Oklahoma Drinking Water at Risk from Oil and Gas Injection Wells

Exposing Oklahoma Corporation Commission's Flawed Drinking Water Protection Policies

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Acknowledgements

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Executive Summary

Locating and protecting underground sources of drinking water is a critical part of addressing the long-term drinking water needs of communities across the country. It is an equally important aspect of siting oil and gas injection wells, in order to avoid potential contamination of these water sources. Oil and gas operators who are dependent on the injection of wastewater and other fluids underground must know the location and depth of current or future sources of drinking water in order comply with federal regulations. However, this is not always the case.

New research shows that the Oklahoma Corporation Commission (OCC) may have permitted oil and gas wells to inject into potential underground sources of drinking water that are supposed to be protected by federal law and off limits to fossil fuel activities.

This analysis of injection well locations and water quality data indicates that the OCC may have failed to protect underground sources of drinking water (USDW) from oil and gas injection wells. The OCC uses Base-of-Treatable (BTW) water maps to define where groundwater must be protected as USDW. However, it appears that injection well permitting has not always followed this rule.

Our analysis found that 18 oil and gas wells were permitted to inject into depths above the BTW, and do not appear to have received aquifer exemption approval required to authorize injection. If the BTW is accurate at these well sites, then these wells are injecting into groundwater, which could serve as a drinking water source and must be protected by the Safe Drinking Water Act.

A similar analysis comparing Oklahoma's BTW water maps to water supply wells, reveals that 6,844 domestic water wells and 175 public water supply wells draw groundwater from below the reported BTW. Since these drinking water wells are extracting useable water, the accuracy of the BTW must be called into question.

Taken together, these troubling revelations make it clear that the BTW is not an adequate tool alone to predict location and depth of USDWs and relying on it presents serious complications. Indeed, Oklahoma drinking water in some cases may be at risk from oil and gas injection wells and without a clear understanding of the locations of USDWs, the extent of the issue is unknown.

Understanding the geologic terrain and groundwater quality is part of the foundation of any oil and gas regulatory agency designed to appropriately manage industrial pollution threats. In order to adequately protect USDWs going forward, Clean Water Action calls on Oklahoma to; 1) conduct a transparent review of the full inventory of Class II wells to determine if any additional wells are injecting into USDWs; 2) immediately halt injection activity at any wells injecting into USDWs without the required aquifer exemption; 3) review methods for determining USDW location and depth and reevaluate the use of the BTW.

Introduction

In the years before our landmark environmental laws existed, water resources were left vulnerable to pollution, in part due to a patchwork of loose state regulations. During this time, rivers caught fire, industries discharged freely into surface waters and the oil and gas industry began injecting billions of gallons of wastewater underground for permanent disposal and to enhance oil recovery. The increase in industrial pollution threats made it clear that a state by state approach to environmental protection was not effective in protecting water resources and more action was needed.

As a result of mounting public pressure to do something about water pollution, Congress passed the Clean Water Act in 1972 and then the Safe Drinking Water Act (SDWA) in 1974, which provided a minimum level of federal protection for drinking water. EPA extended federal protections to water identified as an Underground Sources of Drinking Water (USDW). This is groundwater that currently supplies a public water system or that contains less than 10,000 mg/L total dissolved solids (TDS), a common water quality measurement. EPA's Underground Injection Control (UIC) program implemented the protections mandated by the new federal environmental law.

While it is still widely believed that all USDWs are protected under the SDWA via EPA's UIC program, there is a little known provision that allows certain oil, gas and mining activity to occur in groundwater that would otherwise be protected as a drinking water source. **This provision is called an aquifer exemption**.

EPA developed the aquifer exemption program in the 1980's when oil and gas interests argued that certain oil and gas development would not be possible if every USDW were protected.[1] Instead, they argued, EPA should allow the industry to inject fluids directly into these

relatively high quality aquifers under certain conditions. EPA agreed, and developed criteria for lifting the federal protections in some cases.

Oil and gas companies have used aquifer exemptions for two primary purposes: to inject wastewater underground for permanent disposal, or to inject water, steam, chemicals and other fluids for enhanced recovery (ER) of oil and gas and uranium mining. Aquifer exemptions granted for both practices essentially "write off" underground sources of drinking water, permanently, in order to prioritize oil and gas development.

Previous Clean Water Action investigations have helped uncover significant oversight failures in both the California and Texas aquifer exemption programs. As a result, from 2014 through early 2017, California has taken steps to shut down more than 500 injection wells for illegally injecting into underground sources of drinking water, overturned 10 aquifer exemptions that were incorrectly historically treated as exempt, and is in the process of a full program review that includes methodically reevaluating the status of thousands of additional injection wells and dozens of aquifers in order to confirm they meet the applicable laws and regulations.

