iUTAH Response

to the 2015 (Year 4) Reverse Site Visit Report

RII Award OIA-1208732

Michelle Baker, Ph.D., Project Director and Principal Investigator

Compiled by: Andreas Leidolf, Assistant Director and Project Administrator

Submitted: 23 November 2015

BACKGROUND AND INTRODUCTION

As part of its oversight of Research Infrastructure Improvement (RII) Cooperative Agreements, the National Science Foundation (NSF) invited iUTAH to a Reverse Site Visit (RSV) at NSF headquarters in Arlington, Virginia, on September 10, 2015, during year 4 of the iUTAH project. The RSV provided iUTAH an opportunity to submit a detailed overview of progress relative to established goals and objectives; to report on results, accomplishments, and impacts to date; and to discuss plans for the future sustainability of its research, education, outreach and diversity programs. A panel of independent experts was asked to provide formative and summative assessment of iUTAH's activities based on presentations given by iUTAH researchers and project office staff. The RSV review panel's report was made available to iUTAH on October 23, 2015. In its report, the review panel assessed both strengths and weaknesses of each of the research focus areas (RFAs) and other project elements of the iUTAH research project; and revisited recommendations from the prior RSV on September 25, 2013; culminating in four recommendations intended to benefit the continued success and long-term sustainability of iUTAH. In this document, we detail iUTAH's response to each of these recommendations by outlining specific actions to be taken, key personnel responsible for implementation, and associated timelines for completion.

NSF RSV PANEL RECOMMENDATIONS

1. iUTAH would benefit from explicitly stating how the theoretical foundations and contributions of the team's work will have intellectual significance beyond Utah.

    a) Explain how future endeavors and work to date on theoretical foundations and frameworks will be applicable regionally, nationally, or globally. Describe what theoretically motivated questions the iUTAH data-collection and data-analyses efforts will answer.

    b) Submit a plan for ensuring that the theoretical social science contributions regarding landscape transition and transformation build on progress to date, and that research findings will be disseminated, especially to the scientific community through peer-reviewed publications.

2. Develop a project-wide plan for ensuring the most significant lines of

interdisciplinary inquiry are completed during the remaining project period. This plan should:

a) Ensure that projects focusing on the coupling of natural and human systems are completed;

b) Establish mechanisms for effectively disseminating research results and key findings from across the research focus areas (especially from interdisciplinary investigations) and ensure that they are identified for publication in peer-reviewed journals; and,

c) Identify candidate high-impact high-visibility journals for submitting high-impact research results.

3. While hydrological processes are central to the iUTAH project goals and objectives, it is not apparent that the necessary data, modeling, or expertise have or will take place to address these questions. This issue was raised by the first RSV panel and has not been adequately addressed. Develop a strategy for expanding research capacity in groundwater hydrology, either through team members or collaborations, to ensure that iUTAH has appropriate expertise to address the major research goals that involve hydrological processes.

4. Submit a plan for sustaining project activities and infrastructure beyond the period of the RII Track-1 funding. Address in particular the strategies for:

   a) Securing funding to sustain key infrastructure such as observations in GAMUT and cyberinfrastructure facilities; and,

   b) Submitting proposals to secure funding for research; the plan should specifically address future calls for multidisciplinary and complex collaborative research efforts that would both build on and sustain elements of iUTAH accomplishments.

<u>iUTAH EPSCoR RESPONSE</u>

Recommendation 1—Explicitly state how the theoretical foundations and contributions of the team's work will have intellectual significance beyond Utah.

Explain how future endeavors and work to date on theoretical foundations and frameworks will be applicable regionally, nationally, or globally. Describe what *theoretically motivated questions the iUTAH data-collection and data-analyses efforts will answer.*

RFA1. Our observational and modeling capabilities are designed to address a common knowledge gap in how precipitation is partitioned to both plants and surface water resources: "*How is the amount, routing, and residence time of water related to the biogeophysical structure of the landscape?*" Addressing this question requires coordination among hydrologic subdisciplines and interfacing sciences. Our aim is to catalyze rapid progress in understanding current landscape structure and predicting how climate and land cover changes will affect hydrologic partitioning.

Specifically, Brooks et al. (2015) posed four challenges for the hydrological and water resource community geared both towards improving theoretical understanding of hydrologic partitioning and developing applied, operational hydrologic models useful in a rapidly changing world:

1) Identify the interactions between terrain, lithology, vegetation, and water that control subsurface weathering and allow prediction of subsurface structure. This represents an ongoing, multi-disciplinary effort to understand how and why structure develops. 2) Quantify the amount, residence time, and movement of subsurface water to better predict plant available water and stream flow generation. This work will utilize the growing knowledge on how subsurface structure develops to reconcile ongoing disciplinary questions, including partitioning of plant water sources and the rapid release of stored water. 3) Evaluate the role of terrain complexity in modifying microclimatic influences on water demand. Combined with improved understanding of where plants obtain water, this work will address when and where partitioning to vapor flux is under primary control of subsurface supply vs. climatic demand. 4) Develop focused or targeted observations across a larger range of spatial scales to place site-specific work in regional context. These efforts will use the patterns associated with the rapidly increasing spatial and temporal data on landscape structure to predict dominant processes/controls and thereby sensitivity to change in the vast majority of locations that are not extensively instrumented and studied.

To address these challenges, hydrologists must view colleagues in related fields as stakeholders who help define the spatial and temporal scales of research, which often may be outside those typically used in disciplinary research. In this way, we collaborate with the broader community to advance basic hydrological theory and provide consistent and widely transferrable information to societal stakeholders charged with decision-making in a rapidly changing world[1].

RFA2. Work in iUTAH's social/engineered systems group builds on a broad theoretical framework that recognizes the importance of structural settings on processes of social change and land/water management behaviors. As we noted in our RSV presentation, our social science team believes that individual and organizational water perceptions and behaviors (and land use decisions) are enabled and constrained by natural, engineered, and social structures. Examples of social structures include the relatively stable arrangements or relationships within society (culture, institutions, social stratification) that interact to shape water (and land) use behaviors. In our theoretical model, culture includes shared norms and values; institutional aspects include formal social arrangements (e.g., laws, policies, organizational operational rules and procedures, property rights) and informal social institutions (e.g., churches, families, civil society groups); and social stratification captures the importance of structural drivers including class, gender, ethnic/racial identity, and place of origin.

