LONG-TERM CITIZEN SCIENCE WATER MONITORING DATA:

AN EXPLORATION OF ACCURACY OVER SPACE AND TIME

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TEXAS STREAM TEAM

INTRODUCTION

- **CS Water Quality Monitoring Programs**
- Thousands of volunteer water monitoring groups worldwide
- Long-term, large-scale datasets already exist
- Study focus
  - BUT! - value of CS beyond the data

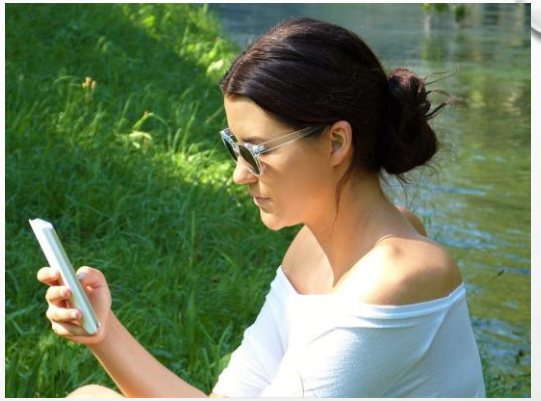


Photo Credit: Wisconsin Department of Natural Resources, CC BY-ND.

TEXAS STREAM TEAM (TST)

- Statewide program, running since 1991
  - Texas Commission for Environmental Quality (TCEQ), QAPP in place throughout
- 25+ years of existing datasets, large area –
  - Long-term data: benefits for research, management
- ***Texas – volunteer data concerns***
- ***Question: How is the TST data being used?***

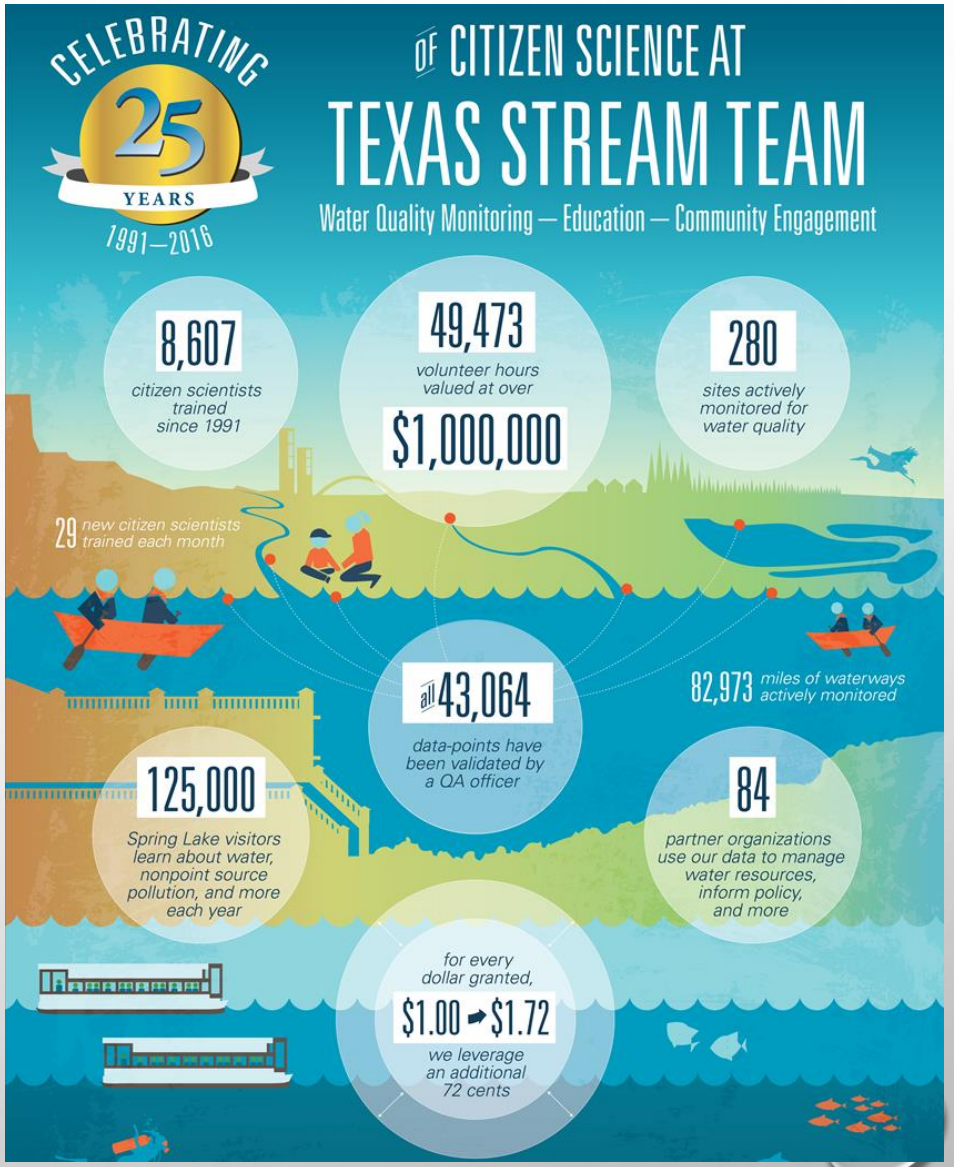


Photo credit: Texas Stream Team, 25th Anniversary Infographic (From TST website accessed at: http://gato-docs.its.txstate.edu/the-rivers-institute/mcwe_new_site/tst/tst_24x37_poster_25th-02.png)

VOLUNTEER DATA: UNDERUTILIZED?