In Texas, Clean Water Action discovered that the Texas Railroad Commission (RRC) has never received an application for an aquifer exemption from an oil and gas operator. Yet the RRC has permitted over 54,000 oil and gas injection wells.[2] It is highly unlikely that all of these wells were injecting into zones with water quality over 10,000 mg/L TDS, or water not federally protected. In at least 2 cases made public so far, the RRC did in fact permit injection into a USDW. The state initiated an internal investigation to explore the full extent of the problem.

These investigations reveal that the oversight and implementation problems in the aquifer exemption program are not isolated, and that a broader exploration of state and federal exemption programs is warranted.

Now this paper introduces a new set of issues in Oklahoma's UIC program that potentially puts some of the state's drinking water at risk. As outlined in detail in the following pages, Oklahoma's oil and gas regulatory agency, the Oklahoma Corporation Commission (OCC), used a measurement called Base of Treatable Water (BTW) as a guide to permitting injection wells. Below the BTW is thought to be water not categorized as a USDW and therefore not protected by the SDWA. This presents two main concerns.

First, broad assumptions about groundwater quality below the BTW exceeding 10,000 mg/l TDS should not be relied upon without additional groundwater sampling. The BTW, created from electric resistivity logs, is not an adequate predictor of USDWs alone, at the state scale.

Our analysis compared the BTW depth, using spatial analysis, to public water supply wells, domestic water wells, and UIC wells throughout the state of Oklahoma. This uncovered 6,844 domestic wells and 175 public supply wells with total depths *deeper* than respective BTW depths. This implies that either these drinking water wells are pulling from low quality water sources that would require significant treatment or the BTW depths are wrong.

Second, using the current BTW analysis, 18 UIC wells were permitted above the BTW. In other words, if the BTW is accurate for determining water quality, these wells are injecting into a USDW. These wells could only operate in compliance with SDWA and UIC regulations, if they obtained an aquifer exemption from EPA. The five exemptions granted in the state up to this point do not appear to exempt the injection zones of these wells. If these wells were improperly permitted without an exemption, they are putting Oklahoma drinking water at risk.

This paper concludes with a number of steps both EPA and Oklahoma can take to improve the aquifer exemption program. In the absence of accurate data and vigilant oversight in the injection well permitting process, drinking water resources risk being sacrificed for the short term needs of the oil and gas industry.

Table 1: Oklahoma approved aquifer exemption summary

ID	Well Class	County	AE Area (sq. miles)	GIS Calculated AE Area* (sq. miles)	Depth and Units	Injection Zone	Injectate Characteristics	Approval Date	Data Quality Category
6_137	V	Harmon, Jackson counties	218	293	1720 feet MSL	Blaine Aquifer		6/21/1989	Precise location
6_140	IID	Pontotoc	12.25	1.50	1276 feet MSL	Beebe field of Viola and Simpson Aquifers	produced water not more than 4,430 mg/L TDS	1/12/1989	Precise location
6_139	IID	Pontotoc	12.25	1.25	1276 feet MSL	Beebe field of Viola and Simpson Aquifers	produced water not more than 4,430 mg/L TDS	1/12/1989	Precise location
6_39	IID	Seminole, Pottawatomie, and Pontotoc		71.40	NA	Beebe field of Viola and Simpson Aquifers		INA	Less precise location and some attributes missing
6_138	IID	Pontotoc, Garvin counties		59.80	800 feet BGS	Pennsylvanian and Simpson aquifers. Pennsylvanian series includes the Ada Sands, Dewey Sands, Dykemann Sands, Lael and Bell City Lime. Simpson series includes the Bromide Sands and McLish Sands.		6/13/1905	Precise location

**Clean Water Action calculation. Area provided in EPA's database varied from the polygons provided by EPA.*

Background on UIC Program in Oklahoma and Aquifer Exemptions

The overlapping concerns about injection wells permitted without an aquifer exemption and the inadequate analysis used in the BTW is best understood via the roots of the oil and gas UIC program in Oklahoma and a current snapshot of aquifer exemptions in the state.

In 1981, EPA delegated authority to Oklahoma Corporation Commission (OCC) to oversee Class II UIC wells, except in Osage County (Osage Nation), where EPA maintains authority.[3] Class II wells inject fluids related to oil and natural gas activities; mainly for enhanced oil recovery (EOR) operations and oil and gas wastewater disposal. In Oklahoma, OCC issues final permits for EOR (Class IIR) and wastewater disposal (Class IID).

