Agricultural Water Management 176 (2016) 270–279

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Methodology for quantifying impacts of urbanization on the water distribution networks of irrigation districts

Gabriele Bonaiti[a,*], Guy Fipps[b]

[a] Extension Program Specialist, Department of Biological and Agricultural Engineering, 2117 Texas A&M University, College Station, TX 77843-2117, United States

[b] Professor and Extension Specialist, Department of Biological and Agricultural Engineering, 2117 Texas A&M University, College Station, TX 77843-2117, United States

ARTICLE INFO

Article history:
Received 29 January 2015
Received in revised form 10 May 2016
Accepted 13 May 2016
Available online 27 May 2016

Keywords:
Fragmentation index
Fragment density index

ABSTRACT

In this paper, a new methodology is presented for analyzing urbanization of irrigation districts within a region. This method is based upon the fragmentation of irrigation water distribution networks (i.e. canals, pipeline, reservoirs, water control structures, etc.) due to urban growth and expansion. Two functions are presented, the fragmentation index which defines the extent that the water distribution network (i.e., canals and pipelines) is impacted by patchy urbanized areas within an irrigation district, and the fragment density index which identifies the most impacted locations in the region. Urban expansion and the use of these indexes are demonstrated through an analysis of 28 irrigation districts located in the Lower Rio Grande Region (LRGR) of South Texas over a 10 year period.

In the LRGR, from 1996 to 2006, the total urbanized area within irrigation districts increased by 28%, and there was a 31% increase in canals and pipelines that became engrossed by urbanization. The engrossment rate of other distribution components varied but was higher, such as 62% for water control structures. The total numbers of network fragments increased by 48%, resulting in a 140% increase of the number of locations with a high fragment density defined as locations with more than 1.4 fragments/km^2 and with a density index >0.5. Locations with a high fragment density index shifted within the region, which is consistent with the dynamics of patchy urbanization in which patches tend to merge together while new patches are generated. Maps of the changes in fragment density index maps from 1996 to 2006 clearly show urbanization trends that can be used for rehabilitation planning and other purposes.

1. Introduction

Urbanization not only impacts the service area of irrigation districts, but also the amount of water flowing through their canals and pipelines, which, in turn can decrease conveyance efficiency and increase water losses. Urbanization also causes fragmentation of irrigated cropland and water distribution networks, with detrimental effects on normal operations and maintenance of districts (Gooch, 2009; Gooch and Anderson, 2008). Few irrigation districts in the US or around the world analyze the effects of urbanization on operation and management procedures, or incorporate urbanization trends into planning for future infrastructure improvements. However, there would be several benefits from this type of analysis such as identifying priority areas for conversion from open canal to pipeline (Lambert, 2011). Gooch (2009) and Gooch and Anderson (2008) analyzed issues related to urbanization, including water rights transfers, changes in delivery systems, relocation of structures, conflict resolving, mitigation measures, and cost analysis.

Several authors have examined fragmentation caused by urbanization on natural land density, urban population and food supply. Ritters et al. (2000) and Wickham and Ritters (2008) measured the temporal change of forest fragmentation in USA between 1992 and 2001 through an analysis of the National Land Cover Database. They calculated the forest density in moving windows which varied from two to 5000 ha, and classified the results based on density thresholds (patch, dominant, and interior forest). Matuschke (2009) used GIS tools to calculate population, and current and projected food consumption densities in developing countries. By combining these two densities, Matuschke created density maps of food consumption (calories/km^2/day) for 2005 and 2050. Shrestha et al. (2011) analyzed land use maps for 1992 and 2001 of the Phoenix metropolitan area which were generated using the National Land Cover Database and validated with detailed land use maps obtained

* Corresponding author.
E-mail address: g.bonaiti@tamu.edu (G. Bonaiti).

