How is Groundwater Quality Affected by Wellhead Impacts from Flooding during Natural Disasters?

White Paper Prepared by the Texas Groundwater Protection Committee (TGPC)
Groundwater Issues (GWI) Subcommittee

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Executive Summary

Intense flooding events such as those occurring with Hurricane Harvey can cause widespread flooding of and damage to private water well systems. Because each water well provides a direct conduit to the aquifer, standards regarding well head protection are administered by the Texas Department of Licensing and Regulation (TDLR).

To evaluate inorganic concentrations in Hurricane Harvey-affected private water wells, more than 400 well users participated in seven free well water sampling events offered in 15 hurricane-impacted counties. Jha (2020) reported that overall, 43.9% of the well samples contained contaminant concentrations that exceeded at least one primary (MCL) or secondary drinking water (SMCL) standard. Arsenic was detected in about 81% of the samples and exceeded the EPA drinking water standard for 3.4% of the samples. Lead was detected in about 25% of the samples, which is relatively high as samples were collected after five minutes of flushing. Contaminant concentrations post-Harvey varied significantly for copper and zinc compared to the previous five years of water samples recorded in the study area counties obtained from the Texas Water Development Board (TWDB).

A total of 8,822 results from well water samples were collected following the hurricane through collaborative efforts between several organizations. As reported in Pieper et al. (2021), in the 10 months after Hurricane Harvey, 29.6% samples (n=2,609 of 8,822) were positive for total coliform (TC) and 11.0% (n=427 of 3,887) were positive for *Escherichia coli* (EC). TC positivity reduced from 35.1% in September to 23.3% in November, highlighting a general decrease in TC contamination. This reduction was also observed with EC trends, which decreased from 15.9% to 3.1% in the same timeframe, suggesting health risk is highest immediately following the storm event. Among participants whose wells were chlorinated following Hurricane Harvey, TC and EC positivity rates were lower when professionals performed disinfection.

Jha (2020), Jha et al. (in prep.) and Pieper et al. (2021) report a submerged wellhead led to statistically significant increases in arsenic, barium, chromium, iron, manganese, zinc, TC and EC concentrations when compared to wells which did not have submerged wellheads.

Research needs include additional investigations regarding temporal effects, health risk characterization and well disinfection best management practices (BMPs). Recommendations target sanitary well seals, well maintenance and water testing.

Acronym List

AgriLife Extension	Texas A&M AgriLife Extension Service
BMP	Best management practices
CFU	Colony Forming Unit
E. coli	*Escherichia coli*
EC	*Escherichia coli*
FIB	Fecal Indicator Bacteria
GCD	Groundwater Conservation District
GWI	Groundwater Issues
MCL	Primary Maximum Contaminant Level, or Primary Water Quality Standard
MCLs	Maximum Contaminant Levels
µg/L	micrograms per Liter
ml	milliliter
ml/L	milliliter per Liter
ppb	parts per billion
ppm	parts per million
QMRA	Quantitative Microbial Risk Assessment
SMCL	Secondary Maximum Contaminant Level, or Secondary Water Quality Standard
TAC	Texas Administrative Code
TDLR	Texas Department of Licensing and Regulation
TC	total coliform
TDS	Total Dissolved Solids
TGPC	Texas Groundwater Protection Committee
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
TWON	Texas Well Owner Network

Introduction

Intense flooding events such as those occurring with Hurricane Harvey which dropped 102-155 cm of rain totaling 76 trillion liters (about 20 trillion gallons or 62 million acre feet) of water on the Texas central and upper Gulf Coast area can cause widespread flooding of and damage to private water well systems.

Because each water well provides a direct conduit to the aquifer, standards regarding well head protection are administered by the TDLR. Well construction and plugging specifications accepted by the TDLR are shown at https://www.tdlr.texas.gov/wwd/wwdspecs.htm. An acceptable completion is shown in Figure 1.

