8 Assessing the Extent of Urban Irrigated Areas in the United States

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8.1 INTRODUCTION

Monitoring of irrigated areas is of critical importance for ensuring global food security and managing the sustainable use of freshwater resources. As such, mapping efforts in irrigated areas have traditionally focused on agricultural irrigated areas

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[1,2]. However, in the United States and in other developed countries that have undergone more recent low-density urbanization, such as Canada and Australia, a growing sector of yet mostly undocumented irrigated areas is to be found within urban environments [3–5]. While not contributing to significant food and fiber production, but rather serving a functional, recreational, and aesthetic purpose [6], the irrigation of urban landscape is responsible for a large component of urban water use in these countries. Estimates of North American cities indicate that, depending on climate, the fraction of residential water use for outdoor purposes ranges from 22–38% in cooler climates to 59–67% in cities with hot and dry climates [7]. During the past several decades, factors such as the low-density character of urbanization accompanied by a cultural predilection towards living in single-family housing surrounded by lush landscaped vegetation have contributed to the large expansion of irrigation in urban areas across all climatic regions of the United States. This expansion is likely to have reached considerable proportions in the United States, where turfgrass, the most common type of urban landscaping vegetation, is reported to cover an area ranging from 11.1–20.2 million hectares (Mha) [8–11]. As a preferred type of urban landscaping vegetation in the United States, turfgrass can be found in all urban settings in a country where the majority of the population live in single-family houses, each surrounded by a lawn. Beyond residential housing, turfgrass is also found along many sidewalks, business parks, institutional buildings, recreational parks, cemeteries, golf courses, etc. Being characterized by nonnative grass species, turfgrass needs to be irrigated at some point during the year to grow in optimal conditions in most parts of the country.

Assessing the extent of urban irrigated areas is, therefore, becoming increasingly important for planning future urban water demand by local water resource planners, to understand the opportunities of water conservation and to help devise regional water policies. However, given the heterogeneous and highly fragmented nature of urban landscaping, mapping and monitoring of urban irrigated areas require the use of high-resolution remote-sensing images (of the order of 1-m [12]). The cost of such images and the computation requirements of their analysis still make direct mapping of irrigated areas elusive for regional assessments of urban irrigated areas. Even at a local scale, estimates of urban irrigated areas, let alone maps, are hard to find. In this study, we explore remote-sensing-based and census-based methodologies to provide a first attempt at estimating the likely urban irrigated area within the conterminous United States, to understand how relevant they are in comparison to irrigated cropland areas.

8.2 HISTORICAL BACKGROUND ON THE ORIGINS OF URBAN IRRIGATED AREAS IN THE UNITED STATES

The diffusion of urban irrigated areas in the United States can be traced back to the planning of the first suburban developments in the late 1800s, when the first landscaped low-density residential areas started to be built for the new middle class that desired escaping the increasingly unhealthy conditions of industrial cities [10,13,14]. The style of English gardens with a lawn was soon adopted as the preferred type of landscape. Campaigns of neighborhood beautification promoted by the various

gardening clubs and the individual homeowners' need to affirm their social status through the exterior appearance of their houses, resulted in increasing yard maintenance. After the first lawnmowers and rubber garden hoses became available, the standards of appearance of a lawn were also soon defined as "a plot with a single type of grass with no intruding weeds, kept mown at a height of an inch and a half, uniformly green, and neatly edged" [13]. Suburban areas accelerated their expansion after World War II, when the availability of loans from the Federal Housing Authority stimulated a housing boom that made relocation to the suburbs and owning a yard affordable to a large proportion of the population. The diffusion of the use of fertilizers and pesticides further contributed to making lawns an urban landscape type of choice for their versatility of surrounding the houses with a formal and neat look, while serving as a private playground. Lawns can be found in urban and suburban areas across the country, from New England to the Southwest. Manicured lawns and lush landscapes remain a form of status symbol, contributing considerably to real estate appreciation [15]. However, because of the significant impact on urban water consumption, water conservation outreach programs and watering restriction ordinances are increasingly targeting lawn-watering practices.

8.3 METHODS

8.3.1 Approaches to Estimating the Extent of Irrigated Urban Vegetation

As a first approximation of the extent of urban irrigation in the conterminous United States, we start from estimates of turfgrass area and then derive irrigated turf area by making adjustments to the total area, based on watering practices.
Recent estimates of turfgrass area are available from turfgrass and green industry surveys for 10 states:

- Illinois [16]
- Iowa [17]
- Kansas [18]
- Maryland [19]
- Michigan [20]
- New Jersey [21]
- New York [22]
- North Carolina [23]
- Virginia [24]
- Wisconsin [25]

While providing detailed information on the extent of turfgrass area in different residential and commercial sectors of these states, these reports are not sufficient to produce a continental estimate. To derive continental estimates, we have two options: (1) use an indirect remote-sensing-based approach, as suggested by Milesi et al. [9]; or (2) use data on the characteristics of new housing provided by the US Construction Census, similar to the method proposed by Vinlove and Torla [26] to estimate the area of residential lawns, and then adjust these estimates to include the total turfgrass area associated with urban and suburban settlements in the United States.

