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

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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 permittable 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 Managed Aquifer Recharge (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 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. Three MAR/GI sites located throughout Northern Utah, two in Logan and one in Salt Lake City, along with a variety of roof drains on the USU campus have been monitored during the first year of the project period to collect baseline stormwater quality data from various land uses (parking lots, roof materials) and to generate initial performance data from the GI treatment systems. Raw data from these sites are located in Appendix A.

The most extensively sampled GI system is located in Logan, Utah, on 300 East along the block between 900 North and 1000 North. This system consists of curb cuts and bioswales designed to divert gutter flow off the roadway and into the bioswales for containment and infiltration. Figure 1 shows a picture of this GI facility and soil pore water sampler placed at the site. This site provides stormwater management for the roadway and adjacent sidewalk on the block between


a.
b.

Figure 1. Curb cut and bioswale GI stormwater treatment system, 300 N Site, Logan, UT. a. Site view along roadway. b. Top of suction cup lysimeters used for pore water sampling.

900 North and 1000 North, and is an experimental system installed by Logan City Public Works in 2012. The bioswale area is covered with turf grass, with small pear trees planted throughout the bioswales primarily for aesthetic value. Roadway runoff as well as ponded and percolating stormwater have been monitored during storm events occurring between September 2015 and September 2016, 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 2015-2016 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. Limited data were collected from this site during the first year of the project period as presented in Appendix A, with samples primarily focused on groundwater underlying the site. Additional suction cup pore water samplers will be 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.

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

The third GI system monitored during the first 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 a UteLite

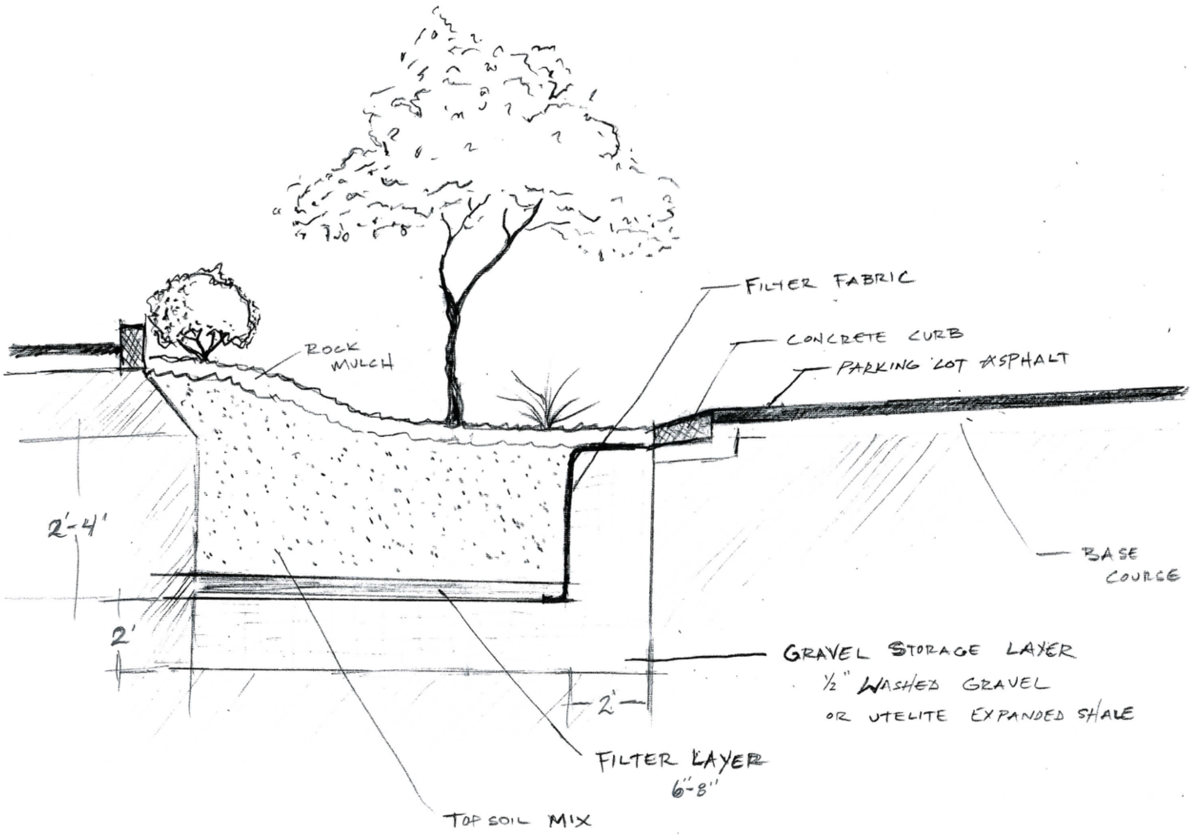


Figure 3. Sketch of the layout of the field test site constructed at the Salt Lake City Public Utilities Headquarters, Salt Lake City, Utah.

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. Figure 4 shows a picture of the "bioretention" area and curb inlet as it looks from the surface, along with two Isco autosamplers located within a storm box, a gutter to allow sampling of runoff from the paved parking area, as well as a large access well installed when the system was initially constructed. After attempting to sample water moving through the gravel or UteLite drainage areas using the large access wells it was determined that the infiltration rates through these layers was too rapid to allow autosampler sample collection, and two additional, smaller sump wells were installed in August 2016, and have be successfully used to collect infiltrating water samples since that time. These sump wells are installed with the top of their 1 ft screens at the bottom of the gravel or UteLite storage layers to sample treated infiltrating water as it moves out of the storage layers.

Finally, a range of roof runoff samples were collected from various roofs across the USU campus beginning in June of 2016. These samples are being collected to quantify the potential pollutant loading generated from these impervious surfaces that throughout the USU campus and across much of the arid southwest, are directed into shallow or deep dry wells without any treatment. The roof types currently being monitored include conventional composite membrane coated

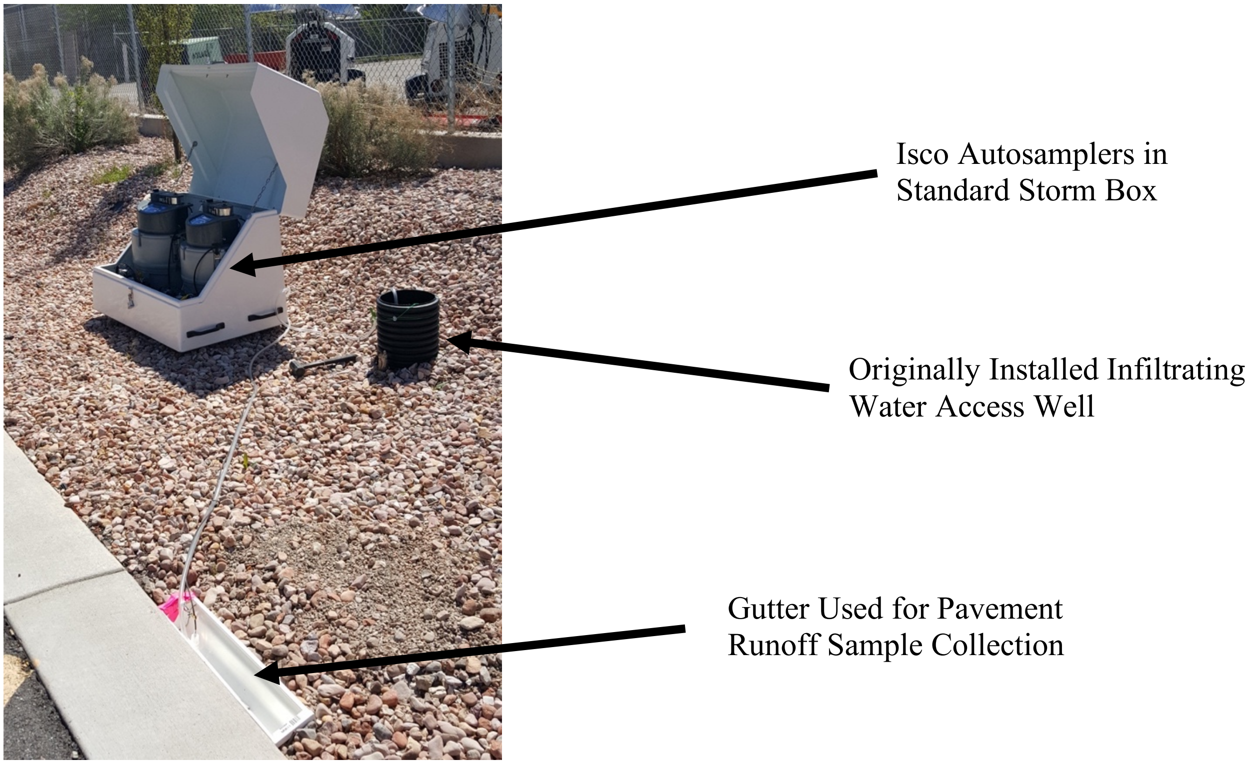


Figure 4. Photo of surface of "bioretention" test site showing monitoring equipment used for runoff and infiltration water sampling at the Salt Lake City Public Utilities Headquarters parking lot, Salt Lake City, Utah.

roofs, standard metal roofs, and solar panel covered roofs. The raw data from these roof surfaces and conveyance piping for the membrane roof are also summarized 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 has been proposed and 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. Various simulation model components planned for the integrated modeling approach are identified in Figure 5, and are in development by the project modeling team. The models simulate flow of and contaminant changes and transport within surface water, vadose zone water, and groundwater. 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 catchments between the Cottams Grove station and station RB_FD_AA. Literature review (Pitt and Voorhees, 2004) and 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 implementation strategies on runoff and pollutant load reductions extrapolated to the larger Salt Lake Valley.