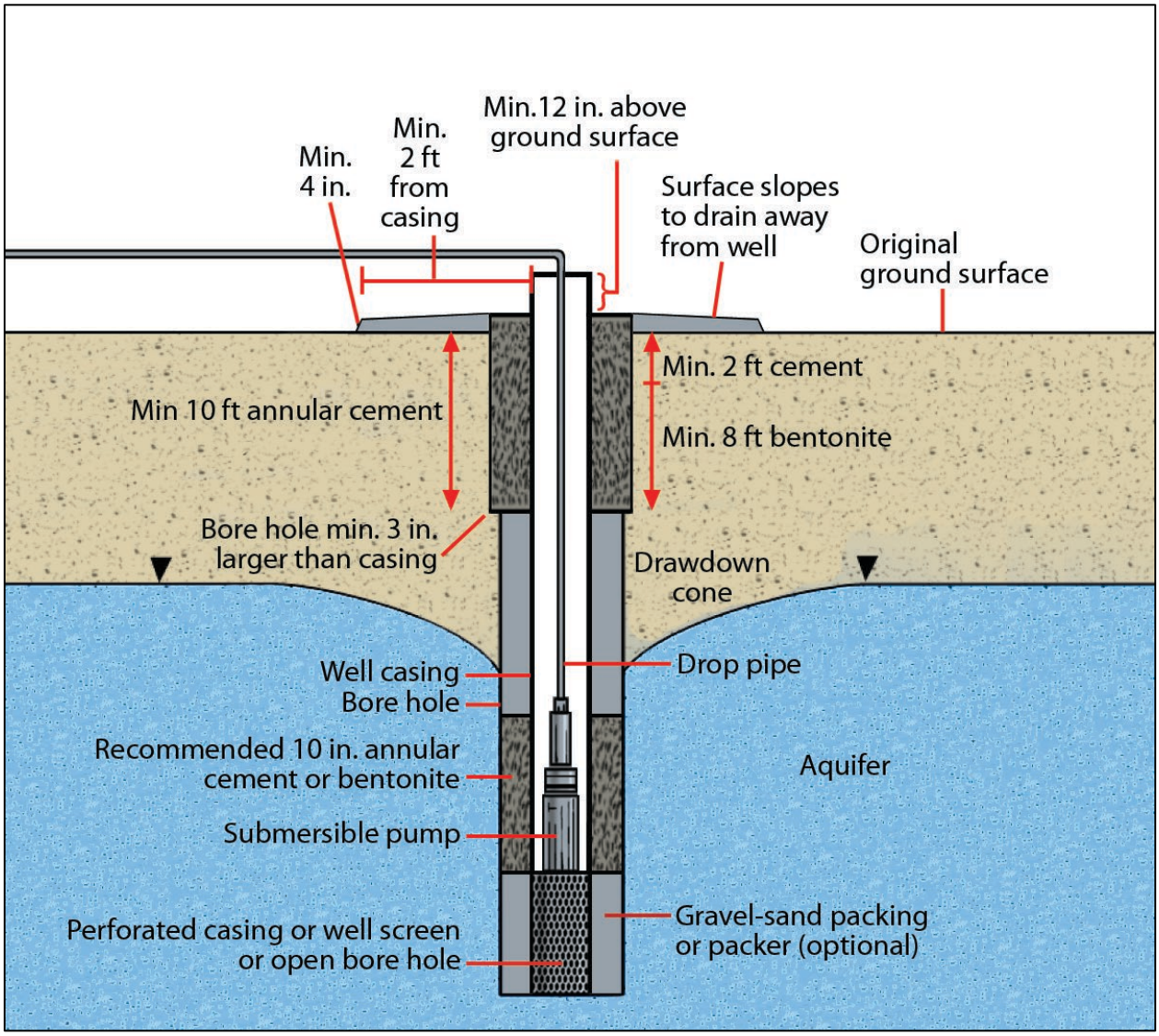

Figure 1. A required well completion that complies with TDLR standards.

As shown in Figure 1, the well casing should be at least 1 foot above the ground and be surrounded by a 4-inch-thick sloping concrete pad for at least 2 feet in all directions. This configuration is expected to protect the well from flooding or ponded water and reduces the potential for contaminants to seep down into the aquifer around the well casing. If a water well in Texas was installed by a licensed well driller after 1983, it should be in compliance with Texas regulations on wellhead construction.

For additional protection during flooding, Texas state law addresses construction of wells in flood-prone areas [16 Texas Administrative Code, section 76.100(a)(5)]:

> *A well shall be located at a site not generally subject to flooding; provided, however, that if a well must be placed in a flood prone area, it shall be completed with a watertight sanitary well seal, so as to maintain a junction between the casing and pump column, and a steel sleeve extending a minimum of thirty-six (36) inches above ground level and twenty-four (24) inches below the ground surface.*

Some Groundwater Conservation Districts (GCDs) establish additional requirements, for example, in its *Rules of the Post Oak Savannah GCD*, the GCD indicates:

> "3. A well must be located at a site not generally subject to flooding; provided, however, that if a well must be placed in a flood prone area, it must be completed with a watertight sanitary well seal and steel casing extending a minimum of 24 inches above the known flood level."