8.3.2 Remote-sensing Approach

Given the ubiquity of turfgrasses in the American urban areas, it can be assumed that a proportion of turfgrass area can be associated with each portion of a built-up area (also called impervious surface area; ISA). Measures of lawn and built-up area, measured from 1-km tiles of high-resolution aerial photography collected along transects from sparsely developed outskirts to dense downtowns of 13 major US centers, indicated that the two variables had a moderately strong relationship (Figure 8.1). The fraction of turfgrass area is inversely related to the fractional ISA, with turfgrass areas increasing as the ISA decreases down to 10%, where the samples of aerial photography suggested that nonsignificant portions of lawn were present. Based on these data, we developed a predictive model that allowed rapid mapping of the turfgrass area for the continental United States, starting from a map of impervious areas [9].

Two national datasets of ISA are currently available for the continental United States. One was produced by the National Oceanic and Atmospheric Administration (NOAA) and provides subpixel fraction of ISA at 1 km^2 spatial resolution. The ISA estimates reported in this map refer to the year 2000/2001 and were obtained by relating satellite-derived radiance-calibrated nighttime city lights, road density, and three Landsat-derived urban land cover classes, to observations of ISA from the above-mentioned high-resolution aerial photography [27]. This ISA data set was used to map the area in the United States potentially under turfgrass [9]. The other national ISA data set was produced by the United States Geological Survey (USGS) by relating Landsat data to measures of imperviousness derived from digital orthophoto quadrangles through regression-tree algorithms [28]. The USGS ISA data set provides a subpixel fraction of ISA at 30-m resolution.

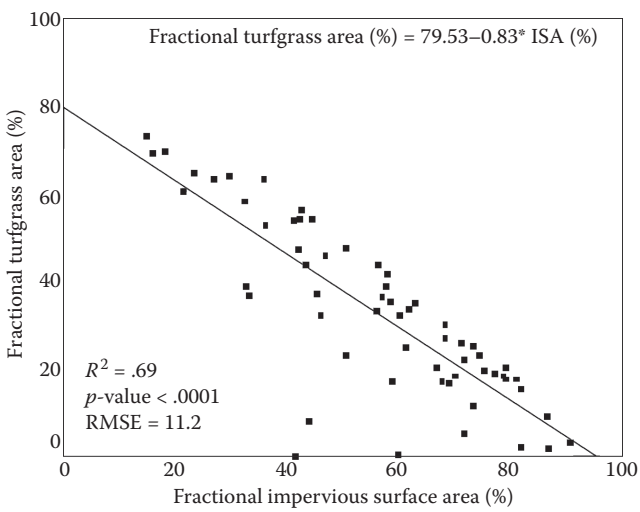

FIGURE 8.1 Scatterplot of the fractional ISA and turfgrass area measurements derived from high-resolution aerial photographs of urban areas across the United States.

Here we apply the turfgrass predictive model developed in Milesi et al. [9] to the USGS fractional ISA. We resample the original USGS ISA 30-m data set to a 1-km grid in Albers Conical Equal Area projection and apply the fractional turfgrass area vs. impervious area predictive equation reported in the plot in Figure 8.1.

8.3.3 Housing Data Approach

The data on the characteristics of new housing [29] offer the possibility to perform a back of the envelope calculation and an attempt of validation of the remote-sensing-based estimates of turfgrass area for the conterminous United States. These data also allow us to gain a perspective on the annual expansion of urban landscaped area.

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We use time series of median lot sizes, median house-floor area, number of stories, and type of parking of sold, new, single-family houses, collected by the US Census Bureau [29]. Nationally aggregated data are available from 1978–2006 (Tables 8.1 and 8.2).

For each year from 1978–2001, we estimate the two measures of newly added turfgrass area, one based on median lot and house size ($\text{Lawn}_{\text{med},t}$; Equation 8.1) and the other based on average lot and house size ($\text{Lawn}_{\text{avg},t}$; Equation 8.2):

$$\text{Lawn}_{\text{med},t} = L_{\text{med},t} - H_{\text{med},t} - P_t - D_t, \tag{8.1}$$

$$\text{Lawn}_{\text{avg},t} = L_{\text{avg},t} - H_{\text{avg},t} - P_t - D_t, \tag{8.2}$$

where, $L_{\text{med},t}$ is the total new lot area in year t based on median lot area, and is obtained by multiplying the total number of new single-family units built in year t (SF_t) by the median lot size of year t; $L_{\text{avg},t}$ is the total new lot area in year t based on average lot area and is obtained as done for $L_{\text{med},t}$ except that average rather than median lot size is used; $H_{\text{med},t}$ (Equation 8.3) and $H_{\text{avg},t}$ (Equation 8.4) refer to total house footprint area; P_t (Equation 8.5) is the total area of parking in year t; D_t (Equation 8.6) is the total area of paved driveways.

