International Water Security Network

Green Infrastructure: A Climate Change Adaptation Strategy for Cities in Arid Lands

Dr. Adriana Zúñiga Terán

Climate Change Adaptation in Urban Settlements
La Paz, Baja California Sur, México
November 17-20, 2015

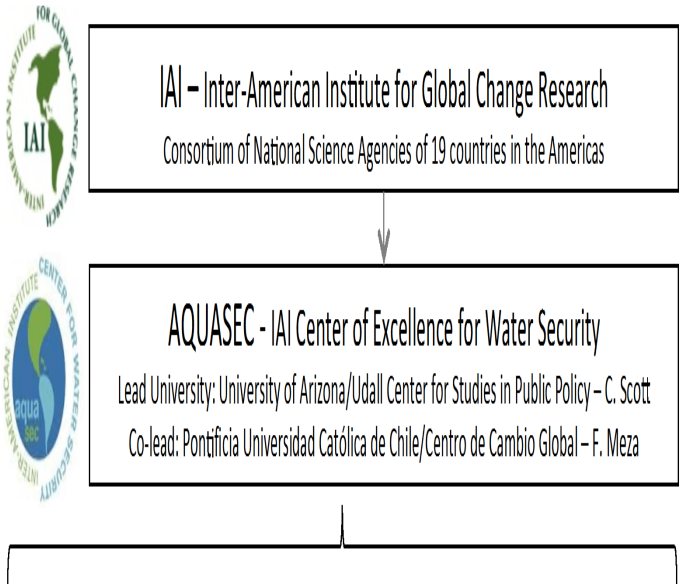
Funded by
Lloyd's Register Foundation

Led by
UWE BRISTOL University of the West of England

In partnership with
MONASH SOUTH AFRICA
The University of Arizona. Udall Center for Studies in Public Policy

AQUASEC: Center of Excellence for Water Security

- Virtual center
- Network
- Umbrella



- NSF-CNH
- IAI Aguascapes
- Lloyd's IWSN – Arid Americas

International Water Security Network

Overview

1. Cities in drylands
2. Climate change projections for cities in drylands
3. Green infrastructure
4. Research project

International Water Security Network

1. Cities in Drylands

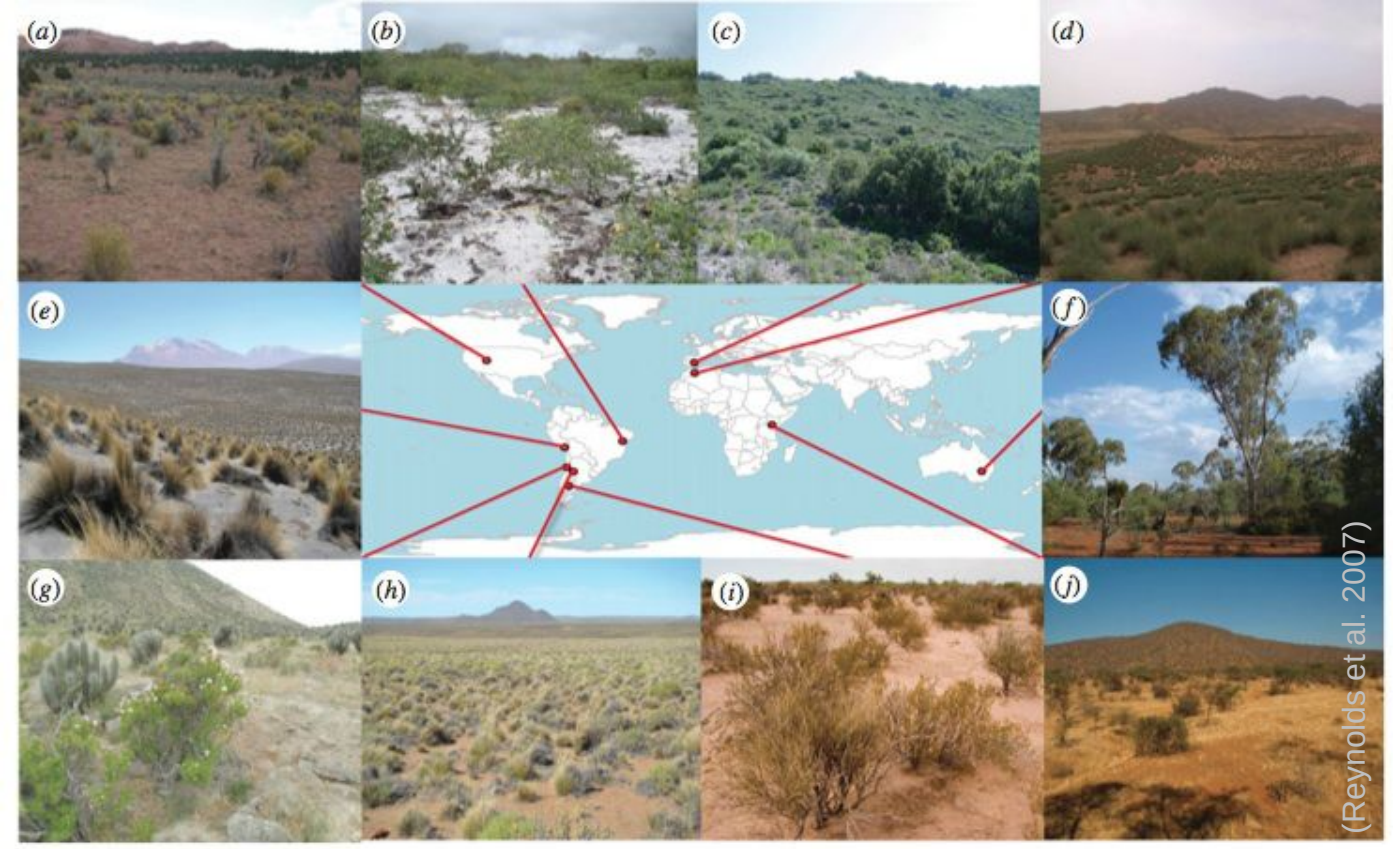
International Water Security Network

Drylands

41% of the land area in the world[1]

Drylands:[2]
- Hyperarid
- Arid
- Semi-arid
- Subhumid

Water scarcity[1]



(1: Reynolds et al. 2007; 2: Safirel et al. 2005; 3: Liu et al 2007)

Scientists = Coupled social-ecological system[3]

