeling area can be summarized into four parts: 1) data collection, 2) literature review, 3) engagement with stakeholders and decision-makers, and 4) surface water modeling and integrating surface and groundwater models.

Water quality data from iUTAH sites along Red Butte Creek, a tributary to the Jordan River, have been collected. In addition, streamflow and water quality data from previous iUTAH sampling efforts for the Jordon River have been acquired. Measured data will be used to calibrate and
Figure 30. Observed and WinSLAMM modeled Rv versus rainfall depth at Commercial Area #1, Logan Utah.

Figure 31. TSS versus Turbidity relationships at stormwater outfalls at the three Logan, Utah, WinSLAMM test sites, and at the 1300 South stormwater outfall to the Jordan River, Salt Lake City, Utah.

validate the Red Butte Creek surface water model, which will then feed into the existing Jordan River surface water model (Figure 32).

A total of 170 publications at the intersection of stormwater management and ecosystem services were reviewed to synthesize how green stormwater management affects ecosystem services. Major
findings show that: 1) most research is conducted at the parcel-scale, 2) nearly a third of all papers reviewed developed frameworks for implementing green stormwater infrastructure, 3) papers discussed ecosystem services, but less than 40% provided quantified ecosystem service measures, 4) no geographic trends in research emerged, 5) studies increasingly integrate engineering, physical science, and social science approaches for a holistic understanding of GI/ecosystem services connections, and 6) standardizing green stormwater infrastructure terminology would provide a more cohesive field of study than the diverse and often redundant terminology currently in use. This research was presented as a poster at the American Geophysical Union (AGU) Fall Meeting in December 2016, and findings have been submitted as a manuscript to *Environmental Research Letters*. The paper was submitted in August 2017, and revised and resubmitted in October 2017.

Stormwater managers in the Salt Lake Valley have been presented with the conceptual ecosystem services framework, metrics, and water quality constituents that are being modeled through biannual SAC meetings being conducted as part of this project. Generally positive feedback has been received regarding the ecosystem service metrics that we have identified (Table 1) that will inform their management plans and decisions. Additionally, a robust decision-making framework using metrics to quantify water quantity and quality ecosystem services has been developed and will be presented to with stakeholders at the Salt Lake County Watershed Symposium in mid-November 2017.

A QUAL2K surface water quality model for Red Butte Creek is currently being developed. A model of the Jordan River exists (von Stackelberg and Neilson, 2014), though we this model will be refined to improve model fit and to couple it with the Red Butte Creek surface water quality and groundwater models described above. Five specific provisioning (water quantity) and regulating (water quality and flood mitigation) ecosystem services have been targeted, as described in Table 1, that will be quantified with surface water modeling to analyze changes in ecosystem services provided from GI system implementation.
**Modeling integration progress.** As stated previously, simulation accuracy for some locations will require matching of boundary flows between simulation models. Sample areas are where: QUAL2KW is simulating surface water quality and heads and flows; MODFLOW-STR are simulating groundwater-surface water seepage and surface water heads and flows; and the groundwater and surface waters are in saturated hydraulic connection. In such locations, the groundwater-surface water seepage is a function of both heads. MODFLOW-STR can compute such seepage. QUAL2KW requires the seepage as input. Software has been developed for use after preliminary QUAL2KW and MODFLOW-STR simulations for the same simulated area. The software: gathers seepage, flow, and surface water stage data from MODFLOW-STR output; compares the STR-computed seepage and surface water flow and head with those used or computed by QUAL2KW. If the values are different (i.e., do not satisfy user-specified convergence criteria), the STR-computed seepage rates are put into QUAL2KW and the simulations are repeated. Achieving convergence halts the process. This software will be applied to ensure QUAL2KW and MODFLOW-STR consistency in all areas of interconnection.

**F. 3. Social science research.** Consistent with initial results noted in the preliminary analysis reported in Year 1, more formal analysis of the key informant interviews has revealed several important patterns. Initially, while most municipal stormwater managers appreciate the potential limitations of conventional detention basins, they remain uncertain about the effectiveness of alternative approaches to control potential flooding in neighborhoods, particularly those that rely on infiltration into shallow or deep aquifers (Figure 33). They do recognize the value of a distributed surface or subsurface infiltration approach as a way to protect surface water, but are concerned about the potential for contamination of underground water resources (particularly for approaches that rely on deep dry wells). However, a number of respondents felt that shallow aquifer recharge with subsequent recovery for non-potable uses could be valuable in some situations, thus extending potable water supplies through substitution of recovered shallow groundwater for potable water currently used for non-potable demands, i.e., landscape irrigation. This latter finding has resulted in a redirection of modeling efforts as described in integrated modeling section above.