The total house footprint area, $H_{\text{med},t}$, is based on median house size ($h_{\text{med},t}$) and number of stories of the newly constructed units, and is calculated as:

$$H_{\text{med},t} = \text{1-story SF}_t * h_{\text{med},t} + \text{2-story SF}_t * (h_{\text{med},t}/2) + \text{split level SF}_t (h_{\text{med},t}/1.5). \tag{8.3}$$

The calculation of $H_{\text{avg},t}$ (Equation 8.4) is similar to that of $H_{\text{med},t}$ except that median house size is replaced with average house size ($h_{\text{avg},t}$):

$$H_{\text{avg},t} = \text{1-story SF}_t * h_{\text{avg},t} + \text{2-story SF}_t * (h_{\text{avg},t}/2) + \text{split level SF}_t (h_{\text{avg},t}/1.5). \tag{8.4}$$

P_t (Equation 8.5) is calculated assuming the following garage sizes: 23 m^2 for a one-car garage, 37 m^2 for a two-car garage, and 56 m^2 for a three-car garage.

TABLE 8.1
Characteristics of New Housing and Estimated New Residential Lawn, Based on Median Lot and House Size

Year	SF×1,000	Median Lot Size (m^2)	Median House Aize (m^2)	1-Story SF (×1,000)	2-Story SF (×1,000)	Split Level SF (×1,000)	1-Car SF (×1,000)	2-Car SF (×1,000)	3-Car or more SF (×1,000)	Carport SF (×1,000)	$A_{Res,med}$ (ha)	Average Median Lawn Size (m^2)
1978	816	910	153	477	241	98	196[a]	359[a]	0[a]	57[a]	59,195	725
1979	708	890	153	402	231	75	163[a]	333[a]	0[a]	42[a]	49,991	706
1980	531	853	146	316	163	52	117[a]	260[a]	0[a]	32[a]	35,671	672
1981	436	804	145	246	151	39	92[a]	227[a]	0[a]	22[a]	27,211	624
1982	411	768	142	234	147	30	82[a]	222[a]	0[a]	21[a]	24,223	589
1983	623	778	147	327	255	41	118[a]	355[a]	0[a]	25[a]	37,252	598
1984	639	791	150	314	286	39	115[a]	377[a]	0[a]	26[a]	38,981	610
1985	688	825	148	330	316	42	117[a]	427[a]	0[a]	21[a]	44,322	644
1986	750	832	153	347	363	40	116	487	0[a]	21	48,586	648
1987	670	864	164	295	340	35	100	473	0[a]	14	44,809	669
1988	676	857	167	289	357	30	83	497	0[a]	12	44,607	660
1989	650	883	173	278	345	27	72	492	13[a]	10	44,037	677
1990	534	929	176	224	283	27	59	410	33[a]	7	38,219	716
1991	509	906	177	210	269	30	53	393	50[a]	6	34,975	687
1992	610	906	177	266	311	33	57	425	64	7	42,206	692
1993	666	899	177	292	344	30	57	463	81	5	45,554	684
1994	670	892	177	300	343	26	60	463	86	5	45,243	675
1995	667	883	175	308	334	25	52	467	90	5	44,399	666

1996	757	855	180	347	383	28	59	528	106	6	47,890	633
1997	804	836	182	366	417	22	64	555	121	6	49,238	612
1998	886	835	186	399	472	15	65	620	135	8	53,951	609
1999	880	843	189	381	489	11	68	615	141	5	54,096	615
2000	877	830	193	387	475	16	62	601	156	5	52,344	597
2001	908	829	195	397	499	12	58	634	163	4	54,009	595
Average		854	168									650

[a] Information on garage type was not available. Values were obtained by polynomial interpolation of the available data.