<u>Stakeholder meeting series</u>: **Uses of TST data largely unknown**

- No official management/regulatory uses
- Partners: anecdotal uses (baseline, red flag events), if used at all
- No citations in peer-reviewed articles

Lit review: common issue throughout citizen science water monitoring field

- Volunteer datasets **not fully utilized** by professionals and scientists
- **Accuracy and applicability** of data
- Top reason not used in scientific publications: **researcher's perceptions of volunteer data quality**
- **Comprehensive lit review; 26 WQ comparison studies (paper under review)**
  - **Comparsion studies – pros and cons**

RESEARCH GOALS

Assess relative accuracy of TST volunteer water quality data (DO, pH, Conductivity) by comparing to professional data & analyzing variations across scales

- **First comparison study to combine large and small-scale, existing and experimental data**
- **Focus on method (usability of datasets)**

RESEARCH QUESTION 1

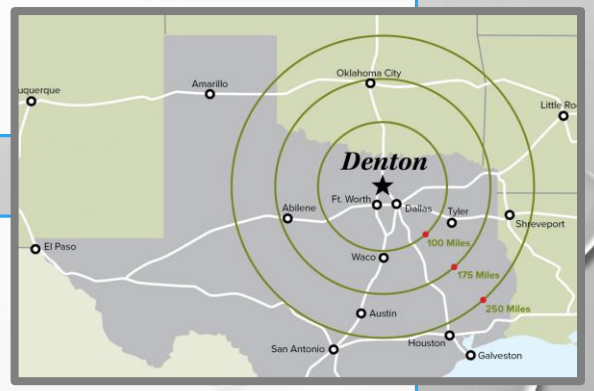
- Existing, Statewide1992-2016 (long-term, large-scale)

RESEARCH QUESTION 2

- Existing, City of Denton, 2009-2017 (long-term, local scale)

RESEARCH QUESTION 3

- Experimental, City of Denton, 2017-2018 (short-term, local)



ABOUT THE DATA: EXISTING, STATEWIDE (RQ 1)

- **RQ 1: Existing, state-wide volunteer data (TST) and professional data (TCEQ & partner agencies) collected from 1992-2016, for water quality parameters of DO, pH and conductivity**

  To be included, sample data must be from:

  1. Station at which TST and TCEQ have a **corresponding** station *(same Station ID and/or within 60m on same stream segment)*
  2. Station with at least 20 samples from each source (~ two years)
  3. Year in which both TST and TCEQ sampled two or more times each

wait…what?

Post-hoc analyses on large-scale, variable WQ dataset, no seasonal controls or data standardization

ABOUT THE DATA: EXISTING, CITY OF DENTON (RQ2)

- **RQ 2: Existing, city-wide volunteer data (TST, City of Denton partner agency) and professional data (City of Denton staff) collected from 2009-2017, for parameters DO, pH and Conductivity**