Full Issue Information and Discussion

Jha (2020), Jha et al. (in prep.) and Pieper et al. (2021) report extreme flooding events in Texas caused widespread damage to private water well systems in the areas affected by Hurricane Harvey in 2017. Through its network of county-based personnel and with collaborators at Virginia Tech and Louisiana State Universities, AgriLife Extension used the Texas Well Owner Network (TWON), an AgriLife Extension outreach program, to organize citizen science well sampling events, deliver materials and coordinate analyses of private well water samples.

Well water samples were analyzed for indicator bacteria (TC and EC), and inorganics including trace elements and heavy metals. In addition, TWON distributed a survey to participating private well owners to characterize: 1) extent of flooding and well damage; 2) well construction and design parameters; 3) well water use and consumption patterns; and 4) use of water treatment. The survey results provide a basis for better understanding of resource and recovery needs during natural disasters. Well owners participating in the free well water sampling events collected and transported their own water samples presumably according to instructions included in the test kits distributed.

Water quality changes associated with Hurricane Harvey

To evaluate inorganic concentrations in Hurricane Harvey-affected private water wells, more than 400 well users participated in seven free well water sampling events offered in 15 hurricane-impacted counties. Jha (2020) reported that overall, 43.9% of the well samples contained contaminant concentrations that exceeded at least one MCL or SMCL standard. Maximum contaminant levels (MCLs) for common ground water constituents are summarized at http://www.twdb.texas.gov/groundwater/data/doc/MCLs.pdf. Texas public water systems must comply with primary (human health related) and secondary (aesthetics related) drinking water standards; however, private water well quality is not regulated.

Concentrations of inorganic constituents in post-Harvey samples

As reported in Jha (2020), arsenic was detected in about 81% of the samples and exceeded the EPA drinking water standard for 3.4% of the samples. Copper was detected in 80% of the samples but exceeded the action level for the primary drinking water standard in only 0.2% of the samples. Similarly, chromium was detected in 61% of the samples while exceedance of chromium drinking water standards was 6.2% of samples. Nitrate was found in 71% of samples, with only 1% of samples above the primary drinking water standard of 10 μg/L. Lead was detected in about 25% of the samples, which is relatively high as samples were collected after five minutes of flushing. The action level for lead is 15 μg/L. Similarly, other elements such as cadmium and uranium were detected in less than 50% of samples. Iron exceeded 300 μg/L (SMCL) in 22.9% of wells and was detected (>10 μg/L) in 71.0%. Twenty-three percent of the samples exceeded 50 μg/L (SMCL) of manganese and 69.0% of samples had detectable concentrations. A summary of results from Jha (2020) is shown in Figure 2.

