Urban Water Innovation Network

Transitioning toward sustainable urban water systems

National Science Foundation
WHERE DISCOVERIES BEGIN

Project A1-2

Impacts of Changes in Climate, Demographics, and Urban Form on Water Supply-Demand Equilibrium, Economic Growth, and Social Equity

PROJECT OUTPUTS

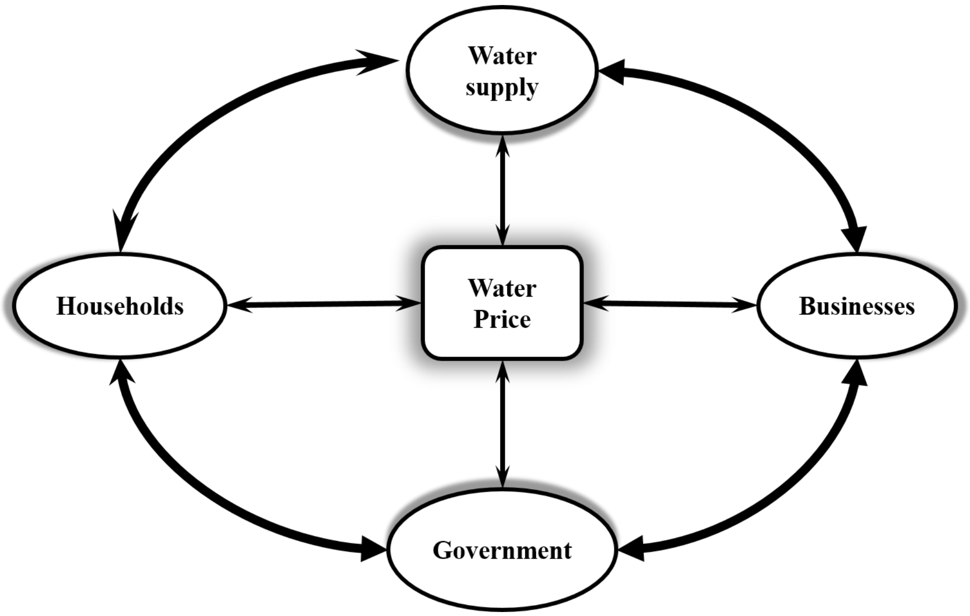
This project will work in tandem with Colorado State University and the IUWM (Project B1-1) to provide not only supply and demand forecasts for urban regions, but also identify the welfare impacts of particular policies and programs on communities and groups of interest.

This project will produce several deliverable materials including:

- Academic papers
- Data describing economic impact for all UWIN study regions
- Maps describing magnitude of economic impacts by region

This project evaluates the economic impacts of water price increases on household income, regional income, and regional employment.

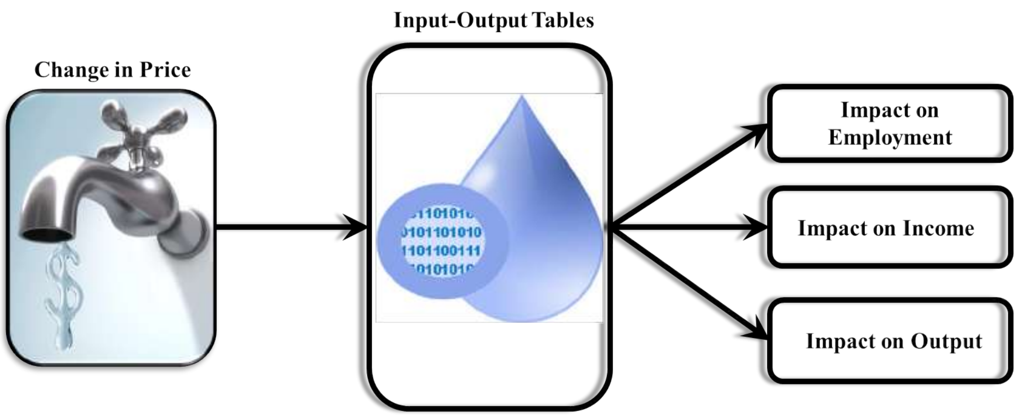
Impacts on business output will also be estimated. This is important to consider given pressures on urban water systems such as aging infrastructure, growing populations, and climate change. These pressures mean that water costs will rise and place economic strains on businesses and households.



From the business side, higher water costs could lead to increases in prices of inputs and salaries, and a lower willingness (and ability to pay) for business outputs by households. This strain on business outputs means that businesses may have to hire fewer workers. In other words, there is a vicious cycle between many elements of water: water supply, water demand, water prices, business income, and household income.

This project will try to understand and map the nature and magnitude of these feedback effects to better understand the impacts of water price trends on regional economics.

Input Output Modeling Overview Graphic



Input-output (IO) tables specify the purchases of households and industries from each other. This information is useful because it can help us understand the industries that use the most water and how changes in price and amount used affect people and businesses. IO tables also help us understand the cumulative impacts of price and use changes by quantifying total regional impacts in terms of income, employment and industry output adjustments.