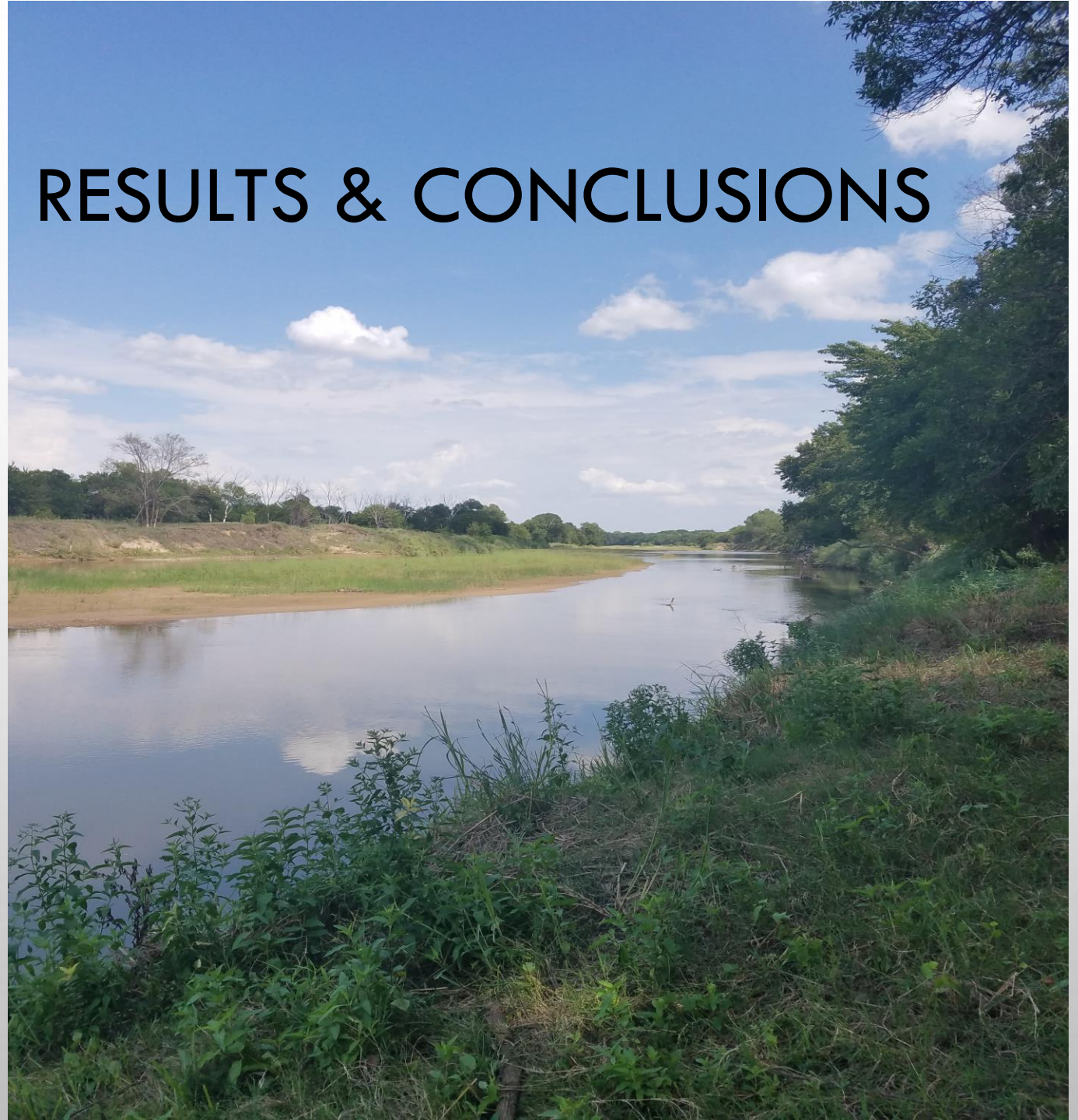
To be included, sample data must be from:

1) Station which TST and City of Denton both sample (**same ID/location**)
2) Station with at least 20 samples for each source
3) Year in which both TST and City of Denton have sampled two or more times,
4) **Vol and pro samples collected within 5 days (paired samples)**

ABOUT THE DATA: EXPERIMENTAL, CITY OF DENTON (RQ3)

- **RQ 3:** City-wide volunteer data (TST, City of Denton partner agency) and professional data (City of Denton) **collected Nov 2017 through May 2018,** for parameters DO, pH and Conductivity
  1) Station at which TST and City of Denton both sample (same ID/location)
  2) Vol and pro samples collected within 5 days (paired samples)
  3) **Sample was collected as part of this study**