International Water Security Network

Social-Ecological Systems

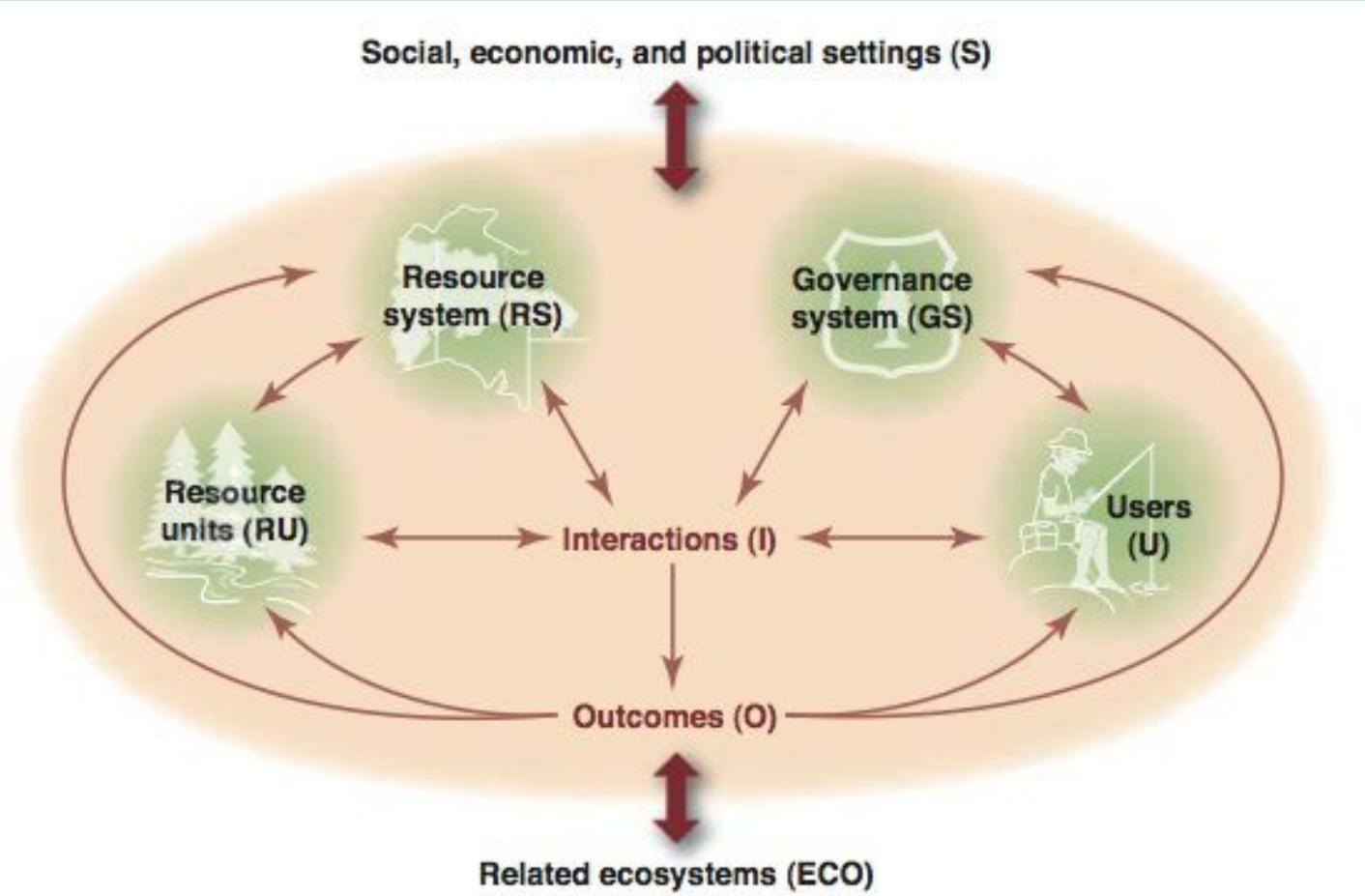
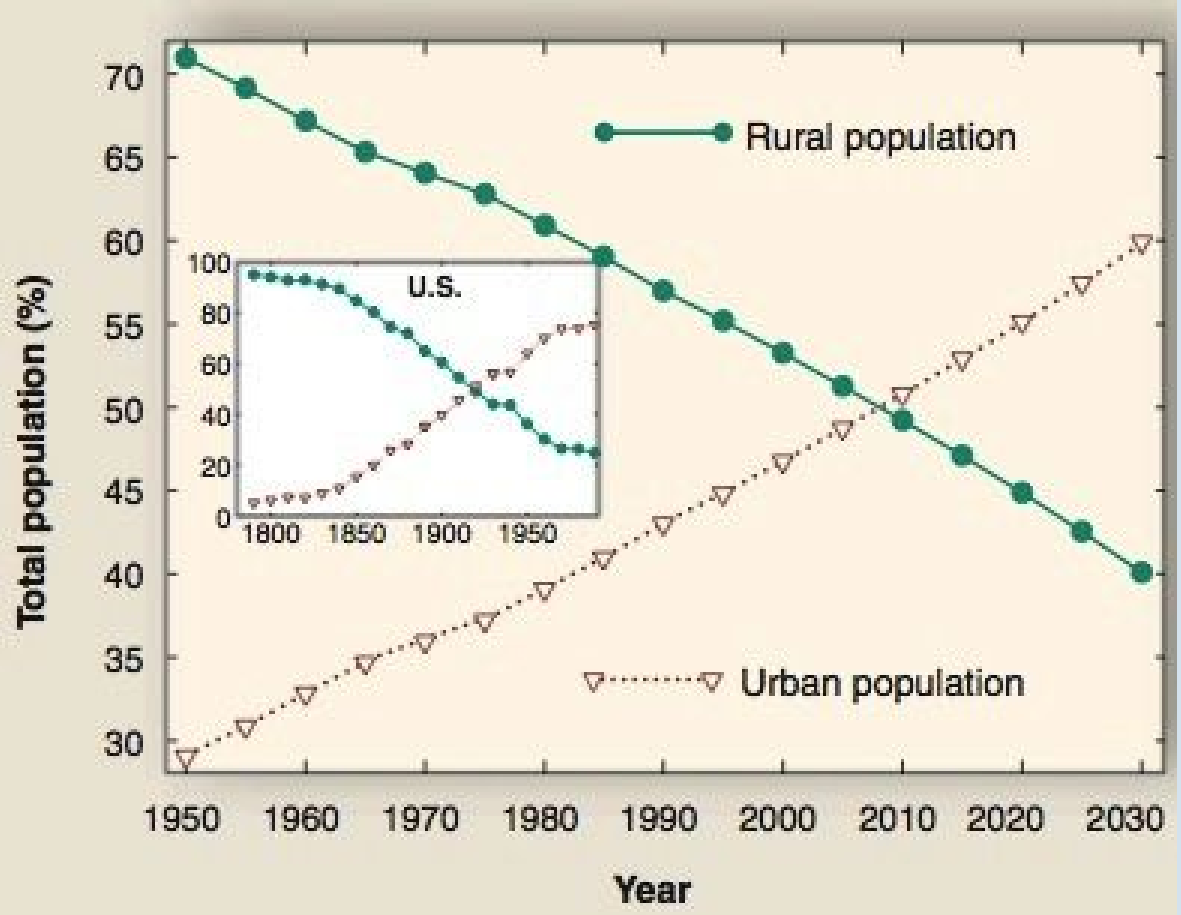


Fig. 1. The core subsystems in a framework for analyzing social-ecological systems.

(Ostrom 2009)

International Water Security Network

Cities in Drylands



Change in world rural and urban population (%) from 1950 to 2030[2]

- Rapidly expanding[1]
- The drier the land, the larger the fraction of population will be living in urban areas[3]

International Water Security Network

(1: Hutchinson and Herrmann 2008; Reynolds et al. 2007; 2: Grimm et al. 2008; 3: Safriel et al. 2005)

Cities in Drylands

The growth of cities in drylands:

- Adds pressure to the ecological systems[1]
- Alters the biogeochemical cycles[1]

Tucson, Arizona

(1: Grimm et al. 2008)

International Water Security Network

2. Climate change projections for cities in drylands

International Water Security Network

Climate Change

Climate change projections for drylands[1]:

- Increase in temperatures
- More prolonged droughts
- More frequent severe storm events