A Los Angeles Department of Water and Power supervisor at the scene of a water main break in Hollywood in May. The 12-inch cast iron pipe was installed in 1931 (Al Seib / Los Angeles Times).

DATA REQUESTS

Data should be provided at the household level, anonymized to block level or with a truncated address. The following data will aid in the analysis:

- Water rate data by provider
- Information about consumer responses (in terms of spending) to changes in water prices
- Information about perceptions of water rates

DATA USE

Information about water rates and water rate trends will be used to understand variations in water rates within and across regions.

PROJECT KEYWORDS

- Water Rates
- Water Prices
- Economic Impacts
- Affordability

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Project A2-1
Land-Atmosphere-Hydrosphere Interactions in Urban Terrain

THE MODEL

The model consists of three coupled elements:

- Weather Research and Forecasting (WRF) atmospheric model
- ParFlow subsurface flow model
- Advanced Urban Canopy Model (UCM) for the urban surface (interface between atmosphere and subsurface) (Fig. 2).

These are highly complex models that require extensive computing and skill to execute. Thus they will be shared only within the scientific community.

However, based on these models' outputs, we could consider the development of simplified interactive tools that can help decision makers understand the benefits and consequences of certain actions and mitigation scenarios we have assessed in our work.

PROJECT KEYWORDS

- Urban Microclimate
- Urban Hydrology
- Urban Canopy
- Water Demand
- WRF & UCM models

The overarching aim of the project is to build the next-generation urban hydro-climatological simulation platform that will combine the state of the science in atmospheric, urban surface, and groundwater models.

Specifically, we will couple the Weather Research and Forecasting (WRF) atmospheric model with the ParFlow subsurface flow model. At the urban interface of these two domains, we will implement and further develop an Urban Canopy Model (UCM) that captures the wide range of radiative, thermodynamic, fluid dynamic, and hydrologic processes operating in urban terrain (Fig. 1).

The new simulation platform will have capabilities that are not available in any current model. Specifically, we aim to use the new model to assess:

- Water demand and cooling impact of canyon trees
- Total urban water demand and how it is modulated by weather
- Influence of surface-groundwater coupling and decoupling on the urban microclimate
- Complex water-climate-energy repercussions of green infrastructure systems (urban irrigation, rainwater tanks, biofiltration systems, green roofs, etc.)
- Thermal comfort in the urban outdoor space

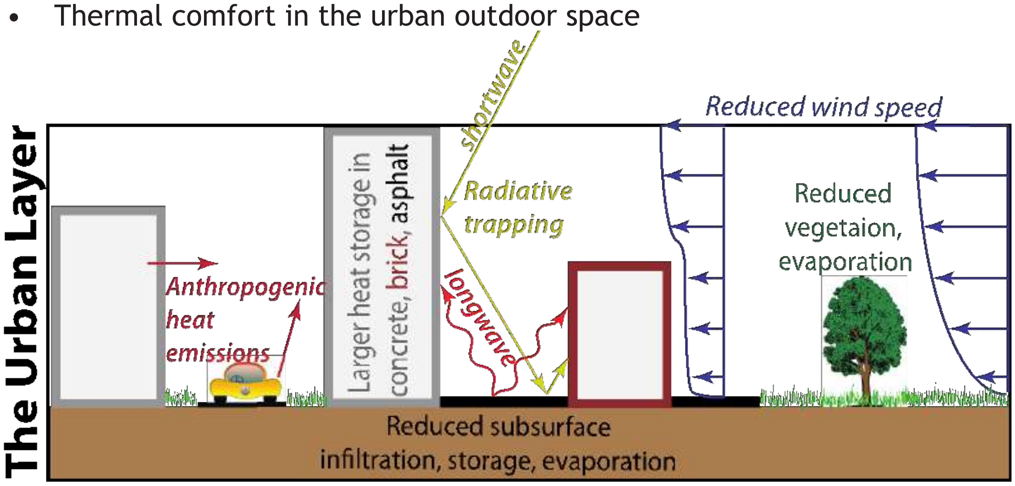

Figure 1. Hydro-climatic processes modified by the urbanization of the land surface

These applications will help us better understand urban sustainability under historic extreme events (e.g., heat waves, floods, droughts) and present conditions. Furthermore, the modeling advances will also be transferred to other teams who are focusing on the impact of future extreme events, and how the cities of the future can reduce their resource use and improve their resilience and sustainability.