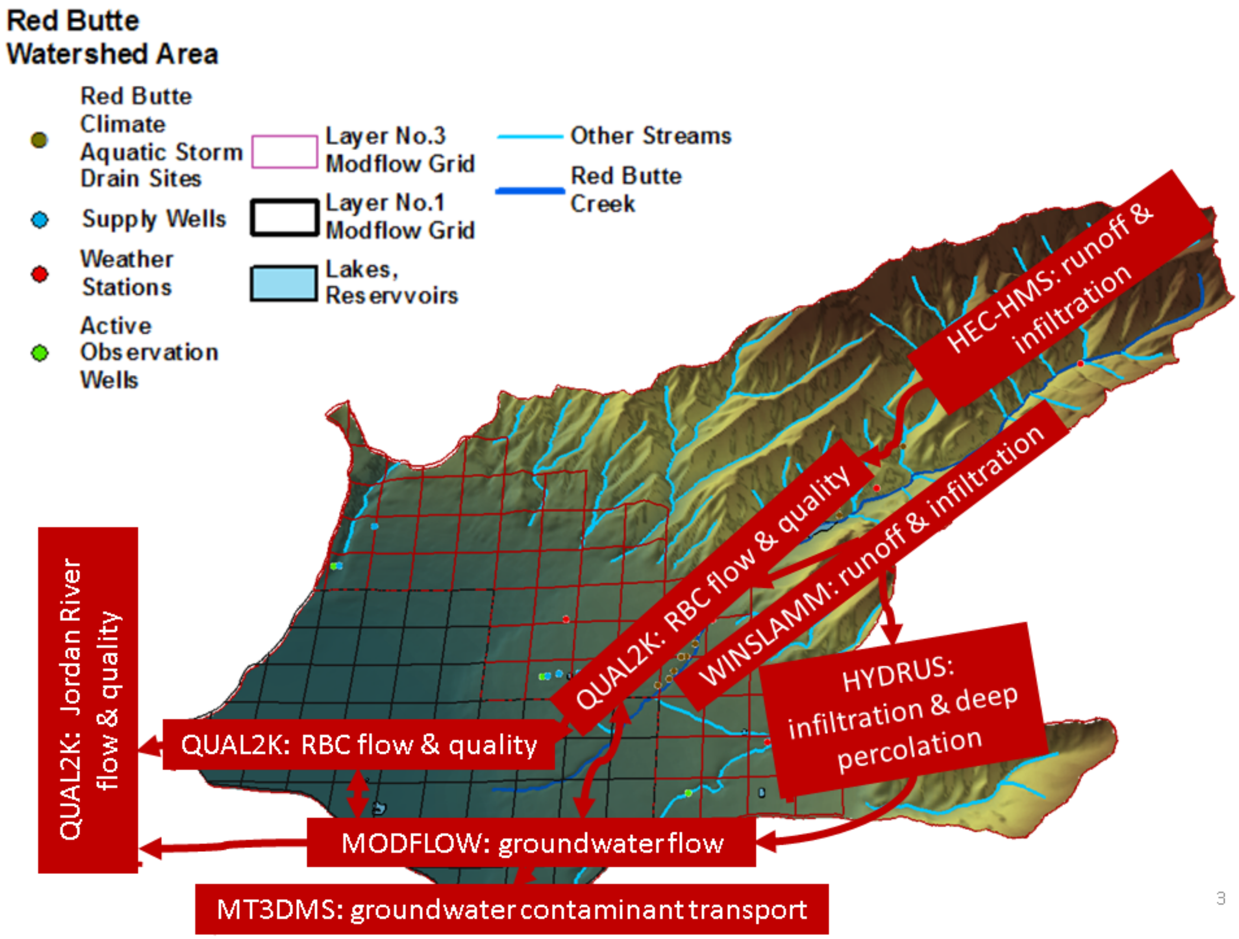


Figure 5. Simulation model components of the integrated simulation modeling approach for the Red Butte watershed area, Salt Lake Valley, Utah.

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.

Models have been established that will be used for the surface water quality/ecosystem services modeling portion of the project, and as indicated in Figure 5 include HEC-HMS and QUAL2K. The inputs and outputs of these models compliment the groundwater models (i.e. MODFLOW, HYDRUS, and MT3DMS), as well as the stormwater quality model (WinSLAMM).

A literature review of research on stormwater management and ecosystem services has been conducted and will be presented at the American Geophysical Union (AGU) conference

Table 1. Ecosystem Services Metrics Used in the Project

Ecosystem Service	Metric (Units)
Increased Summer Baseflow	Duration of Low Flow Conditions (days)
Flood Attenuation	Flood Magnitude (m^3/s), Duration (minutes), Rate of Change of Slope of Hydrograph
Process Water Quality Contaminants (nutrients, salts, metals…)	Pollutant Concentration (mg/L), Conductivity (S/m)
Maintenance of Natural Thermal Regime	Maximum Weekly Average Temperature (°C) & Maximum Daily Temperature (°C)
Aquatic Biodiversity	Habitat Suitability Curves for Fish Species of Interest (e.g., Bonneville cutthroat trout, Utah chub, rainbow trout)

December 2016. Research in this area is still developing. The paper proposes themes and questions for future research at the intersection of ecosystem services and stormwater management.

A. 3. Social science research. Much of the first year was spent working with members of the science team to identify the specific MAR/GI practices that would be the focus of our in-field monitoring (Component 1), integrated modeling (Component 2) and social science research. During Year 1, a graduate student working under the supervision of Dr. Jackson-Smith completed an updated literature review related to social and institutional drivers and barriers for adoption of stormwater green infrastructure. Once the semi-structured Key Informant interview schedule was finalized, Dr. Jackson-Smith Submitted application and received permission from Utah State University's Institutional Review Board and EPA Human Subjects Research Office to carry out Key Informant interviews. During Year 1, interviews were completed with 17 key informants – including City and County Stormwater Managers or Public Works Directors, State stormwater regulatory agency staff, and representatives from the private engineering consultant sector. Based on these preliminary Key Informant interviews, it appears there is a growing interest in distributed systems to capture stormwater on-site, and although deep dry wells are of most concern to the Key Informants, concerns about potential groundwater contamination from any of the infiltration-oriented MAR/GI systems included in the interviews outweighed currently perceived advantages relative to boosting scarce potable water supplies.

Stakeholder engagement meetings were held and the preliminary Stakeholder Advisory Committee meeting has been scheduled for October 2016, representing an accelerated timeframe based on the original project timeline for this component of the project.

B. Key Personnel

All Key Personnel 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, has a PhD student, Ennea Fairchild, working under him who has remained at USU pursuing her PhD in Social Science from USU, and who will remain active on this project through its completion in 2018.

C. Expenditures to Date

Based on the original timeline proposed for the project, approximately 25% of the project tasks are complete compared to the originally planned 33% project completion by the end of Year 1 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 2016. Expenditures through the end of Year 1 of the project period were at 63% of funds originally requested, and it is anticipated that the budget expenditure rate will increase during Year 2 of the project as task timeline revisions and activity reprioritization are completed by the project team.

Spending on Component 3, Social Science, activities were similar to the proposed budget – mainly salary and benefits for Dr. Jackson-Smith's summer salary and his PhD student (spent in Summer 2016), as well as domestic travel expenses incurred to conduct field interviews with key informants. Dr. Jackson-Smith's move to Ohio State will necessitate some modest adjustments in the budget for this portion of the project in Years 2 and 3. The main proposed change will shift 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. Questions regarding budget revisions for this component of the project have been discussed with the EPA Project Officer, and a revised budget and budget narrative to reflect these changes will be submitted early in Year 2 of the project period to ensure timely approval of revised budget requests.

D. 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 are 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. 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 this procedural error has been corrected. All other QC samples, i.e., CCVs, blanks, replicate samples have generally passed QC checks, so that data quality for actual sample batches is believed to not have been compromised for those spike samples that did not pass QC.

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), has rapidly responded 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.

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; and (d) private sector engineers that were all selected to participate in the interviews. Interviews with additional informants to complement the existing sample will continue through Fall 2016 until saturation is reached. To ensure scientific integrity and protection of research subjects, all social science research methods have been reviewed and approved by the USU Institutional Review Board and EPA Human Subjects Research Office.

E. Results

E. 1. MAR/GI system monitoring. A major objective of Year 1, Component 1 activities was 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 and Salt Lake County Public Utilities sites), from large scale drainage areas (1300 South, Salt Lake City site), and roof drains, were collected and analyzed for various rainfall events occurring during Year 1 of the project. Raw data for these sites are included in Appendix A. Table 2 shows summary data for pavement runoff pollutant concentrations from both the 300 East site in Logan, Utah, and the Salt Lake City Public Utilities site in Salt Lake City, Utah. Both sites are associated primarily with drainage from pavement surfaces, with the Public Utilities site 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 2, disaggregation of these data will be carried out to evaluate relationships between pollutant concentrations and rainfall event return periods. Another note related to data in Table 2, based on overlapping 95% Confidence Intervals, the only parameter different between the two sites is Total P, which is significantly higher at the 300 East site, adjacent to landscaped areas, compared to the Public Utilities parking lot site.