TABLE 8.2
Characteristics of New Housing and Estimated New Residential Lawn, Based on Average Lot and House Size

Year	SF×1,000	Average Lot Size (m^2)	Average House Size (m^2)	1-Story SF (×1,000)	2-Story SF (×1,000)	Split Level SF (×1,000)	1-Car SF (×1,000)	2-Car SF (×1,000)	3-Car or more SF (×1,000)	Carport SF (×1,000)	$A_{Res,avg}$ (ha)	Average Lawn Size (m^2)
1978	816	1,743	163	477	241	98	196[a]	359[a]	0[a]	57[a]	126,580	1,551
1979	708	1,623	164	402	231	75	163[a]	333[a]	0[a]	42[a]	101,341	1,431
1980	531	NA	158	316	163	52	117[a]	260[a]	0[a]	32[a]	NA	NA
1981	436	NA	159	246	151	39	92[a]	227[a]	0[a]	22[a]	NA	NA
1982	411	1,287	157	234	147	30	82[a]	222[a]	0[a]	21[a]	45,061	1,096
1983	623	1,524	162	327	255	41	118[a]	355[a]	0[a]	25[a]	83,012	1,332
1984	639	1,343	166	314	286	39	115[a]	377[a]	0[a]	26[a]	73,466	1,150
1985	688	1,636	164	330	316	42	117[a]	427[a]	0[a]	21[a]	99,339	1,444
1986	750	1,472	168	347	363	40	116	487	0[a]	21	95,698	1,276
1987	670	1,635	177	295	340	35	100	473	0[a]	14	95,868	1,431
1988	676	1,321	182	289	357	30	83	497	0[a]	12	75,252	1,113
1989	650	1,286	186	278	345	27	72	492	13[a]	10	69,665	1,072
1990	534	1,381	190	224	283	27	59	410	33[a]	7	61,759	1,157
1991	509	1,326	190	210	269	30	53	393	50[a]	6	55,865	1,098
1992	610	1,660	191	266	311	33	57	425	64	7	87,535	1,435
1993	666	1,625	191	292	344	30	57	463	81	5	93,133	1,398
1994	670	1,625	190	300	343	26	60	463	86	5	93,686	1,398

1995	667	1,644	190	308	334	25	52	467	90	5	94,354	1,415
1996	757	1,600	194	347	383	28	59	528	106	6	103,552	1,368
1997	804	1,549	199	366	417	22	64	555	121	6	105,583	1,313
1998	886	1,478	202	399	472	15	65	620	135	8	109,902	1,240
1999	880	1,545	206	381	489	11	68	615	141	5	114,764	1,304
2000	877	1,656	210	387	475	16	62	601	156	5	123,716	1,411
2001	908	1,490	212	397	499	12	58	634	163	4	112,856	1,243
Average		1,520	182									1,303

[a] Information on garage type was not available. Values were obtained by polynomial interpolation of the available data.

The carports built each year are assumed to be half for one-car garage and half for two-car garages:

$$P_t = (\text{1-car garage SF}_t * 23 + \text{2-car garage} \times \text{SF}_t * 37 + \text{3-car garage SF}_t * 56 + \text{carport} \times \text{SF}_t/2 * 23 + \text{carport SF}_t/2 * 37). \quad (8.5)$$

The calculation of D_t (Equation 8.6) assumes driveways to be of the size of 33 m^2 for a one-car garage, 56 m^2 for a two-car garage, and 84 m^2 for a three-car garage. The driveways for the houses with carports are assumed to be half the size of those with one-car garages and half the size of those with two-car garages:

$$D_t = (\text{1-car garage SF}_t * 33 + \text{2-car garage SF}_t * 56 + \text{3-car garage} \times \text{SF}_t * 84 + \text{carport SF}_t/2 * 33 + \text{carport SF}_t/2 * 56). \quad (8.6)$$

Total residential turfgrass area based on median values is calculated by multiplying the 1978–2001 average median residential lawn area by the total number of single-family houses from the 2000 US Census. This measure provides a lower limit of the total residential area under turfgrass. An upper limit of the total residential turfgrass area, based on average lot and house sizes, is calculated by multiplying the 1978–2001 average residential lawn area by the total number of single-family houses from the 2000 US Census.

To obtain a total turfgrass area, including the turfgrass found in commercial areas, schools, golf courses, athletic fields, etc., we use available information from turfgrass and green industry surveys on the fraction of turfgrass found in private residences (Table 8.5). Across the 10 states for which recent turfgrass surveys are available, on average, private residences make up 68.3% of the total turfgrass area.

Total turfgrass area is calculated as:

$$A_{\text{tot,med(avg)}} = A_{\text{Res,med(avg)}} / f_{\text{Res}}, \quad (8.7)$$

where, $A_{\text{Res,med(avg)}}$ is the total residential turfgrass area calculated either from median or from average lawn area averaged throughout the 1978–2001 period, and f_{Res} is the average fraction of turfgrass area found in private residences across the surveyed states.