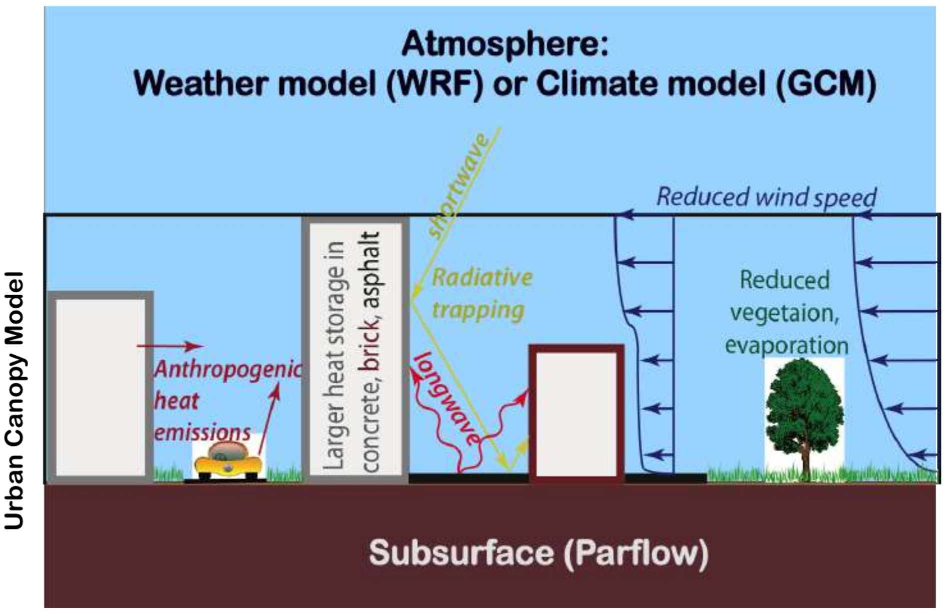

Figure 2: Coupled three models platform

The research team focuses on the urban environment under a changing climate, including land-atmosphere interactions, urban heat islands and the long-term sustainability of cities.

The team's primary objective is to advance the understanding of urban climate in the scientific community, as well as to foster sustainable urban development for future generations.

Dr. Bou-Zeid's current research specifically focuses on combining numerical, experimental, and analytical tools to study the basic dynamics of flow and transport in environmental systems.

Dr. Welty is interested in developing an end-to-end system of field-deployed sensors and fully coupled groundwater-surface water mathematical models to quantify and predict the urban hydrologic cycle and coupled biogeochemical cycles from neighborhood to regional scales.

Groups developing new technologies or interested in the assessment of existing ones can collaborate with this project to develop assessment studies for these technologies.

DATA REQUESTS

The project will require current and past land use data and data for urban water and energy consumption.

DATA USE

The data will be used as input to the simulations, and to develop mitigation scenarios.

OUTPUTS

The project deliverables can be categorized into:

1.) Advanced urban models that can be transferred to other groups and that allow the investigation of processes and mitigation options that have thus far been over-simplified in models such as urban trees and subsurface-surface coupling.

2.) Assessment of various mitigation technologies that can reduce water and energy use in cities.

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Project A2-2
Projecting Future Environmental Change in Urban Areas

THE MODEL

The Weather Research and Forecasting model from the National Center for Atmospheric Research is freely available and widely used:

http://wrf-model.org/index.php

DATA NEEDS

As a complement to the ICLUS data set, additional high resolution projections of urban land use change over the 21st century would be helpful for the six UWIN regions (centered around the following cities):

- Portland
- Los Angeles
- Phoenix-Tucson
- Denver
- Baltimore
- Miami

Data and projections for the following (approximate) years are especially valuable: 2000, 2050, 2100.

DATA USE

These projections would provide an alternative to the ICLUS data set and would be used to test the sensitivity of our model results to urban expansion projection.

Heat waves are among the deadliest of natural phenomena, and their intensity, duration and frequency are projected to increase substantially over the 21st century due to greenhouse gas (GHG) induced climate change. Moreover, cities tend to be warmer than surrounding rural areas, and urban areas are projected to expand considerably in the coming decades.

This project investigates whether these two drivers of urban heat – climate change and urban development – dynamically interact to lessen or exacerbate projections of warming in cities. It also assesses the efficacy of various adaptation and mitigation strategies (e.g., cool and green roof implementations), and potential tradeoffs in terms of water use for irrigation. Finally, it examines impacts of climate change, urban development, and heat mitigation strategies on precipitation patterns.

These objectives are achieved with decadal-scale regional climate modelling of the continental U.S., as well as high-resolution simulations of heat wave events for all UWIN regions. The Weather Research and Forecasting (WRF) model is applied for multiple scenarios at the beginning, middle and end of the 21st century, dynamically downscaling global climate model output for the latter periods. Urban expansion scenarios are derived from the EPA Integrated Climate and Land-Use Scenarios (ICLUS) data set.