Tucson, Arizona

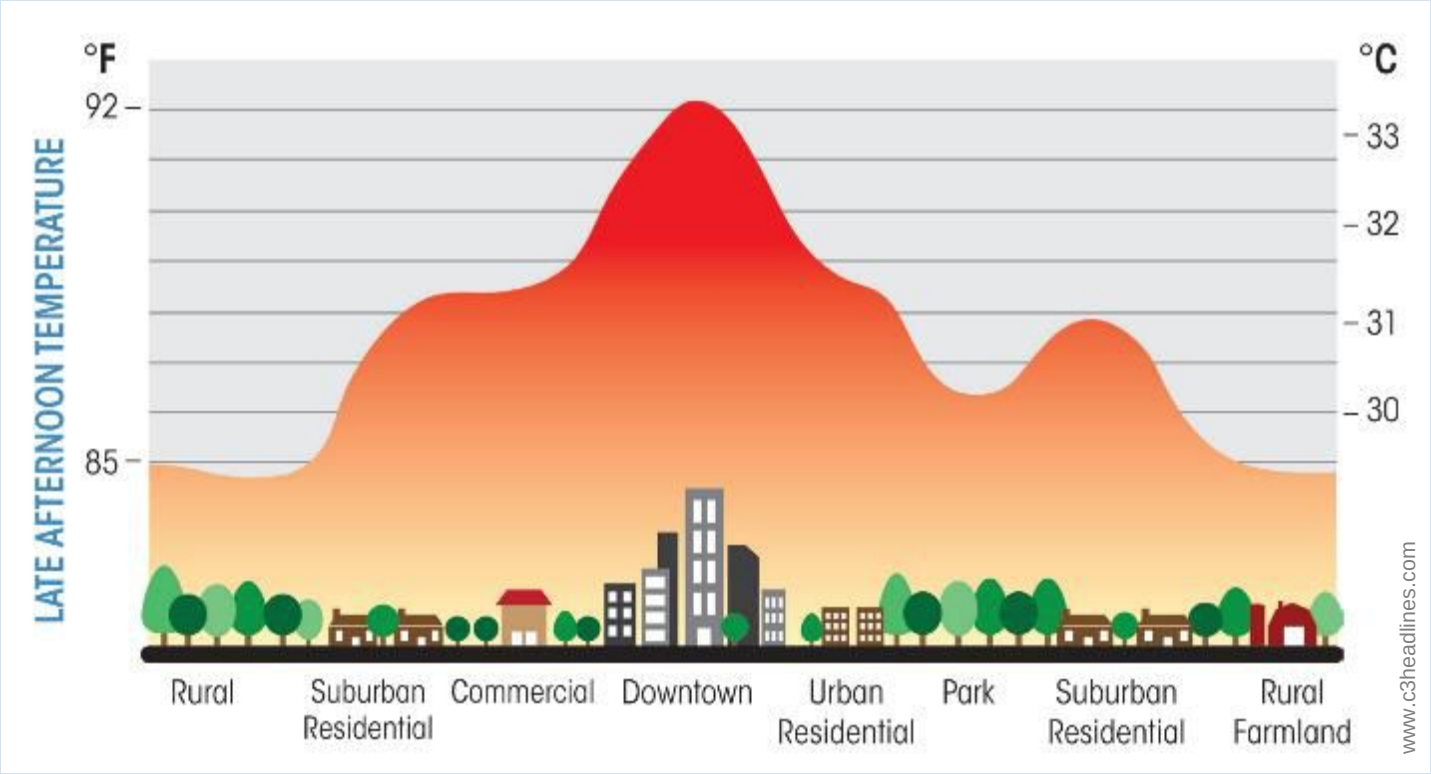
(1: Maliva and Missimer 2012)

International Water Security Network

Climate Change

Increase in temperatures:

- Exacerbates the *urban heat island* effect
- Poses a serious health risk to people living in hot regions



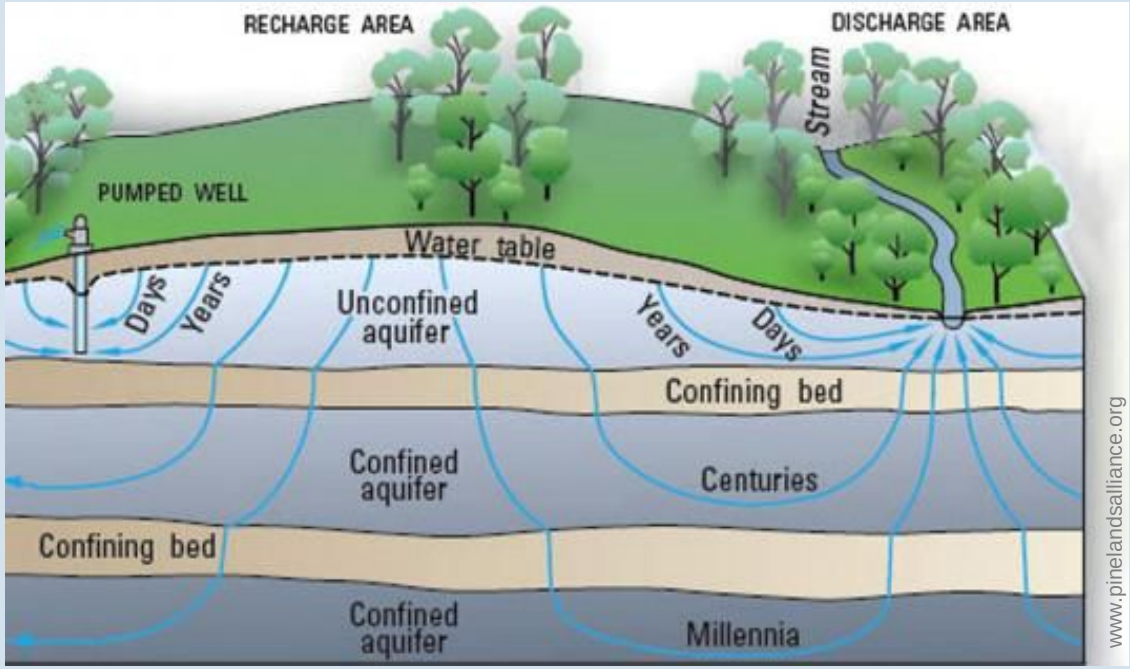
Urban heat island effect

International Water Security Network

Climate Change

Prolonged droughts:

- Groundwater is an important water source for cities in drylands
- Climate change threatens water security in arid lands



International Water Security Network

Climate Change

More frequent severe storm events:

- Produce flooding
- Damage the urban infrastructure
- Decrease water quality – nonpoint source pollution

International Water Security Network

Drainage Systems in Drylands

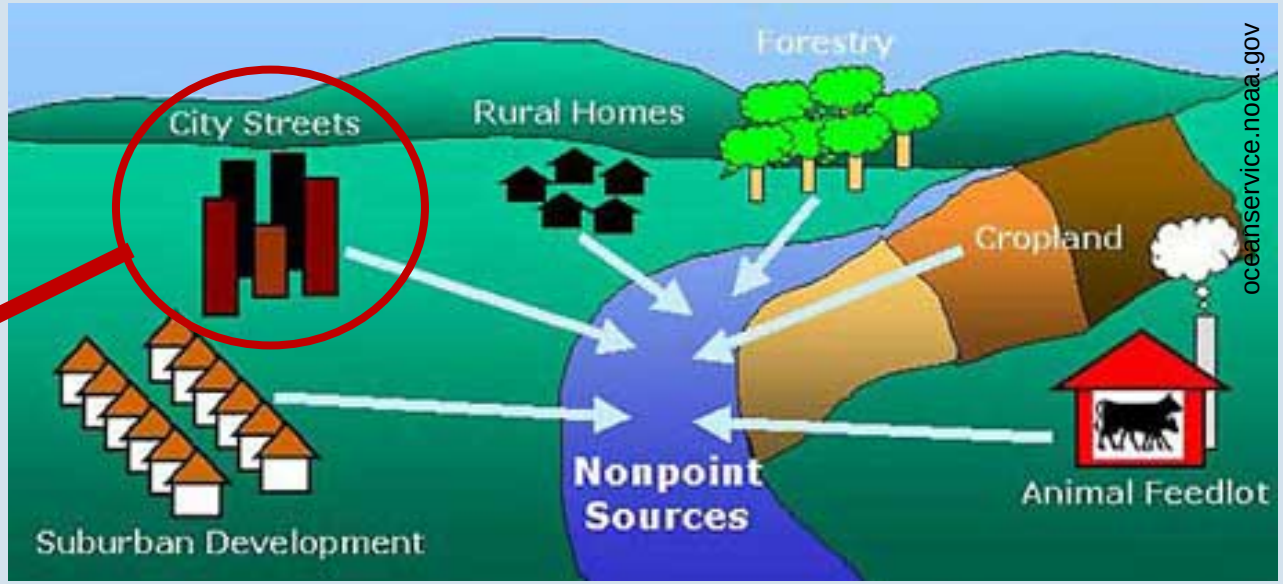
Low frequency in rain events makes it cheaper to repair urban infrastructure than install drainage system

International Water Security Network

Nonpoint source pollution

Definition: Pollution that comes from different sources

water.epa.gov



oceanservice.noaa.gov

Water flow across paved streets pick up oil left by vehicles, resulting in polluted runoff

International Water Security Network

Sustainability in Cities

Cities provide opportunities for sustainability[1]

(1: Ernstson et al. 2010)

International Water Security Network

3. Green Infrastructure

International Water Security Network

Greenspace

Definition:

Public outdoor space dominated by vegetation

Parks

Washes/greenways

Sports fields

International Water Security Network

Green Infrastructure

Definition:

Areas dominated by vegetation and covered by natural pervious surfaces where rainwater is directed for retention/detention allowing water infiltration into the aquifers in the place (*in situ*).