In the conversion of total turfgrass area to urban irrigated area, we are aware that although most of the turfgrass area can be expected to be equipped for irrigation (i.e., through automatic sprinklers or through a rubber hose and manual sprinklers), not every lawn and landscaped area across the country is irrigated. A recent survey of 1005 American adult homeowners indicated that 38% never water their lawns [30]. For example, many eastern states are humid enough during the growing season, so that many homeowners do not water their lawns. As these states are also densely populated,

a considerable pressure on water resources for indoor consumptive use contributes to triggering frequent water bans for outdoor water use during dry years. In other parts of the country where the climate is drier and the population is smaller, watering of urban landscapes is more common, as otherwise turfgrasses could not survive or would turn brown and dormant for most of the dry season. Percentages of house owners watering their lawns in different geographic areas are available only for a few regions (Table 8.3). We will assume that 40% of the turfgrass area in the northeastern states, 60% in the southeastern and central states, and 80% in the western states are watered. The assumptions on the prevalence of irrigation for each state are reported in Table 8.5.

8.4 RESULTS AND DISCUSSION

8.4.1 Total Turfgrass Area

The estimates of total turfgrass area obtained from the various methods are summarized in Table 8.4.

The estimates of turfgrass area for each state derived from the USGS ISA data set are listed in Table 8.5, along with the estimates derived from the NOAA ISA by

TABLE 8.3
Prevalence of Watering Practices in Various States

State	House Owners Watering their Lawns (%)	Source
Iowa	35	USDA National Agricultural Statistics Service & Iowa Agricultural Statistics Service [17]
New Jersey	75	Govindasamy et al. [21]
New York	15	New York Agricultural Statistics Service [22]
North Carolina	68	Osmond and Hardy [31]
Virginia	50	Aveni [32]
Oregon	74	Nielson and Smith [33]
United States	38	Anonymous [30]

TABLE 8.4
Summary of Total Turfgrass Area and Urban Irrigated Area from Various Approaches

Approach	Total Turfgrass Area (ha)	Urban Irrigated Area (ha)
USGS-based	11,172,171	6,665,332
NOAA-based	16,163,436	9,602,148
US Census-based	7,263,980	4,503,668
US Census-based	14,564,101	9,029,743

TABLE 8.5
Estimates of Total Turfgrass Area Derived from Remote-sensing Approaches and Turf Surveys, along with the Proportion Assumed to be Irrigated

State	NOAA-based Turfgrass Area (ha)	USGS-based Turfgrass Area (ha)	Turfgrass Survey (ha)[a]	Turfgrass Area Assumed to be Irrigated (%)
Alabama	314,134	202,119		60
Arizona	256,665	197,615		80
Arkansas	210,678	141,329		60
California	1,118,838	853,814		80
Colorado	247,878	182,113		80
Connecticut	247,614	147,067		40
Delaware	55,255	30,846		40
District of Columbia	5,685	6,227		40
Florida	1,174,029	766,200		60
Georgia	569,874	385,985		60
Idaho	93,541	63,820		80
Illinois	575,386	537,902	624,665 (61)	40
Indiana	385,159	287,210		40
Iowa	228,978	165,595	514,534 (47)	40
Kansas	199,662	167,007	309,423 (21)	60
Kentucky	243,975	158,244		60
Louisiana	336,979	217,969		60
Maine	97,698	54,427		40
Maryland	254,171	151,175	459,237 (83)	40
Massachusetts	429,714	292,310		40
Michigan	461,845	447,658	764,492 (83)	40
Minnesota	318,354	233,235		40
Mississippi	200,147	123,706		60
Missouri	345,604	275,787		60
Montana	73,071	59,004		80
Nebraska	115,201	95,355		80
Nevada	93,124	84,697		80
New Hampshire	111,757	63,736		40
New Jersey	396,434	254,108	360,342 (75)	40
New Mexico	153,904	71,275		80
New York	641,950	360,596	1,387,393 (82)	40
North Carolina	816,036	355,305	864,247 (68)	60
North Dakota	56,676	36,978		80
Ohio	671,807	527,373		40
Oklahoma	269,306	174,423		80
Oregon	198,784	149,597		80
Pennsylvania	728,516	429,059		40
Rhode Island	52,026	42,837		40
South Carolina	405,089	194,811		60
South Dakota	69,352	45,254		80

TABLE 8.5 (Continued)

State	NOAA-based Turfgrass Area (ha)	USGS-based Turfgrass Area (ha)	Turfgrass Survey (ha)[a]	Turfgrass Area Assumed to be Irrigated (%)
Tennessee	419,245	257,523		60
Texas	1,320,628	1,041,741		80
Utah	120,869	96,580		80
Vermont	52,150	26,042		40
Virginia	458,507	261,428	553812 (52)	60
Washington	362,650	309,111		80
West Virginia	149,612	82,070		60
Wisconsin	313,486	233,104	485299 (64)	40
Wyoming	55,527	32,920		80

[a] The fractions (%) of turfgrass found in private residences are given in parentheses.

