

Supplemental information appendix for:

**Documenting Trends in Water Use and Conservation Practices on U.S. Golf
Courses**

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- 2 pages of text on method for calculating water budgets
- Tables S1 – S9
- Figures S1 and S2

SUPPLEMENTAL TEXT

Water budget determination. The water budget (acre-feet/acre) for each respondent's location was calculated based on the Landscape Water Requirement (LWR) equation (Environmental Protection Agency, 2014) shown below, with addition of a leaching fraction:

$$LWR = \frac{1}{DULQ} \times [(ETo \times KL) - Ra] \times A \times Cu \times LF$$

Where:

- LWR = Landscape water requirement for the hydrozone (gallons/month)
- DULQ = lower quarter distribution uniformity (dimensionless)
- ETo = Local reference evapotranspiration (inches/month)
- KL = Landscape coefficient for the highest water-using plant in that hydrozone (dimensionless)
- Ra = Allowable rainfall, designated by WaterSense as 25% of the site's peak monthly rainfall
- A = Area of the hydrozone (square feet)
- Cu = Conversion factor (0.6233 for results in gallons/month)
- LF = Leaching Fraction

For calculation of the LWR, the following modifications were made:

- Units were changed from inches to feet for ETo and rainfall (Ra). Square feet were changed to acres for area measurements. As a result, the equation simplifies and the conversion factor (Cu) drops out.
- ETo values for each survey location were computed using the Hargreaves ET equation (Allen et. al., 1998), which provides reference evapotranspiration (ETo)

estimates when only maximum temperature, minimum temperature and estimated extraterrestrial solar radiation based upon latitude are available.

- $KL = 0.7$ which is midway between cool season (0.8) and warm season (0.6) values (University of California, 2015).
- $DULQ = 0.7$, which is midway between high and low irrigation efficiency for irrigation using rotors (Wilson and Zoldoske, 1997).
- Ra was computed using a daily water banking algorithm assuming a root depth of 4 inches with a soil water holding capacity of 0.25 inches water per inch of soil. Rainfall exceeding the water holding capacity of the soil was not banked. Evapotranspiration is subtracted from the soil water bank on a daily basis. If the soil water bank is over-drafted, it is assumed that irrigation is required to match the overdraft. Total water requirement from irrigation is the total overdraft computed on a daily basis and summed over the year. Daily weather data was obtained as described in the manuscript.
- A = total irrigated acres at each facility
- $LF = A$ leaching fraction of 1.15 (15%) was included only for the proportion recycled water used by each facility. This addresses the increased salinity in recycled water sources compared to the corresponding potable water source (Ayers and Westcot, 1985).

The water budget/acre data shown in Figure 1 and Table 7 is therefore:

$$\text{Water budget (acre – feet/acre)} = \frac{LWR}{\text{total irrigated acres}}$$

Supplemental Table S1. 2014 survey responses characterized by agronomic region, golf course type, and number of holes. To compensate for under- or over-representation when compared to the U.S. golf course proportions, data was weighted as described in Table S2. Data for total U.S. golf facilities provided by the National Golf Foundation. Facilities refer to a business location where golf can be played on one or more golf courses.

	U.S. Golf Facilities		Survey Response	
	Number	% of Total	# responding	% of total respondents
All facilities	15,386	100	1,950	100
Region				
North Central (NC)	3,925	25.5	411	21.1
Northeast (NE)	2,677	17.4	270	13.8
Pacific (PA)	638	4.1	107	5.5
Southeast (SE)	3,046	19.8	383	19.6
Southwest (SW)	1,201	7.8	216	11.1
Transition (TR)	2,795	18.2	345	17.7
Upper West/Mtn (UW)	1,104	7.2	218	11.2
Type				
Daily fee	8,984	58.4	789	40.5
Municipal	2,480	16.1	353	18.1
Private	3,922	25.5	808	41.4
Holes				
9	4,152	27	160	8.2
18	9,827	63.9	1,478	75.8
27+	1,407	9.1	312	16.0

Supplemental Table S2. Weighting process. U.S. golf courses were classified into one of 16 groups based on characteristics such as course type, number of holes and green fees. The proportion of each group within the total golf universe was determined for 2006 and 2014 surveys, as shown below. To calculate weighting factors the proportions below were divided by the proportions of each group in the survey pool.