Table 3 presents a summary of data associated with the major stormwater discharge channel at 1300 South in Salt Lake City, during dry and wet periods, along with Jordan River water samples collected during Year 1 of the project (raw data in Appendix A). As discussed below, these data will be used to validate the WINSLAMM stormwater model, and are of interest because of water quality impairment caused by stormwater entering the Jordan River. Looking at overlapping confidence intervals for these analytes, Table 3 data indicate that stormwater channel concentrations are enriched only in DOC, chromium and nickel in response to storm events, and that this stormwater discharge represents a significant contributor of Total P, DOC, and chromium to the Jordan River during storm events.

Pollutant generation from various roof materials is summarized in Table 4 (raw data in Appendix A), and includes a commercial membrane roof on the Engineering building, runoff from a PV

Table 2. Stormwater Runoff Pollutant Concentrations from the 300 East, Logan, and Salt Lake Public Utilities GI Monitoring Sites, Collected during Year 1 of the Project*

			300 East, Logan				Salt Lake City Public Utilities			
Analyte	Units	MDL	Average	StDev	95% CI	n	Average	StDev	95% CI	n
TN	mg/L	0.12	1.5	1.6	0.60	27	1.2	0.65	0.20	40
TDN	mg/L	0.123	1.2	1.3	0.55	22	1.4	1.7	0.52	41
TP	mg/L	0.035	0.58	0.58	0.22	27	0.22	0.33	0.10	40
TDP	mg/L	0.017	0.27	0.25	0.11	22	0.13	0.21	0.06	39
NO3-N	mg/L	0.03	0.20	0.23	0.12	14	NA	NA	NA	0
NH3-N	mg/L	0.017	0.08	0.21	0.11	14	NA	NA	NA	0
DOC	mg/L	0.80	26.0	37.0	13.7	28	12.6	10.7	3.0	49
EC	µS/cm	NA	85.2	60.0	37.2	10	135	108	28.8	54
pH	Units	NA	7.3	0.4	0.3	10	7.3	0.73	0.24	36
TSS	mg/L	0.67	174	361	268	7	59.4	80.0	19.6	64
VSS	mg/L	0.67	176	NA	NA	1	26.0	26.3	6.9	56
Al	mg/L	4.0	2,627	5,804	2,189	27	691	936	213	74
Cr	µg/L	0.05	12.5	28.1	10.6	27	6.9	10.4	2.4	74
Fe	mg/L	7.0	2,279	5,516	2,080	27	651	897	204	74
Ni	µg/L	0.40	5.9	6.7	2.5	27	4.8	4.4	1.0	74
Cu	µg/L	0.80	15.9	17.3	6.5	27	20.2	13.2	3.0	74
Zn	mg/L	2.5	258	723	273	27	73.1	40.6	9.2	74
As	µg/L	0.20	3.6	8.4	3.3	25	1.2	0.85	0.19	74
Cd	µg/L	0.15	0.46	1.1	0.40	27	0.12	0.13	0.029	74
Pb	µg/L	0.35	4.5	7.9	3.0	26	3.0	3.5	0.80	74

* 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.

array, and runoff from an associated metal roof. In addition, emergency overflow drains were also sampled during several rainfall events in 2016. Only a limited number of samples were collected during Year 1 of the project from the metal and PV roofs, and additional sampling is planned for Year 2 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 generate pH values higher than the membrane roof, while for the metal roof, iron and nickel are higher and copper and lead appear lower than the membrane roof. Due to the very limited number of samples from the PV and metal roof and their high variability no concentration differences appear between them. These results are very preliminary, and will be more completely evaluated as additional sample results become available during Year 2 of the study. Finally, lead concentrations in drainage from the PV and membrane roofs are particularly high, and further analysis of these concentrations in the roof drains will be carried out during

Table 3. Pollutant Concentrations from the 1300 South, Salt Lake City Stormwater Discharge during Dry Conditions and Storm Events, and Jordan River Samples Collected during Year 1 of the Project*

			Dry Periods				Storm Events				Jordan River			
Analyte	Units	MDL	Average	StDev	95% CI	n	Average	StDev	95% CI	n	Average	StDev	95% CI	n
TN	mg/L	0.12	2.3	1.3	1.29	4	1.4	0.41	0.13	40	1.1	0.23	0.26	3
TDN	mg/L	0.123	1.8	0.8	0.81	4	1.4	1.3	0.41	42	1.0	0.3	0.30	3
TP	mg/L	0.035	0.12	0.12	0.09	6	0.54	1.24	0.38	40	0.04	0.04	0.04	3
TDP	mg/L	0.017	0.11	0.11	0.09	6	0.08	0.06	0.02	40	0.52	0.85	0.96	3
NO3-N	mg/L	0.03	1.74	0.62	0.70	3	0.94	0.34	0.15	19	NA	NA	NA	0
NH3-N	mg/L	0.017	0.04	0.03	0.04	3	0.08	0.09	0.08	5	NA	NA	NA	0
DOC	mg/L	0.80	2.9	1.4	0.88	9	60.2	128	30.7	67	3.1	1.0	0.8	6
Al	mg/L	4.0	439	337	249	7	816	1,226	305.3	62	429	261	209	6
Cr	µg/L	0.05	2.7	1.2	0.91	7	65.2	135	33.56	62	3.2	1.7	1.33	6
Fe	mg/L	7.0	418	232	172	7	753	1,107	275	62	404	208	166	6
Ni	µg/L	0.4	1.7	0.45	0.33	7	3.6	2.6	0.6	62	2.1	1.6	1.3	6
Cu	µg/L	0.8	10.3	6.1	4.5	7	15.7	17.6	4.4	62	9.3	7.4	5.9	6
Zn	mg/L	2.5	73.4	80.6	59.7	7	34.1	31.3	7.8	62	47.6	37.8	30.3	6
As	µg/L	0.2	4.0	2.5	1.9	7	2.6	1.7	0.42	62	4.9	1.8	1.40	6
Cd	µg/L	0.15	0.15	0.20	0.15	7	0.32	1.7	0.43	62	0.20	0.28	0.22	6
Pb	µg/L	0.35	6.0	8.8	6.5	7	3.6	4.0	1.0	62	3.3	2.5	2.0	6

* 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.

Year 2, with samples on the membrane roof itself collected to investigate potential sources of lead 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 has the most complete GI system performance results available from systems sampled during Year 1 of the project. Estimated pollutant removal through his GI system based on bioswale input (bay ponding and pavement runoff samples, Appendix A) versus 24-inch lysimeters concentration data measured during Year 1 of the project are shown in Figure 6. For those pollutants taken up by vegetation and soil through the bioswale system, removal efficiency ranged from a high of 93.4% for aluminum, to a low of 29.1% for nickel. For a large number of pollutants, their 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 P and Total dissolved P, DOC, EC, copper, cadmium, and arsenic. Of particular concern are significant increases (> 550%) in EC values indicating dissolution of salts, increases in DOC (>100%) suggesting the mobilization of organic carbon, and subsequent releases of arsenic close to the drinking water standard for arsenic (10 µg/L) that is assumed to have occurred due to increased carbon loadings and biostimulation of the bioswale soils. Monitoring of this bioswale system, along with the monitoring of a test bioretention system constructed at the University of Utah, will continue through Year 2 of the project to specifically focus on DOC loading, and 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.

Table 4. Pollutant Concentrations from Various Roof Samples Collected throughout USU Campus during Year 1 of the Project*

			Membrane Roof, ENGR Building				Photovoltaic Roof				Metal Roof			
Analyte	Units	MDL	Average	StDev	95% CI	n	Average	StDev	95% CI	n	Average	StDev	95% CI	n
TN	mg/L	0.12	3.1	2.1	0.59	47	3.1	0.78	1.08	2	2.7	NA	NA	1
TDN	mg/L	0.123	2.7	1.7	0.47	49	2.8	0.70	0.97	2	2.6	NA	NA	1
TP	mg/L	0.035	0.46	0.67	0.18	50	0.18	NA	NA	1	0.21	NA	NA	1
TDP	mg/L	0.017	0.24	0.23	0.06	50	0.13	0.09	0.13	2	0.24	NA	NA	1
NO3-N	mg/L	0.03	0.51	0.51	0.15	48	0.66	0.19	0.27	2	0.57	NA	NA	1
NH3-N	mg/L	0.017	1.1	0.94	0.27	48	0.79	0.25	0.35	2	1.0	NA	NA	1
DOC	mg/L	0.80	22.0	28.9	11.5	24	28.1	NA	NA	1	25.3	NA	NA	1
EC	µS/cm	NA	55.0	49.3	16.8	33	60.6	20.4	28.3	2	43	NA	NA	1
pH	Units	NA	6.4	0.30	0.10	33	8.0	0.11	0.15	2	7.8	NA	NA	1
TSS	mg/L	0.67	18.3	40.8	11.5	48	NA	NA	NA	0	NA	NA	NA	0
VSS	mg/L	0.67	83.5	77.1	107	2	NA	NA	NA	0	NA	NA	NA	0
Al	mg/L	4.0	3,828	7,089	1,927	52	9,416	13,775	15,587	3	1,924	144	199	2
Cr	µg/L	0.05	2.6	4.3	1.2	52	13.8	20.0	22.6	3	4.0	0.41	0.57	2
Fe	mg/L	7.0	911	1,667	453	52	7,679	11,357	12,852	3	1,863	222	307	2
Ni	µg/L	0.40	8.3	19.5	5.3	52	8.3	11.0	12.5	3	2.0	0.27	0.37	2
Cu	µg/L	0.80	91.0	190	51.6	52	33.5	42.1	47.6	3	12.5	6.2	8.5	2
Zn	mg/L	2.5	130	256	69.5	52	145	185	210	3	127	72.9	101	2
As	µg/L	0.20	1.0	1.1	0.29	52	3.7	5.0	5.7	3	1.3	0.23	0.31	2
Cd	µg/L	0.15	0.32	0.55	0.15	52	0.44	0.63	0.71	3	0.13	0.08	0.11	2
Pb	µg/L	0.35	14.0	28.3	7.7	52	11.5	15.3	17.3	3	3.1	1.1	1.5	2

* 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.