**E. 4. Key Findings**

**Research Component 1** – Based on existing MAR/GI system monitoring that has taken place during Years 1 and 2, a wide range of pollutant concentrations result when data from a range of rainfall events are combined even at a specific site. Disaggregation of these data will continue to be carried out in Year 3 to evaluate potential relationships between pollutant concentrations and rainfall event return periods. For the three sites treating primarily pavement runoff (300 East and the Early Childhood Education Building, USU, in Logan, and the Salt Lake City Public Utility parking lot site), overlapping 95% Confidence Intervals of measured runoff pollutant concentrations during Year 2 showed differences among sites for TN and Cr (Public Utilities and Early Ed being higher), TDN, TP and TDP (higher at the Early Ed site), and Cu and Pb (higher at the Public Utility site).
Figure 33. Perceived effectiveness of different approaches to managing municipal stormwater in Utah for flood control, protection of surface water, protection of groundwater and for aquifer recharge.

Monitoring of pollutant generation from various roof materials indicates that both the PV and metal roofs generate pH values higher than the membrane roof. Unexpectedly high lead and aluminum levels generated by the membrane roof system will be evaluated further in Year 3 through monitoring membrane roof pooled water samples as well as roof discharge to adjacent dry wells to determine if roof drain piping is the source of this metal loading. Finally, many of the MAR/GI systems being monitored appear to be releasing contaminants to underlying soils. The 300 East bioswale continues to release dissolved solids as indicated by elevated EC values, and continues to be a net producer of low concentrations of dissolved arsenic. Filter media used at the Public Utilities bioretention site continues to release nitrate, EC, Al, Cr, Ni, As, and Cd. The UteLite Expanded Shale generally performs better than the construction pea gravel, but does not provide metal and nutrient uptake that is claimed by the supplier. The vegetated parking strip at the Early Childhood Education building showed increasing concentrations of ammonia and Al, Fe, and Ni with depth. The one bright spot in Year 2 monitoring results is the dry well infiltration system located at the Engineering Building on the USU campus that is yielding an average 68% removal of all pollutants being analyzed in the study.

Research Component 2 – The use of historic Red Butte Creek direct runoff (entering Red Butte Reservoir) was evaluated to recharge a principal water supply aquifer near the mouth of Red Butte
Canyon via a grassed infiltration basin. With available aquifer parameters (0.67 ft/day hydraulic conductivity, 0.25 saturated water content, 305 ft depth to water), it was predicted to take about 3 months for significant percolating water to reach the water table of the principal aquifer. There is a possibility that extraction pumping during the immediately following summer months could capture most of the recharge to provide secondary water. The background groundwater velocity is probably too great, however, to allow capturing most of the recharged water if it is stored in the aquifer for a year. If springtime stormwater captured by new LID-GI near the mouth of Red Butte Canyon is channeled into grassed infiltration basins for gravity infiltration, the stormwater is unlikely to reach the water table in sufficient quantities in time to be extracted and used during the immediately following summer months. The SAC is not in favor of the idea of injecting stormwater, without significant treatment, into a water supply aquifer. In addition, the SAC cited water rights and environmental regulatory concerns. The SAC was in favor of exploring the possibility of injecting newly captured stormwater into a shallow aquifer not used for culinary water supply, where the water table is close to the ground surface and the recharge could provide secondary water supply. The best sites to explore for recharging aquifers using stormwater from new LID-GI would: (a) be in the central portions of Salt Lake Valley where the water table of the shallow aquifer is close to the ground surface, (b) have sufficient unsaturated zone thickness to permit needed recharge mounding, and (c) have sufficiently slow groundwater flow velocity that all or most of the recharge water could be captured and extracted for secondary water use.