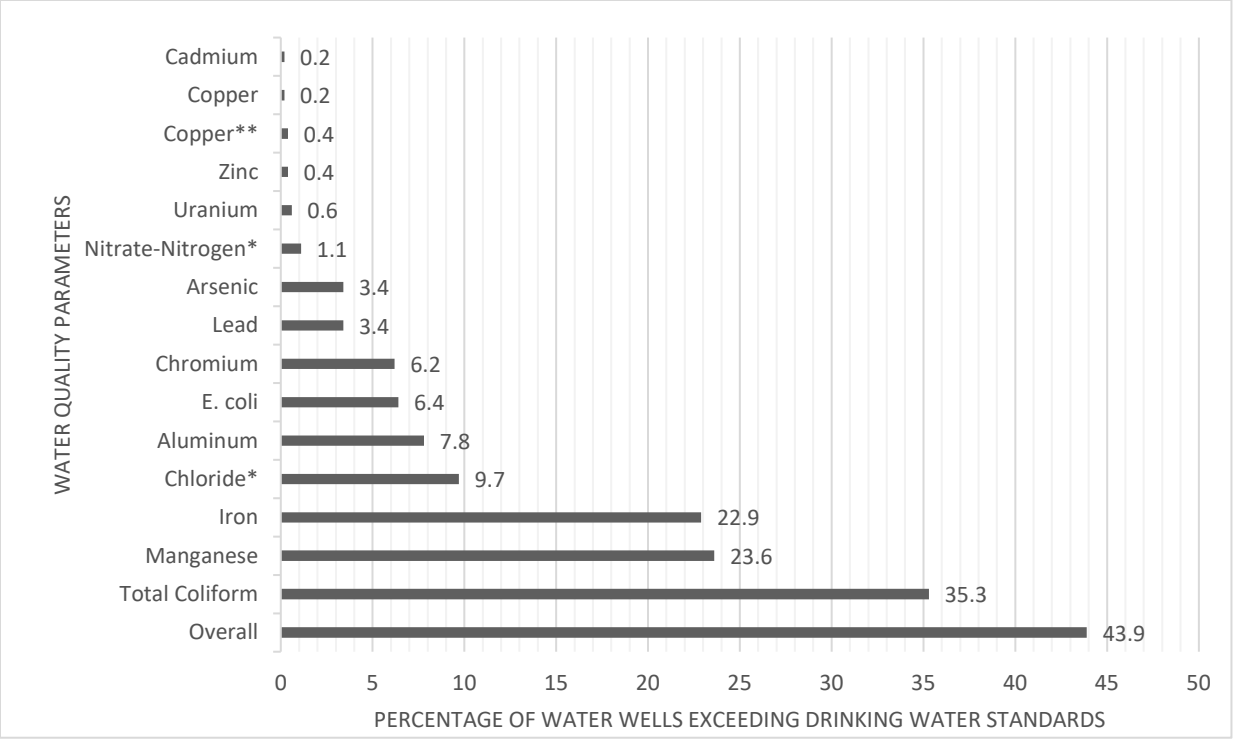

Figure 2. Overall Percentage of Private Water Wells That Exceeded at Least One Primary or Secondary Drinking Water Standard and Percentage That Exceeded for Individual Drinking Water Standards
*n=338 for Chloride and Nitrate-Nitrogen
**Copper has an action level for both Primary and Secondary Drinking Water Standards

Comparison of inorganic concentrations in samples collected pre-Harvey vs. post-Harvey

Jha (2020) compared inorganic concentrations in wells surveyed post-Harvey to well water contaminant concentrations for the study area available in the TWDB database for the five years before Hurricane Harvey. Contaminant concentrations post-Harvey varied significantly for copper and zinc compared to the previous five years of water samples recorded in the study area counties obtained from the TWDB. No significant difference was found for the other elements reported in Jha (2020), which were: sodium, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium, calcium, titanium, vanadium, chromium, iron, manganese, cobalt, nickel, arsenic, selenium, boron, strontium, molybdenum, silver, cadmium, tin, barium, lead, and uranium. Statistical tests indicated that concentrations of copper and zinc (n=435) were significantly higher than before Hurricane Harvey (n = 49). Interestingly, copper and Zinc are alloys of brass.

Changes in concentrations of microbial indicators

To evaluate concentrations of microbial indicators in Hurricane Harvey-affected private water wells, a total of 8,822 results from well water samples collected following the hurricane through collaborative efforts between several organizations (Texas A&M

AgriLife Extension Service (TWON); Virginia Tech University; Brazoria, Fort Bend and Harris Counties; and the Houston Health Department) were summarized by Pieper et al. (2021).

As reported in Pieper et al. (2021), in the 10 months after Hurricane Harvey, 29.6% samples (n=2,609 of 8,822) were positive for TC and 11.0% (n=427 of 3,887) were positive for EC. Coliform bacteria contamination rates were significantly higher after Hurricane Harvey compared to samples collected in the Texas Gulf Coast through TWON programming during non-flooding conditions when 19.6% (n=469) were TC positive and 3.9% (n=281) were EC positive (unpublished data). Specifically, for counties in the Hurricane Harvey affected areas, for 2014-2017 (pre-Hurricane Harvey only), TWON recorded screening results collected through nine events for nine counties. TWON also recorded EC screening results collected through eight events for eight counties.

For Texas statewide, excluding events for affected counties following Hurricane Harvey, under routine (non-flood) conditions from 2014-2019, TWON well water screening efforts (N=2470) recorded the presence of TC in 34.2% of samples and the presence of EC in 5.4% of samples (unpubl. data). Samples were collected by well owners and brought to events for screening through mobile laboratory techniques.

These baseline contamination rates are consistent with other coastal aquifers well testing campaigns (Swistock et al. 2013, Pieper et al. 2016, Dai et al. 2019). With TC rates 1.5 times higher and EC rates 2.8 times higher after Harvey, there is a clear need to test well water immediately after flooding to protect the health of those who remain reliant on or resume using their private wells post-flooding.