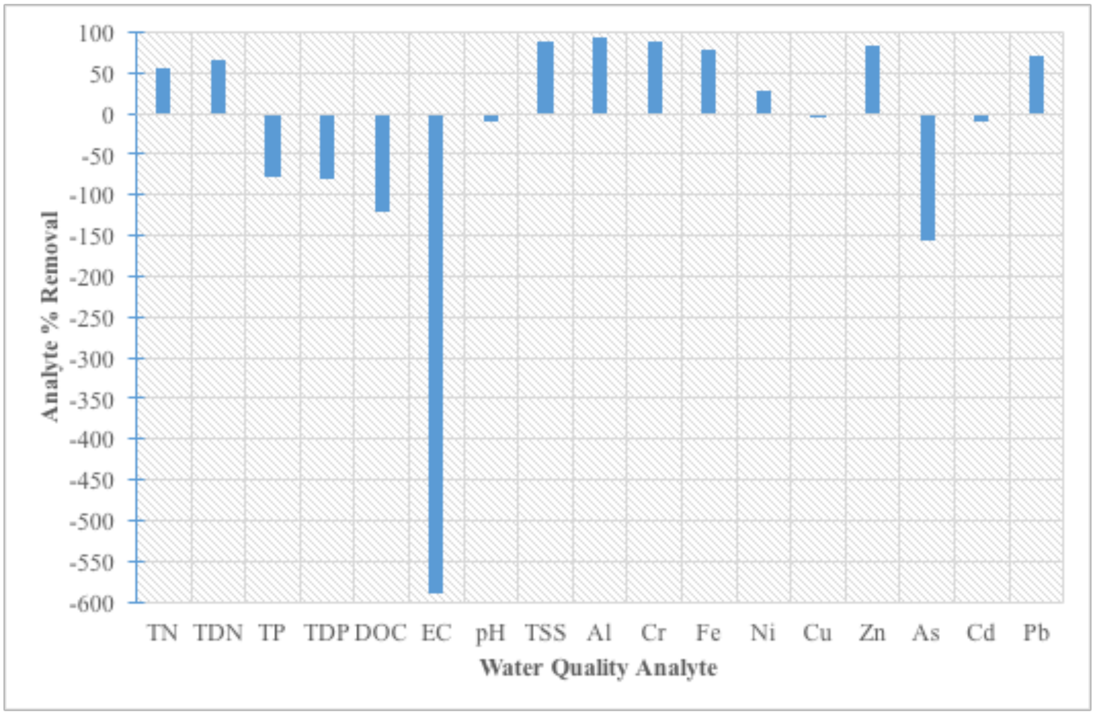


Figure 6. Pollutant removal efficiency through the 300 East bioswale GI system, Logan, Utah.

E. 2. Integrated systems modeling. Figure 7 shows the boundaries of Red Butte Creek Watershed and Salt Lake County. The pinkish grid shows unconfined aquifer Layer 1 cells within an original USGS-calibrated MODFLOW groundwater model. The black grid shows aquifer Layer 3 cells of the same model. Model Layer 3 and underlying Layers 4 through 7 (not shown) represent the principle water supply aquifer of Salt Lake Valley.

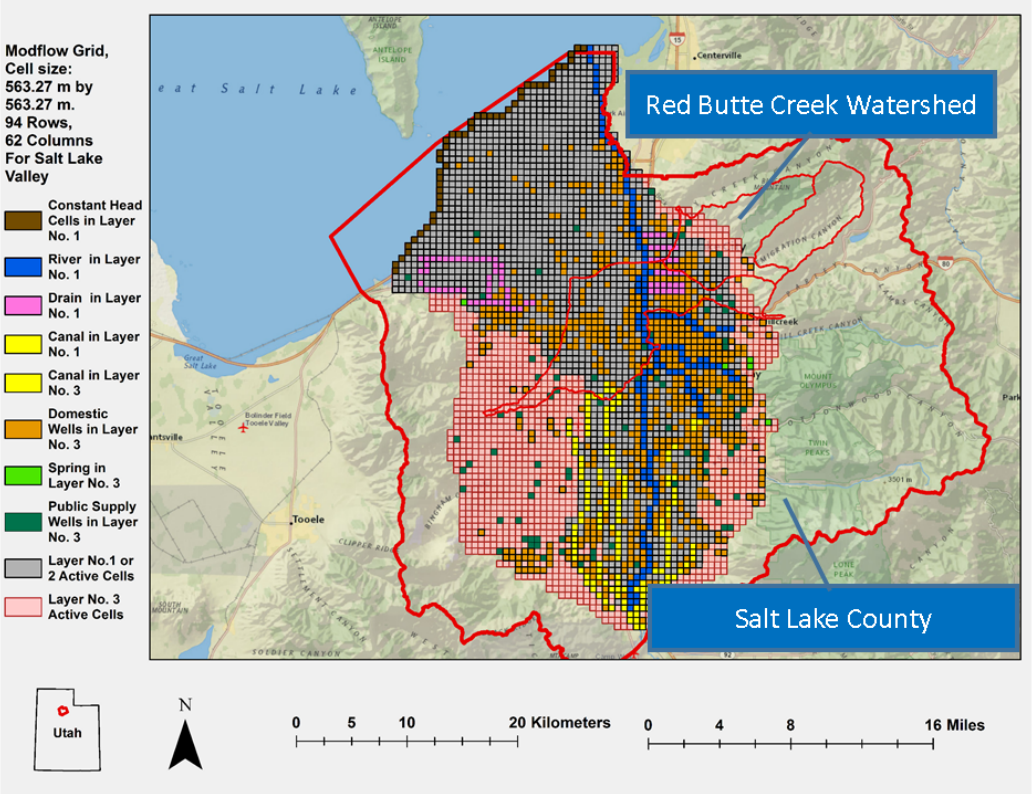
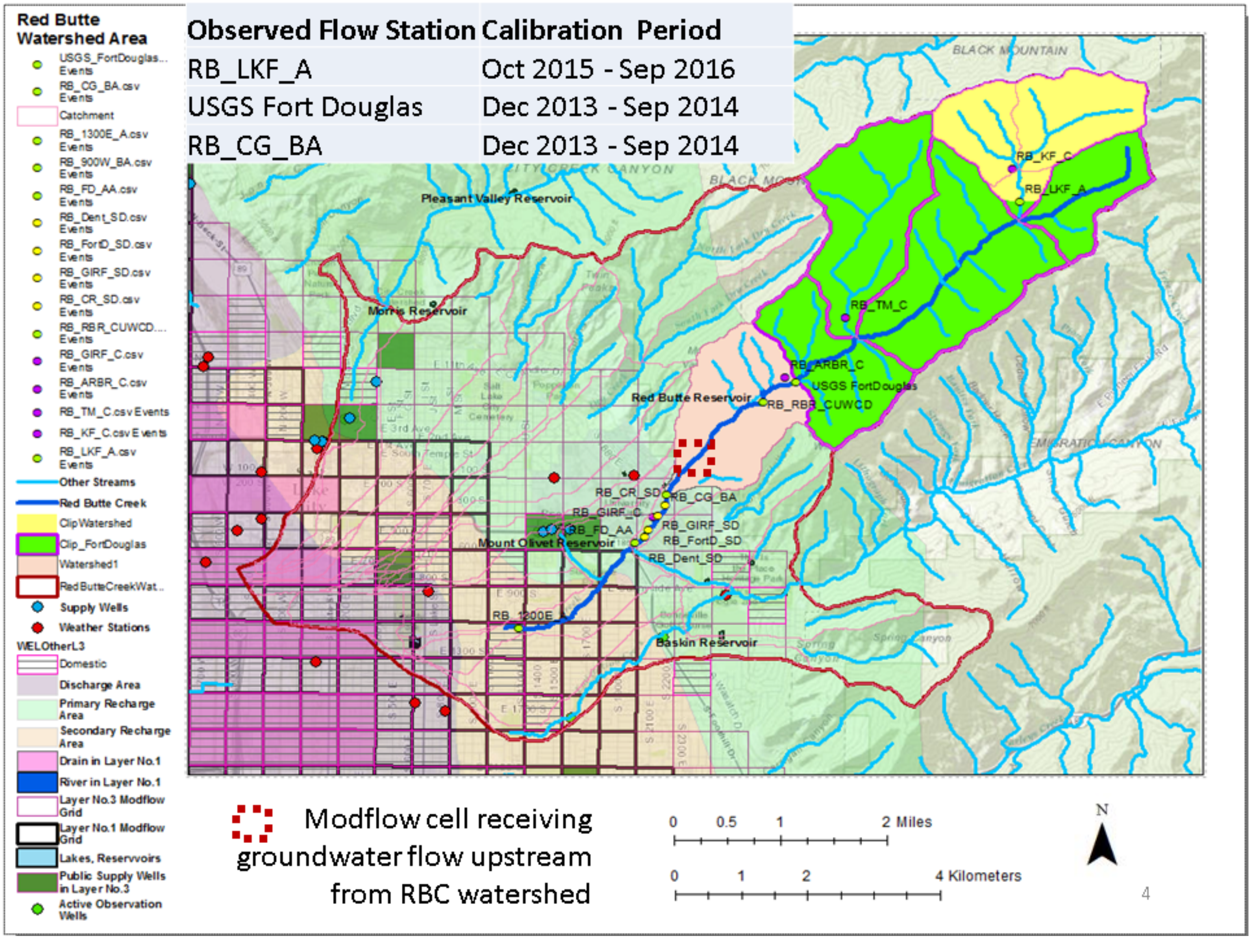


Figure 7. Salt Lake County, original MODFLOW groundwater model grid, and Red Butte Creek Watershed.