http://dx.doi.org/10.1016/j.agwat.2016.05.023
0378-3774/

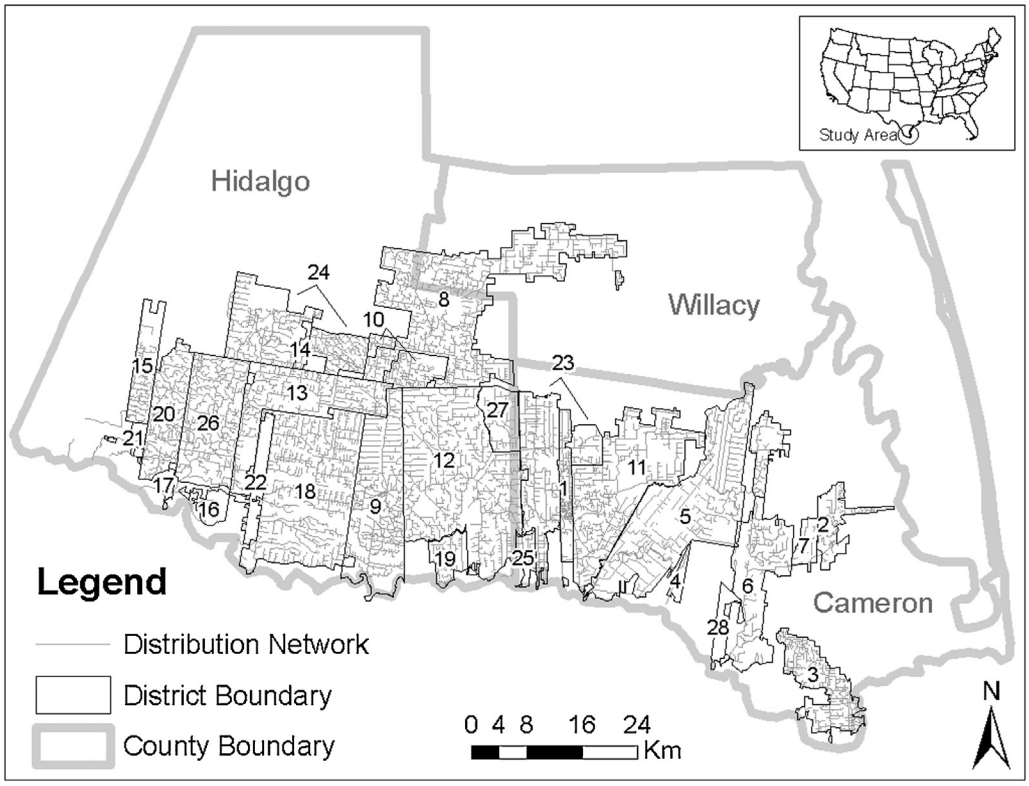

Fig. 1. Location map: county boundaries, irrigation district boundaries, and irrigation distribution network.

Table 1
Water rights held by irrigation districts in the Lower Rio Grande Region (TCEQ, 2013).

District			Agricultural Water Right (10^6 m^3)	Other uses (10^6 m^3)
ID	Legal name	Abbreviation		
1	Adams Garden Irrigation District No.19	Adams Garden	23.11	–
2	Bayview Irrigation District No.11	Bayview	22.74	0.28
3	Brownsville Irrigation District	BID	46.70	4.73
4	Cameron County Water Improvement District No.16	CCWID16	4.95	–
5	Cameron County Irrigation District No.2	CCID2	182.36	11.25
6	Cameron County Irrigation District No.6	CCID6	67.12	0.02
7	Cameron County Water Improvement District No.10	CCWID10	10.72	–
8	Delta Lake Irrigation District	Delta Lake	216.20	10.11
9	Donna Irrigation District-Hidalgo County No.1	Donna	116.03	8.49
10	Engelman Irrigation District	Engelman	23.50	0.10
11	Harlingen Irrigation District-Cameron County No.1	Harlingen	125.68	23.82
12	Hidalgo and Cameron County Irrigation District No.9	HCCID9	212.35	21.17
13	Hidalgo County Irrigation District No.1	HCID1	101.68	10.89
14	Hidalgo County Irrigation District No.13	HCID13	5.37	–
15	Hidalgo County Irrigation District No.16	HCID16	37.93	2.22
16	Hidalgo County Irrigation District No.19	HCID19	11.16	–
17	Hidalgo County Water Control and Improvement District No.18	HCWCID18	4.11	–
18	Hidalgo County Irrigation District No.2	HCID2	169.96	30.90
19	Hidalgo County Water Improvement District No.5	HCWID5	18.05	–
20	Hidalgo County Irrigation District No.6	HCID6	43.06	7.17
21	Hidalgo County Municipal Utility District No.1	HCMUD1	1.51	0.47
22	Hidalgo County Water Improvement District No.3	HCWID3	10.43	17.37
23	La Feria Irrigation District-Cameron County No.3	La Feria	95.51	6.35
24	Santa Cruz Irrigation District No.15	Santa Cruz	97.02	0.15
25	Santa Maria Irrigation District-Cameron County No.4	Santa Maria	12.56	0.07
26	United Irrigation District of Hidalgo County	United	60.90	29.13
27	Valley Acres Water District	Valley Acres	25.69	0.62
28	Valley Municipal Utility District No.2	VMUD2	7.25	0.98
Total			1,753.65	186.30

from local government. Shrestha analyzed land fragmentation by applying landscape metrics which quantify spatial patterns based on shape, size, number and related spectral signatures. The analysis was conducted on 15 × 15 km moving windows.

This paper presents and demonstrates the effectiveness of a new methodology for identifying the dynamics of urban growth and effects on irrigation water distribution networks by calculating the extent that the distribution network is encompassed and fragmented by urban areas. The methodology is applied to irriga-