Temporal trends in microbial contamination following Hurricane Harvey

Pieper et al. (2021) report that more than half of the samples (5,181; 58.7%) were collected within the first month of recovery (September), and 1,000+ samples were collected in each of the following two months. After November, only a few hundred samples were submitted monthly (maximum of 274), but there was continued interest in testing through June (10 months post-Harvey). TC positivity reduced from 35.1% in September to 23.3% in November, highlighting a general decrease in TC contamination.

This reduction was also observed with EC trends, which decreased from 15.9% to 3.1% in the same timeframe, suggesting health risk is highest immediately following the storm event. Over time and in some cases, following shock chlorination, frequency of occurrence for TC and EC dropped to concentrations similar to non-disaster results recorded by TWON.

These reductions were likely associated with remediation efforts (e.g., well disinfection, flushing, or regular water use), natural attenuation of microbes within groundwater supplies or well water, and/or the decline in number of samples collected (Gilliland et al. 2020, Atherholt et al. 2015, John and Rose 2005, Scoullos et al. 2019).

Among participants whose wells were chlorinated following Hurricane Harvey, TC and EC positivity rates were lower when professionals performed disinfection. Specifically, TC and EC positivity rates were 15% and 0% when well professionals were hired, compared to 31% and 2% when residents performed the disinfection (Boellstorff et al. 2019, Pieper et al. 2020). As noted earlier, for all wells tested through November, microbial indicator positivity decreased over time so that TC positivity decreased for all wells to about 23% and EC positivity decreased to about 3%, similar to results for residents who chlorinated their wells themselves.

Drawing conclusions is challenging without data documenting coliform loading before disinfection, but these findings are in keeping with prior research highlighting concerns with residents performing chlorination procedures (Eykelbosh 2013, Gilliland et al. 2020). Well disinfection protocols in 34 states were reviewed by Pieper et al. (2020). The study provides more information on the science-based evidence that disinfection procedures reduce microbial loading in well water; reviews inclusion of disinfection principles in state-level emergency protocols; and explores research gaps potentially hindering disinfection efficacy.

Submerged wellheads during Hurricane Harvey

Private wells can be impacted by floodwater through several pathways, but wellhead submersion is often considered the primary mechanism and can result in direct contamination of the well water supply (Pieper et al. 2020). In some cases, proper private water well management and maintenance can reduce or even prevent contamination (e.g., extending the well casing >12 in. above the ground surface, installing sanitary well cap; Exner and Spalding 1985; Swistock and Sharpe 2005).

Jha (2020), Jha et al. (in prep.) and Pieper et al. (2021) report a submerged wellhead led to statistically significant increases in arsenic, barium, chromium, iron, manganese, zinc, TC and EC concentrations when compared to wells which did not have submerged wellheads. About 32-43% (depending on sampling time frame) of event participants indicated that their wellhead had actually been submerged under flood water as a result of the hurricane. Immediately after the hurricane, wellheads that were submerged were much more likely to have TC (56% vs. 37%) and EC (23% vs. 3%) present than were wells that were not submerged. However, 10 to 28 weeks after Harvey, TC and EC presence were similar for Harvey-submerged and non-submerged wells.

Changes in the understanding of the likelihood of flooding for a particular area are reflected through ongoing updates to the FEMA National Flood Hazard Layer (https://www.fema.gov/national-flood-hazard-layer-nfhl).

Damaged wellheads during Hurricane Harvey

A damaged well system refers to wells having damaged well casing, wiring, and piping systems resulting from well areas being impacted by the hurricane. Manganese concentrations were higher in wells damaged by Harvey than for undamaged wells (Jha 2020).

Around 18% of the well systems in the samples analyzed for bacteria were damaged during Hurricane Harvey with 80% of those wells having submerged wellheads, which likely contributed to the bacterial contamination indicated when these wells were tested immediately after the hurricane.

Gonzales (2008) found that wellhead protection does play a role in bacterial contamination of water wells. Gonzales reported that a strong statistical difference in TC bacteria contamination for wells sampled in Colorado with varied wellhead protection. It was found that all the wells having poor wellhead protection tested positive for TC, while 60% of the wells having fair wellhead protection tested positive for TC. Moreover, only nine percent of wells with good wellhead protection tested positive for TC.