Green infrastructure in the University of Arizona main campus

Green infrastructure considers the water cycle

International Water Security Network

Greenspace

Greenspace in rural vs. urban environments

UNDEVELOPED → **URBAN**

Natural System Conditions

High plant cover
Low runoff production
Low nutrient export

Low plant cover
High runoff production
High nutrient export

Human System Conditions

Low population density
Sparse social networks
Highly visible ecosystem services

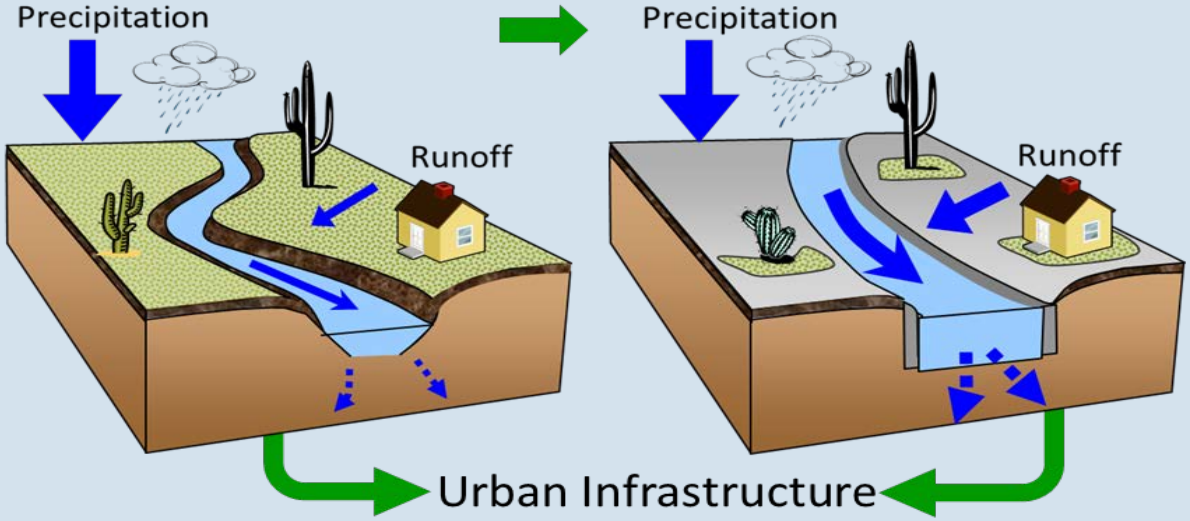
High population density
Dense social networks
Low visibility ecosystem services

(From NSF Proposal by Meixner et al. 2015)

International Water Security Network

Green Infrastructure

Runoff with green infrastructure vs. without



Vs.

(From NSF Proposal by Meixner et al. 2015)

International Water Security Network

Green Infrastructure

Through slope, curb cuts, and detention basins, rainwater is infiltrated into the aquifer, while providing a greenspace for the people

International Water Security Network

Green Infrastructure

Boulevards may function as green infrastructure

Curb cuts, slope, and swales are combined to direct rainwater to small basins - infiltration areas