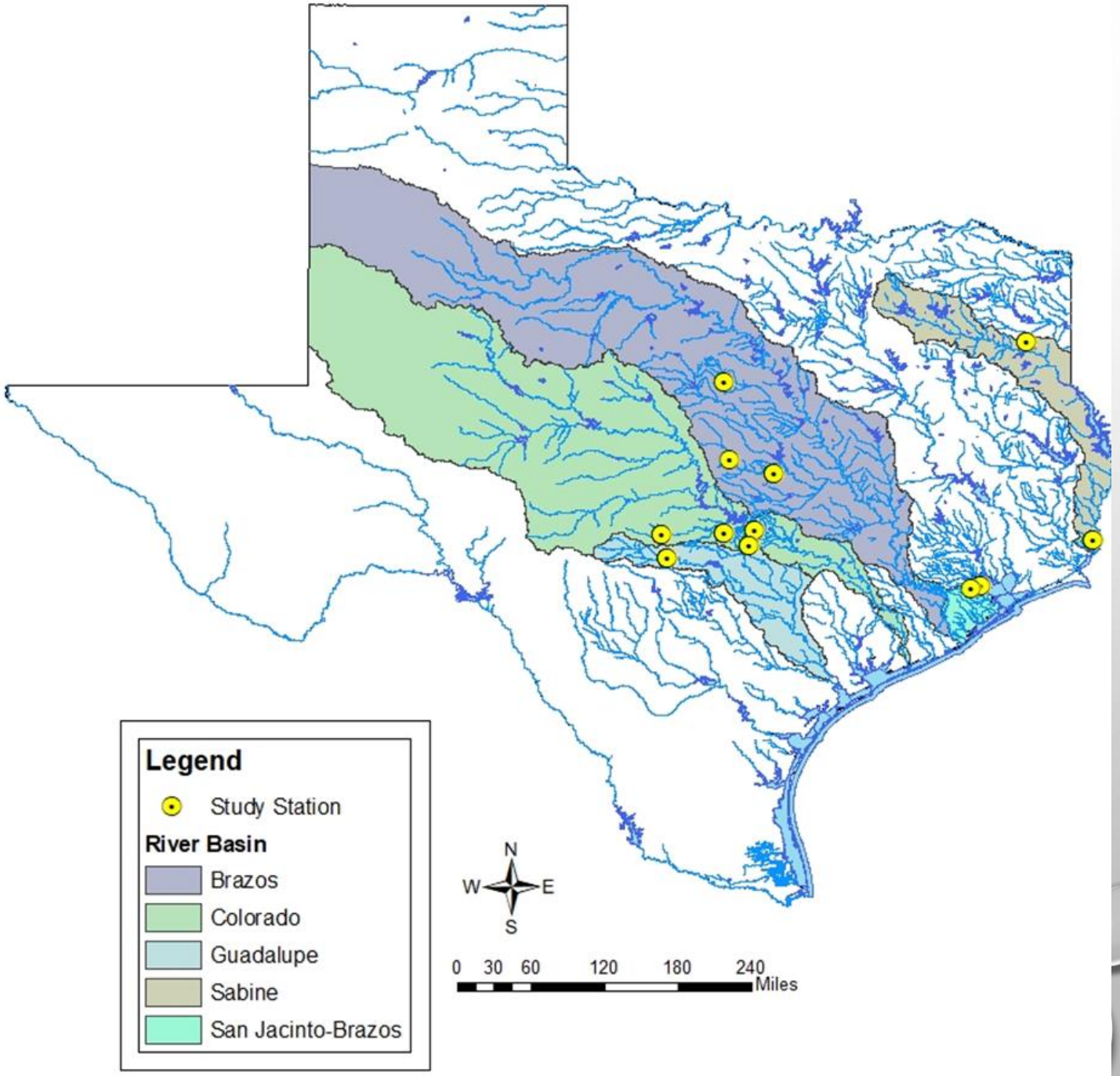
RESULTS & CONCLUSIONS



RQ 1: STATEWIDE

Figure 1. Map of Study Stations. Existing Statewide Water Monitoring Station Locations, with River Basins

(12 stations, 5 river basins)



RESULTS - RQ 1: EXISTING, STATEWIDE

- **234 professional, 350 volunteer samples, 12 stations, 38 separate years**
  - Samples analyzed by year/station for each of the parameters (DO, pH, conductivity)
  - Univariate KSD test for normality, removed analyses that violated conditions of model for normal distribution (25 ANOVAs)
- Result: **82 station/year ANOVAs**
  - Each representing an analysis of variance between the volunteers and professionals, at one station for one year, for one of the parameters (DO, pH or conductivity)

***Table 1*. Statewide ANOVA Results by Station and Year.** Results of all ANOVAs (*Pr* > *F*) for each station and year, by parameter. Values in bold indicate a statistically significant variation between volunteer (TST) and professional (TCEQ) data. Notes: An "x" denotes a value removed due to missing, corrupted, or not normally distributed data.

Station	Year	DO	pH	Cond
15520	1999	0.947	0.236	0.069
15520	2000	x	0.342	x
15520	2001	0.944	0.748	0.411
15188	1996	0.447	x	x
11505	1992	**0.001**	x	x
11505	1993	**0.028**	**0.009**	x
11505	1994	0.242	0.427	x
16404	1999	**0.025**	0.063	x
13486	1992	0.696	x	**< 0.0001**
13486	1993	0.662	**0.0002**	0.162
12052	1998	**0.008**	**< 0.0001**	0.113
12052	1999	0.088	x	x
12052	2000	0.099	x	x
12052	2001	0.285	**0.011**	x
17472	2012	0.690	x	0.848
17472	2013	0.115	x	0.391
17472	2014	x	0.389	0.845
17472	2015	x	0.520	0.652
17472	2016	x	**0.038**	0.954
15964	2001	0.072	x	0.195
15964	2002	0.699	x	0.940
15964	2003	x	x	0.384
12500	1998	**0.002**	0.145	**< 0.0001**
12500	1999	0.290	0.647	**< 0.0001**
12500	2001	0.0972	0.831	0.309
12500	2002	0.908	0.887	0.8801
12500	2003	x	0.743	0.065
12500	2004	x	0.746	0.341

Table 1 cont.

Station	Year	DO	pH	Cond
12602	2012	**0.022**	x	0.388
12602	2013	x	x	x
12602	2014	**0.030**	0.067	0.770
12602	2015	0.098	x	0.116
12602	2016	0.202	0.245	**0.018**
17070	2003	0.747	0.217	0.360
12448	2005	0.625	0.068	0.271
12448	2006	0.892	0.201	0.986
12448	2007	0.960	x	0.525
12448	2008	0.059	0.758	0.363

***TABLE 2*. STATEWIDE ANOVA METADATA.** Percent agreement between TST volunteer and TCEQ professional data based on ANOVA results (T*able 1*) for all statewide models run and for each parameter.

Data Category	# ANOVAs	# Statistically Significant	Total Percent Agreement
Total Statewide	82	16	**80.49%**
DO	30	7	**76.67%**
pH	24	5	**79.17%**
Conductivity	28	4	**85.71%**

***TABLE 3*. STATEWIDE ANOVA METADATA BY RIVER BASIN.** Percent agreement between TST volunteer and TCEQ professional data based on GLM results (Table 1) for all statewide models, broken down by river basin.