Continuing Research Needs

- Much of the present white paper discusses well water quality analyzed immediately after Hurricane Harvey passed, between 11 September to 16 October 2017. Future research investigating longer-term, temporal effects would be beneficial.

- Studies related to potential risk characterization due to fecal indicator bacteria (FIB) exposure post-Harvey could be achieved through Quantitative Microbial Risk Assessment (QMRA) modeling.

- There is a need for research-based water well disinfection BMPs.

Conclusion and Recommendations

Flooding that causes wellhead inundation is especially likely to lead to private well water contamination. Immediately after Hurricane Harvey, wellheads that were submerged were much more likely to have TC (56% vs. 37%) and EC (23% vs. 3%) present than were wells that were not submerged. In addition, a submerged wellhead led to statistically significant increases in arsenic, barium, chromium, iron, manganese, and zinc when compared to wells which did not have submerged wellheads.

To ensure well users have the capacity and capability to protect themselves and their families from flood-associated hazards, there is a critical need for targeted outreach to prepare for and appropriately respond during a flood event. Recommendations include:

- Wellheads should be cased to above any previous flood level even if that height exceeds the 36 inches from the ground for wells located in floodplains as specified in the Texas Administrative Code. Financial assistance for wellhead modifications

could be provided through a state fund available to well owners, water well drillers, pump installers or local groundwater conservation districts.

- Wellheads in flood-prone areas and those wells which have been previously flooded should be completed with a watertight sanitary well seal.

- At a minimum, well owners should have their well water tested yearly for *E. coli* by a certified laboratory. It is also recommended that well water is tested for nitrate-nitrogen and total dissolved solids (TDS) every few years. Following a flood, a private water well should be tested by a certified laboratory for *E. coli* and other constituents of concern.

- Older wells without proper casing, sealing and protective slabs, or with other problems, should be brought up to current standards. Wells should be upgraded by removing well pits, installing caps, extending casings as appropriate, and moving such activities as pesticide mixing, tank rinsing or gasoline storage farther from the well.

- Those well owners with submerged wellheads especially need attention and if necessary, assistance that may include providing funding for private water well testing for well owners in counties with natural disaster designations due to flooding.

TGPC GWI Subcommittee members include, but are not limited to:

- Texas Commission of Environmental Quality (TCEQ);
- Texas Water Development Board (TWDB);
- Railroad Commission of Texas (RRC);
- Texas Department of State Health Services (DSHS);
- Texas Department of Agriculture (TDA);
- Texas State Soil and Water Conservation Board (TSSWCB);
- Texas Alliance of Groundwater Districts (TAGD);
- Texas A&M AgriLife Research (AgriLife Research);
- Bureau of Economic Geology of The University of Texas at Austin (UTBEG);
- Texas Department of Licensing and Regulation (TDLR);
- Texas Parks and Wildlife Department (TPWD);
- Texas Tech University (TTU);
- Texas A&M AgriLife Extension Service (AgriLife Extension); and,
- United States Geological Survey (USGS).

The primary goals of the TGPC GWI Subcommittee are to:

- Facilitate interagency communication for assessment programs addressing groundwater contamination;
- Coordinate and assist member agencies with monitoring programs for:
  - Ambient groundwater conditions;
  - Pesticides; and,
  - Emerging contaminants or constituents of concern;
- Support the intent of the *Texas Groundwater Protection Strategy* (https://www.tceq.texas.gov/assets/public/comm_exec/pubs/as/188.pdf) by:
  - Reviewing published data reports, and evaluating data independent of published reports, to assist in the determination of the effectiveness of existing regulatory programs and to identify potential groundwater contaminants not addressed by existing regulatory programs;
  - Developing recommendations for consideration by the TGPC to address potential groundwater contamination identified through monitoring and data review; and,
  - Developing white papers on the groundwater issues listed in their biannual *Activity Plan* which summarize the best available scientific data on a specific groundwater issue, identify areas where there is insufficient scientific data to thoroughly assess the issue, evaluate the effectiveness of existing regulatory programs to address the issue, and provide recommendations or policy options to the TGPC regarding the issue.

The above recommendations or policy options represent the opinion of the TGPC GWI Subcommittee and do not necessarily reflect the views and policies of each participating organization. The United States Geological Survey (USGS) may have contributed scientific information, only.

For more information about this white paper, please contact the TGPC (https://tgpc.texas.gov/contact-us/).

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