One key aspect of our theoretical approach is to recognize the importance of governance arrangements in the study of water use and land management across our study areas. A number of our efforts are aimed at documenting the diverse institutional, policy, and governance discourse settings across the Wasatch Range Metropolitan Area (WRMA). Another key focus is the exploration of the role of natural biophysical structure or ecological conditions in shaping human perceptions and environmental behaviors. A number of our projects are assessing how 'objective' indicators of landscape ecological quality are or are not related to 'subjective' perceptions of water resource conditions.

In each case, the lessons learned in the WRMA will directly speak to the dynamics of coupled water systems in cities located along snowmelt-dependent mountain systems in the American West (and in other similar semi-arid regions). However, the results have broader applicability to integrated social-natural systems theory that transcends the specifics of the study area. Our current and planned RFA2 publications (described later in this document) use broader social science and

---

[1] Brooks, P.D., J. Chorover, Y. Fan, S.E. Godsey, R.M. Maxwell, J.P. McNamara, and C. Tague. 2015. Hydrological partitioning in the critical zone: recent advances and opportunities for developing transferable understanding of water cycle dynamics. Water Resources Research 51, doi:10.1002/2015WR017039.

geographic theory to motivate the empirical research. Implications for the larger intellectual community are highlighted. Ultimately, we hope that the integrated research and conceptual models developed by iUTAH will be known as exemplars of excellent coupled systems theory and scientific research.

RFA3. Through project-wide collaboration, iUTAH has produced a comprehensive conceptual framework for the study of water. Referred to as iSAW (integrating Structure, Actors, and Water to study socio-hydro-ecological systems, Figure 1), the framework achieved three main objectives: i) to develop an interdisciplinary framework for water resources research and management that is flexible and capable of focusing on water issues across scales (e.g., city to region) and domains (e.g., water quantity and quality, transitioning, and urban landscapes); ii) to identify a common ground and facilitate collaborations by providing a nexus for building a shared understanding of the complex water system in which we are collaboratively conducting research; and iii) to recognize key components and linkages within human–water systems to identify and address knowledge gaps and guide collaborative research designs. The iSAW framework provides a generalized conceptual model that identifies key biophysical and social components and linkages, as well as a roadmap for coupled human-water systems research that can help to guide future interdisciplinary work addressing water management problems and other natural resource issues. The intellectual merit of this framework was published in *Earth's Future* in 2015 (Hale et al. 2015[2]). The ongoing modeling activities of iUTAH are based on the iSAW framework, and the iSAW framework is applicable to address water issues in other regions and natural resource domains beyond water.

---

[2] Hale, R.L., A. Armstrong, M.A. Baker, S. Bedingfield, D. Betts, C. Buahin, M. Buchert, T. Crowl, R.R. Dupont, J.R. Ehleringer, J. Endter-Wada, C. Flint, J. Grant, S. Hinners, J.S. Horsburgh, D. Jackson-Smith, A.S. Jones, C. Licon, S.E. Null, A, Odame, D.E. Pataki, D. Rosenberg, M. Runburg, P. Stoker, and C. Strong. 2015. iSAW: Integrating Structure, Actors, and Water to study socio-Hydro-ecological systems. *Earth's Future*, doi: 10.1002/2014EF000295.

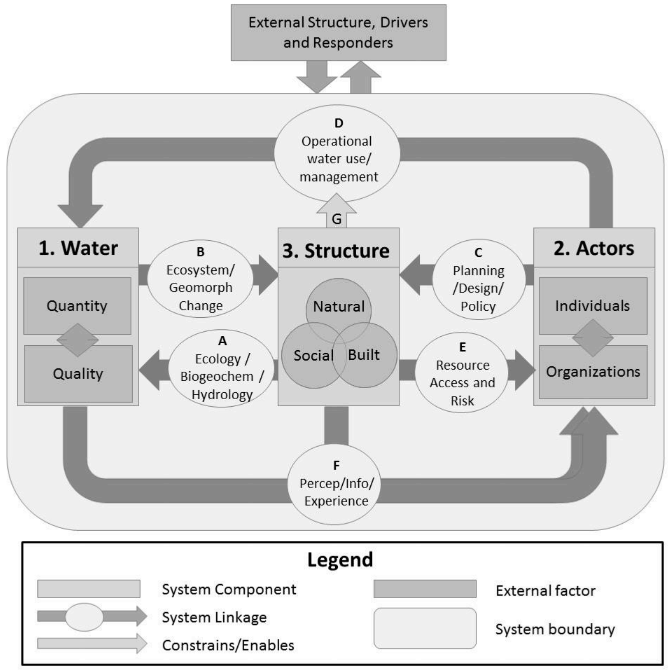

Figure 1.The iSAW conceptual framework (Hale et al. 2015).

The associated manuscript has averaged more than ten reads per month on ResearchGate (http://researchgate.net) since its publication in February 2015. Intellectual challenges of coupled modeling include i) representing processes (often non-linear) for which we have incomplete understanding and information, and ii) linking processes through models that operate at different spatial and temporal scales. We are currently testing and addressing these challenges in multiple ways. First, we are chaining models with disparate spatial and temporal resolution and extent. Ongoing work includes using Weather Research and Forecasting (WRF) climate modeling and data (Strong et al. 2014[3]; Scalzitti et al., *in review*[4]) as input to a rainfall-runoff model (Betts et al., *in prep.*), which will in turn provide groundwater estimates for future climate models. We are also testing software component interfaces to model linkages and feedbacks between future land use alternatives and stormwater management (Buahin and Horsburgh, *in prep.*). While these model applications are developed for Utah,

---

[3] Strong, C., A. Kochanski, and E. Crosman. 2014. A slab model of the Great Salt Lake for regional climate simulation. *Journal of Advances in Modeling Earth Systems*, **06**, doi: 10.1002/2014MS000305.