The infiltration and deep percolation model being used in the project is HYDRUS. The groundwater flow and transport models are MODFLOW (Harbaugh, 2005.) and MT3DMS, respectively. The surface water quality model is QUAL2K. The 18.8 km^2 RBC watershed ranges in elevation between 1500 and 2400 m. Figure 8 shows the locations of the six water flow and four climate stations within RBC watershed (iUTAH EPSCoR, 2015b). Figure 8 also shows monitoring locations of four storm drains that discharge into RBC (iUTAH EPSCoR, 2013). To our knowledge, no government agency regularly measures groundwater well levels within the watershed.

Because only relatively short periods of detailed precipitation and flow data are available for RBC watershed, a stepwise process is being used to calibrate stream flow runoff. Separate calibrations are being performed for the data periods listed in Figure 8 for the three sub-watersheds distinctly colored in the figure. From higher to lower elevations, these sub-watersheds provide runoff measured at the Lower Knowlton Fork Aquatic (RB_LKF_A), USGS Fort Douglas, and Cottams Grove Basic Aquatic (RB_CG_BA) stations, respectively.



Observed Flow Station	Calibration Period
RB_LKF_A	Oct 2015 - Sep 2016
USGS Fort Douglas	Dec 2013 - Sep 2014
RB_CG_BA	Dec 2013 - Sep 2014

Figure 8. Red Butte Creek Watershed water depth, flow monitoring locations, and sub-watersheds for HEC-HMS calibration. (compiled and modified from iUTAH EPSCoR. 2015a; Lambert 1995; State of Utah, 2016a, 2016b).

Rainfall-runoff modeling includes estimating infiltration volumes or rates. Calibrating to match RBC flow at Cottams Grove provides a volume balance for RBC. The volume balance will aid in estimating the rate of groundwater flowing downgradient toward Salt Lake Valley.

Figure 9 shows that the Cottams Grove Basic Aquatic station marks the transition from upstream rural area to downstream urbanized area. This project will evaluate the impact of applying MAR/GI techniques to the urbanized catchments immediately downstream of the Cottams Grove station.

HEC-HMS has been initially, calibrated to predict flow after storm events at the USGS Fort Douglas flow monitoring location. Input included topographic data (State of Utah, 2016a), and the Table 5 soils data (USDA, 2016), for the Figure 10 sub-basins (State of Utah, 2016a). A short, 365-day preliminary calibration period was initially used because not as much quality controlled data existed for the period of the trial calibration, as exists now. The initial calibration period was January through December 2015.

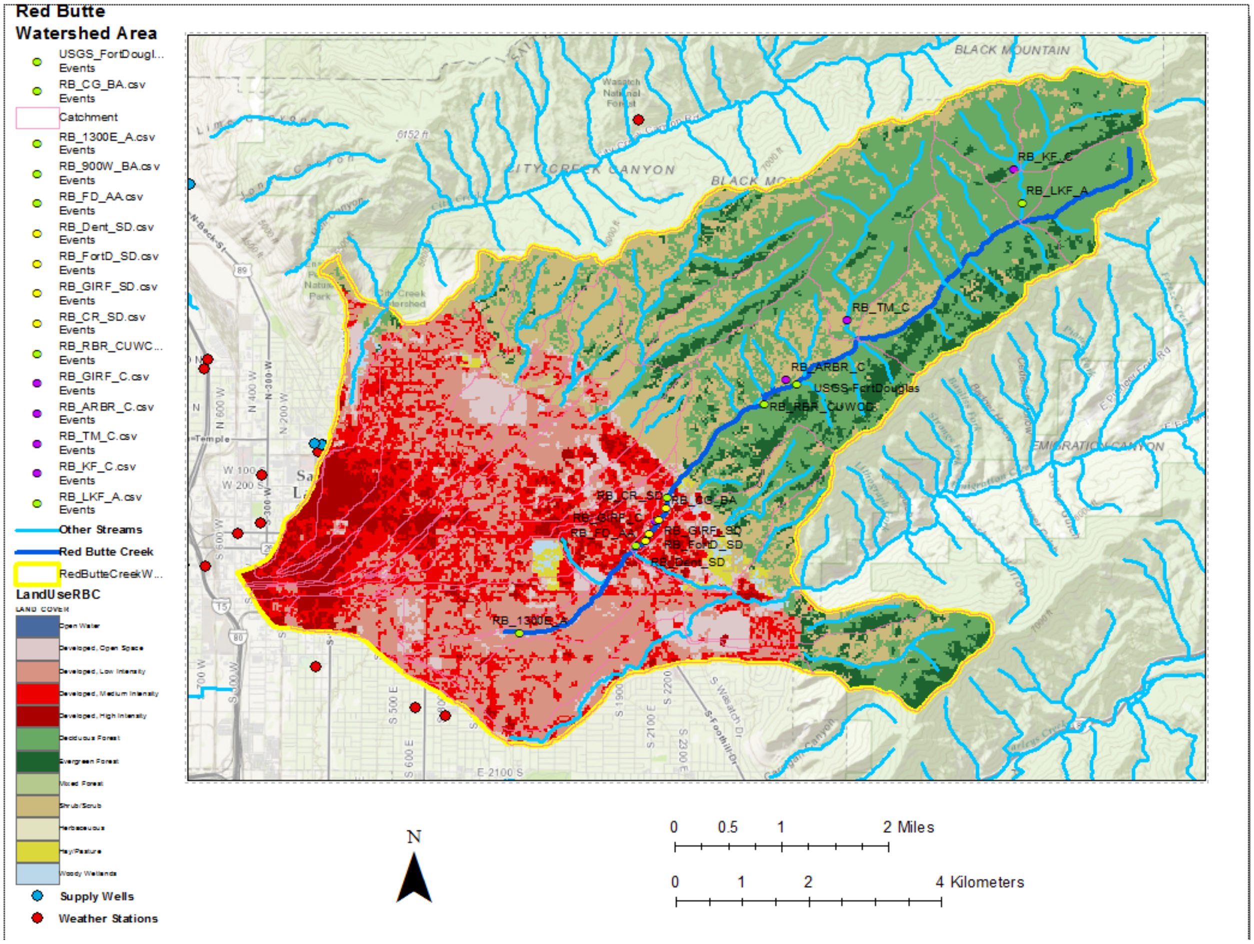


Figure 9. Red urbanized area of Red Butte Creek watershed (State of Utah, 2016a).

Table 5. Soil parameter data from SSURGO (USDA, 2016) for sub-watersheds providing runoff to Fort Douglas USGS flow monitoring location.

Sub-basin	Surface Depression Storage (mm)	Maximum Soil Storage (cm)	Maximum Soil Storage (mm)	Maximum tension zone Storage (mm)	Maximum Infiltration Rate (um/s)	Maximum Infiltration Rate (mm/hr)	Soil percolation Rate (mm/hr)	GW1 Percolation rate (mm/hr)
1	1	16.629	166.29	143.57	8.54	30.75	35.18	35.18
2	1	17.4	174	149.93	8.42	30.31	33.25	33.25
3	1	19.76	197.6	165.1	8.25	29.70	31.18	31.18
4	1	16.128	161.28	141.44	8.51	30.62	30.12	30.12
5	1	17.355	173.55	142.94	12.03	43.30	43.33	43.33
6	1.49635	20.575	205.75	172.3	15.42	55.53	41.03	41.03
7	3.207317	18.941	189.41	164.83	17.05	61.39	35.78	35.78