Facility type	Number of holes	Green fee	2006		2014	
			Number of facilities	Proportion	Number of facilities	Proportion
Daily fee	9	<\$40	2,874	0.179	2,637	0.171
Daily fee	9	\$40+	140	0.009	147	0.010
Daily fee	18	<\$40	2,575	0.160	2,032	0.132
Daily fee	18	\$40-\$70	2,128	0.133	2,499	0.162
Daily fee	18	>\$70	749	0.047	924	0.060
Daily fee	27+	<\$40	215	0.013	148	0.010
Daily fee	27+	\$40-\$70	332	0.021	331	0.022
Daily fee	27+	>\$70	249	0.016	266	0.017
Municipal	9	all	745	0.046	728	0.047
Municipal	18	<\$40	797	0.050	533	0.035
Municipal	18	\$40-\$70	574	0.036	849	0.055
Municipal	18	>\$70	50	0.003	116	0.008
Municipal	27+	all	252	0.016	254	0.017
Private	9	all	831	0.052	640	0.042
Private	18	all	3,090	0.192	2,874	0.187
Private	27+	all	451	0.028	408	0.027
Total			16,052	1.000	15,386	1.000

*Green fees reflect peak season, weekend rates

Supplemental Table S3. Median acre-feet/acre/year when reported based on metered data, estimates, or a combination of metered plus estimated data. Within a row, values followed by the same letter are not significantly different from one another at the 95% confidence level. N = number of respondents.

	Metered		Estimated		Combination	
	acre-ft/A/yr	N	acre-ft/A/yr	N	acre-ft/A/yr	N
2005	1.33b	1,180	0.85a	789	1.37b	289
2013	1.24b	1,035	0.79a	366	1.01b	272

Supplemental Table S4. Comparison of Fisk distribution and normal distribution estimates of acre-feet/acre for the measure of central tendency, $p=0.50$. For the normal distribution, the mean approximates $p=0.50$, and for the Fisk distribution, the median approximates $p=0.50$. The Kolmogorov-Smirnov goodness of fit evaluation (KS fit) indicates that there is little chance when the test distribution model fit to the data is due to chance ($p \leq 0.1$). See also Figure S2.

	2005		2013	
	<i>p</i> =0.50	KS fit	<i>p</i> =0.50	KS fit
Fisk distribution (median)	0.9	0.1	0.8	0.1
Normal distribution (mean)	1.7	0.3	1.6	0.3

Supplemental Table S5. Percent golf facilities using each water source

	Lakes and ponds		Canals		Rivers, streams, creeks		Wells		Recycled		Municipal drinking water	
	2005	2013	2005	2013	2005	2013	2005	2013	2005	2013	2005	2013
Region	Percent of golf facilities using each source											
North Central	51.7	54.7	0.6	0.1	16.3	26.0	57.8	60.9	3.5	7.0	8.2	7.9
Northeast	58.9	66.5	1.6	0.4	15.8	21.9	41.2	46.8	3.5	1.6	19.7	15.4
Pacific	22.2	25.0	4.3	1.2	16.1	12.9	45.3	40.4	12.6	23.1	21.1	23.3
Southeast	59.3	64.3	3.8	3.9	11.4	11.1	45.2	46.9	23.7	30.5	8.4	8.4
Southwest	7.6	8.7	8.6	10.4	4.9	3.6	45.6	47.1	33.5	45.5	31.1	31.5
Transition	70.1	68.1	0.5	0.3	16.7	22.9	32.5	33.3	5.3	6.5	19.4	20.2
Upper West/Mountain	17.3	28.6	21.7	16.2	25.8	27.1	38.1	46.9	14.6	18.1	17.6	15.9
U.S.	48.5	51.9	4.3	3.6	15.7	20.0	45.3	48.0	10.9	15.3	15.3	15.0

Supplemental Table S6. Water use regulations, Percent of golf courses with required water use reporting, recurring annual water allocations, and with additional mandatory water restrictions in the past 5 years that were more stringent than normal allocations.

	Required water use reporting		Recurring annual allocations		Additional mandatory water restrictions	
	2005	2013	2005	2013	2005	2013
Region	Percent of golf facilities					
North Central	57.7	62.3	11.5	23.5	4.4	2.1
Northeast	50.6	63.8	24.7	33.3	28.8	4.6
Pacific	28.9	25.0	13.7	15.0	2.0	13.9
Southeast	36.5	65.0	34.8	42.6	21.4	26.4
Southwest	57.2	53.3	36.4	40.8	11.8	18.6
Transition	35.4	48.4	10.4	23.4	14.5	4.2
Upper West/Mountain	50.9	36.0	36.1	34.7	31.3	19.1
U.S.	48.4	55.0	21.7	30.3	15.8	10.7

Supplemental Table S7. Percent of 2014 survey respondents who have written plans to deal with the issues listed below. For those respondents with written plans, the “required” column indicates the percent with which those plans were required by state or local authorities. In the majority of cases, respondents developed plans voluntarily, even when not required to by authorities.

