Urban vegetation cooling service at Metropolitan Phoenix (final report)

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1 Part 1: Static Analysis – Collective Action

The case of urban vegetation cooling service at Metropolitan Phoenix, Arizona, USA is an addition case to the original Common-Pool Resource (CPR) database. This case was created in 2013 by Yujia Zhang at Arizona State University. Metropolitan Phoenix is one of the fastest growing regions in the southwest U.S. In contrast to its rapid urban expansion, this area possesses inadequate natural resources and faces unique challenges of sustainable development. The commons dilemma in this case is to balance the tradeoffs between heat mitigation and water consumption by optimal design and efficient irrigation of urban green space.

1.1 The Commons Dilemma

At Metropolitan Phoenix, vegetation cooling is one of the effective approaches to mitigate extreme heat during summer time. However, irrigation of vegetation requires water resources that are limited in this semiarid region(Gober *et al*, 2009). The commons dilemma in this case is to balance the tradeoffs between heat mitigation and water consumption by optimal design and efficient irrigation of urban green space, which includes public, commercial and residential green space.

The current urban green space can be better designed and rearranged to achieve the goal of effective heat mitigation. Historical and present land use plan as well as the mosaic of residential landscape lead to a quite heterogeneous distribution of urban green space, causing unequal access of vegetation cooling services among residents. This increases the heat vulnerability of the entire urban system and contributes to the high heat morbidity and mortality rates during hot summer.

On the other hand, water use can be significantly reduced by efficient and regionally appropriate designs, plant selection, and irrigation practices(ADWR). The sizeable portion of water use is usually due to the improper selection of plant type, poor irrigation practice or leaky or inefficient irrigation systems, which occur in both public and private green space managements(DCDC, 2013). In addition, general public usually has insufficient knowledge in plant selection and water conservation, which causes great difficulty in the effective design of residential green space.

Urban Heat Island

As urban areas develop, changes occur in their landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape. The intensity of the urban heat island depends on land surface characteristics, including the amount of vegetation and impervious surfaces and how effectively surface materials absorb or reflect radiation (EPA).

After 50 years of rapid urbanization, the cool nights once characteristic of Phoenix's desert climate are increasingly rare during the hot summer months and the consequences for human society are well recognized(Gober *et al*, 2009). Higher temperatures increase the potential for heat stress, especially among vulnerable populations (Harlan *et al*, 2006); reduce human comfort generally (Baker *et al*., 2002); raise the costs of cooling buildings during summer months of peak energy use, and increase residential water demand (Guhathakurta and Gober, 2007). The UHI also creates challenges for revitalizing downtowns with dense, mixed-use development to support a pedestrian-oriented lifestyle.

One strategy to mitigate the UHI in Phoenix is to use irrigated landscape treatments. However, researches show that trees and grass may have different impacts on temperature. Myint *et al.* (2013) shows that trees can lower surface temperatures more effectively than turf grass in desert urban environments. In addition, the mitigation effect of grass has a threshold around 40 percent, which means lower than 40 percent grass cover is not effective in reducing temperature. Consequently, xeriscaping of low water use trees is a better choice than lawn for heat mitigation and water conservation.

1.2 Biophysical Context

Residing in the semi-arid Sonoran desert, metropolitan Phoenix contains twenty-five cities and towns and totally covers 23,890 sq km. This region undergoes serious issues of extreme heat, especially during the summer months when daytime temperatures regularly exceed 40 ^{o}C(Chowa *et al*. 2012). Periodic heat waves are exacerbated by a growing urban heat island (UHI), which can raise nighttime temperatures by more than 6 ^{o}C.

As an effective way of heat mitigation, urban green space roughly accounts for 10 percent of the urban area. Besides public and commercial green space, residential green space constitutes a significant portion of the urban environment. In terms of water use, approximately 60 to 70 percent of municipal water use is consumed by outdoor vegetation irrigation(DCDC, 2013). The water supply of this region relies on four sources: approximately 29 percent from local rivers in the Salt-Verde watersheds, 26 percent from the Colorado River, 39 percent from groundwater ,and 6 percent from effluent(ADWR, 2010).

As the simple approach to adjust water consumption, the water price of Phoenix varies between low and high seasons annually. However, water price of the region has been typically low. Phoenix residents have the fifth-lowest water bill of the nation's 20 largest cities. This is because, historically, water was not allocated to users on the basis of market mechanisms, but instead by a set of legal and political regulations that ensure an inexpensive supply to municipal and agricultural customers(Wentz and Gober, 2007). Residents in this region who benefit from the lifeline channel through the Sonoran Desert are paying only 45 percent of the project's $3.6 billion cost. The difference is a national burden. Water supply diversions paid for in part by federal or state tax funds. But when new water supply projects are financed by customers directly, higher water price is expected (Walton, 2010).

Hard infrastructure of water resource

The Central Arizona Project(CAP) is a 336 miles long system of aqueducts, tunnels, pumping plants and pipelines. It conveys water about 190 miles from the Colorado River at Lake Havasu on the Arizona-California border through a system of canals to Phoenix, Tucson and beyond. The system is capable of carrying up to 1.8 million acre-feet each year.

The Salt River Project (SRP) conveys surface water from the Verde River and Salt River watersheds that lie to the north and east of Phoenix. The SRP system is composed of six dams, 1,300 miles canals and 255 high capacity wells.