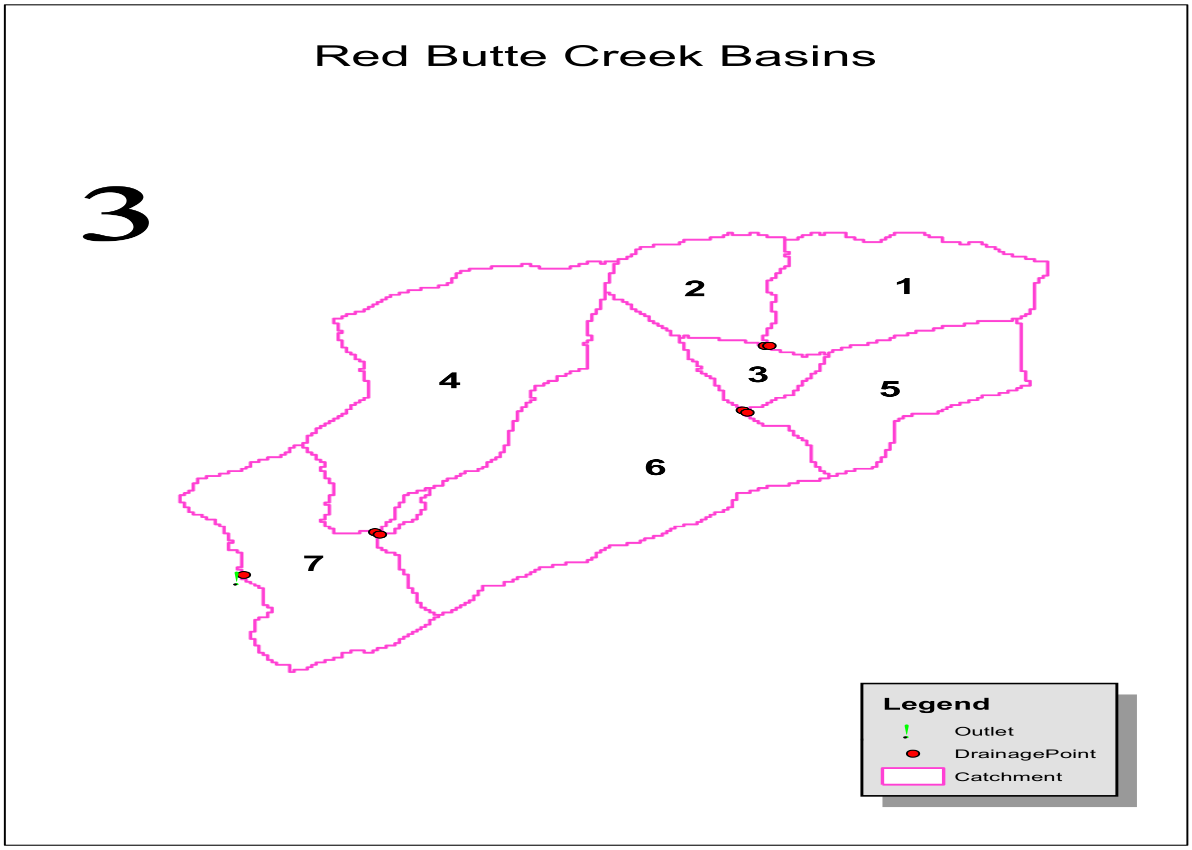


Figure 10. Sub-basins providing runoff to flow at the Fort Douglas USGS monitoring station (*gis.utah.gov*).

Figure 11 compares the resulting simulated Fort Douglas flow rates with observed values during 2015. Because simulation did not consider the snow melting process, HEC-HMS poorly predicted peak flow when snow was melting.

A temperature index method for determining snowmelt is now being used within HEC-HMS. The modeling team is interactively communicating with the HEC-HMS lead developer to implement HMS' relatively new snowmelt simulation ability (personal communication, William Scharffenberg).

Duration and periods of data availability differ with monitoring site (Table 6). The USGS Fort Douglas site has long-term flow data. Average annual streamflow at that USGS site ranges from 0.058 m^3/s to 0.416 m^3/s. (iUTAH EPSCoR, 2015a).

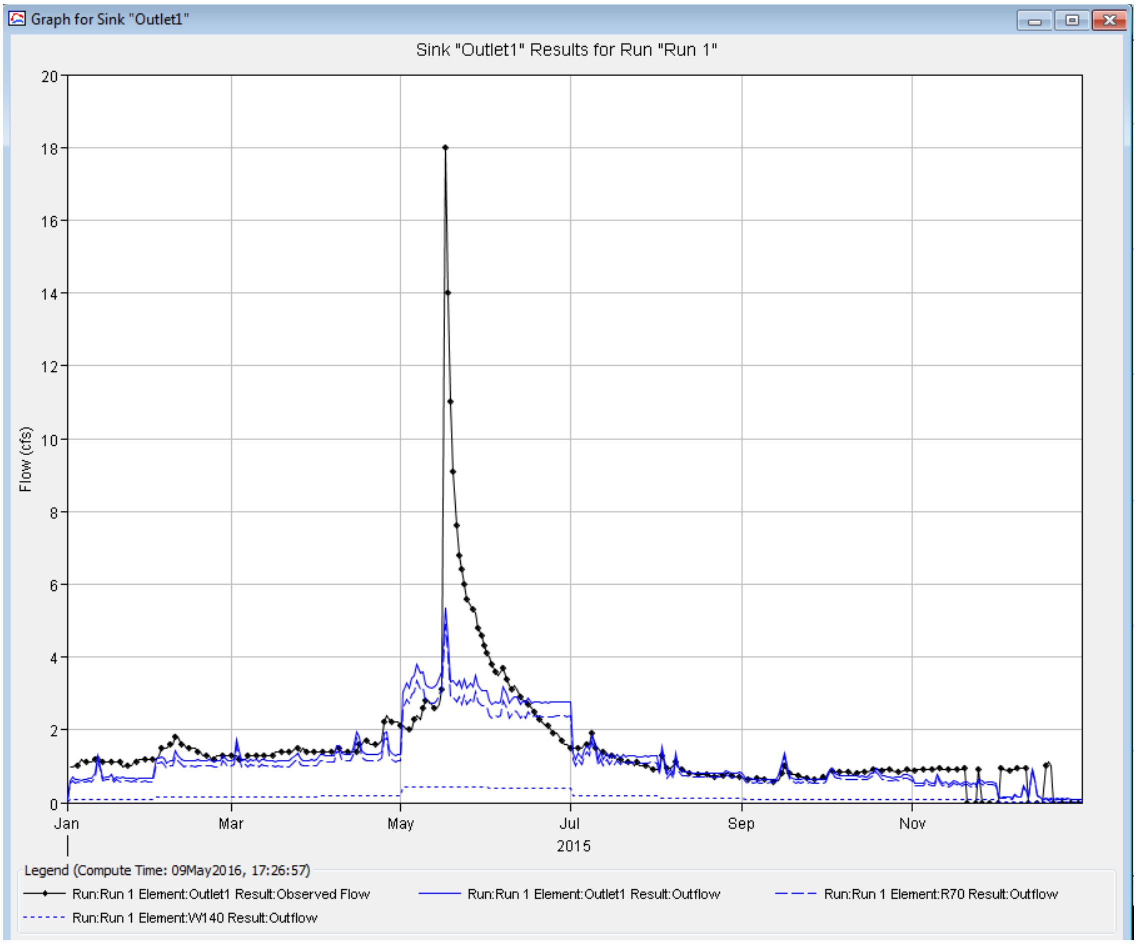


Figure 11. Observed and simulated flows at Fort Douglas USGS site, without simulating snowmelt, in 2015.

Table 6. Water quantity data availability within Red Butte Creek Watershed. (derived from iUTAH EPSCoR, 2015b; USGS, 2016)

Site Name	Variable	Data Type	Time-Step	Source	Available from
Lower Knowlton Fork Aquatic (RB_LKF_A)	Discharge	Raw data	15Min	Iutah	9/29/2015
USGS FortDouglas	Discharge	Quality Controlled data	Daily	USGS	1/1/1964
Central Utah Water Conservation District (RB_RBR_CUWCD)	Discharge	Raw data	1 hour	CUWCD	1/6/2014
Red Butte Gate Basic Aquatic (RB_RBG_BA)	Discharge	Derived Product	15 Min	Iutah	1/30/2014
Cottams Grove Basic Aquatic (RB_CG_BA)	Discharge	Derived Product	15 Min	Iutah	8/22/2013
Foothill Drive Advanced Aquatic (RB_FD_AA)	Discharge	Derived Product	15 Min	Iutah	8/26/2013
Knowlton Fork Climate (RB_KF_C)	`Precipitation	Quality Controlled Data	15 Min	Iutah	9/19/2013
	Snow depth	Quality Controlled Data	15 Min	Iutah	7/12/2013
Todds Meadow Climate (RB_TM_C)	`Precipitation	Quality Controlled Data	15 Min	Iutah	12/2/2013
	Snow depth	Quality Controlled Data	15 Min	Iutah	11/18/2013
Above Red Butte Reservoir Climate (RB_ARBR_C)	`Precipitation	Quality Controlled Data	15 Min	Iutah	8/22/2013
	Snow depth	Quality Controlled Data	15 Min	Iutah	6/19/2013
Green Infrastructure Climate(RB_GIRF_C)	`Precipitation	Quality Controlled Data	15 Min	Iutah	8/21/2013
	Snow depth	Quality Controlled Data	15 Min	Iutah	7/23/2013

By applying Arc-GIS tools to digital elevation data (State of Utah. 2016a), the boundaries of the catchments immediately downstream of the Cottams Grove station have been developed (Figure 12). The four storm drains shown in Figure 8 capture the runoff from these catchments and discharge their flows to RBC between the Cottams Grove station and the downstream station RB_FD_AA.

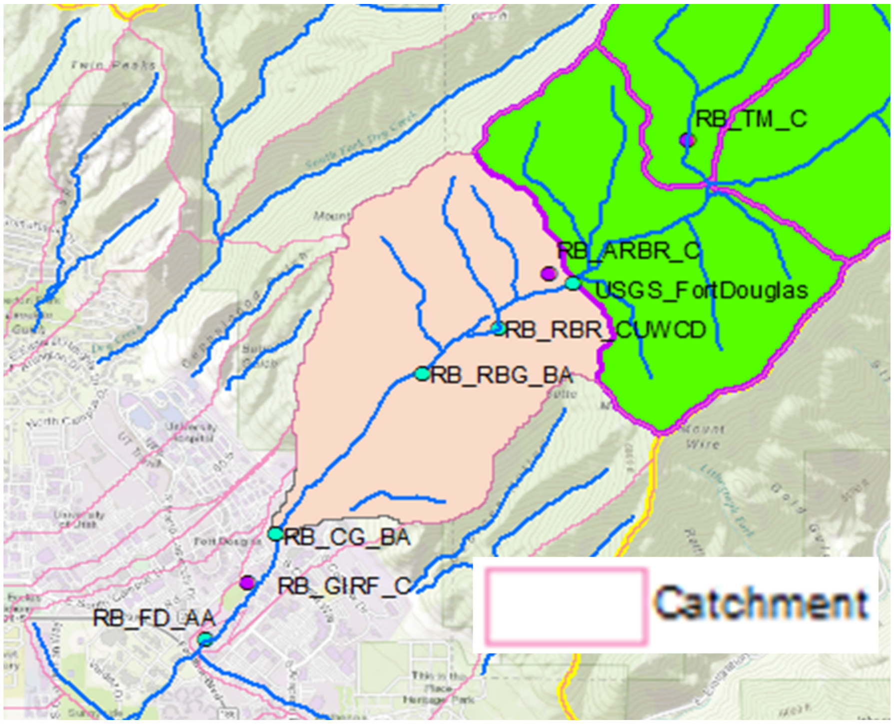


Figure 12. Boundaries of catchments downstream of Cottams Grove (RB_CG_BA) flow monitoring location (modified from State of Utah, 2016a).

