How evapotranspiration varies across urban neighborhoods- application of LUMPS model

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Introduction

The greater-Phoenix metropolitan area has endured drought conditions for almost a decade as well as felt effects of the urban heat island phenomenon in summer months. The primary aim of this pilot study is to quantify the amount of water-loss through evapotranspiration in varying neighborhoods. LUMPS: Local-scale Urban Meteorological Parameterization Scheme is a linked set of simple equations designed to calculate heat fluxes for the urban environment. Heat fluxes can be modeled using net all-wave radiation, basic information on surface cover (areas of vegetation, buildings, and impervious materials), morphometry (roughness element height and density), and standard weather observations (air temperature, humidity, wind speed, and pressure). Urban landscapes differ among the greater-Phoenix area; plant and surface cover can affect the amount of water used to maintain such landscapes and contribute to evapotranspiration rates. Preliminary results of LUMPS show that different land cover fractions are controlling the heat flux throughout the system at different times of the day.

Materials and Methods

In this study the Local scale Urban Meteorological Parameterization Scheme (LUMPS; Grimmond and Oke 2002) was applied to estimate outdoor water use for selected neighborhoods in the Phoenix metropolitan region. LUMPS has been shown to simulate the components of the urban surface energy balance (see Fig. 1) consistently with a high accuracy (Grimmond and Oke 2002). The model is a further development of the work of Hanna and Chang (1992) that treats vegetation and built surfaces in one tile. Net all-wave radiation is modeled according to Offerle *et al.* (2003). Heat storage is determined using the Objective Hysteresis Model (Grimmond and Oke 1999). The turbulent sensible and latent heat fluxes calculations are based on urban modifications to deBruin and Holtslag (1982). The fraction of vegetation f_{veg} present allows for differentiation between partitioning of sensible and latent fluxes λE (with λ latent heat of vaporization and E evapotranspiration) where the latter is given by:

$$\lambda E = \frac{\alpha}{1 + (\gamma / s)} \left(Q^* - \Delta Q_s \right) + \beta$$

with α and β being empirical parameters, Q^* net radiation, γ psychrometric constant, ΔQs heat storage flux, and s slope of the saturation vapor pressure-versus-temperature curve. The parameter α is a linear function of f_{veg} which was derived from measurements of latent heat fluxes in urban areas that differed by fraction cover of vegetation (Grimmond and Oke 2002).

Data Inputs

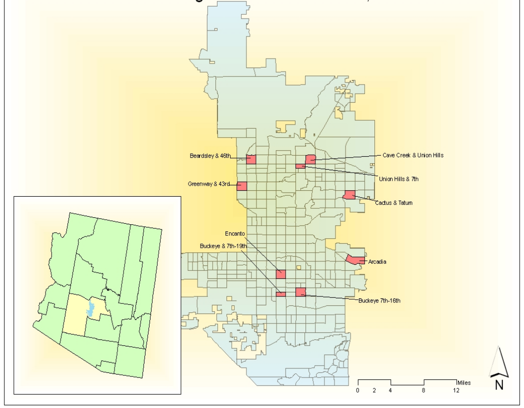
Hourly meteorological data from surface stations, such as air temperature, relative humidity, wind speed, wind direction, incoming solar radiation was taken from Sky Harbor International Airport from the month of June 2000.

Fraction Covers (Table 1) are gross approximations using land cover classification files from work by Stefanov (2001) as well as land parcel information from the Assessor's office of Arizona. Experimental aggregation of land cover classifications was necessary in order to correspond to the LUMPS model inputs.

Table 1. Percentage of land cover for each classification of LUMPS input

Neighborhood	Buildings	Impervious Surfaces	Unmanaged Soil	Vegetation	Water	Building Height
Arcadia	21.86	13.64	5.00	53.00	6.50	5.24
Beardlsey & 46th	28.30	15.30	24.20	28.40	3.80	5.20
Buckeye 7th-16th	21.30	51.70	21.00	5.90	0.10	5.06
Buckeye 7th-19th	7.60	75.30	13.20	3.80	0.10	4.88
Cactus & Tatum	32.40	14.30	16.50	36.00	0.80	5.41
Cave Creek & Union Hills	19.60	17.90	59.30	2.90	0.30	5.38
Encanto	15.60	42.50	25.50	16.00	0.40	4.95
Greenway & 43rd	31.50	13.60	49.90	4.90	0.10	5.18
Union Hills & 7th	30.70	22.50	40.50	6.00	0.30	4.95

Selected neighborhoods for Phoenix, Arizona



Results

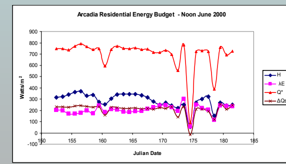


Figure 1. Example of the urban surface energy budget at noontime for June 2000 in Arcadia neighborhood where:

H= sensible heat
λE= latent heat
Q*= net all-wave radiation
ΔQ_s= heat storage

Based on the surface energy balance:

$$(Q^* = Q_H + Q_E + \Delta Q_S)$$

from Grimmond & Oke (2002).

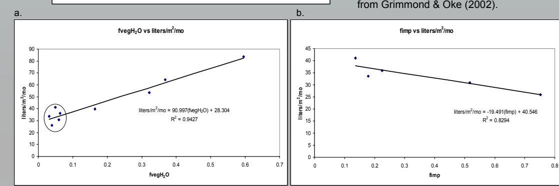


Figure 2 (a): Illustrates the impact of the fraction of vegetation and water cover (f_{vegH2O}) on monthly water loss. **(b)**: Circled segment of Fig 2 (a) indicates the relationship between the fraction of impervious cover (f_{imp}) and monthly water use in loss (<0.1) vegetative fraction sites.

Conclusions

Across the nine City of Phoenix neighborhoods, the following preliminary conclusions are evident for the month of June, 2000:

1. There is a highly significant correlation between the fraction of area of vegetation/water (f_{vegH2O}) and the evaporative fluxes to the atmosphere, and thus in the liters/m^2 per month in the various census tracts (see Fig. 2). Results show a large range from ca. 25 to over 80 liters/m^2 per month.
2. Below the threshold of f_{vegH2O} of 0.10, liters/m^2 per month across five lower moisture locations are not related to variable f_{vegH2O}, but inversely to f_{imp} - the fraction of impervious surface area.
3. According to the LUMPS model, an increase of 10% vegetation equates to 9.1 liters/m^2 per month of water lost. For an average residential lot, this is 8800 liters per month and could increase water use by ~15% in June.

References

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