Research Component 3 – There appears to be a number of serious social, political, and legal obstacles to using deep dry wells as a means to recover stormwater through managed recharge to deep aquifers. There is much more receptivity (and fewer concerns) about approaches that rely on infiltration and recharge of shallow (non-culinary) aquifers. As a result, the modeling team has shifted its focus to develop tools that could help cities and developers identify the optimal spatial configurations of distributed shallow stormwater infiltration and recovery systems. The team is also working to clarify the legal status of water rights associated with recovery of infiltrated stormwater in Utah.

F. Planned Activities for the Subsequent Reporting Period

F. 1. MAR/GI system monitoring. Additional samples from the Green Meadow field demonstration site will be collected from paired suction cup soil pore water samplers at 6 and 9-inch depths in replicate plots vegetated with cattail, sedge, sunflower, Baltic rush, inland salt grass, and bunch grass species. In addition, paired 12 and 20-inch lysimeters samples will be collected from the 300 East site to allow comparison of the performance of GI/MAR systems as a function of vegetation type across turf and a range of common GI plant species at the Green Meadows site. Additional roof and dry well samples, and samples from the parking strip at the Early Childhood Education Building will be collected during Year 3 to continue to evaluate steady-state pollutant removal potential from these MAR/GI systems. A green roof on the Early Education building at USU will be instrumented to evaluate water quality improvements provided by that roof treatment compared to conventional roofing materials. Sampling of a field bioretention study site at the University of Utah campus continues to be delayed, but may be feasible during the Spring and Summer of 2018 if the site is finally operational by then. This would provide an opportunity to evaluate pollutant removal performance of an additional range of Utah native plant species. Collaboration efforts with the City of Spanish Fork in the Utah Valley south of Salt Lake City continues, as they have adopted mandatory LID for new developments in their municipality, consisting primarily of shallow infiltration systems (D-blocks).
The relationship between elevated DOC and arsenic mobilization will continue to be explored through sampling at the 300 East and Green Meadows sites in Logan, and University of Utah field bioretention site if it comes on-line in early 2018. Baseline soil conditions (total arsenic, labile arsenic, etc.) have been quantified in the 300 East, Green Meadows, and University of Utah background soils, and will be used to determine the predictability of potential arsenic mobility in MAR/GI stormwater management systems in Utah based on on-going monitoring data collected at the three sites during Year 3 of the project period.

In addition, disaggregation of pollutant loading data from the field sites will continue to explore relationships between pollutant concentrations and storm intensity and duration using rainfall data available from each of the field sites. If pollutant load versus storm return period relationships can be developed, improvements can be made to rainfall runoff inputs to the integrated modeling effort.

F. 2. Integrated system modeling. As a result of the first meeting with the Stakeholder Advisory Committee (SAC) at the beginning of Year 2 of the project, the calibration and verification effort for the refined MODFLOW model discussed above has been redirected. Simulation of stormwater injection via deep wells has been replaced by prioritization of model development for MAR/GI shallow infiltration systems because of initial concerns expressed by both municipal government and consulting firm representatives on the SAC. Direct aquifer recharge via deep dry wells remains a component of the project due to its widespread use throughout the Southwest. Further analysis and discussion with the SAC carried out during Year 2 of the project have highlighted the SAC’s broad concern over groundwater contamination potential, and any aquifer recharge and recovery was recommended strongly to be limited to use in secondary water systems rather than any potential potable uses. There was also a desire to provide modeling and model scenarios at a much smaller scale than relevant for watershed planning, i.e., at the development rather than watershed scale. This localized modeling and planning interest is reflected in social science interactions planned for the SAC as described in Section F.3 below.