[4] Scalzitti J., C. Strong, and A. Kochanski. *In review*. A 26-year high-resolution dynamical downscaling over the Wasatch Mountains: synoptic effects on winter precipitation performance. *Journal of Geophysical Research-Atmospheres.*

emerging methods to couple water system linkages and feedbacks are novel and can be applied elsewhere.

Our postdoctoral research associate focused on coupled human-natural system modeling, Krishna Khatri, is an engineer with two decades of professional and academic experience modeling water resources from the perspective of risk and uncertainty analysis. He has posed and will pursue over the next two years a series of theoretically motivated questions aimed at developing globally applicable methods for studying and managing water in coupled human and natural systems (CHANS): i) How do we develop a comprehensive framework for defining and achieving resilient CHANS; ii) What novel approaches are needed to support decision making in CHANS faced with multiple sources of compounding uncertainty; and iii) How should we quantify resilience in a sociotechnical system, and what are the adaptation pathways available in transitioning to resilience?

The conceptual and modeling frameworks that Dr. Khatri is developing will present a methodology for analyzing the main attributes of CHANS that address system complexities and uncertainties, leading to quantitative approaches for defining and incorporating resiliency in a system. The research advances addressing dynamics of sociotechnical systems; dealing with the deep uncertainties due to the future change pressures (social and climate changes) and system complexity; and quantifying resilience in a complex system; will have significant contributions in the areas of CHANS and should be applicable to any sociotechnical system and at any scale/region.

Cyberinfrastructure. The iUTAH Cyberinfrastructure (CI) Team is advancing innovative cyberinfrastructure that addresses current challenges in collaborative data collection, management, visualization, and analysis within a large and diverse research group. These challenges are not unique to iUTAH. Other major research and observatory efforts such as the Critical Zone Observatories (CZOs), Long Term Ecological Research (LTER) sites, Water Sustainability and Climate watersheds (WSC), and other groups are grappling with the same challenges, including how to build an effective cyberinfrastructure that enables standardized data collection, management, and sharing across a network of aquatic and terrestrial sites managed by a consortium of disparate organizations.

Within this space, the iUTAH CI Team is well aligned (via participation and leadership) with ongoing cyberinfrastructure development projects such as the CZO Integrated Data Management System (CZOData); the Consortium of

Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), Hydrologic Information System (HIS), and HydroShare projects; the Community-Driven BiG CZ Software System for Integration and Analysis of Bio- and Geoscience Data in the Critical Zone (BiG CZ); the Observations Data Model Version 2 (ODM2) project; and others. Given our involvement across these projects, we are adopting and extending existing work for iUTAH's cyberinfrastructure, with feedback and cross-pollination with these others efforts. Because of this, the work of the iUTAH CI Team has already had a lasting intellectual significance beyond iUTAH.

The following is a snapshot of how work to date has generated intellectual contributions:

1. We have demonstrated how to adapt the conceptual underpinnings and software stack from the CUAHSI HIS (Horsburgh et al. 2009[5]) to store, manage, and publish an operational data store for the GAMUT environmental sensor network. In Jones et al. (2015)[6], we describe the hardware, software, and data workflow used to enable near real time, online availability of observational data from GAMUT network sites. We have captured this data in a general context that anyone needing to develop similar functionality could implement for managing streaming sensor data from environmental sensor networks. The iUTAH GAMUT implementation is interoperable with CUAHSI HIS and the Water Data Center, which gives it national and international significance.
2. In developing the iUTAH GAMUT data workflow and cyberinfrastructure, we realized the need for standardized and repeatable quality control of environmental sensor data across monitoring sites, watersheds, organizations, and technicians. This is a common challenge experienced by anyone who is collecting time series data from a large number of environmental sensors. In Horsburgh et al. (2015)[7], we describe an open-

---

[5] Horsburgh, J.S., D.G. Tarboton, M. Piasecki, D.R. Maidment, I. Zaslavsky, D. Valentine, and T. Whitenack. 2009. An integrated system for publishing environmental observations data. *Environmental Modeling and Software*, 24:879-888, doi:10.1016/j.envsoft.2009.01.002.

[6] Jones, A.S., J.S. Horsburgh, S.L. Reeder, M. Ramirez, and J. Caraballo. 2015. A data management and publication workflow for a large-scale, heterogeneous sensor network. *Environmental Monitoring and Assessment*, 187:348, doi:10.1007/s10661-015-4594-3.

[7] Horsburgh, J.S., S.L. Reeder, A.S. Jones, and J. Meline. 2015. Open source software for visualization and quality control of continuous hydrologic and water quality sensor data. *Environmental Modelling & Software*, 70:32-44, doi:10.1016/j.envsoft.2015.04.002.

source, Python-based software system for performing scripted quality control on environmental sensor data. This software preserves the provenance of data edits in a Python script that is automatically generated as users perform visual quality control editing via a graphical user interface. This software can be used by anyone that is managing time series of data from environmental sensors.

3. The work of the CI Team in collaboration with RFA3 has resulted in important new understanding of some of the technical challenges in coupling environmental models. In Buahin and Horsburgh (2015)[8], we describe some of the computational challenges of loose model coupling, including increases in simulation time and mass balance error that result as the number and complexity of coupled model components increases. We explore potential solutions, including loose coupling of models using variable time stepping options. We are now applying what we have learned to new, open-source software implementations of international standards such as the Open Modeling Interface (OpenMI) that enable decomposition of existing environmental models into simpler model components that can be re-composed into more holistic and accurate representations of water systems. These new developments will be of interest to the international component-based modeling community.
4. The CI Team has also teamed up with researchers from RFA2 to design and develop specialized software and visualization techniques for providing web-based visualization of social science survey data. Our specific use case for iUTAH was a presentation of results from the RFA2 survey of water-related questions that was administered to a large, random sample of Utah adults in public venues via iPads. However, the open source software we developed is capable of displaying results from any quantitative survey using a variety of visualization techniques (Jones et al., *in review*[9]). The software is generalizable and can be reused by anyone wishing to implement visualization of quantitative social science survey data, which is an important class of social science data.