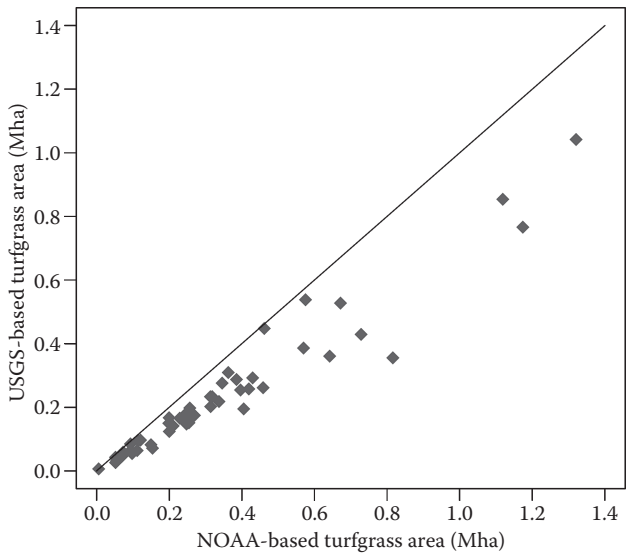

FIGURE 8.2 Scatterplot of the two remote-sensing-based estimates of total turfgrass area aggregated by state.

Milesi et al. [9] and, where available, the estimates provided by the turfgrass and green industry surveys. The total turfgrass area estimated from the USGS ISA is 11,172,171 Mha, a surface considerably lower than the previously estimated area of 16,163,436 Mha based on the NOAA ISA.

The USGS-based turfgrass area estimates are smaller than the NOAA-based estimates for all states except the District of Columbia (Figure 8.2), with a median difference of 33%, and differences greater than 50% for the states of New Mexico,

North and South Carolina, and Vermont. The differences between the two turfgrass area estimates are greater than the differences among fractional ISA estimates due to differences in the distribution of fractional ISA values within each data set. The USGS ISA data set has a larger fraction of pixels with less than 10% ISA, for which the lawn estimation model assumes no lawn, as these are assumed to be rural areas.

The statewide estimates of turf area reported in recent turfgrass and green industry surveys available for 10 states are higher than those based on remote-sensing data (Figure 8.3). In general, they compare best with the NOAA-based turfgrass estimates, with a Pearson correlation coefficient of .73. For Illinois, New Jersey, and North Carolina, the turf area assessments from the industry and the NOAA-based approach differ by less than 10%. The largest difference is found over the state of New York, where the survey estimate is 50% larger than the NOAA-based estimate. The survey estimates display a weaker correlation with USGS-based turfgrass estimates, with a Pearson correlation coefficient of .5. The USGS-based turfgrass estimates are between 30% and 80% smaller than the areas reported in the surveys. One of the reasons for surveys reporting a greater turfgrass surface than the remote-sensing-based approaches is that the extrapolation of the survey data to the whole state is based on averages from the polled data, which are likely to be influenced by larger values. Another reason for the difference in state estimates is that the remote-sensing approach assumes no turfgrass present at less than 10% ISA, to avoid the prediction of excessively large turfgrass area in rural areas, where other types of cover may predominate. States with a large proportion of sparse rural development may indeed have a significant surface of turfgrass.

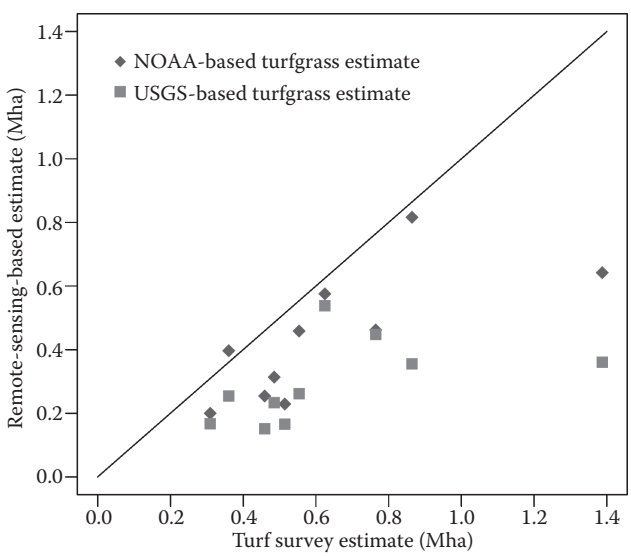

FIGURE 8.3 Scatterplot of turfgrass area derived from surveys and from remote-sensing-based approaches.