River Basin	# ANOVAs	# Statistically Significant	Total Percent Agreement
Sabine	8	0	100.00%
San Jacinto-Brazos	8	4	50.00%
Brazos	14	6	57.14%
Guadalupe	10	3	70.00%
Colorado	42	4	90.48%

- Statistical values for basin not obtained, but clear differences observed
- Indicates that location of sampling station may have an impact on accuracy
- Future studies

RESULTS - RQ 2: EXISTING CITY OF DENTON

- **159 vol/pro paired samples, 6 stations, 24 sampling years**
  - (Same as RQ 1) Samples analyzed by year/station for each parameter (DO, pH, conductivity)
  - Univariate KSD test for normality
    - pH and conductivity data **not normally distributed ; all Conductivity data = log transformation**
    - **All pH analyses** run using a **non-parametric Kolmogorov-Smirnoff Two-Sample (KST) test** using the NPAR1WAY procedure in SAS 9.4. (*KST statistics are shown in the analytical tables for all pH values for RQ2,3*).
  - Group Analysis: Discovered DO Bias (2 mg/L)
- Result: **70 total analyses** (ANOVAs for DO and conductivity, and KST for pH)

DO – SYSTEMATIC BIAS ADJUSTMENT

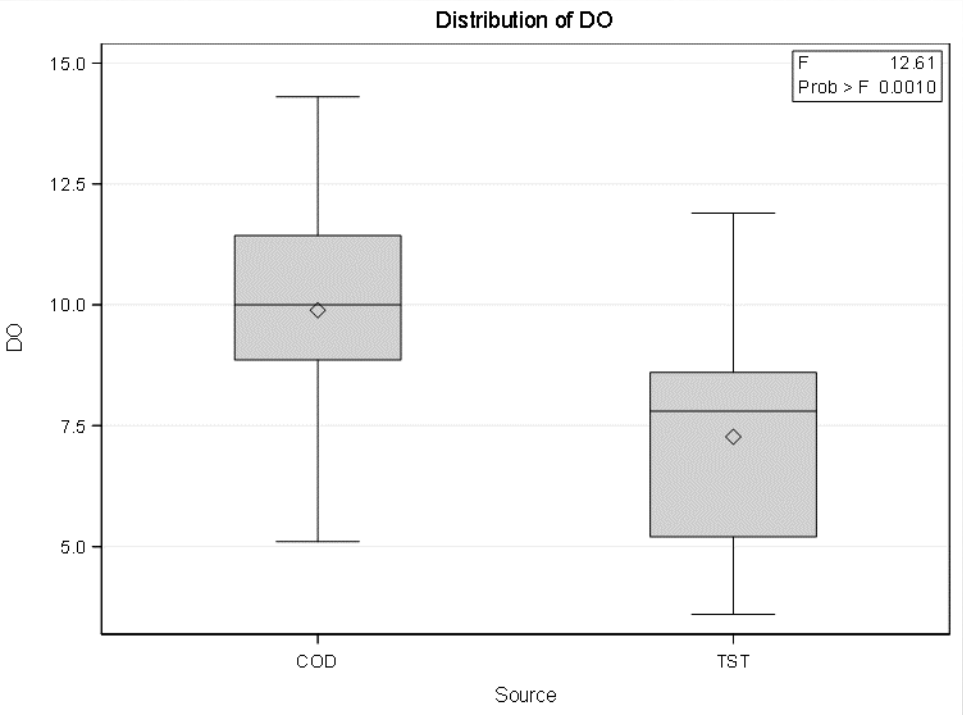


Figure 4. **Boxplot of City of Denton DO data – Bias Uncorrected**. All professional (COD) DO samples compared to all volunteer (TST) DO samples showing systematic bias across all years and stations.