---

[8] Buahin, C.A., and J.S. Horsburgh. 2015. Evaluating the simulation times and mass balance errors of component-based models: an application of OpenMI 2.0 to an urban stormwater system. *Environmental Modelling & Software*, 72:92-109, doi:10.1016/j.envsoft.2015.07.003.

[9] Jones, A.S., J.S. Horsburgh, D. Jackson-Smith, M. Ramirez, C.G. Flint, and J. Caraballo. *In review*. A Web-based, interactive visualization tool for social environmental survey data. *Environmental Modelling & Software.*

As we move into the last two years of the project, the CI Team will continue to support the data management, analysis, and visualization needs of both RFA1 and GAMUT, as well as RFA2 and the social science datasets. We will also focus on enabling iUTAH researchers to publish their finished datasets. The following areas will receive particular attention:

1. We will develop software, data models, and workflows for enabling collection, management, and publication of environmental observations derived from physical samples. Over the past two years, large numbers of water quality samples have been collected and are now in the process of being analyzed for integration with the continuous GAMUT data. We will leverage developments from ODM2 (Horsburgh et al. 2015b[10]) and CZOData to facilitate integration of sample-based observations with continuous sensor data from GAMUT. We will work synergistically with these projects to advance the cyberinfrastructure available for managing data within large scale environmental observatories like GAMUT and the CZOs.
2. We will continue our focus on advancing software technologies and technical approaches for enabling coupled modeling. Additional challenges to be addressed include the integration of component-based models with driving datasets, visualization of model inputs and outputs, and resolving temporal and spatial misalignment of coupled models. These challenges are all relevant to component-based modeling, which is an internationally active area of research.
3. Finally, we have already developed innovative functionality that enables iUTAH researchers to publish finished datasets via the iUTAH data repository (http://repository.iutahepscor.org). Moving forward, we will work with individual investigators and research groups to facilitate the publication of iUTAH datasets, which are now beginning to mature as graduate students are finishing their projects. By doing so, we will ensure that iUTAH datasets are published, citable, and well described with metadata so they can be reused, broadening the impact of iUTAH products. As part of our sustainability plan, we are also investigating partnerships with long term data archives, including the Utah State University Library, to

[10] Horsburgh, J.S., A.K. Aufdenkampe, E. Mayorga, K.A. Lehnert, L. Hsu, L. Song, A.S. Jones, S.G. Damiano, D.G. Tarboton, D. Valentine, I. Zaslavsky, and T. Whitenack. *In review*. Observations Data Model 2: A community information model for spatially discrete Earth observations. *Environmental Modelling & Software*.

ensure that we have a long term archival option for published iUTAH datasets.

Submit a plan for ensuring that the theoretical social science contributions regarding landscape transition and transformation build on progress to date and that research findings will be disseminated, especially to the scientific community through peer-reviewed publications.

Issues of landscape transition and transformation represent one of the more important foci for iUTAH's social/engineered systems group. A more focused manifestation of this broader theoretical/conceptual model is reflected in the theoretical basis for the models of landscape transition and change developed by iUTAH Ph.D. student Enjie Li. Her dissertation research draws from the social science, human geography, and policy and planning literatures to highlight the importance of various factors in the agricultural-to-urban landscape transition that is re-shaping the WRMA: i) biophysical landscape characteristics; ii) demographic pressures/change; iii) historic land use trends; and iV) local/regional planning and land use policies.

The biophysical characteristics of landscapes depict the potential constraints and drivers of certain types of land use changes, and help explain historical trends and spatial patterns affecting the WRMA landscape transformation. Also, through understanding the biophysical constraints of Utah's arid urbanizing landscape, an alternative planning strategy, conceptualized as "Water-Smart Growth Planning," is proposed to better adapt to the local biophysical environment, with emphasis on protecting Utah's water resource and directing growth in a more water-sustainable direction. By linking spatial land use data with census data, growth density distribution, and demographic changes in response to urban growth types and patterns, we will be able to understand how land use change affects demographic structures across different social communities. This analysis lays the foundation for simulating future land use change and informing policy choices. By analyzing WRMA's past 30-year (1987-2015) historical land use change, generalization of the land use trends will be used as baseline for predictive growth scenarios. Also, paired with data on local/regional planning and land use policies, historical land use records will be used to evaluate the effectiveness of past land use policies and planning strategies, and to guide future land use planning and policy-making.

The team working on landscape transition modeling is currently working on or has plans for up to six publications over the next two years. These include:

1. A manuscript using SLEUTH modeling and historic land use data to explore and visualize future land use change scenarios, and to investigate the performance and implications of various growth theories and planning policies in relation to linking land and water.

   Publication: "Water-Smart Growth Planning: Linking Water and Land in the Arid Urbanizing American West", submitted to the *Journal of Environmental Planning and Management* in September 2015.

2. A manuscript characterizing historical urban growth patterns across the WRMA over a 30-year time period, compare growth types across jurisdictional boundaries to assess how localities vary, seek to explain the mechanisms behind such differences, and contribute to urban growth theory.

   Publication: "Analyzing Urban Growth in Utah's Wasatch Range Metropolitan Area," to be submitted to a geography or urban journal (e.g., *Urban Geography*, *Cities*, or *Environment and Planning B*) in Spring 2016.

3. A manuscript analyzing the spatiotemporal dynamics of changing agricultural land uses under rapid regional urbanization, and contribute to theory about the relationships between agricultural and urban landscape transformations.

   Publication: "Transformation of Agricultural Land in the Face of Rapid 21st Century Urbanization: Are we Losing Ground?", to be submitted to *Land Use Policy* in Spring 2016.

4. A manuscript characterizing the spatial configurations of the WRMA's 30-year landscape transformation in the context of rapid urban growth and addressing agricultural adaptions to this urbanization; the goal is to identify examples and lessons learned about the co-existence of agriculture and urban development, and policy implications for future growth strategies.