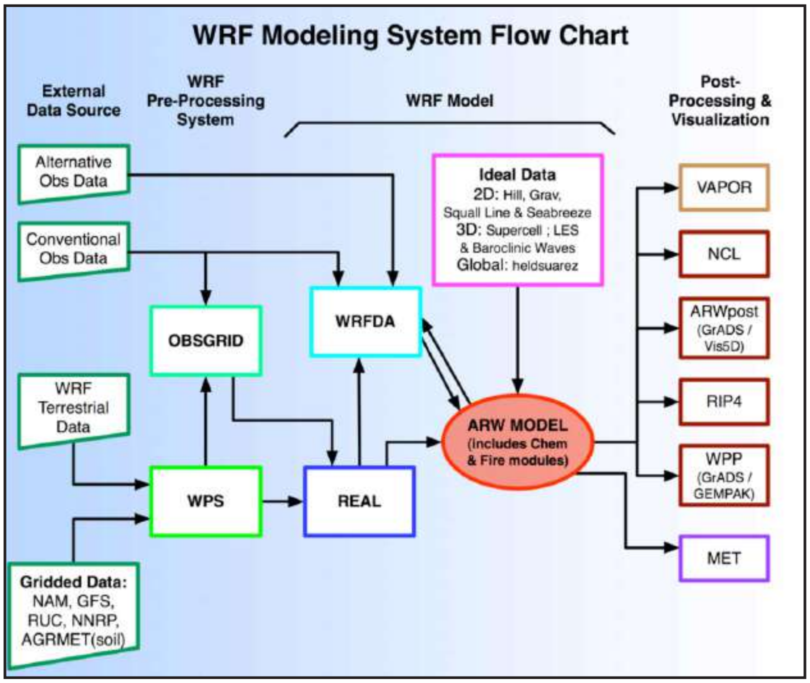

Figure 1: Component programs of the WRF Modeling System (source: WRF user's page)

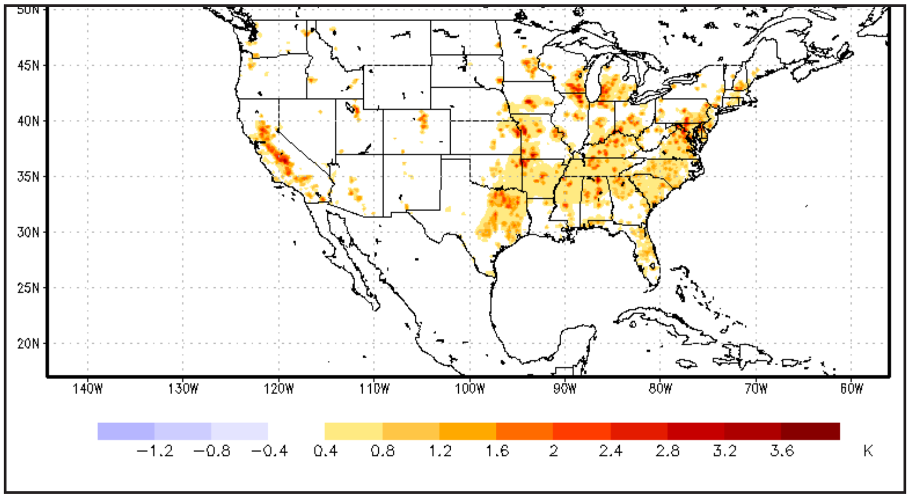

Figure 1: Dynamically-downscaled 2090-2100 mean summertime **change in near-surface air temperature due to projected urban development** between 2000 and 2100 (A2 SRES scenario). Future climate scenario is RCP 8.5; warming due to greenhouse gas induced climate change not shown.

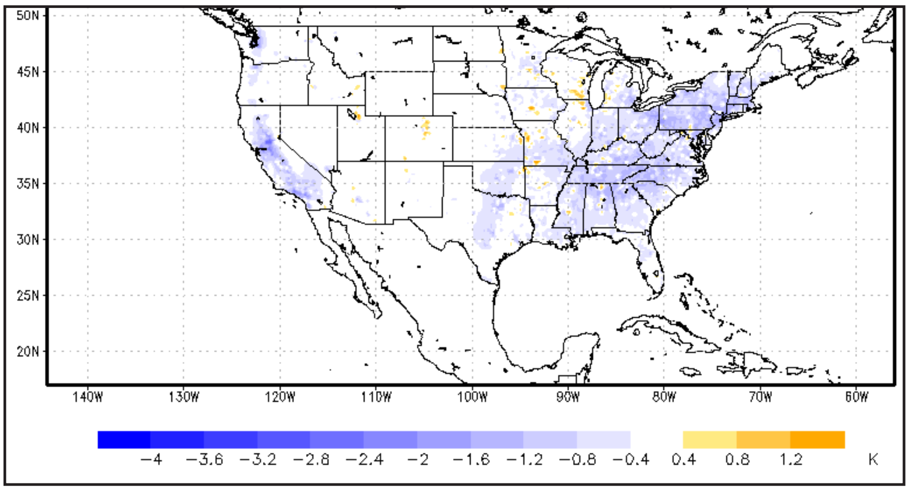

Figure 2: Same as figure one with the addition of **uniform cool roof application on roofs** in 2100.