International Water Security Network

Green Infrastructure

Circles at street intersections slow down traffic and prevent flooding

International Water Security Network

Green Infrastructure

There are multiple opportunities for developing green infrastructure in cities

Slope of paved areas

Infiltration areas

Slope of paved areas

International Water Security Network

Green Infrastructure

There are multiple opportunities for developing green infrastructure in cities

Street in Hermosillo after a rain event

International Water Security Network

Green Infrastructure

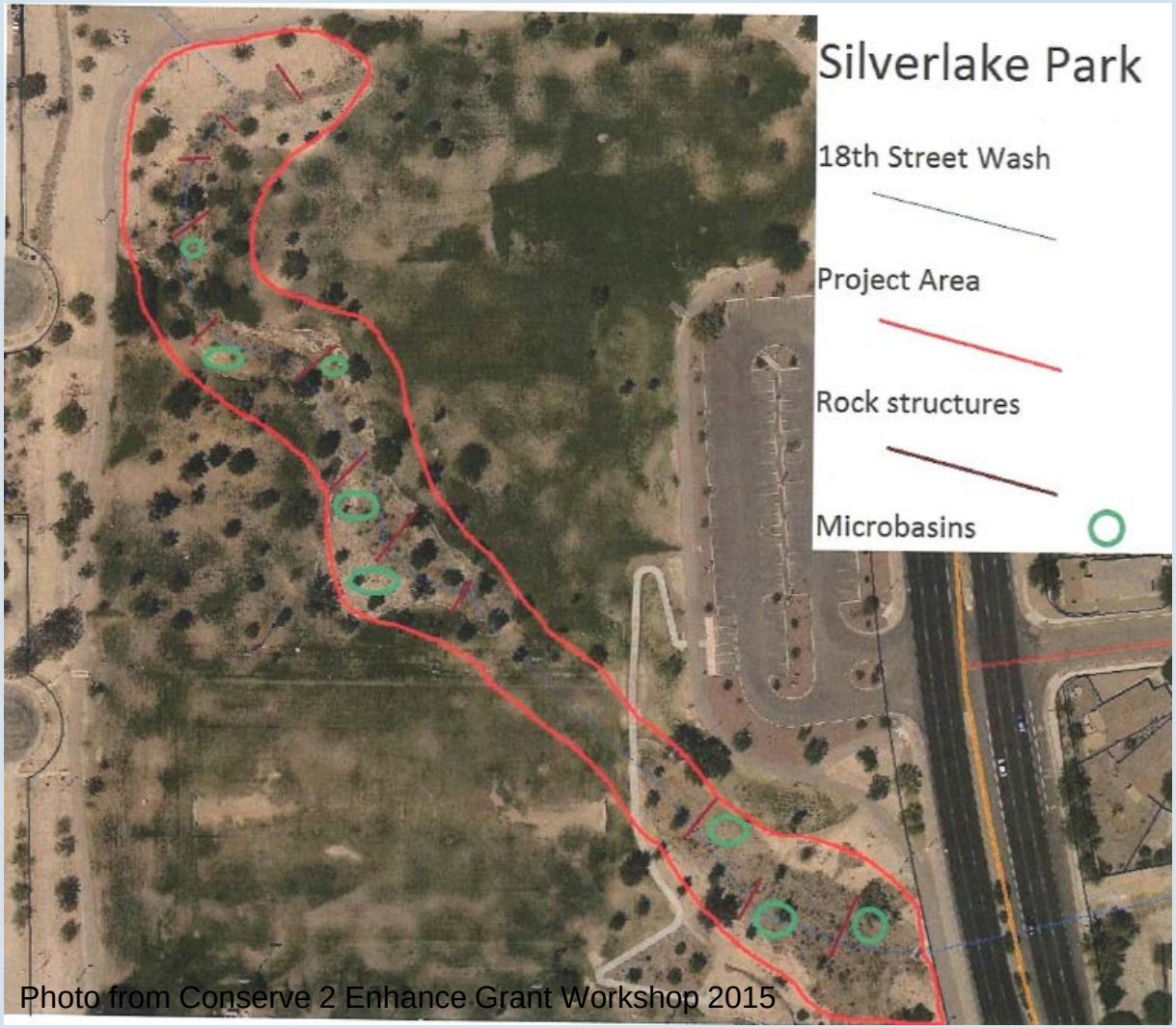


Photo from Conserve 2 Enhance Grant Workshop 2015

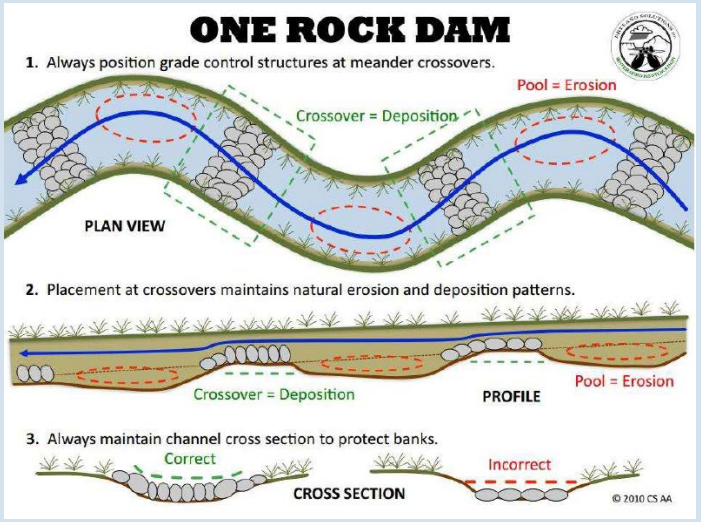
Greenspace can be modified so it can function as green infrastructure:

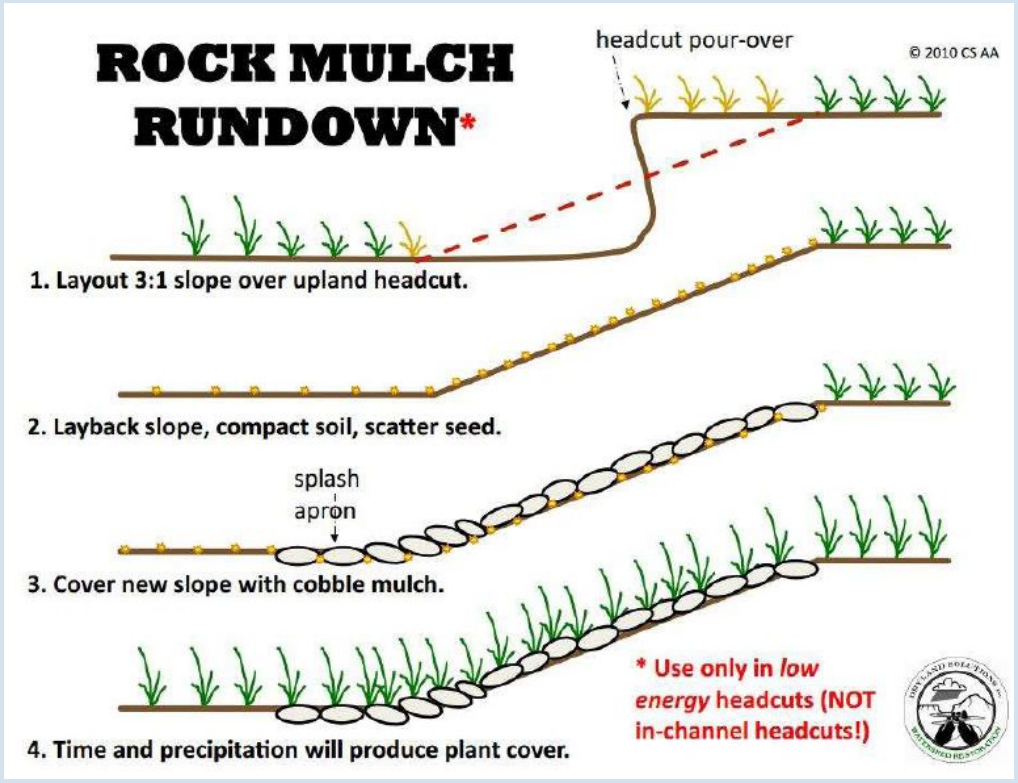
1. Identify the natural drainage systems
2. Delineate the project area
3. Design retention/detention areas and basins