After finalization of HEC-HMS calibration for LKF sub-watershed, HEC-HMS calibration for the rest of the Red Butte Watershed upstream of Red Butte Reservoir will be accomplished. HEC-HMS calibration includes demonstrating a reasonable mass balance by pursuing multiple lines of evidence. Simulated surface water flows and groundwater flows leaving an area should both reasonably match observed values or values estimated by other means. Validation of the calibrated model(s) will be done using Water Year 2017 data when they become available. This will enable computing estimates of surface water and groundwater inflow to Salt Lake Valley for alternative scenarios. Year 3 aquifer recharge scenarios will consider locations where, after stormwater injection, it would be practical and legal to extract the injected water for secondary water use. Site characteristics include: (a) intentional recharge would enter an unconfined aquifer having already-degraded water quality, that is not a principal water supply aquifer; (b) a water table close enough to the ground surface that extraction after injection would be cost-effective; (c) a water table far enough from the ground surface that injectate would not cause problems or reach other water resources or the ground surface; and (d) the background groundwater velocity is slow enough that all or virtually all of the injectate could be captured by extraction during the summer months after injection. These criteria were generated from SAC observations concerning Year 2 simulations of using stormwater infiltration and principal aquifer recharge through a thick water supply aquifer vadose zone. The MODFLOW model mesh will be refined in a region that satisfies these criteria, near Red Butte Creek and the Jordan River. This MODFLOW refinement will match boundary conditions with the Salt Lake Valley model.
A more localized Stormwater-MAR model will be constructed to allow using hydrogeological features representative of the center of the Salt Lake Valley and will be constructed at a development scale as requested by members of the SAC. The model will be able to compute aquifer recharge and recovery for a development sized planning area (i.e., 40 to 80 ac), presenting a realistic range of GI-LID flow discharges and recovery options for municipal entities to consider on a site by site basis for municipal planning purposes. This will allow its broad application in Salt Lake Valley. Finally, after receiving input assumptions from the QUAL2KW modeling group, MODFLOW-STR or –SFR and QUAL2KW input parameters will be synchronized so that both models use or compute identical stream stage, flow, and seepage with the aquifer.

The calibration and validation of WinSLAMM will continue at the three small Logan Utah watersheds through the first months of Year 3 of the project, then will move to the application of WinSLAMM to the much larger (25 square mile), much more diverse land use area in the Salt Lake watershed discharging to the Jordan River. Once the WinSLAMM urban rainfall/runoff model is calibrated and validated, it will then be used to assess changes in runoff volume and pollutant loading expected from MAR/GI implementation strategies to be evaluated in the Red Butte Creek drainage, and in the central valley simulations to be carried out during the latter half of Year 3 of the project. These WinSLAMM generated runoff/pollutant load changes will then be used to determine vadose zone model inputs that feed into groundwater and surface water models described above.

Activities related to the Year 3 ecosystem services component of project integrated systems modeling includes: 1) simulation modeling, 2) continued integration of models, and 3) robust decision-making. The surface water quality model for Red Butte Creek is currently being calibrated and validated, using observed data. The Red Butte Creek surface water quality model will then be coupled to the Jordan River surface water quality model. There is already a working QUAL2K model of the Jordan River, which will be updated with more recent data. Once these models have been calibrated and validated, upscaled results from the WinSLAMM modeling effort for specific MAR/GI alternatives will be integrated into various groundwater and surface water simulation scenarios. Output from both the vadose zone and groundwater modeling effort related to surface water runoff, and groundwater recharge and pollutant loading are expected to have an impact on resulting ecosystem services, and these effects over time with climate change and anthropogenic activities, will be estimated with the use of the finalized ecosystem services metrics in Table 1 and continued integration of all simulation models. Robust decision-making identifies management strategies that consistently provide desired ecosystem services. In other words, alternatives will be evaluated to identify those that are robust to changes like climate change or increasing water demands. The coupled simulation models will be used to evaluate the robustness of different management strategies and to analyze the tradeoffs related to ecosystem services, between water quantity and water quality changes driven by different MAR/GI stormwater management strategies implemented across the Salt Lake Valley.

F. 3. Social science research. Early in Year 3 (beginning December 2017), data from the online survey of stormwater managers in MS4 permitted cities will be collected and analyzed. In the summer of 2018, focus groups with neighborhood residents will be organized in locations near actual installations of stormwater systems designed to improve infiltration and shallow aquifer recharge. The social science team will continue to lead the work of the SAC, including organizing a ½ day participatory modeling workshop retreat tentatively planned for May 2018. This retreat will provide a more hands-on opportunity for the SAC members to explore the capabilities of the
draft integrated systems models, to become acquainted with the robust decision-making process that will aid in identifying a set of feasible and viable scenarios for simulations to be completed by the end of the project.

G. Publications
One manuscript has been generated and submitted for review as a result of the completion of Year 2 project activities. The manuscript has been submitted to Environmental Research Letters, and has the initial citation information as follows:

A number of conference presentations and posters have also been completed by the project team, and citations for these are listed below.


Upcoming presentations and posters:


Copies of the submitted manuscript and all poster and platform presentations have been submitted to the EPA Project Officer under separate cover.


**H. References**