   Publication: "The Good, the Bad, and the Ugly: 30 Years of Land Use Changes in Wasatch Range Metropolitan Area, Utah," to be submitted to a geography journal (e.g., *Applied Geography* or *Landscape and Urban Planning*) in Summer 2016.

5. A manuscript comparing and assessing the performances of three widely-used land use change models: SLEUTH, Artificial Neural Network, and Support Vector Machines, using Cache County, Utah as a case study.

   Publication: "Performance Comparison for SLEUTH, ANN, and SVM for Land Use Simulation," to be submitted to a land use modeling journal (e.g., *Computer, Environment, and Urban Systems*) in Fall 2016.

6. A manuscript coupling a land use model with a hydrologic model by using OpenMI Framework.

   Publication: "Land-use Impacts on Storm-runoff Generation: Scenarios of Land-use Change and Simulation of Hydrological Response," to be submitted to a water resources journal (e.g., *Water*, *Journal of Hydrology*) in Fall 2016.

Recommendation 2—Develop a project-wide plan for ensuring the most significant lines of interdisciplinary inquiry are completed during the remaining project period.

Ensure that projects focusing on the coupling of natural and human systems are completed.

Researchers in iUTAH's coupled human-natural systems group will ensure that projects focusing on the coupling of natural and human systems are completed by leveraging three complementary project assets described in subsections below. First, our new iUTAH *model inventory* provides a technically detailed catalogue of our existing and in-development modeling capabilities and has helped us visualize and organize discussions about model coupling opportunities and challenges. Second, the new iUTAH postdoctoral research fellow, Krishna Khatri, has outlined his *research agenda* for the remainder of the project to leverage his two decades of professional and academic experience using models to study water in coupled human and natural systems. Third, we will continue to expand our cross-campus *team interactions* focusing on model coupling through monthly videoconferences, regular workshops, conference breakout sessions, and targeted group collaborations. These activities span both top-down and bottom-up efforts initiated by, respectively, the RFA3 co-leads Courtenay Strong and Sarah Null, and individual RFA3 researchers, to ensure the most significant lines of interdisciplinary inquiry and modeling are completed during the remaining project.

Model Inventory. The new model inventory led by David Rosenberg includes summaries of responses to select participant questions and data visualizations that synthesize model attributes and coverage across the portfolio of at least twelve models currently active in iUTAH. The model inventory also compares current model couplings to potential couplings. The analysis revealed that many model couplings are possible. Pointed discussion among the team is planned to narrow the set of potential couplings to a few that are motivated by problems and use-cases that iUTAH can solve or address by deploying a select set of coupled models. The inventory also helped to identify the range of spatiotemporal resolutions employed by our various models, presenting opportunities for innovation using the iUTAH Model Coupling System developed by Tony Castronova at Utah State University.

Figure 2, taken from the inventory, shows the current suite of iUTAH models mapped onto the iSAW conceptual model (Figure 1). Vertical extent in the figure represents the number of models addressing each specific iSAW component or linkage and shows that our models cover all iSAW linkages and components, but that we have comparatively weak coverage in the Water Quality and Organizational Actor components as well as the PIE (perceptions, information, and experience) and Ecosystem/Geomorphic Change linkages. An app was also developed to interactively choose which models are shown on the iSAW model. This work builds from the iSAW conceptual model developed in year 2 of this project to identify and direct future coupled modeling research activities.

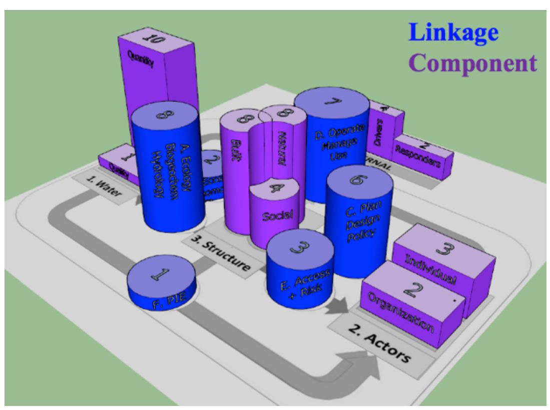

Figure 2.The current suite of iUTAH models mapped onto the iSAW conceptual model.

Postdoctoral Research on Coupled Human and Natural Systems (CHANS). Drawing motivation from the iSAW framework and its associated water research questions, Krishna Khatri is leading development of a modeling framework to simulate key dynamics of the CHANS relevant to sustainability outcomes. This work recognizes the need for a resilient system to address the challenges to be faced by rapid rates of urbanization, population growth, and climate change, including shifting societal expectations, new regulations, increasing water demand, and ecosystem changes.

Key research questions to be considered include: i) What will be a comprehensive framework for building a resilient CHANS; ii) How can we deal with the complexities associated to the CHANS; iii) What are the novel techniques for decision making under uncertainties; iv) How will plausible changes in the climate and other uncertain socio-economic factors impact long-term water availability (water quality and quantity); v) How can we quantify resilience in a sociotechnical system; vi) What could be the adaptation pathways towards a sustainable and resilient CHANS?.

This research activity will involve interfacing with ongoing modeling work in iUTAH and data provided by stakeholders (such as Western Water Assessment, Salt Lake City Department of Public Utilities [SLCDPU], and Utah Division of Water Quality [UDWQ]). It will apply the modeling outputs of climate change and extreme events analysis in the context of Utah and Salt Lake City; modeling results of land use changes developed by Enjie Li at Utah State University and University of Utah researcher Reid Ewing; socioeconomic forecasting by regional governmental institutions; and water demand data from SLCDPU. The work builds on a calibrated instantiation of the Environmental Protection Agency's (EPA) Hydrologic Simulation Program Fortran (HSPF) watershed model Khatri now has running at the University of Utah, along with plans to use the Water Evaluation and Planning (WEAP) System model for Salt Lake City and to further develop existing probabilistic models for other components of the analysis including water demand, uncertainty and resiliency. Courtenay Strong is serving as Khatri's mentor, and this work will progress through inter-campus collaborations across iUTAH and the active participation of key stakeholders (e.g., Erica Gaddis, UDWQ).