	Drought plan		Water management plan		Stormwater plan		Preventive irrigation maintenance plan	
	W/plan	required	W/plan	required	W/plan	required	W/plan	required
Region	Percent of golf facilities							
North Central	4.6	12.7	7.0	12.7	8.0	54.3	16.5	3.6
Northeast	20.1	77.9	18.6	53.3	6.9	61.7	13.0	14.8
Pacific	16.9	22.7	18.0	22.9	12.5	80.0	21.9	5.3
Southeast	20.2	51.0	28.7	43.9	24.4	52.8	30.6	14.2
Southwest	27.6	35.9	29.2	51.2	30.5	74.5	33.2	20.9
Transition	8.0	46.2	13.5	37.1	9.8	65.2	17.4	13.8
Upper West/Mountain	18.9	23.0	16.3	41.3	15.6	70.9	19.3	4.6
U.S.	14.1	44.5	16.8	40.5	13.9	63.0	20.5	11.3

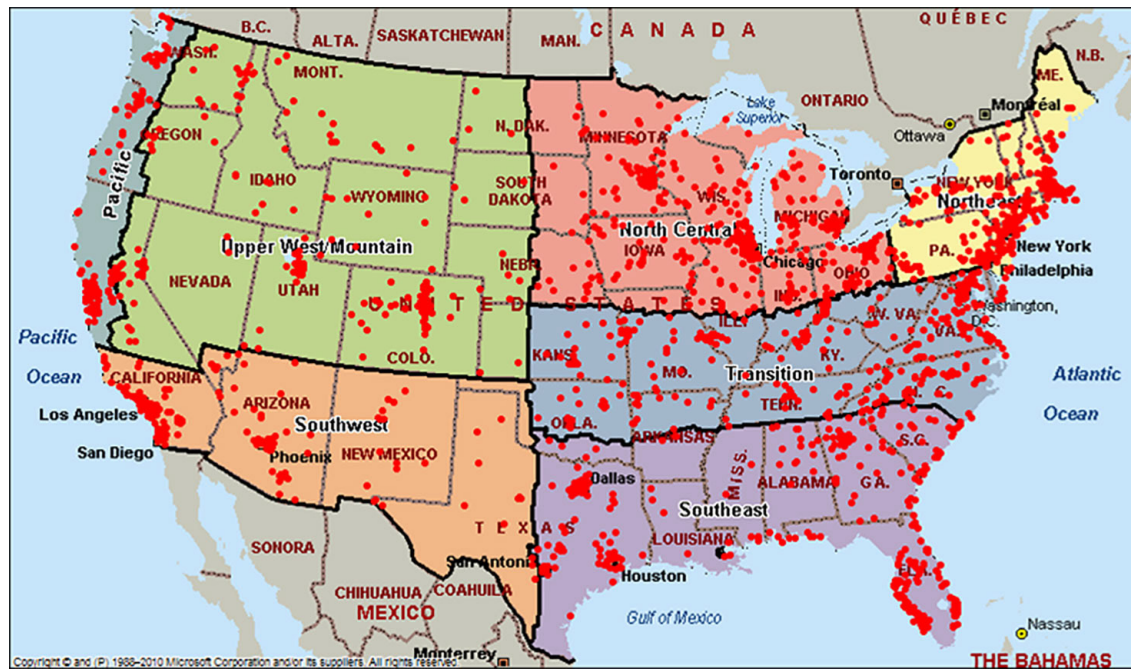
Supplemental Table S8. Projected national water use in acre-feet/year. Golf facilities were broken into 21 categories based on size (9, 18 and 27+ holes) and agronomic region, for 2005 vs. 2013. Data was weighted as described in the text. Reading within each two column row, mean values followed by the same letter are not significantly different at the 90% confidence level. Projected water use values were determined by multiplying the appropriate mean value by the number of U.S. golf facilities in each of the 21 categories shown.