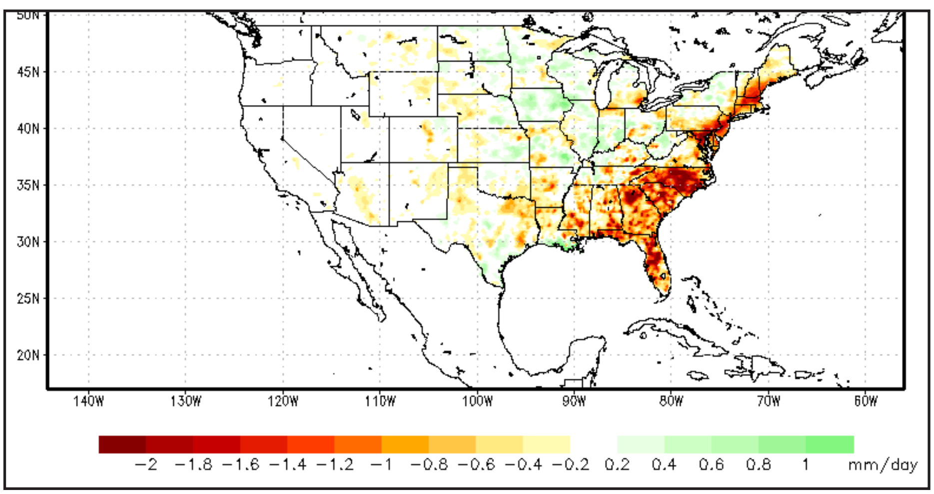

Figure 3: Same as figure 2 but for **change in precipitatio**n instead of temperature

PROJECT OUTPUTS

The central outputs of the model inform the efficacy of simulated urban adaptation choices. Additionally, the current model application informs the following:

- The degree to which adaptation choices can successfully reduce targeted pressures
- Resilience of adaptation strategies in the context of changing external forces
- Potential co-benefits and unintended consequences that require quantification prior to prioritization of solutions.

A key question relates to **how, or whether, judicious use of water can be successful** in reducing the UHI effect ((e.g., through incorporation of green infrastructure such as green roofs), quantifying this resultant impact on energy demand, with implications for GHG emissions, and importantly, how such targeted solutions may increase population resiliency through, for example, reduced heat related mortality and morbidity.

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Project A2-3

Assessing the Thermal Comfort Implications of Water-Supported Urban Infrastructure at the Human Scale

Reducing the adverse health impacts of heat exposure in cities has emerged as a shared priority among researchers, practitioners, and policymakers involved in many aspects of urban systems.

Many of the strategies currently in place to reduce health risks related to heat exposure rely on water resources. UWIN project A2-3 investigates what will happen to the thermal comfort of urban residents, and risks of heat-related illness, in the face of changes to urban water systems driven by climatic variability and infrastructure modification.

The first project objective is to assess the microclimatic conditions experienced by urban dwellers through the course of their daily lives, integrating indoor, outdoor, and transit-based exposures into metrics oriented around people rather than places.

- To make this assessment, we use large-scale time-activity data sets and direct observations, combined with high-resolution information about urban microclimates.

The second project objective is to quantify how changes in urban infrastructure, especially infrastructure elements supported by water, as well as changes in the urban climate, will impact the thermal comfort and risk of heat-related illness of urban residents.

- This objective will be achieved by combining time-activity and exposure information with projections from other UWIN projects.

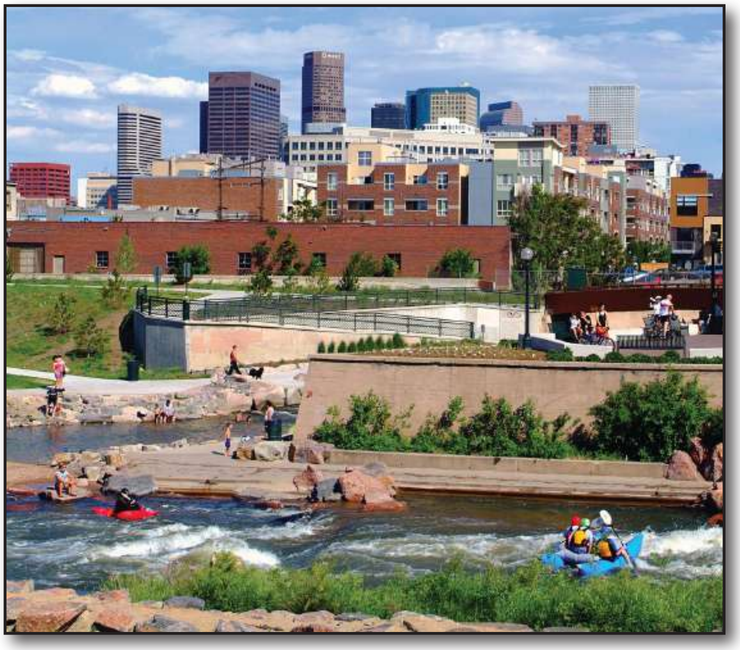
The project incorporates the perspectives of public health sector stakeholders gathered through a series of interviews across the UWIN study regions to ensure that research activities are aligned with public health priorities.