Team Interactions. iUTAH's coupled human-natural systems group will continue to build coupled modeling strength through monthly videoconferences coordinated and hosted by Martin Buchert of the University of Utah, along with our semi-annual conference breakout sessions with agendas set by RFA3 co-leads Sarah Null and Courtenay Strong in consultation with the modeling teams. Additionally, we will continue our series of coupled modeling workshops. In our February 2015 workshop, we discussed the challenges posed by our specific research questions and established collaborative teams focused on advancing specific modeling activities (e.g., several groups are now using growth models from Utah State University and the University of Utah to drive water demand and evapotranspiration in hydrologic models). Organized by Sarah Null, Courtenay Strong, and Martin Buchert, our 2016 workshop will provide opportunities for further advances in technical aspects of coupled modeling, along with panel-style dialogues with stakeholders, likely from the agricultural sector which was identified as an increasingly important research component during our 2015 workshop. Our initial workshop was well-received by participants because it provided time and space for RFA3 researchers to brainstorm and work together. In the initial workshop we identified modeling linkages (discussed previously in this document) that we are actively pursuing. We regularly communicate about opportunities to pursue continued external funding (e.g., NSF Innovations at the Nexus of Food, Energy and Water Systems), and the agenda for our 2017 workshop will include time for strategizing how we can most effectively leverage our mature modeling assets to address the most compelling emerging research questions.

Establish mechanisms for effectively disseminating research results and key findings from across the research focus areas (especially from interdisciplinary investigations); ensure that they are identified for publication in peer-reviewed journals; and identify candidate high-impact high-visibility journals for submitting high-impact research results.

Given the mature stage of the iUTAH project, now in year 4 of a 5-year research program, we find ourselves uniquely positioned to disseminate key findings of our faculty and student researchers to the scientific community and the public at large: with our integrated socio-environmental observatory fully built-out, and the second generation of iUTAH graduate students nearing completion of their degrees, we expect that publication of iUTAH's research results will increase exponentially over the next two years. While much of this happens organically within our cross-institutional and interdisciplinary research groups, iUTAH, through its Project Office and Leadership Team, has established several mechanisms to promote these activities. Weekly conference calls of the iUTAH Leadership Team have, over the past few months, focused regularly and consistently on articulating a project-wide strategy for impactful, synthetic, interdisciplinary contributions to the scientific literature on water systems. The iUTAH Project Office, by providing financial support for publication of iUTAH research and actively encouraging open access for these contributions, is also playing an important role in facilitating the effective dissemination of our work. Our All-Hands Meetings—conducted three times a year in Spring, Summer, and Fall—provide an important forum for our researchers to discuss ideas for manuscripts, and collaborate on writing projects. At the most recent All-Hands

Meeting on November 13, 2015 at the Natural History Museum of Utah in Salt Lake City, all three RFAs and the CI/GAMUT Team hosted breakouts focused entirely or in part on planning writing activities for the next year. Monthly conference calls held by all RFAs serve as an important venue for researchers to follow up with each other, discuss their progress, and solicit input on working manuscripts. Another critical mechanism for collaborative, synthetic writing projects are targeted workshops, such as those held by iUTAH's coupled human-natural systems group.

Collectively, these mechanisms have allowed us to develop a road map for dissemination of iUTAH's most impactful research over the course of the next two years. Topics or working titles, timelines for submission, lead authors, target outlets, and current status of these manuscripts are identified in Table 1.

Table 1. Plans for synthetic, interdisciplinary manuscripts through the end of 2016.

Topic/Working Title	Timeline for Submission	Lead Author(s)	Target Journal	Status
Evolution of the world's water towers: urbanization, climate change, and water resources along mountain fronts.	February 2016	Baker	Frontiers in Ecology and the Environment	In progress
Introducing the GAMUT water quality/quantity network	February 2016	Aanderud	BioScience Environmental Monitoring and Assessment Environmental Modelling & Software	In progress
Linking real-time GAMUT measurements with point measurements from synoptic sampling in the Red Butte Creek and Logan River watersheds	Fall 2016	Horsburgh	Water Resources Research	In planning stage
Linking urban typology and GAMUT data	Fall 2016	Jackson-Smith		In planning stage
Building collaboration in environmental research: a socio-eco-hydrological observatory for interdisciplinary water resources research	Spring or Summer 2016	Leidolf Brunson	Frontiers in Ecology and the Environment BioScience	In planning stage
As western cities grow, where will the water go?	Fall 2016	Jackson-Smith		In planning stage
Vulnerability to long term climate change	Fall 2016	Khatri	PNAS	

Recommendation 3— Develop a strategy for increasing research capacity in groundwater hydrology, either through team members or collaborations, to ensure that iUTAH has appropriate expertise to address the major research goals that involve hydrological processes.

Over the past year, iUTAH has been actively engaged in addressing the review panel's concern over insufficient research capacity in the area of groundwater hydrology. We agree with the panel that it is critical to include quantitative groundwater observations and modeling, not alone, but in close coordination with existing climate, surface water, ecohydrological, and hydrometeorological efforts. iUTAH's approach to understanding the hydrologic cycle and probing the influence of human activities on hydrological processes very much mirrors the theoretical foundations and frameworks being developed by scientists affiliated with NSF-funded CZO, the former Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) Science and Technology Center, and recent community efforts developed with NSF Hydrological Synthesis funding and through CUAHSI. Indeed, iUTAH's physical research infrastructure investments have been aimed at increasing our jurisdiction's capacity to compete for future CZO or similar observatory programs. Our observational and modeling capabilities in ecohydrology are designed to address a knowledge gap in how precipitation is partitioned to subsurface storage vs. plant and surface water resources – put simply, "What happens to a raindrop?" Fundamentally, addressing this knowledge gap requires answering the question "How is the amount, routing, and residence time of water in the subsurface related to the biogeophysical structure of the landscape?"

iUTAH's ecohydrology team has been tackling this and related questions, over the past several years, and the expertise in hydrologic science continues to grow and diversify. At the onset of the iUTAH project in 2012, and through the end of year 2 (including the timing of our first RSV), we had limited expertise in subsurface hydrology: key participants included Bethany Neilson and Michelle Baker, both of whom have experience measuring and modeling groundwater/surface water interactions; and Scott Jones, who is a soil physicist. Other participants included several experts in plant-water interactions, including Dave Bowling, Jim Ehleringer, Rick Gill, and Diane Pataki. While not directly funded by iUTAH, through collaboration via Utah's Track 2 project CI-WATER, iUTAH engaged Norm Jones, a GIS-based groundwater flow modeler.