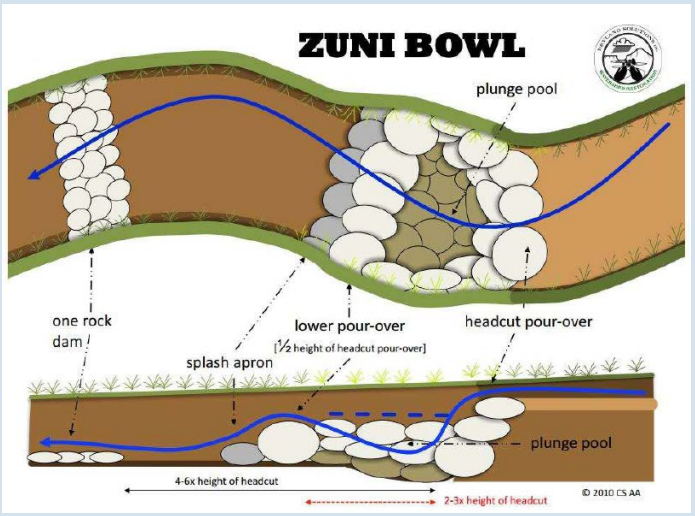
International Water Security Network

Green Infrastructure

It is important to consult with experts before implementation







Images from Conserve 2 Enhance Grant Workshop 2015

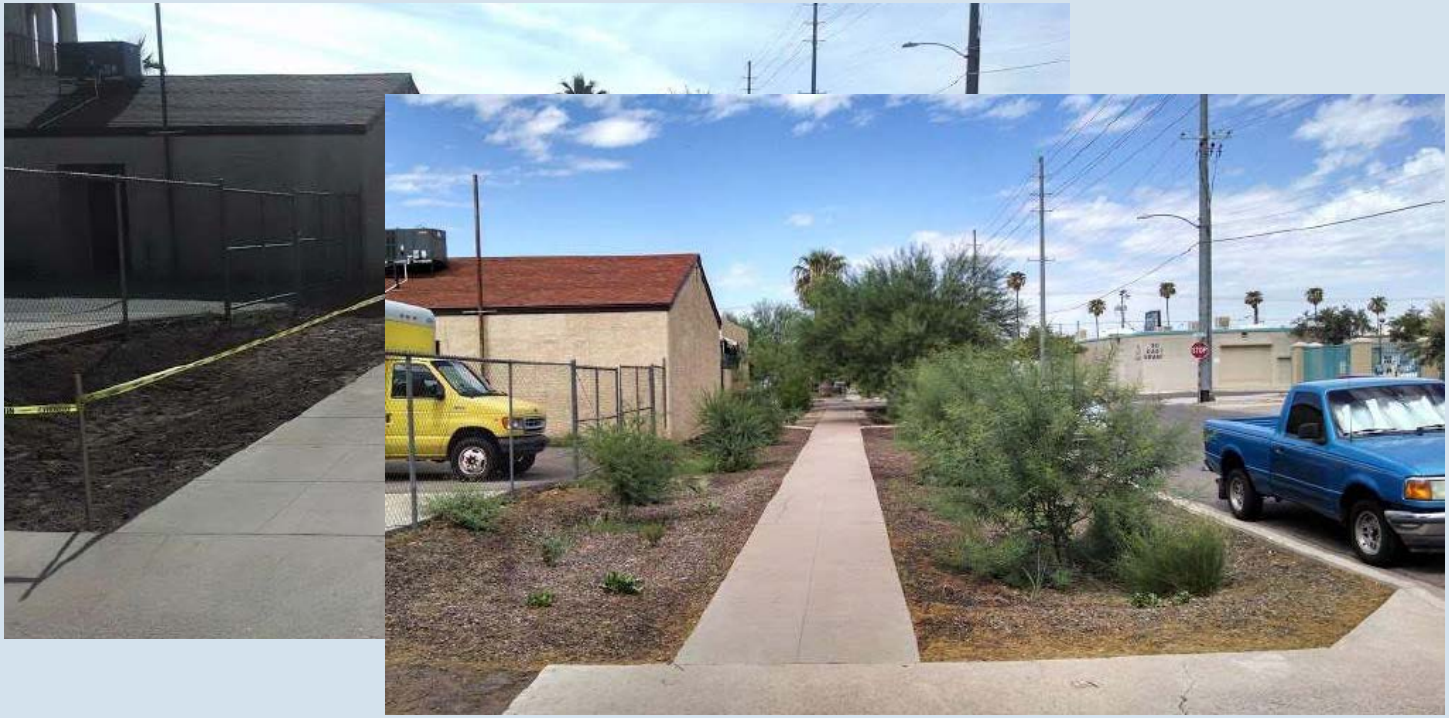
International Water Security Network

Green Infrastructure

Photo from Conserve 2 Enhance Grant Workshop 2015

International Water Security Network

Green Infrastructure



Photos from Conserve 2 Enhance Grant Workshop 2015

International Water Security Network

Green Infrastructure

Photos from Conserve 2 Enhance Grant Workshop 2015

International Water Security Network

Green Infrastructure

Opportunities for community interaction

International Water Security Network

Green Infrastructure & Climate Change

- **Drought**
  - Recharges aquifers[1]
  - Reduces run off[1]
  - Increases water quality

- **Increased temperature**
  - Reduces temperatures in cities[2]
  - Alleviates the urban heat island effect[1]

- **More frequent severe storm events**
  - Reduces flooding risk[1]
  - Prevents damage to urban infrastructure

Coupled social – ecological systems[3]

(1: Ernstson et al. 2010; 2: Shashua-Bar et al. 2011; 3: Ostrom 2009)

International Water Security Network

Social-Ecological Systems

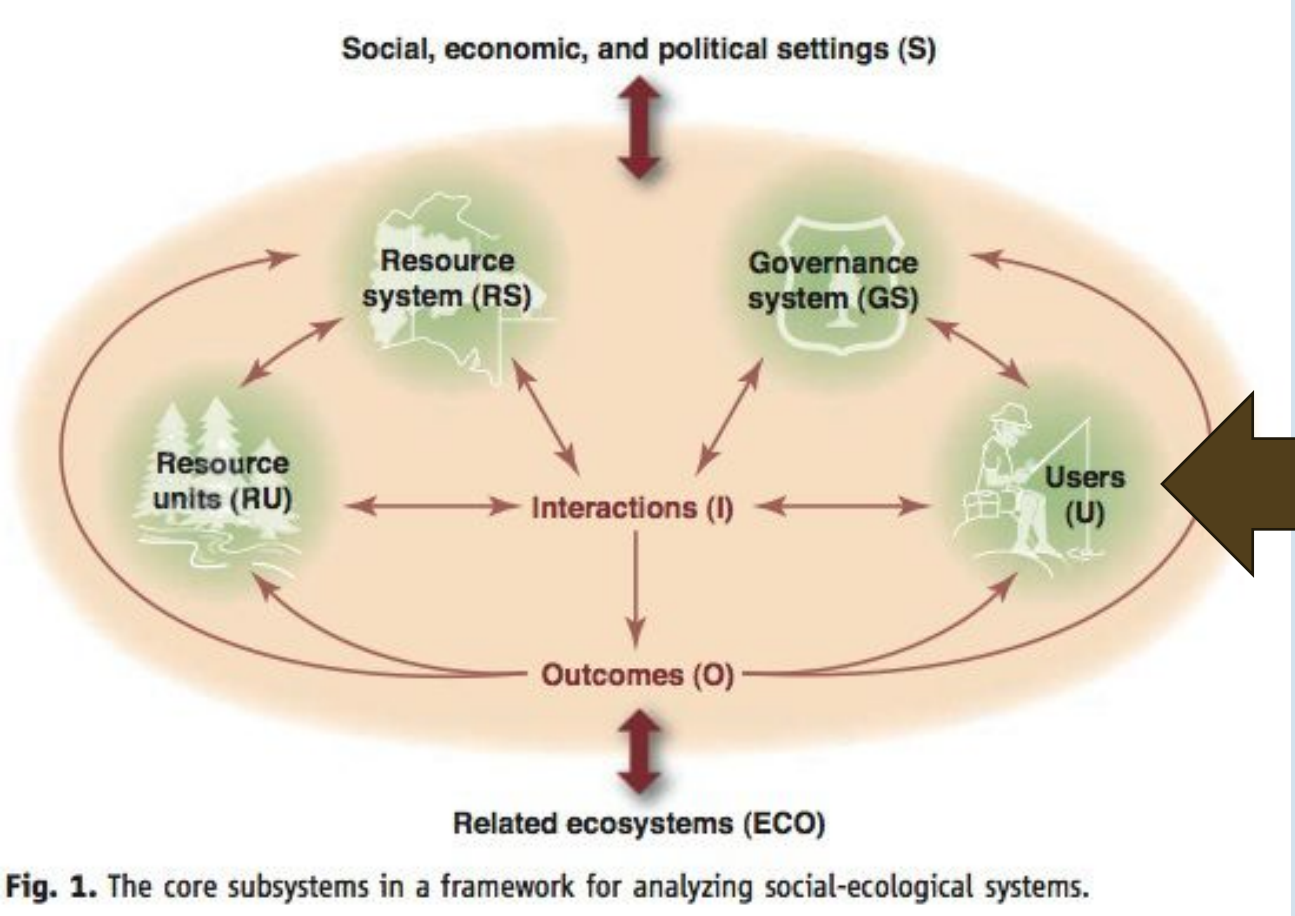


Fig. 1. The core subsystems in a framework for analyzing social-ecological systems.

My dissertation

(Ostrom, 2009)

International Water Security Network

Greenspace & Wellbeing

Greenspace improves human wellbeing:

- Physical health[1]:
  - Provides opportunities for recreational activities
  - Improves air quality
- Mental health[2]:
  - Reduces stress, noise, and overcrowding feelings
- Social health[3]:
  - Provides opportunities for social interaction

Santa Cruz River Park

((1: Herrick 2009; Samet 2011; 2: Chu et al. 2004; 3:Francis et al. 2012)

International Water Security Network

Conclusions from Dissertation[1]

Sabino Canyon – Coronado National Forest

Walkable neighborhoods with access to greenspace:

- Improve wellbeing in urban residents.
- Enhance conservation support.
- Increase the number of users of greenspace.

International Water Security Network

(1: Zuniga-Teran 2015)