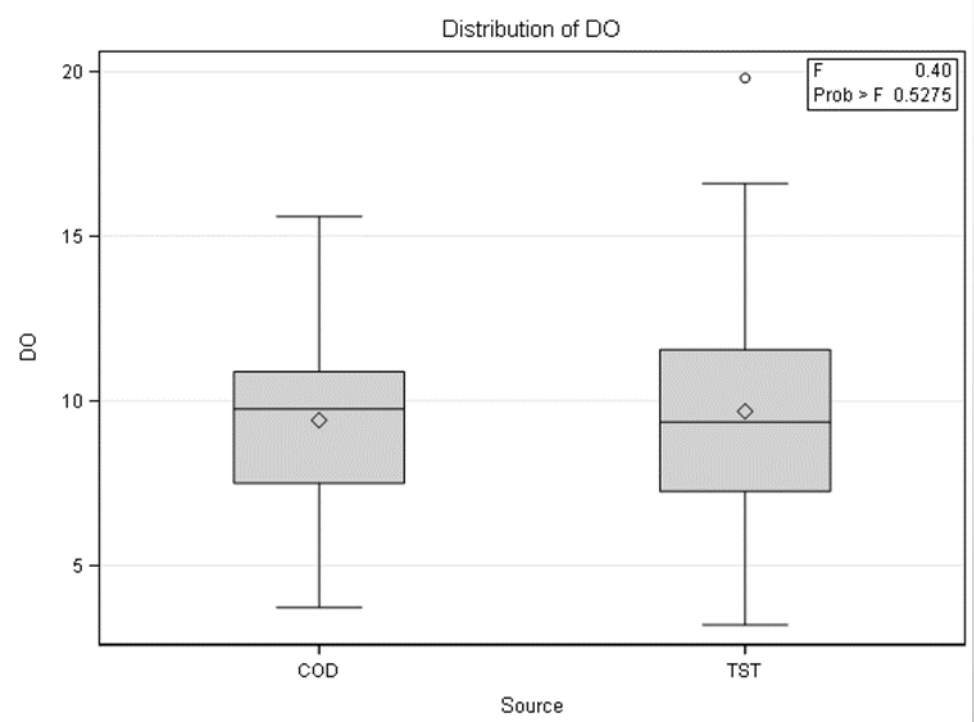


Figure 5. **Boxplot of City of Denton DO data – Bias Corrected**. All professional (COD) DO samples compared to all volunteer (TST) DO samples when systematic bias corrected by adding 2 mg/L to all volunteer samples.

RQ 2: EXISTING CITY OF DENTON

***Table 6*. City of Denton ANOVA/KST Results by Station and Year.** Results of all ANOVAs (*Pr* > *F*) for each station and year for DO and conductivity, and KST ((pr>KSa) for pH. Values with an asterisk indicate a statistically significant variation between volunteer (TST) and professional (City of Denton) data. Note: An "x" denotes a value removed due to data that was not normally distributed.

Station	Year	DO	pH	Cond
1	2009	0.4786	0.1389	0.1252
1	2010	0.9682	0.2898	0.6479
1	2011	0.6515	0.9251	0.9716
1	2014	0.6852	0.0815	0.8362
1	2016	0.9251	0.9639	0.3446
1	2017	0.5999	**0.0366***	0.2565
17	2017	0.4047	0.9639	0.9173
34	2009	0.9433	0.9639	0.5974
34	2010	0.1716	0.0815	0.5901
34	2014	0.9536	0.2700	0.2371
34	2016	0.7452	0.9639	0.3994
34	2017	0.2829	0.2700	0.6971
51	2009	**0.0155***	0.0815	0.9839
51	2010	0.5810	0.5176	0.2436
51	2011	0.4731	0.2700	0.8393
51	2014	0.7534	0.2898	0.3624
51	2017	0.1088	0.0996	0.7956
62	2009	0.1320	0.5176	0.8280
62	2010	0.6905	**0.0366***	0.8230
62	2011	0.9219	0.0649	0.6845
62	2016	**0.0393***	0.2700	0.3147
62	2014	x	**0.0366***	x
62	2017	0.0265	**0.0366***	0.9838
91	2017	0.1493	0.2106	0.5900

***TABLE 7*. CITY OF DENTON ANOVA METADATA.** Percent agreement between TST volunteer and City of Denton professional data based on ANOVA/KST results (*Table 6*) for all models run and for each parameter

Data Category	# Analyses	# Statistically Significant Analyses	Total Percent Agreement
Total Denton	70	6	**91.43%**
DO	23	2	**91.30%**
pH	24	4	**83.33%**
Conductivity	23	0	**100%**

RESULTS – RQ 2 – GROUP ANALYSES (DO, COND.)

- Paired samples, more localized dataset = group analysis between vol and pro across all stations and years

- **No significant difference between volunteer and professionals for DO and Conductivity**

Table 8. Group ANOVAs for Historic City of Denton Data. The statistical variation (Pr>F) between volunteer and professional data across all stations and years (2009-2017) for both DO and conductivity.

Parameter	# Samples	DF	Type III SS	Coeff Var	F Value	Pr>F
DO	184	1	3.4060	30.546	0.40	**0.5275**
Cond	184	1	0.0330	5.6719	0.24	**0.6230**

RQ 2 – PH GROUP ANALYSIS

Table 9. Group KST test for pH for Historic City of Denton Data. The non-parametric test showing the statistical variation (Pr>KSa) between volunteer and professional pH data across all stations and years (2009-2017).