Following the iUTAH leadership change at the end of year 2, iUTAH made efforts to address the first set of RSV recommendations by recruiting additional partners to enhance our expertise in hydrologic science, including experts in subsurface processes and water partitioning in the critical zone. These include Paul Brooks, a watershed hydrologist and biogeochemist with expertise in using hydrochemical signatures to understand the interactions among terrain, lithology, vegetation, and water as related to subsurface weathering rates and structure; Gabe Bowen, an earth scientist who uses stable isotope records to probe current and paleo water cycle dynamics at basin and continental scales; and Greg Carling, a hydrogeologist and low temperature geochemist with expertise in snow and groundwater geochemistry. An important collaborator from the United States Geological Survey (USGS), Matt Miller, a regional/basin scale hydrologist with expertise in baseflow estimation from continuous data, was also recruited to guide analysis of sensor output from aquatic GAMUT stations. Together, work by this team provides multiple windows into subsurface processes: geochemical tracers, ecohydrology, and geophysics. Additional expertise related to groundwater was also recruited to our social/engineered systems group: Ryan Dupont, an environmental engineer with expertise in soil and groundwater remediation, including the use of natural attenuation and bioaugmentation to enhance stormwater quality and subsurface storage; and Eric Edwards, an environmental economist whose work largely focuses on groundwater rights and collective action, as well as surface water markets.

Within the past few months, both leading into and following our recent RSV, iUTAH has continued to explore important collaborations to enhance our expertise in hydrological processes, particularly related to groundwater. Kip Solomon is a senior faculty member in Geology and Geophysics at the University of Utah, and a leading expert on mountain block recharge, with experience both locally in the WRMA, as well as worldwide. He is currently co-advising Ph.D. student Andrew Gelderloos on low dimensional models relating subsurface water storage to both evapotranspiration and streamflow, and is working with iUTAH to design novel seepage meters to complement existing observatory infrastructure. Larry Spangler, a hydrogeologist with the USGS, is an expert on karst hydrogeology, especially in the Bear River Range, where our Logan GAMUT stations are located. iUTAH (through Bethany Neilson) has arranged for a meeting and field trip with Dr. Spangler on December 4, 2015, during which we hope to pique his interest in collaborating with iUTAH in interpreting data from the Logan River. Finally, the College of Science at Utah State University, as part of a cluster hire in water science, recently opened a search for an expert in numerical modeling of groundwater systems, with particular interest in a new faculty member who can address issues of groundwater recharge and transport in relation to climate change. Michelle Baker is chair of this search, which has an application review date of December 11, 2015. We hope the new hire will start in July or August 2016 and may wish to engage with our modeling efforts in year 5 of our project.

Recommendation 4—Submit a plan for sustaining project activities and infrastructure beyond the period of the RII Track-1 funding.

Sustaining project activities and infrastructure beyond the period of Track-1 funding is a key objective for the iUTAH Leadership Team and project participants over the next 18 months. The Leadership Team is taking a multi-faceted approach to secure resources to sustain key research infrastructure that comprise the backbone of the iUTAH socio-environmental observatory (GAMUT, cyberinfrastructure, Green Infrastructure Research Facility, GIRF, and analytical laboratories). Our strategy includes working with the State EPSCoR committee and university government relations officers, university administrators, city and county stakeholders, and federal funding programs.

iUTAH has been engaging the State EPSCoR committee and university government relations officers with presentations and outreach documents since project inception. Several months ago, we prepared a 1-page iUTAH by-the-numbers fact sheet to communicate our accomplishments through year 3; developed a 2.5-page white paper with a description of key accomplishments needed for sustaining our successes; and drew up an itemized cost break-down for sustaining GAMUT and cyberinfrastructure. The Executive Committee of the State EPSCoR Committee has recently replaced the position of State EPSCoR Committee Chair with Paul Brooks of the University of Utah, who led the SAHRA Science and Technology Center in Arizona before relocating to Utah in 2014. Dr. Brooks was chosen because of his extensive experience in interacting with state and federal legislators, and because of his proven ability to effectively communicate iUTAH's sustainability needs to stakeholders and policy makers across our state. This appointment became effective on November 15, 2015, and will be followed by a meeting of the Executive Committee and State Chair with iUTAH leadership, scheduled for the first week of December 2015. We are confident that this will allow us to codify our strategy for a legislative request by iUTAH Project Director Dr. Michelle Baker with support from the iUTAH Leadership Team and State EPSCoR Committee Chair.

University administrators, in particular the Vice Presidents for Research (VPR) at Brigham Young University, the University of Utah, and Utah State University, have been unanimously supportive of iUTAH as a sustained presence in the state, and recognize the need for continued institutional collaboration moving forward. Toward that end, these administrators signed a memorandum of agreement in summer 2015.

Other institutional resources are also being pursued. Alan Harker, VPR at Brigham Young University, recognizes the importance of maintaining observatory infrastructure for his faculty, and has verbally committed to finding resources to maintain this foundation in subsequent years as NSF funds terminate. Similarly, Nancy Huntly, the Director of the Ecology Center at Utah State University, values the observatory infrastructure and has verbally indicated support in part to maintain the Logan GAMUT sites. iUTAH leadership is in conversation with these administrators and will pursue a memorandum of agreement to acquire partial or full support for technical maintenance of this core infrastructure. Timeline for such support will be negotiated by May 2016, as iUTAH leadership continues to work through the State EPSCoR Committee. Tom Parks, the VPR at the University of Utah, has already committed to sustaining technical support for the Red Butte Creek sites. Again, iUTAH Project Director Dr. Michelle Baker, with support from the iUTAH Leadership Team and State EPSCoR Committee, will work to formalize these commitments.