For the area where aquifer recharge quantity and quality will change due to MAR/GI system implementation, the USGS model is being refined to have cells using at 38.5 ft x 38.5 ft horizontal discretization. This size is used based upon aquifer storage and recovery (ASR) simulations that are being performed for a water supply company within Salt Lake Valley. As in that ASR project, for this EPASTAR project, the 7-layer vertical discretization used by the USGS model will be retained.

Because GI applications have not yet been simulated, groundwater modeling was begun by simulating the impact of channeling storm water runoff into a deep infiltration well. The concept initially presented to Salt Lake City Public Utilities was to inject stormwater runoff into an aquifer near cell 37_51 in Figure 13, where RBC flow enters a subsurface pipe for conveyance to the Jordan River.

Figure 14 approximately illustrates the reduction (in top view) of MODFLOW row heights and column widths near and within the Figure 13 target area. Within the yellow rectangular outline, cells are 38.5 ft x 38.5 ft in horizontal dimensions. Cell size refinement necessitated adjustments in other MODFLOW inputs, such as river conductance.

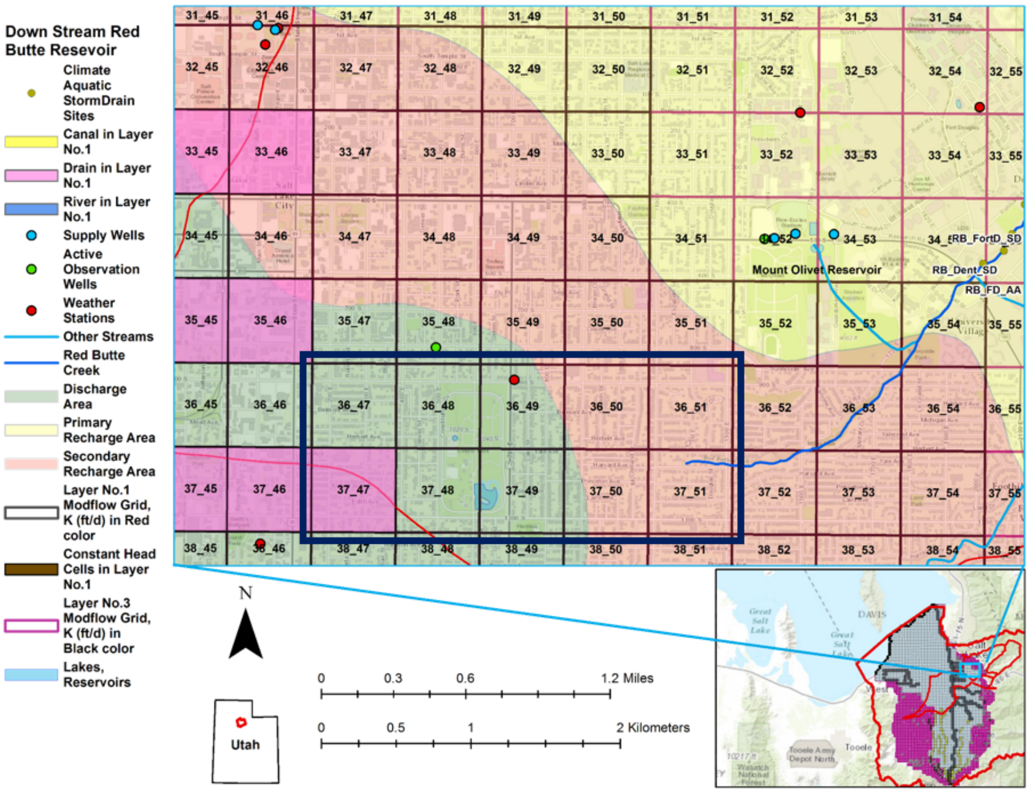


Figure 13. Grid of USGS MODFLOW implementation, and target area for grid refinement.

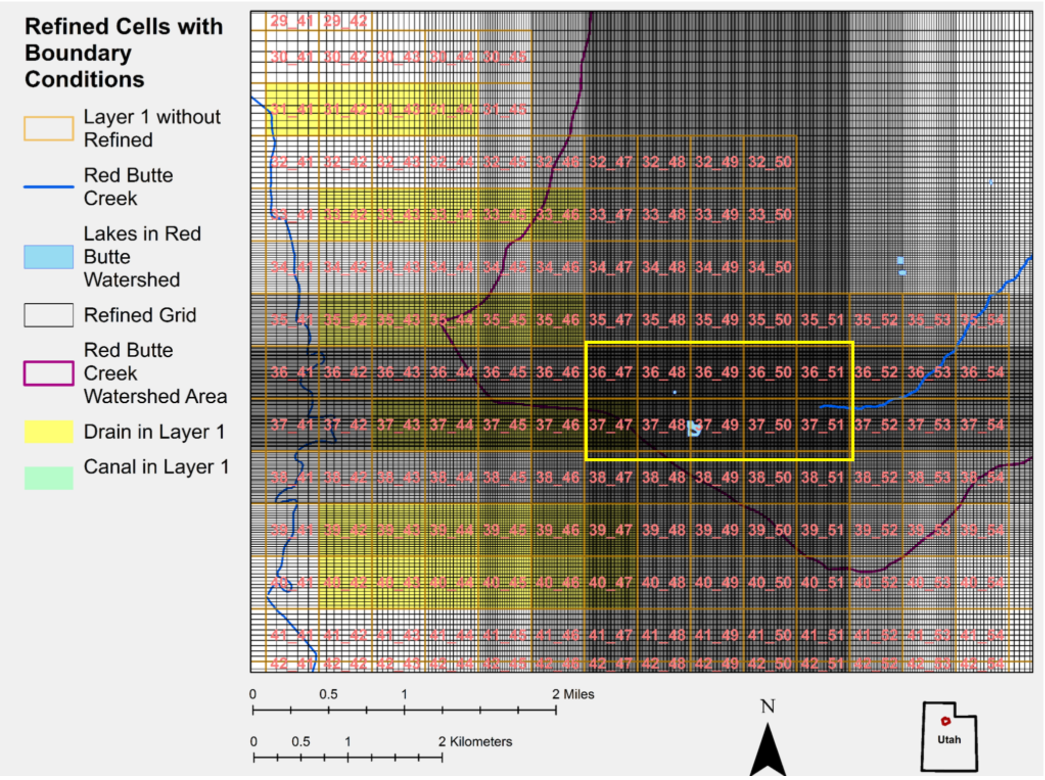


Figure 14. Refined MODFLOW mesh near location at which Red Butte Creek water enters the subsurface pipeline.

E. 3. Social science research. Results from Key Informant interviews completed to date (which do not reflect all perspectives and which are not yet based on a systematic coding and analysis of the transcripts) suggest that the awareness of, interest in, and use of various types of MAR/GI systems to capture and infiltrate stormwater varies widely across local stormwater program managers in Utah. Most respondents have heard and seen examples of all five types of practices explored in the interviews, but conventional extended detention ponds (and, in some cases, traditional piped systems) are still the dominant method used to manage stormwater in Utah communities.

There is a growing understanding of and interest in methods to use distributed systems to capture stormwater on-site using both above-ground (rain garden, bioswale, tree box) and below-ground (D-blocks, R-tanks, shallow vaults and dry wells) technologies. However, a number of concerns were expressed about the suitability and effectiveness of some of these practices at managing the multiple goals of stormwater managers (preventing flooding, protecting surface and ground water quality, and enhancing local water supplies). We have information about the perceived advantages and disadvantages of each of the various MAR/GI stormwater management options included in the interviews. Drivers of interest in these two types of MAR/GI practices is overwhelmingly coming from perceptions about future state and federal regulatory requirements – the most rapid rate of adoption is in places where managers are convinced that this will soon be required and they wanted to get ahead of the curve.

Relatively few of our informants see deep dry wells as a viable method to manage stormwater in this area. They reported strong concerns about the potential for contamination of groundwater aquifers that are the source of most municipal drinking water in this region. They also feel that local governments are not in a good position to assess the safety or reliability of these technologies and suggest that state regulation and oversight is probably required.

To date, concerns about potential groundwater contamination from any of the infiltration-oriented MAR/GI systems included in the interviews outweighed perceived advantages relative to boosting scarce potable water supplies (no one saw them as meaningfully contributing to potable water reserves). However, a few respondents felt that they could see ways that shallow aquifer recharge might be able to be recovered in a manner that could be used for non-potable uses 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.