Turfgrass estimates based on the housing-units approach using median lot and house size are reported in Table 8.2, while the estimates based on average lot and house size are reported in Table 8.3. The data on median lot size, median house size, type of parking, and assumptions of driveway size would indicate that the average single-family house, built between 1978 and 2001, averaged a median lawn size of 650 m^2. The total number of single-family houses in the United States by 2000 was 76,313,410 (66% of all the housing units [34]). Multiplying this lawn size by the total number of single-family houses in the United States, we obtain an estimated 4,961,298 ha of turfgrass area in private residences. Given that turfgrass area can also be found in multifamily housing complexes, commercial lots, around institutional and recreational areas, and other open spaces, the US Census value must be adjusted to account for this portion of nonresidential turfgrasses. The turfgrass industry surveys reported that residential turfgrass area ranges between 20% and 83% of the total turfgrass area in the surveyed states, averaging 68.3%. Based on these data, the total estimate of turfgrass area amounts to 7,263,980 ha. On the other hand, if we repeat the calculations, basing them on average lot and house size, the average lawn size of single-family houses built between 1978 and 2001 would be 1303 m^2, leading to an estimate of 9,947,281 ha in residential turfgrass area and 14,564,101 ha of total turfgrass area.

While the estimate based on the US Census using median lot and house size was likely to underestimate the total turfgrass area, the method based on average lot and house sizes had a tendency to overestimate it. The housing-unit approach suggests that the estimate of total turfgrass for the United States is closer to the estimate provided by the USGS-based approach. On the other hand, all the turfgrass area reported by the industry surveys point to a much larger surface under turfgrass, likely to surpass the NOAA-based estimates of turfgrass area.

8.4.2 Urban Irrigated Area

The estimates of urban irrigated area, obtained by adjusting the total remotely sensed areas for the fraction that is likely to be watered in each state, are reported in Figure 8.4 along with the irrigated area under cropland. The total turfgrass area that is expected to be irrigated at some point during the growing season, according to the assumptions reported in Section 8.3, is 6,665,332 ha, according to the USGS-based lawn estimate, and 9,602,148 ha, according to the NOAA-based estimates.

An estimate of urban irrigated area can also be obtained from the housing-based turfgrass estimates using the results from a national lawn care poll, indicating that 62% of Americans water their lawns [30]. Using these data, it can be estimated that the surface of urban irrigated area would range between 4,503,668 and 9,029,743 ha.

In comparison, the total cropland area irrigated within the conterminous United States, reported by the Agricultural Census [35], amounts to 22,310,529 ha, with the largest shares represented by forage land (4,156,032 ha) and corn for grain (3,929,445 ha). The estimates of urban irrigated area produced by this study would therefore rank turfgrass as the single largest irrigated crop in the country. Texas, California, and Florida have large irrigated areas, both in croplands and in turfgrass. In many states,