		9 hole		18 hole		27 hole		All	
		2005	2013	2005	2013	2005	2013	2005	2013
Region	Metric	Acre-feet/year							
North Central	mean	27.45b	21.4a	76.56b	60.8a	133.33b	93.4a	64.62b	50.5a
	projected	38,589	27,628	181,455	139,590	46,531	30,823	266,575	198,041
Northeast	mean	18.5b	16.5a	48.1b	39.7a	87.9b	65.7ab	42.7b	35.2a
	projected	14,224	12,027	84,798	69,426	17,908	12,741	116,930	94,194
Pacific	mean	105.8b	58.4a	170.1a	180.8a	458.1b	692.1ba	165.9a	169.2a
	projected	22,542	11,614	63,289	67,624	27,946	292,771	107,811	107,185
Southeast	mean	68.7b	16.8a	263.6b	182.3a	692.1ba	390.2ab	281.5b	179.8a
	projected	43,594	8,986	567,869	388,130	292,771	151,409	904,234	548,524
Southwest	mean	108.6a	182.6b	429.6a	430.4a	976.7b	881.2a	435.8a	440.5a
	projected	29,867	47,479	330,395	334,865	170,927	149,805	531,189	532,149
Transition	mean	33.2a	52.9b	92.1a	63.8b	183.5a	123.1b	82.4a	64.9b
	projected	26,847	37,662	178,386	120,198	37,801	23,519	243,034	181,379
Upper West/Mountain	mean	81.5a	88.3b	249.8b	216.7a	402.7b	374.2a	192.3b	178.9a
	projected	35,272	36,740	146,131	133,494	27,382	27,314	208,785	197,548
U.S.	mean	46.5a	43.9a	156.0b	127.5a	413.0b	301.0a	148.9b	120.8a
	projected	210,935	182,136	1,552,324	1,253,328	615,299	423,557	2,378,558	1,859,021

Supplemental Table S9. Mean and projected national water use, in acre-feet/year, for different sources of water in 2005 vs. 2013. All U.S. golf facilities were split into 21 categories based on size (9, 18 and 27+ holes) and agronomic region, for 2005 vs. 2013, and weighted means were computed for each category. Reading within each two column row, mean values followed by the same letter are not significantly different at the 90% confidence level. Projected water use values were determined by multiplying the appropriate mean value by the number of U.S. golf facilities in each of the 21 categories shown. Cells with no values shown indicates that there was insufficient data to compute a value. Small differences in total water volumes estimated in this table vs. the estimates in Tables 1 and A9 are the result of insufficient data to compute a projected value for water sources that are very rarely used.

		Open (Lakes/ponds)		Canals		Rivers,streams,creeks		Wells		Recycled		Municipal (potable)	
		2005	2013	2005	2013	2005	2013	2005	2013	2005	2013	2005	2013
Region	Metric	acre-feet/year											
North Central	mean	37.6b	24.3a	20.8		49.0b	21.2a	54.6b	38.6a	24.4a	33.2b	33.6b	21.9a
	projected	80,160	52,130	473		32,935	21,610	130,035	92,242	3,509	9,045	11,418	6,794
Northeast	mean	26.4b	16.4a	26.2b	12.0a	26.1b	18.6a	29.4b	23.5a	21.5a	52.5b	29.9b	17.2a
	projected	42,609	29,115	1,178	140	11,305	10,867	33,134	29,386	2,082	2,219	16,153	7,071
Pacific	mean	56.0b	39.2a	518.6a	715.9b	137.3a	144.0b	109.9a	116.6a	125.2a	170.6b	80.5a	135.8b
	projected	8,075	6,228	14,583	5,291	14,369	11,734	32,352	29,891	10,253	24,975	11,053	20,101
Southeast	mean	216.7b	85.4a	179.0b	109.1a	156.6b	90.6a	149.7b	89.4a	191.6a	207.4b	84.6b	53.5a
	projected	412,809	167,640	21,866	12,822	57,316	30,642	217,577	127,824	145,611	192,849	22,706	13,731
Southwest	mean	276.3b	174.6a	627.1b	482.9a	225.4a	265.1b	407.7b	356.0a	371.3b	351.6a	192.7b	181.8a
	projected	25,594	18,296	65,576	60,808	13,412	11,420	226,782	202,430	151,653	193,394	73,118	69,201
Transition	mean	61.6b	29.8a	76.2b	6.0a	63.6b	28.4a	47.7b	40.9a	80.7a	103.6b	45.0a	44.3a
	projected	127,418	56,571	1,167	54	31,310	18,138	45,721	38,039	12,682	18,856	25,817	25,034
Upper West/Mountain	mean	134.9b	79.3a	163.4b	145.8a	184.7b	130.9a	134.8a	135.8a	162.5b	125.8a	49.2a	122.9b
	projected	25,340	25,095	38,511	26,053	51,651	39,179	55,755	70,368	25,786	25,165	9,433	21,548
U.S.	mean	92.7b	51.3a	209.0a	210.2a	84.4b	51.9a	102.0b	78.6a	200.9b	172.5a	69.0a	67.6a
	projected	722,007	409,766	143,355	115,020	212,298	159,674	741,357	580,204	351,576	466,503	169,698	155,667

Supplemental Figure S1. Distribution of survey responses received in seven different agronomic regions.



Supplemental Figure S2. Comparison of Fisk (log-logistic) distribution (green curve) vs. the normal distribution (red curve) for acre-feet/acre data from the 2005 (top graph) and 2013 (bottom graph) survey datasets. See also Table S4. Blue bars represent the frequency histogram for survey results.