E. 4. Key Findings

Research Component 1 – Based on existing MAR/GI system monitoring that has taken place during Year 1, 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 be carried out in Year 2 to evaluate potential relationships between pollutant concentrations and rainfall event return periods. For the two sites treating primarily pavement runoff (300 East in Logan and the Salt Lake City Public Utility parking lot site), overlapping 95% Confidence Intervals of measured runoff pollutant concentrations indicate that the only parameter different between the two sites is Total P, which is significantly higher at the 300 East site, adjacent to landscaped areas, compared to the Public Utilities parking lot site. Monitoring results from the major stormwater discharge channel at 1300 South in Salt Lake City indicate that stormwater channel concentrations are enriched only in DOC, chromium and nickel in response to storm events, and that this stormwater discharge represents a significant contributor of Total P, DOC, and chromium to the Jordan River during wet weather conditions. Monitoring of pollutant generation from various roof materials indicates that both the PV and metal roofs generate pH values higher than the membrane roof, while for the metal roof, iron and nickel are higher and copper and lead appear lower than the membrane roof. Unexpectedly high lead levels generated by the membrane roof system will be evaluated further in Year 2 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 lead. Finally, elevated levels of DOC and arsenic were found in 300 East 24-inch deep pore water samples suggesting the biostimulation of arsenic reduction in this bioswale system.

Research Component 2 – A wide range of rainfall/runoff, surface water, groundwater and vadose zone models must be used and integrated to model the complex problem of evaluating MAR/GI impacts of stormwater capture and groundwater recharge on surface water/groundwater quality and ecosystem services. Standard model configuration will generally have to be modified to adequately accommodate small scale MAR/GI systems that might be implemented across a watershed. Snowmelt simulation is important to incorporate into surface flow modeling to effectively capture spring runoff events.

Research Component 3 - There is a growing understanding of and interest in methods to use distributed systems to capture stormwater on-site, and although deep dry wells are of most concern to the Key Informants, concerns about potential groundwater contamination from any of the infiltration-oriented MAR/GI systems included in the interviews outweighed perceived advantages relative to boosting scarce potable water supplies.

F. Planned Activities for the Subsequent Reporting Period

F. 1. MAR/GI system monitoring. Both additional sampling locations at existing sites, and expansion of the system monitoring network with additional sites are planned for the second year of the project. Additional sampling locations at the Green Meadow field demonstration site will include the placement of paired suction cup soil pore water samplers at 6 and 24-inch depths in replicate plots vegetated with cattail, sedge, and sunflower species. These additional sampling locations will allow comparison of the performance of GI/MAR systems as a function of vegetation type across turf at the 300 East site and the three common GI plant species at the Green Meadows site. Additional roof samples will also be collected during Year 2 to investigate potential sources of lead in the roof drain piping used to convey membrane roof drainage into adjacent dry wells. Additional field site locations will include several dry wells and a green roof at the USU campus, an additional field bioretention study site at the University of Utah campus evaluating the pollutant removal performance of an additional range of Utah native plant species, deep dry well systems installed at the Daybreak Community in Salt Lake Valley, and shallow infiltration systems (D-blocks) installed throughout the City of Spanish Fork in the Utah Valley south of Salt Lake City. The Daybreak and Spanish Fork sampling sites were identified from interactions with the project’s Stakeholder Advisory Committee.

The relationship between elevated DOC and arsenic mobilization at the 300 East site will be verified in Year 2, DOC and arsenic releases will be monitored at the field bioretention test site being constructed at the University of Utah. Baseline soil conditions (total arsenic, labile arsenic, etc.) will be quantified in both the 300 East and University of Utah field bioretention site to determine the predictability of potential arsenic mobility in MAR/GI stormwater management system.

In addition, disaggregation of pollutant loading data from the field sites to explore relationships between pollutant concentrations and storm intensity and duration will be carried out 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 Technical Advisory Committee (TAC) 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 TAC. 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 TAC will be carried out during Year 2 of the project, however, to provide TAC members with deep dry well performance data from the literature, as well as from dry wells in the Cache and Salt Lake Valleys collected by this project, to answer questions they have regarding groundwater contamination potential and required pre-treatment controls to ensure groundwater protection.

The MODFLOW mesh in the area where the simulation of shallow infiltration MAR/GI systems will be implemented will be refined to accommodate block scale systems. Refinement requires modifying other input data, and adequately matching the heads, volume balances, and flow rates (river-aquifer and drain-aquifer seepage, and evapotranspiration), computed by the USGS MODFLOW implementation at a scale relevant to these MAR/GI system configurations (38.5 ft x 38.5 ft horizontal dimension). After refining the MODFLOW grid near the Cottam Grove station, and validating the refined model, assumed seepage rates between aquifers and the RBC and Jordan River will be evaluated, and requirements for changing nearby MODFLOW boundary conditions will be determined. USGS MODFLOW implementation specifies aquifer recharge through permeable materials beneath RBC. From a volume balance of the upstream watershed, the quantity of groundwater flowing downgradient near the Cottam Grove station will be estimated. That groundwater flow estimate will be used to define boundary inflows in the area (see MODFLOW cell with dashed red boundary, just upstream of Cottams Grove in Figure 7).

Simultaneously with above activities, a new concept for optimizing sustainable groundwater use strategies that have specified resilience to adverse climatic conditions will be tested. Concerns were expressed by members of the TAC regarding water rights and the ability of municipal governments to recover stormwater temporarily stored in shallow aquifer systems via MAR/GI systems, and modeling techniques that have been developed for single well injection/recovery analysis will be modified to address areal injection (via MAR/GI systems) and single or multiple well recovery. This modeling approach will be applied to a small hypothetical area within the RBC watershed to enable operational parameters to be modeled to ensure the recovery of only that stormwater captured and "stored" during a single season so that others existing water rights are not compromised due to MAR/GI system stormwater harvesting. This storage/recovery assessment technique will be implemented it for the entire Salt Lake Valley aquifer once the approach is validated, assuming widespread MAR/GI system implementation.

We have not yet considered contaminant transport or mass loading within runoff simulations. After flow simulation have been satisfactorily calibrated and validated, contaminant loading and transport calibration/validation will be completed.

The development of a WINSLAMM model for the urban portion of the RBC watershed is underway and is to be completed during Year 2 of the project. Three small urban watersheds in Logan, Utah, are being used for initial WINSLAMM pollutant loading calibration. These watersheds are being monitored as part of a related iUTAH project and provide continuous data for stormwater runoff volume, turbidity, pH, and total phosphorous for a range of mixed use urban land uses, and provide a means of verifying pollutant load versus land use correlations that are an integral part of the WINSLAMM model. In addition, data being collected from the 1300 South stormwater discharge into the Jordan River provides a continuous flow and water quality data stream from the iUTAH GAMUT monitoring network along with grab samples collected by this project (Year 1 raw data located in Appendix A) to enable validation of the calibrated WINSLAMM model using an independent data set from a much larger (25 square mile), much more diverse land use area in the Salt Lake watershed. 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 the latter half of Year 2 and in 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.

Vadose zone simulations will begin during Year 2 of the project. With input from WINSLAMM, HYDRUS will be used to simulate infiltration, deep percolation to the water table, and contaminant transport and transformation in the unsaturated zone in areas below locations of MAR/GI implementation. As discussed above, MODFLOW and MT3DMS will be used to simulate groundwater flow and saturated zone contaminant transport and transformation. To more accurately represent the impact of aquifer recharge by stormwater near water supply wells, a finer spatial discretization than the USGS MODFLOW implementation by Lambert (1995) (1/3 mile x 1/3 mile) must also be used.

Baseline ecosystem services for the RBC and Jordan River will be quantified using metrics listed in Table 1 during Year 2 of the project. An existing QUAL2K model of the Jordan River will be updated using more recent continuous monitoring data available for the Jordan River, and a similar QUAL2K model for Red Butte Creek will be completed, using both current climate conditions and future climate change predictions. Stormwater management has effects on ecosystem services, and changes in these ecosystem services related to various MAR/GI stormwater management strategies will be evaluated beginning in Year 2 of the project in close collaboration with the WINSLAMM, and vadose zone/saturated zone model effort discussed above. Output from the groundwater modeling effort related to surface water recharge and pollutant loading from groundwater 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 consistent ecosystem services metrics. In Year 3, an optimization model will be developed 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. Year 2 activities to be conducted as part of Component 3 will involve on-going interactions with stakeholders, and expansion of Key Informant and stakeholder surveys. A Stakeholder Advisory Committee (SAC) meeting, involving nine key stakeholders, was convened in October 2016, to review project goals and objectives, to solicit input from the SAC regarding additions to our Key Informant pool, to provide input on research plans and emphases, and to plan for future SAC meetings during Year 2 of the project period. This October 2016 was instrumental in identifying other Stakeholder groups that should be included in the project SAC, in identifying additional MAR/GI field sites to be monitored in Year 2 of the project, and in helping reprioritize the modeling effort to be carried out in Year 2 of the project.

Additional Year 2 activities in the social science Component 3 portion of the project will include: 1) completion of Key Informant interviews, transcriptions of interview recordings, and systematic coding and analysis of interview transcripts; 2) development and implementation of an on-line survey instrument to validate results of the Key Informant interviews among a larger population of municipal stormwater managers; and 3) organization of a second SAC meeting in Spring 2017 to update the SAC on findings from Components 1 and 2, to review the outcome of Key Informant Interviews and on-line survey results to date, and to solicit recommendations on locations for community public focus group meetings where MAR/GI systems have been implemented.

G. Publications

No new publications have been generated in the completion of Year 1 project activities. A number of conference presentations have been completed by the project team, and citations for these have been previously submitted to the EPA Project Officer.

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