The Phoenix active management area has 2397 ground water wells, and the median well yield is 1,280 gpm. In 2005, groundwater withdrawals amount to 813,000 acre-feet, with 24,100 acre-feet of natural recharge and 110,303 acre-feet of artificial recharge leading to 678,597 acre-feet of overdraft (ADWR, 2010).

1.3 Attributes of the Community

The existence of urbanized Phoenix is a testament to the power of human planning in the face of severe climatic uncertainty associated with its desert environment. This region experienced an evident population explosion over the past two decades. From 1990 to 2010, the population has grown by 79.9%. In 2010, Maricopa County became the nation's fourth largest county with a population of nearly 4.0 million (U.S. Bureau of the Census).

This region experiences severe public health issues caused by extreme heat. The heat-related death rate during summer months was three to seven times greater than that of U.S average. According to the report of Maricopa County Department of Public Health, from 2008 to 2012, there are 414 heat-related deaths and 7757 heat-related illness.

In terms of residential green space, socioeconomic status, especially income, has a strong impact on resident's accessibility to vegetation cooling service. Many inner-city low income, minority neighborhoods has few or no vegetation cover, whereas suburban neighborhoods with higher income and education level tend to have more oasis landscapes(Harlan *et al*, 2006).

Furthermore, different landscape styles(xeric, lawn, oasis) vary in popularity among low, middle and high income homeowners. Low income homeowners tended to prefer lawn in both front and back yards. Middle income homeowners preferred desert landscaping in their front yards but lawn or oasis landscaping in backyards. High income homeowners prefer between desert and oasis in their front yards, and oasis landscaping in backyards(Larsen and Harlan, 2006). In addition, landscape legacy also affects people's preference. Long-time residents prefer grassy yards more than newcomers, who tend to prefer desert-like ‘xeric’ yards(DCDC , 2013).

1.4 Rules in Use

Boundary rule

1. The rights of water use and land cover modification are determined by public and private land ownership.

2. Established by the 1980 Arizona Groundwater Code, Metropolitan Phoenix lies within the Phoenix active management area(AMA). The Phoenix AMA is tasked by statute to achieve safe-yield by the year 2025 through the increased use of renewable water supplies and decreased groundwater withdrawals in conjunction with efficient water use.

3. If residential parcel locates within the boundary of the homeowner’s association (HOA), the homeowner has to comply with the rules and restrictions set by the HOA.

Position rule

1. The Arizona Department of Water Resource is in charge of the ground water management of the Phoenix active management area.

2. Jurisdictions within the Phoenix active management area officially adopt the regulatory low water use plant lists and incorporate it into ordinances and design guidelines for development. The lists also serve as a non-regulatory resource for residents.

3. The Maricopa Association of Governments serves as the leading regional planning agency for the Metropolitan Phoenix area. It coordinates with cities' planning and zoning division’s to design the land use plan and zoning ordinance, which governs

land use and irrigation standards within each zoning classifications.

4. City's department of parks and recreation is responsible for planting, maintaining and irrigating vegetations at public green space, by following official standards.

5. Homeowner’s Association oversees the maintenance of the neighborhood via a binding set of codes, covenants and restrictions (CCRs).

6. Private property owners are responsible for planting, maintaining and irrigating vegetation at commercial(golf course, resort) and residential green space.

Pay off rule

1.Home owners can get financial rebate from water authority if they convert lawn to xeriscaping.

2.Homeowner’s Association has the ability to collect fees and issue fine for non-compliance.

1.5 Summary

The commons dilemma of heat mitigation and water conservation at Metropolitan Phoenix is challenging and complex issue. Land use planning and water availability are two major factors that control the development of urban green space. In addition, vegetation has economic, water, and social equity implications that vary dramatically across neighborhoods and need to be managed through informed environmental policies(Jenerette *et al*, 2011). Optimal design of urban green space requires multi-sector collaboration and joint efforts from public and private landowners.

Due to the complex mechanism of vegetation cooling process, many knowledge gaps still exist in the biophysical and social dynamics of using this service to mitigate heat. To some extent, this explains the insufficient public understanding on the vegetation cooling effect, the choice of plants and their environmental outcomes. Continuous efforts have to be devoted in supporting researches and raising public awareness on the importance of vegetation cooling.

Part 2. Dynamic Analysis - Robustness

2.1 Shocks, Capacities , Vulnerabilities

Shocks

Rapid population growth will be a great potential shock on heat mitigation and water conservation. Future growth is projected to bring the metropolitan population to more than 7 million residents by 2030 (ADES). Evidently, it will accelerate urban expansion and increase municipal water demand. Continuous urban sprawl will aggravate the magnitude and intensity of urban heat island, and in the meanwhile increase the challenge of optimal green space design. On the other hand, future drought and uncertainty on climate change may cause severe water shortage and elevate the temperature of this region.

Capacities

Future water support will not only come from the continued transition of agricultural land to urban uses, but also from the more efficient use of existing supplies(Wentz and Gober, 2007). Proper design of urban green space and irrigation practice can help reduce extreme heat and water consumption. The rapid dynamic of urban land use change at both local and regional scale present opportunities for optimal allocation of urban green space.

Vulnerabilities

Urban risk shows that the unequal distribution of vegetation cooling service among different income groups became more evident from 1970 to 2000(Jenerette *et al*, 2011). Legacy of urban development has left poor and minority populations in deteriorated urban spaces where there are structural constraints on improving environmental conditions(Harlan *et al*, 2006). Policy-makers must be aware of this gap and create proper strategies to improve the environment of the most vulnerable neighborhoods in this region.

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