Social-Ecological Systems

Postdoctoral Research

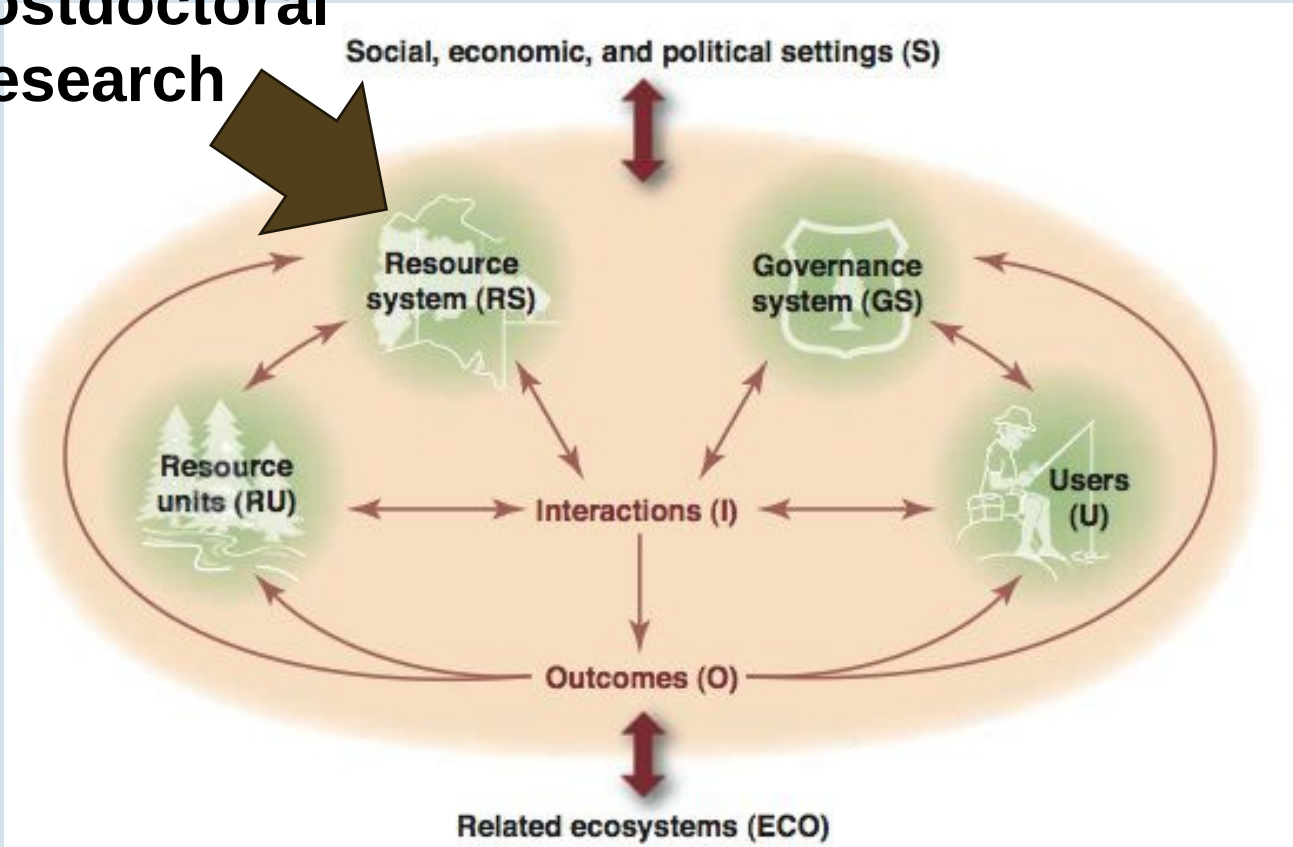


Fig. 1. The core subsystems in a framework for analyzing social-ecological systems.

(Ostrom, 2009)

International Water Security Network

4. Research Project

International Water Security Network

Research Project

Green infrastructure as a climate change adaptation strategy in Hermosillo, Mexico

Adriana Zuniga-Teran and Rolando Diaz Caravantes

METHODS:

1. Analysis of vegetation abundance and temperature
2. Stormwater management and vegetation abundance
3. Survey to the residents

Hermosillo, Sonora

International Water Security Network

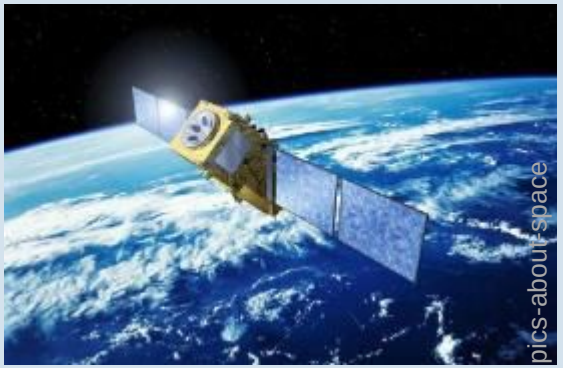
Research Project

METHODS

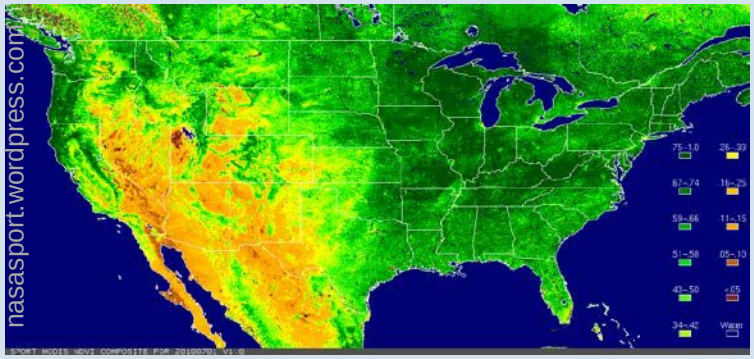
SECTION 1: Analysis of vegetation abundance and temperature

- Vegetation abundance: Normalized Difference Vegetation Index – NDVI[1]

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$



Landsat Satellite



NDVI

(1: Halper et al. 2012)

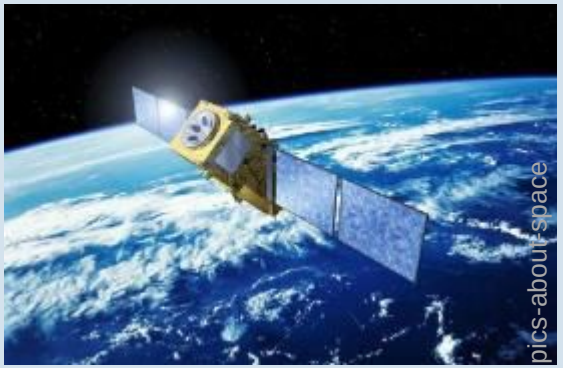
International Water Security Network

Research Project

METHODS

SECTION 1: Analysis of vegetation abundance and temperature

- Vegetation abundance: NDVI
- **Temperature:**
  1. **Above canopy – Landsat thermal band with emissivities from NDVI[1]**
  2. **Below canopy – HOBO Data Loggers**



Landsat Satellite

HOBO Data Logger

(1: Halper et al. 2012)

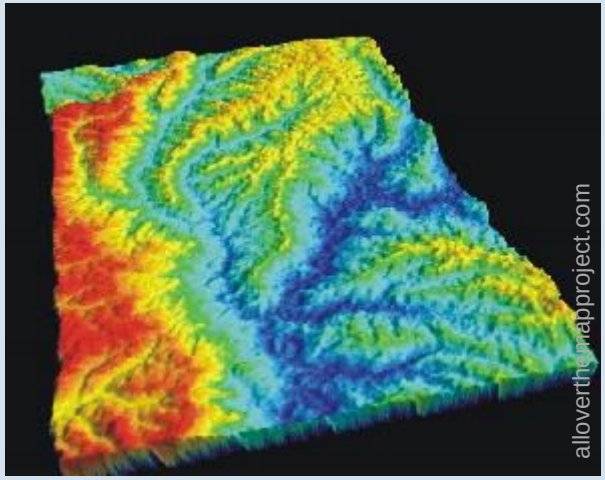
International Water Security Network

Research Project

METHODS

SECTION 2: Stormwater management

1. Using a Digital Elevation Model (DEM)[1], identify flood-risk areas
2. Identify flood-prone areas in the city – GIS shapefile[1]
3. Spatial analysis between flood prone areas and vegetation abundance - NDVI



Digital Elevation Model - DEM

(1: “Shuttle Radar Topography Mission” 2015; 2: INEGI)