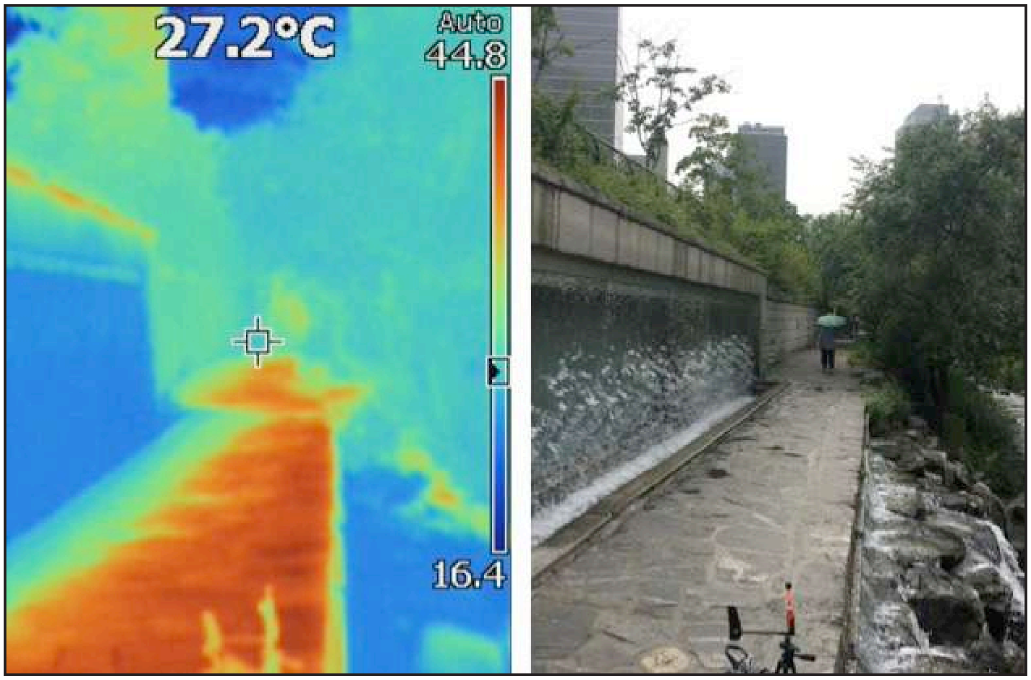
For example, a common strategy to improve thermal comfort in cities is the expansion of urban tree canopy and green space. Our project aims to support the decision-making process before deploying this intervention by capturing the impacts to human health and well-being.

PROJECT OUTPUTS

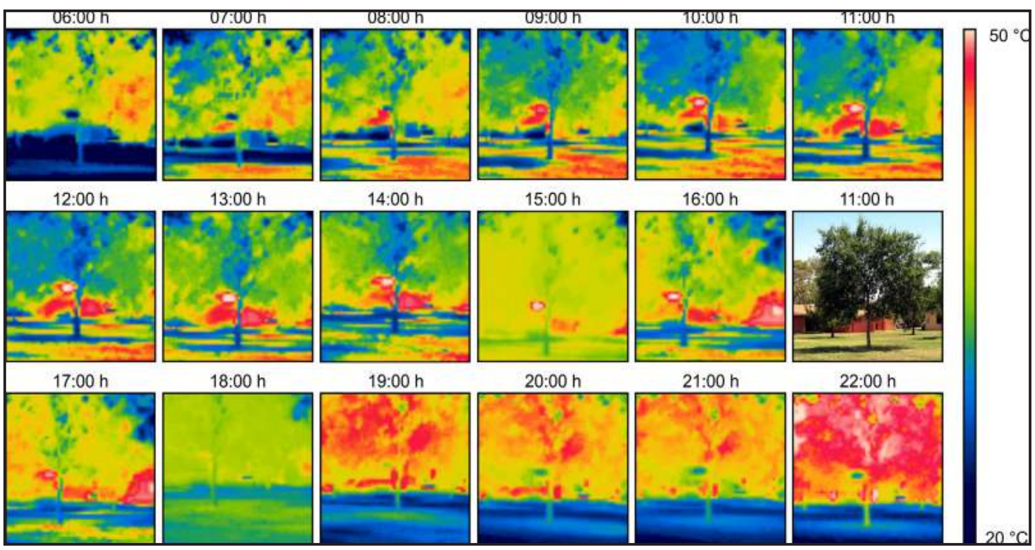
Project A2-3 is intended to benefit a wide range of decision-makers by providing more detailed information and a more comprehensive perspective regarding the implications of changes to the urban thermal environment and urban water systems for human health.

Project results will be of interest to those considering changes to urban infrastructure that have the potential to directly or indirectly impact the thermal experience of urban residents.





Thermal imagery of a decorative urban water feature in Seoul, Korea, highlights contrasts in surface temperatures between hardscapes and pavement and flowing water. Subsequent analysis of data collected by a portable weather station (right side of photo) will help determine the impact of the water features on air temperature and human comfort. Photo credit: Lexie Herdt, Texas Tech University.



Hourly thermal imagery of an elm tree over grass in the North Desert Village, Phoenix, AZ. The photographs reveal how surfaces around the tree, and the tree itself, heat and cool over the course of a sunny summer day. The impact of shade on grass surface temperatures is particularly evident in the late morning and early afternoon imagery. Photo credit: Ariane Middel, Arizona State University.

DATA

Project A2-3 will generate four different types of data outputs:

1. Direct micrometeorological characterizations of environments utilized by urban dwellers;
2. Information about time-activity patterns of urban residents;
3. Modeled thermal stress of urban residents in current and modeled future conditions; and
4. Transcripts and analysis of health sector perspectives on urban water systems and implications for heat-related illness.