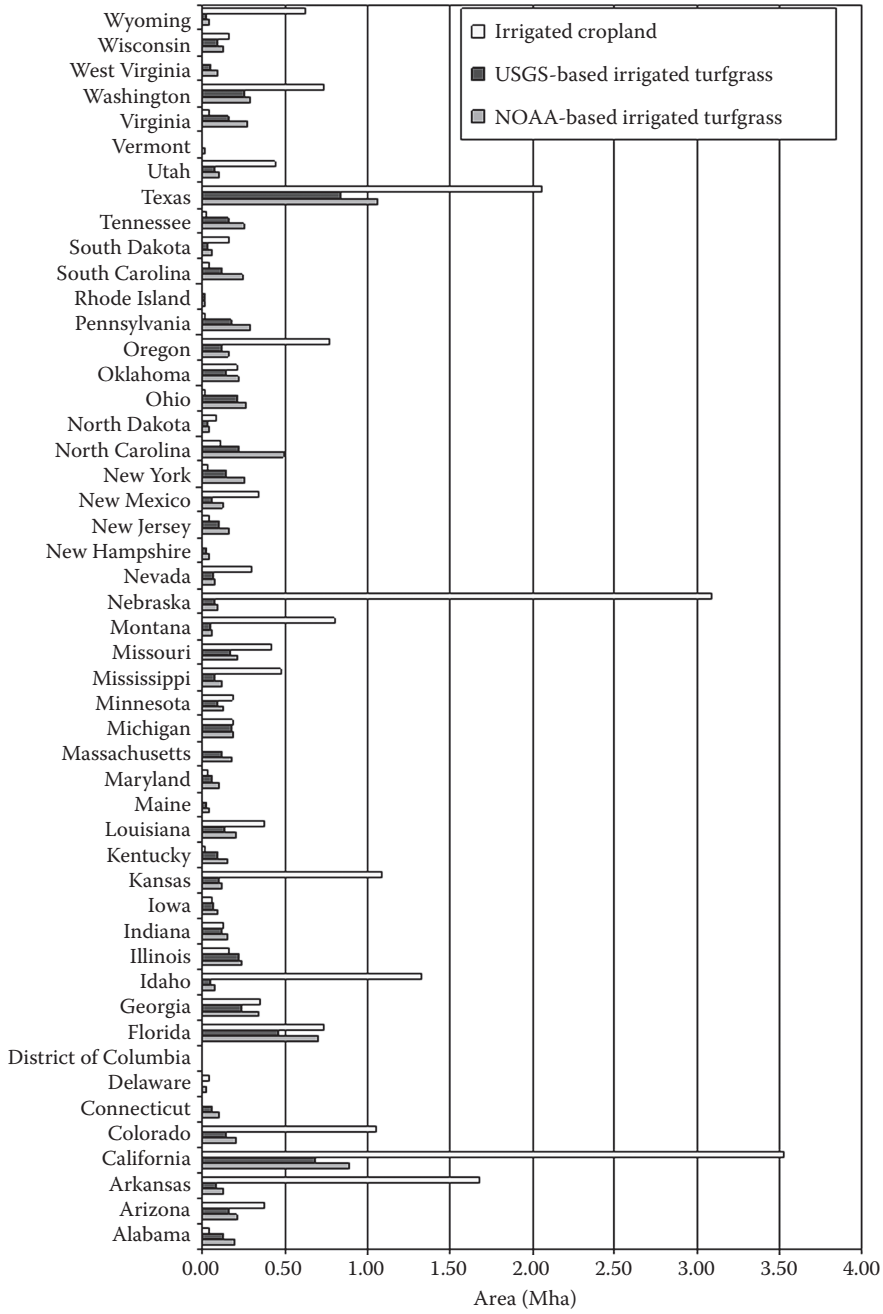

FIGURE 8.4 Distribution of irrigated turfgrass and cropland across the conterminous United States.

such as North Carolina, New York, Ohio, and Virginia, the turfgrass irrigated area is estimated to largely surpass the cropland irrigated area. In many other states, the cropland and turfgrass irrigated areas have comparable surfaces.

8.4.3 Recent Growth Trends of Turfgrass Area vs. Irrigated Cropland Area

Between 1978 and 2001, 16,366,000 new houses were constructed and sold. Over this period, the yearly addition of these houses to the American landscape has contributed to an average of 44,209 ha a year based on data of median lot and house size, and 91,909 ha a year based on average lot and house-size data. This increase does not account for the growth in turfgrass area in nonresidential lawns, which is expected to be considerable, though likely to have proceeded at a slower rate than the expansion in new construction. The expansion of turfgrass in private residences is of the same order of magnitude as that of cropland irrigated areas, which between 1978 and 2002 have increased, on average, by 83,312 ha a year. While the expansion in irrigated cropland has somewhat stabilized over the recent decades, urban growth is expected to continue.

Factors other than urban growth have contributed to the water use by irrigated landscapes. One of these factors is the diffusion of automated sprinklers that, while providing a more uniform cover and therefore improving the efficiency of water application, are often a cause of overwatering, as they are more likely to be left running when meteorological conditions are such that no irrigation is required. A study of water use data from 1129 houses in 14 North American cities [36] indicated that houses in dry and warm climates that rely on automatic sprinklers to water their landscape use, on average, 33.4 inches (84.8 cm) of water (61% more than houses with mobile sprinklers attached to a hose). In cooler and wetter climates, the installation of automatic sprinklers increases water use by 37%, from 6.7 inches (17.0 cm) to 9.2 inches (23.4 cm).

AU: Is 'them' referring to 'lengthening of the growing season'. Please clarify.

Another factor that has likely contributed to increased water use over the past few decades is a lengthening of the growing season. Although experimental data that link them to increased water use are not available, it can be speculated that a lengthening of the frost-free season in the United States [37] may have triggered an earlier start of the sprinkling season, especially with the expansion of automatic sprinklers, which once programmed at the beginning of the spring tend to be kept running with the same fixed schedule until the fall comes and irrigation is suspended for the winter season.

8.5 CONCLUSION

Irrigation in urban areas makes up a large and growing sector in developed countries like the United States, where a cultural predilection towards well-maintained landscapes predominates. In this study, we attempted estimating the urban irrigated area in the conterminous United States by comparing different approaches.

Depending on the method used, the total irrigated turfgrass area ranges from the most conservative 4,503,668 ha, obtained by using time series on the characteristics of new housing collected by the US Census, to 9,602,148 ha, based on a relationship between remote-sensing-derived built-up area and turfgrass area. The estimates of urban irrigated area represent an area equivalent to 20–43% of the total cropland irrigated area.

As the methods explored are based on different assumptions, it is not possible to determine the most reliable one. An advantage of the remote-sensing-based method is that it provides a level of geographical detail to the estimates of total irrigated turfgrass that is not possible to achieve with US Census-based data.

With increasing population, wealth, and a warming climate, the expansion of irrigated areas in urban settings can be expected to continue, causing increasing pressure on finite freshwater resources not only in urban areas located in dry climates, but eventually also in those located in temperate climates.

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