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)			
KS	0.332368	*D*	0.664776
KSa	4.508464	*Pr > KSa*	**<.0001**

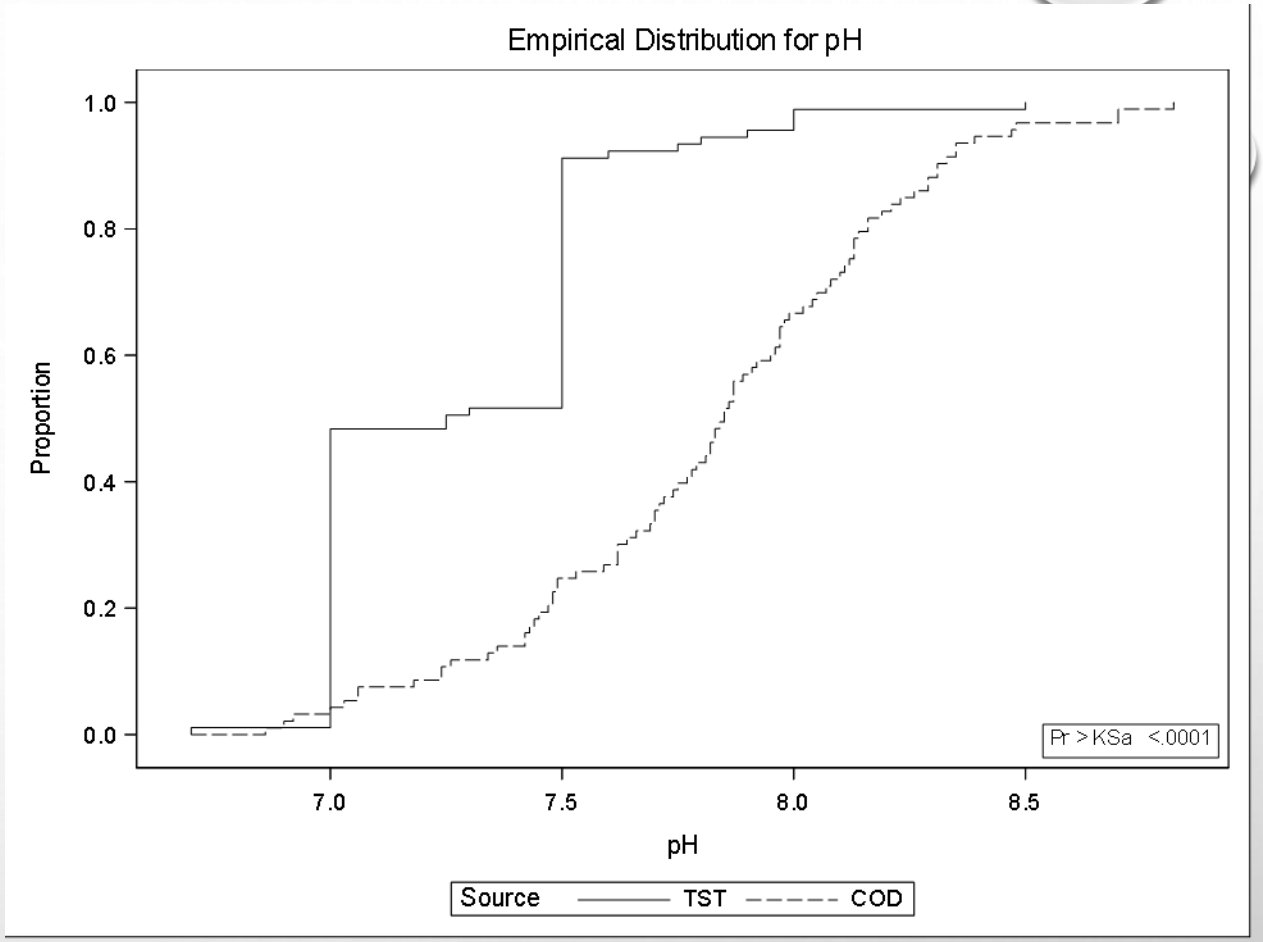


Figure 6. Distribution of pH for Historic City of Denton Data. The distribution of the volunteer (TST) and professional (COD) data at all stations for all years (2009-2017), with the KST statistic showing a significant difference between the two datasets.

Raw data: 90% of volunteer pH data either a 7 or 7.5

RESULTS - RQ 3: EXPERIMENTAL, CITY OF DENTON

- **21 vol/pro paired samples (total 42 samples), November 2017- May 2018, 10 stations**

- Group ANOVAs for DO and conductivity, KST test for pH (*Same as RQ2 Group Analyses)*
- Differences from RQ2: Experimental, shorter time frame, 4 additional sites

Table 10. Group ANOVAs for Experimental City of Denton Data. The statistical variation (Pr>F) between volunteer and professional data across all stations for both DO and conductivity.

Parameter	# Samples	DF	Type III SS	Coeff Var	F Value	Pr>F
DO	42	1	3.9929	24.9227	0.70	**0.4076**
Cond	42	1	0.50317	8.5887	1.60	**0.2132**

RQ 3 RESULTS

Table 11. Group KST test for pH for Experimental City of Denton Data. The non-parametric test showing the statistical variation (Pr>KSa) between volunteer and professional pH data across all stations for 2017-2018.