PROJECT KEYWORDS

- Thermal Stress
- Microclimate/Urban Climate
- Human Health Impacts
- Urban Infrastructure
- Heat Exposure
- Public Health

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Project A2-4

Assessment of Innovative Building Systems and Urban Infrastructure to Mediate Impacts on the Urban Water Cycle, Heat Island, and Regional Climate

Buildings are fundamental components of the urban environment host to many intersections between water, energy and people. Buildings must mediate the basic social demand for physical space and shelter with the basic living demands for water and energy.

Our research will help better understand the intersections of these demands through scientific modeling and experimentation to better characterize the nexus between energy and water experienced by society, which is often localized or originated in design and operation of buildings the their urban infrastructure.

Buildings act as a crux for the nexus between water, energy and materials. We research the most critical manifestations of these interactions related to buildings and their supporting urban infrastructure in three overarching themes:

1) The urban climate and its relationship to dissipation of water and energy through local urban form, infrastructure, and microclimates

2) The energy-water nexus and the role of buildings as the fulcrum connecting mutually dependent water and wastewater demands with energy and water supply

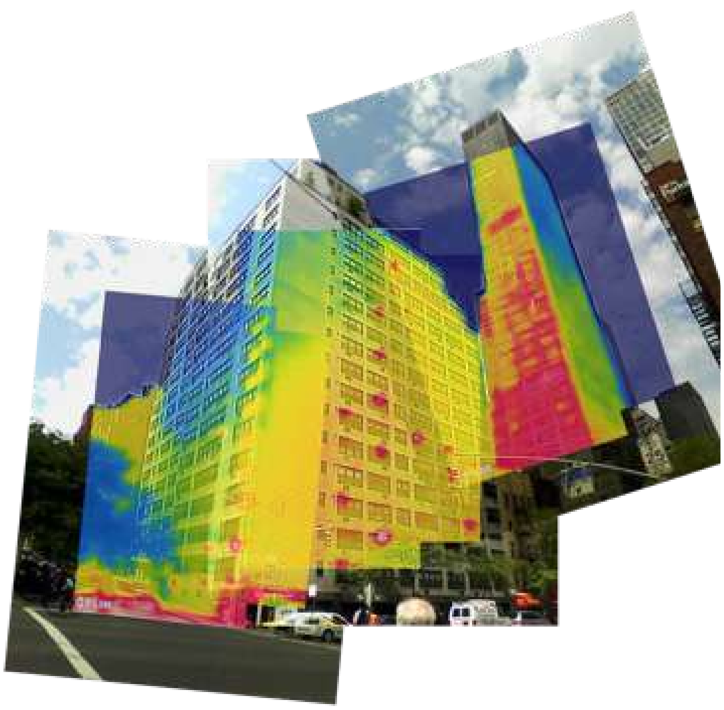
3) The design opportunities latent in architecture and the analysis of building systems and infrastructure for more sustainable water and energy solutions

This project will engage with water sustainability through study of energy, buildings, ecology and people, uncovering and bridging the gaps in knowledge that exist between disciplines of fundamental applied science and creative design research. As demonstrated by our thermal imaging research (pictured right) there is much information that can be represented through simple overlay of data onto the form of the city.

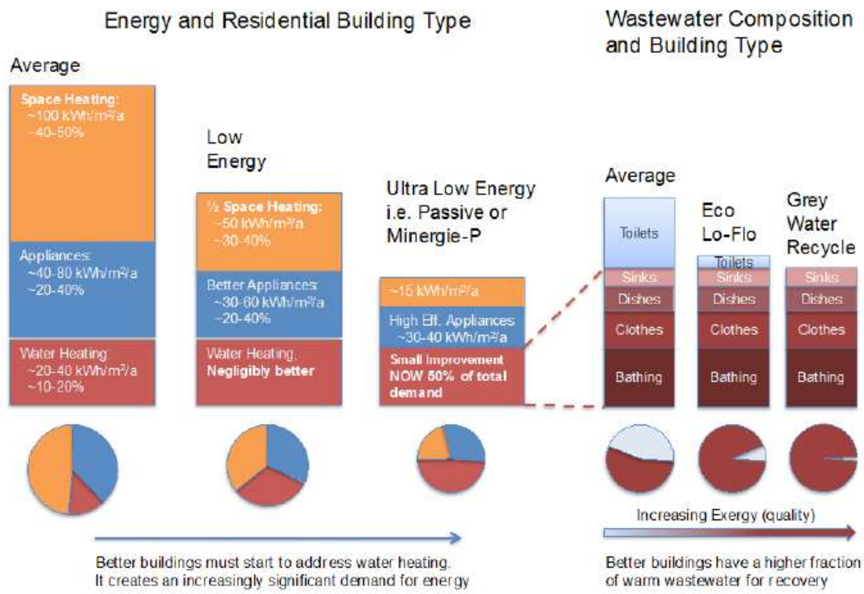
PROJECT OUTPUTS

Project A2-4 provides pragmatic context for the main component of the urban environment (buildings) in both scientific and design analysis. We are planning to setup models where input on region building typologies and water and energy demands can be checked.