International Water Security Network

Research Project

METHODS

SECTION 3: Survey of the residents

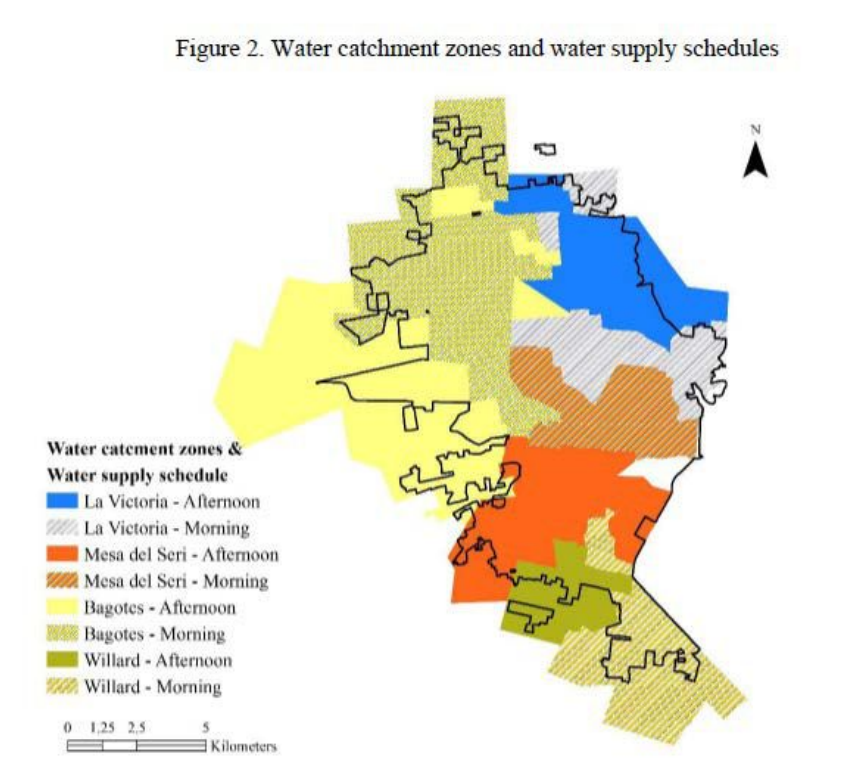
1. Thermal comfort[1]
2. Mood[2]
3. Perception of crime[3]
4. Wellbeing -12-ISFHS[4]
5. Experience flooding during rainy season

(1: Shashua-Bar et al. 2012; 2: Yin et al. 2012; 3: Zuniga-Teran 2015; 4: Ware Jr et al. 1996)

International Water Security Network

Research Project

METHODS



Spatial analysis example in Hermosillo[1]

- Spatial analysis – GIS[2]
- Statistical analysis – SPSS[3]
  - Bivariate correlation
  - Analysis of variance (ANOVA)

(1: Reyes-Castro 2015; 2: ESRI – “Geographic Information Systems 2013; 3: “IBM SPSS Software” 2015)

International Water Security Network

Research Project

HYPOTHESES:

1. Areas that have a higher level of vegetation (NDVI) will be related to lower temperatures

2. People who live in areas with higher level of vegetation will report higher levels of thermal comfort, better mood, less crime in the neighborhood, and better health

3. Areas that have higher level of vegetation will be correlated with fewer and smaller areas affected by floods

4. People who live in neighborhoods with higher level of vegetation will report less floods in their neighborhood

International Water Security Network

Research Project

BROADER IMPACT:

1. Green infrastructure can act as a climate change adaptation strategy – temperature, droughts, storm events

2. Green infrastructure can mitigate climate change:
   - Vegetation – carbon sink
   - Enhanced thermal comfort - walking & biking – less use of car
   - Less energy load for HVAC systems in buildings

3. Increase water security – replenish aquifers, enhance water quality

4. Improve quality of life in cities – comfort, mood, crime, wellbeing

5. Provide habitat for species – ecosystem services

International Water Security Network

www.watersecuritynetwork.org
www.twitter.com/water_network

The Project is funded by **Lloyd's Register Foundation**, a charitable foundation helping to protect life and property by supporting engineering-related education, public engagement and the application of research.

For more information, see: www.lrfoundation.org.uk

International Water Security Network

References

- Chu, Annette, Alice Thorne, and Hilary Guite. 2004. “The Impact on Mental Well-Being of the Urban and Physical Environment; an Assessment of the Evidence.” *Journal of Public Mental Health* 3 (2): 17–32.
- Ernstson, Henrik, Sander E. van der Leeuw, Charles L. Redman, Douglas J. Meffert, George Davis, Christine Alfsen, and Thomas Elmqvist. 2010. “Urban Transitions: On Urban Resilience and Human-Dominated Ecosystems.” *Ambio* 39 (8): 531–45.
- Francis, Jacinta, Billie Giles-Corti, Lisa Wood, and Matthew Knuiman. 2012. “Creating Sense of Community: The Role of Public Space.” *Journal of Environmental Psychology* 32 (4): 401–9. doi:10.1016/j.jenvp.2012.07.002.
- Grimm, Nancy B., Stanley H. Faeth, Nancy E. Golubiewski, Charles L. Redman, Jianguo Wu, Xuemei Bai, and John M. Briggs. 2008. “Global Change and the Ecology of Cities.” *Science* 319 (5864): 756–60.
- Halper, Eve B., Christopher A. Scott, and Stephen R. Yool. 2012. “Correlating Vegetation, Water Use, and Surface Temperature in a Semiarid City: A Multiscale Analysis of the Impacts of Irrigation by Single-Family Residences: Correlating Vegetation, Water Use, and Surface Temperature in a Semiarid City.” *Geographical Analysis* 44 (3): 235–57. doi:10.1111/j.1538-4632.2012.00846.x.
- Herrick, Clare. 2009. “Designing the Fit City: Public Health, Active Lives, and the (re)instrumentalization of Urban Space.” *Environment and Planning A* 41 (10): 2437–54. doi:10.1068/a41309.
- Hutchinson, Charles, and Stefanie Herrmann. 2008. *The Future of Arid Lands- Revisited: A Review of 50 Years of Drylands Research*. Paris, France: UNESCO.
- “IBM SPSS Software.” 2015. Accessed March 10. http://www-01.ibm.com/software/analytics/spss/.
- Liu, Jianguo, Thomas Dietz, Stephen R. Carpenter, Carl Folke, Marina Alberti, Charles L. Redman, Stephen H. Schneider, et al. 2007. “Coupled Human and Natural Systems.” *AMBIO: A Journal of the Human Environment* 36 (8): 639–49.
- Maliva, Robert, and Thomas Missimer. 2012. *Arid Lands Water Evaluation and Management*. Environmental Science and Engineering. Berlin, Heidelberg: Springer Berlin Heidelberg. http://link.springer.com/10.1007/978-3-642-29104-3.
- Ostrom, E. 2009. “A General Framework for Analyzing Sustainability of Social-Ecological Systems.” *Science* 325 (5939): 419–22. doi:10.1126/science.1172133.
- “Overview | Geographic Information Systems.” 2013. Accessed October 25. http://www.esri.com/what-is-gis/overview.
- Reyes Castro, Pablo A. 2015. “Dynamics of Dengue Transmission in the Arid Region of Sonora, Mexico.” Dissertation, Tucson, AZ: University of Arizona.
- Reynolds, James F., D. Mark Stafford Smith, Eric F. Lambin, B. L. Turner, Michael Mortimore, Simon PJ Batterbury, Thomas E. Downing, et al. 2007. “Global Desertification: Building a Science for Dryland Development.” *Science* 316 (5826): 847–51.
- Safriel, Ariel, and Zafar Adeel. 2005. “Chapter 22: Dryland Systems.” In *Ecosystems and Human Well-Being: Current State and Trends*. Vol. 1.
- Samet, Jonathan. 2011. “Community Design and Air Quality.” In *Making Healthy Places. Designing and Building for Heatlh, Well-Being, and Sustainability*. Washington DC, USA: Island Press.
- Shashua-Bar, L., D. Pearlmutter, and E. Erell. 2011. “The Influence of Trees and Grass on Outdoor Thermal Comfort in a Hot-Arid Environment.” *International Journal of Climatology* 31 (10): 1498–1506.
- “Shuttle Radar Topography Mission.” 2015. Accessed November 6. http://www2.jpl.nasa.gov/srtm/.
- Ware Jr, John E., Mark Kosinski, and Susan D. Keller. 1996. “A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity.” *Medical Care* 34 (3): 220–33.
- Zuniga-Teran, Adriana A. 2015. “From Neighborhoods to Wellbeing and Conservation: Enhancing the Use of Greenspace through Walkability.” Tucson, AZ: University of Arizona.

International Water Security Network