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)			
KS	0.285714	*D*	0.5714
KSa	1.851640	*Pr > KSa*	**0.0021**

- **Slight increase in variability of pH data**
- **No other difference between experimental and existing data**

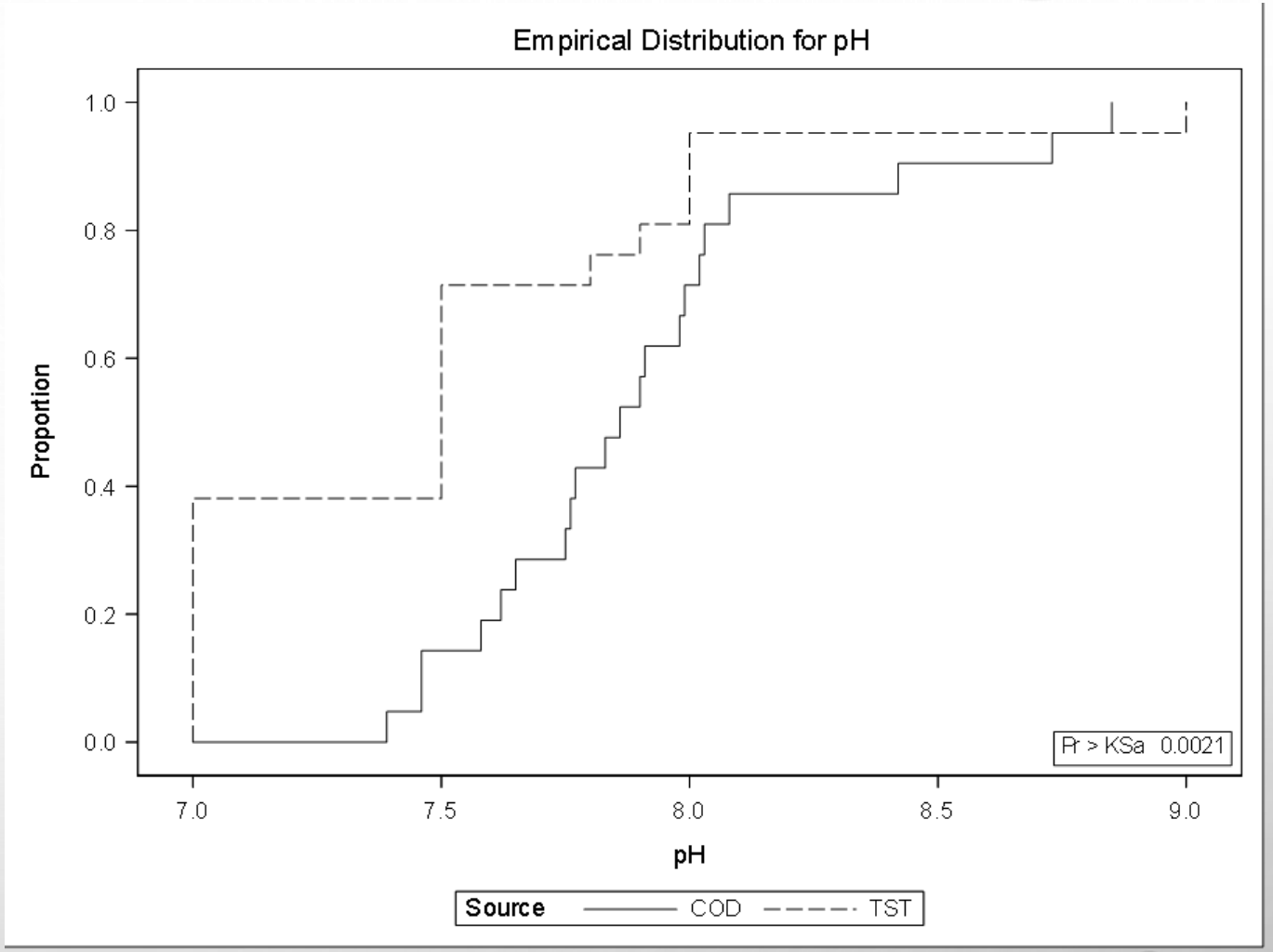


Figure 7. Distribution of pH for Experimental City of Denton Data. The distribution of the volunteer (TST) and professional (COD) data at all stations for 2017-2018, with the KST statistic showing a significant difference between the two datasets.

STUDY LIMITATIONS

- **Limitation unique to this study:** "Group M" Bias
  - **Existing City of Denton data: 4 out of 6 stations, and 63 out of the total 70 analyses**
  - **Results unique to them? (Do, pH)**
- Dedicated volunteer bias in citizen science
  - *(Lowry and Fienen 2013)*
- Would results apply across scales?
  - Statewide: used stations with 20 or more samples
  - More experienced volunteers, could influence accuracy

Photo Credit: Houston Chronicle, Jerry Baker. "Luis Stuart, a Texas Stream Team volunteer"

CONCLUSIONS

"Texas Stream Team trains 10,000th citizen scientist"

Despite post-hoc constraints:

LARGE-SCALE	EXISTING	UNPAIRED
• Increased variability in time, space, and collecting agencies	• No experimental controls, • No standardization of equipment or protocol	• Vol/Pro samples possibly months apart • Sites up to 60m apart • No seasonal controls

Existing TST citizen scientist data show 80% overall agreement with professional data for DO, pH and conductivity over program's entire duration, statewide

Local analysis with paired samples even higher (91%)

- **Inform increased utilization of large-scale TST datasets that already exist**
  - **CS WQ programs worldwide with similar program structure**

THANK YOU!

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