Over the past eight months, iUTAH researchers and the Leadership Team have been reaching out to a diverse group of local agency stakeholders to highlight our infrastructure, its potential utility to their needs, and to help frame research and modeling activities; in an effort to build community buy-in to the value-added nature and import of NSF's investment. These efforts have already led to several contracts from state and city/county agencies that expand on NSF's investment and have the potential to lead toward long-term sustainability of iUTAH's infrastructure. Utah State University, through the efforts of Jeff Horsburgh, is in the process of negotiating the installation of additional infrastructure in local canal systems in Logan City that are used both for agricultural and stormwater conveyance. The agreement would include support for technical staff to maintain new physical infrastructure and cyberinfrastructure. These ongoing negotiations are overseen by Drs. Horsburgh and Baker, with support from the iUTAH Leadership Team and State EPSCoR Committee.

iUTAH researchers and leadership are also pursuing external funds to maintain and expand the iUTAH infrastructure, both human and physical (Table 2), and collaborative culture (Table 3).

Table 2. Plans for interdisciplinary proposal submission to enhance and sustain iUTAH's physical and human infrastructure beyond 2017.

Targeted Program	**Proposal Timeline**	**Responsible Party**	**Proposal Theme**	**Proposal Status**	**Anticipated Output**
EPA STAR: Systems-based strategy to improve the nation's ability to plan and respond to water scarcity and drought due to climate change	Full proposal submitted 10/24/2014	Barber (PI)	Climate variation, eutrophication, and adaptation in urban watersheds	Funded (11/05/2015) $1,250,000	System-wide quality and quantity model of the Jordan River watershed (Salt Lake Valley) to improve sustainable planning efforts. Enhances/sustains iUTAH's coupled modeling and stakeholder engagement efforts.
NSF Research Experiences for Undergraduates Site	Full proposal submitted 08/26/2015	Baker (PI)	REU Site: Sustainable water- and air-sheds for cities (SWAC-REU)	In review $677,137	Site REU program to sustain iUTAH iFellows for another 5 years.
U.S. Army Research Office, BAA - Materials: Earth Materials and Processes	Full proposal due 12/11/2015	Pardyjak (PI)	The impact of the evolution and distribution of urban soil characteristics on land-atmosphere interactions	In preparation	Project would maintain collaborations in urban ET and continued use of the laser scintillometer and other equipment purchased in part with iUTAH resources
NSF Research Traineeship (NRT)	Letter of intent due 12/22/2015 Full proposal due 02/22/2016	Huntly (PI)	Climate adaptation	In preparation	Traineeship program would use the published iSAW model as means to enhance collaboration and graduate training in sustainability science.

Table 2. Continued.

Mountain Accord (Utah): Dashboard for the Wasatch Front	RFP anticipated with due date in December 2015	Bowen or Baker (PI)	Environmental monitoring program and dashboard for ecosystem health in Utah's Wasatch Range	In planning stage	Project would sustain iUTAH cyberinfrastructure and collaborations to assemble data sets on health of Wasatch Mountain Ecosystems
NSF Long-Term Ecological Research – new semi-arid site	Preliminary proposal due 02/02/2016	Bowling (PI)	Drought-sensitive montane ecosystems: controls of winter and summer precipitation on ecological processes	In planning stage	Would leverage/sustain montane iUTAH GAMUT stations in three watersheds.
NSF Long-Term Ecological Research – new semi-arid site	Preliminary proposal due 02/02/2016	Adler (PI)	Sagebrush-steppe	In planning stage	Would leverage iUTAH EOD programs and cyberinfrastructure.
NSF Science and Technology Centers: Integrative Partnerships	Preliminary proposal tentatively due 12/2016	Baker (PI)	Institute for Urban Air- and Hydro-Systems (iUTAH)	In planning stage	Would sustain iUTAH infrastructure (human and physical) while expanding to western US region and incorporating air quality

Table 3. Plans for interdisciplinary proposal submission by iUTAH participants that continue/sustain collaborations and/or extend methods developed by iUTAH participants in order to enhance our jurisdiction's profile in sustainability science, but that may not directly sustain physical infrastructure.

Targeted Program	Proposal Timeline	Responsible Party	Proposal Theme	Proposal Status	Anticipated Output
NSF Decision, Risk and Management Sciences	Full proposal submitted 8/18/2015	Flint (co-PI, lead for USU)	Changing community risk perception and action in response to forest insect disturbance in north-central Colorado	In review	Extends iUTAH social science methods to bark beetle disturbance in Colorado.
NSF Engineering Research Centers (ERC): Partnerships in Transformational Research, Education, and Technology	Pre-proposal submitted 10/24/2014	Tarboton (co-PI, lead for USU)	Engineering research center for regional water resource sensing and decision support (REWARDS)	In review	State-of-the-art water resource remote sensing instruments, platforms, algorithms, and decision support systems that enable us to monitor our water resource systems with unprecedented accuracy.
NSF Atmospheric Chemistry Program	Full proposal submitted 8/13/2015	Bowen (PI)	Collaborative Research: Combustion-derived vapor as a mediator of meteorology and air quality in the urban atmosphere	In review	Modeling and observational methods will be used to determine what fraction of urban water vapor arises from combustion, and how its accurate representation improves models of atmospheric chemistry.

Table 3. Continued.					
NSF Coupled Human and Natural Systems	Full proposal due 11/17/2015	Codding (PI)	Climate Change, Ecosystem dynamics, and traditional livelihoods in the piñon-juniper woodlands of southern Utah	In preparation	Proposal focuses on firewood collection by the Navajo people on piñon-juniper woodlands of Utah and how sustainable that is in a changing climate.
NSF Coupled Human and Natural Systems	Full proposal due 11/17/2015	Pataki (PI)	Gardening practices and the California drought: studying an unprecedented urban turf removal program from a systems perspective	In preparation	iUTAH collaborators would address adaptation to drought and ecosystem response in California