We plan to output results from both models and experiments on the local effects of water cooling systems on climate and energy performance. We also plan to better characterize the value of thermal energy in



Above: Thermal image overlay demonstrating the interactions between buildings surfaces and the environment around them



Above: Illustration of the growing importance of hot water as we move toward more high performance buildings that first address space heating and cooling. In addition more high performance water systems separate grey and black water, leading to a concentration of higher potential warmer grey water sources.

Our research into the urban climate will include the development and utilization of new models as well as new sensors and field experiments to examine the relationship between climatic conditions and how water and energy dissipate in cities. We compare the role building air conditioning using dry versus wet heat exchange systems.

Dry heat exchangers, such as those used by common window air conditioners and small residential and rooftop units, have lower system efficiencies and are less expensive than larger water driven cooling towers that achieve lower heat rejection and temperatures and higher efficiency by exploiting the wet bulb temperature of the air through evaporative cooling.

There are questions that remain to be answered about the local climatic impact on humidity from cooling towers, which we will investigate with distributed sensor platforms measuring humidity variations due to evaporative cooling deployment and the placement of these devices within the geometry of the urban fabric.

We will also consider novel design opportunities for new systems that integrate the benefits of evaporative cooling into the building facade construction. Novel building simulations of the basic systems as well as the new concepts tools will be connected to data from the wider urban climate models being developed by UWIN colleagues to more broadly characterize the urban setting.

DATA

With the data developed for a specific building and for consideration of a neighborhood climate we can leverage tools for building facade thermal performance analysis to better characterize the heat transfer between people and their surroundings.

Data to be collected include:

- Statistics for percentage of built space using evaporative cooling towers
- Rate of water consumption
- Humidity levels around evaporative cooling systems
- Localized surface temperature data for mean radiant temperature mapping

PROJECT KEYWORDS

- Energy-Water Nexus
- Microclimate/Urban Climates
- Urban Infrastructure Design
- Thermal Imaging
- Evaporative Cooling Systems
- Heat Exchange Systems

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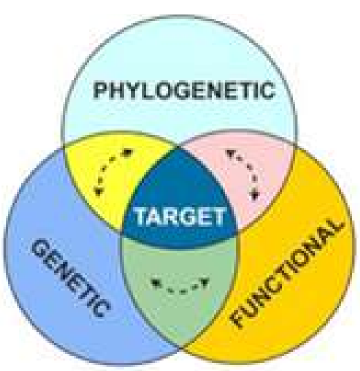
Project A3-1
Urban Vegetation Biodiversity and Ecosystem Functioning

PROJECT OUTCOMES

Our work will help develop assessments of vegetation distributions to improve human well-being in the context of urban warming and drought.

We will look toward identifying plant communities that maximize water use efficiency in supplying urban ecosystem services. People will benefit through better assessments of the water use by vegetation and the services provided by vegetation to better manage their landscapes. This project plans to produce the following:

- Estimates of plant water use and benefits
- Quantification of biodiversity and ecosystem functioning
- Improved modeling approaches that include biodiversity
- Management blueprint for species selection, and landscaping



This project looks to better understand how plants and vegetation influence the trade-off between provisioning of ecosystem services and use of water resources.

We explore components of plant density and diversity as key components of the vegetation-hydrology nexus. Key ecosystem services we look to evaluate are climate cooling and well-being of urban residents.

We are using combinations of field surveys, embedded environmental sensors, and remotely sensed imagery of the urban environment. In a recent example of this work we linked field measurements of evaporation with a tower mounted on a trailer with satellite based imagery of vegetation to generate a whole-city map of evaporation.

Research Questions

How do urban plant communities differ phylogenetically?

How do phylogenetic relationships influence plant functional diversity?

Do different urban vegetation communities lead to different ecosystem service and hydrologic relationships?

How do GI vegetation and ecosystem functioning vary within and among cities?

Our project will generate new data that quantify both distributions of urban vegetation and the microclimate influence of vegetation across the UWIN network of cities.

Picture left: Infrared gas analyzer and 3D sonic anemometer mounted to tower and moved throughout the landscape to measure the evaporative fraction lost to develop a relationship between satellite derived greenness (NDVI) and evaporative fraction. Pictured right: examples of air temperature sensors, called iButtons, that will be deployed throughout eight US metropolitan areas.

ENVIRONMENTAL SENSORS

In 2017 and 2018, we will be deploying more than 300 air temperature sensors throughout eight metropolitan areas that represent the breadth of different climates within the United States.

On the ground, we are surveying the biodiversity of green infrastructure throughout the United States to compare both types of green infrastructure and regions. This work is looking to assess how biodiversity influences the functioning and sustainability of green infrastructure projects.

Together these tools will help evaluate how outdoor water use contributes to urban sustainability and resilience to environmental changes. We are exploring both vegetation writ-large within the urban environment and green infrastructure in particular.

PROJECT KEYWORDS

- Urban Biodiversity
- Ecosystem Services
- Remote Sensing
- Environmental Sensors
- Green Infrastructure

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