According to a recently published EPA database,[4] there are five approved aquifer exemptions in Oklahoma *(Table 1)*. Four were approved for Class IID wells and one for Class V wells.[5] The Class V aquifer exemption (labeled as 6_137) in the southwestern corner of the state *(See Figure 5)*, Harmon and Jackson counties) was granted for the Blaine aquifer, at 1,720 feet deep, and spans 218 square miles. This exemption was granted on 6/21/1989.

The remaining four aquifer exemptions were for Class IID wells. However, there appears to be inconsistencies and issues with the underlying EPA dataset. For example, the GIS polygon boundary area calculated in this research differed greatly from the area provided in the EPA dataset *(Table 1)*. Also, the approval date for

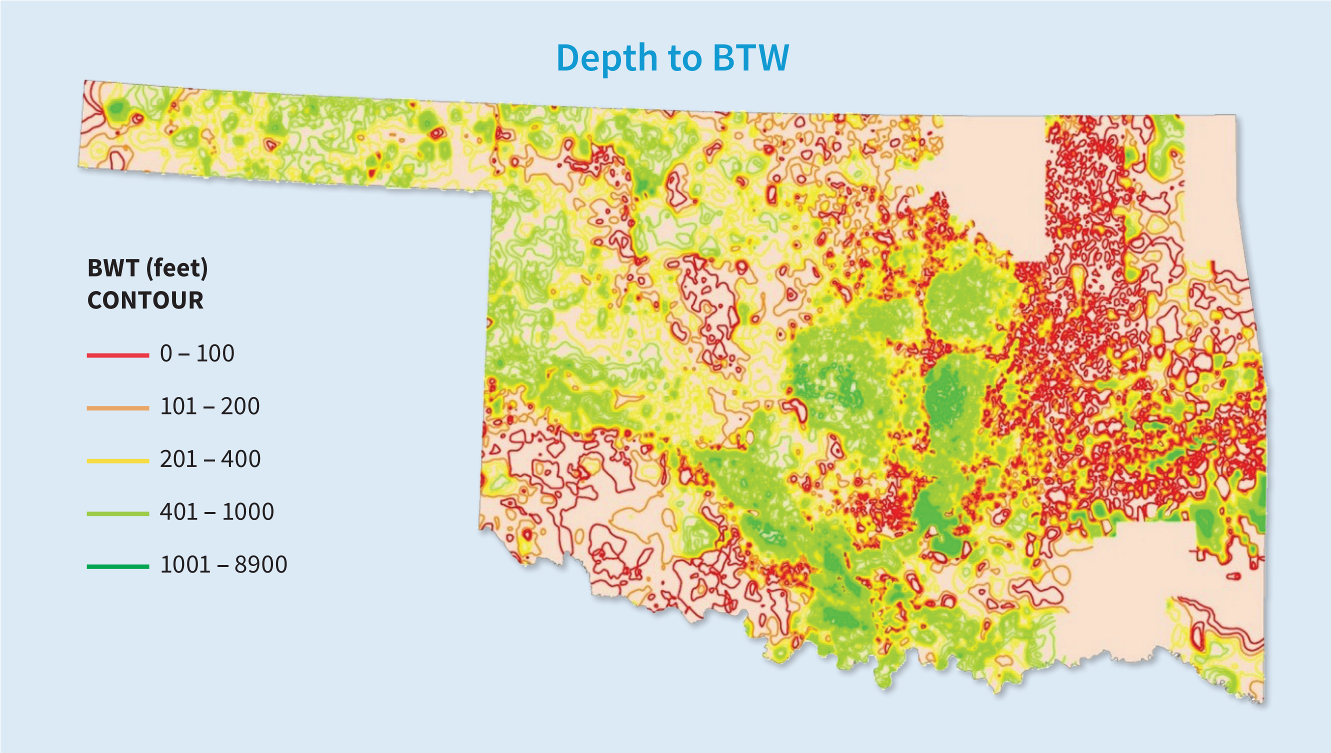

Figure 1. *Base-of-treatable water (BTW) contours across the state. Contours represent depth to the BTW surface, already accounting for relative land elevation. Note that several counties do not have contours established.*
Clean Water Action generated map. Source Data: http://www.owrb.ok.gov/maps/pmg/owrbdata_GW.html

6_138 was listed as "6/13/1905", which was decades before the inception of the UIC program. No water quality data was provided in the aquifer exemption spreadsheet, and it is unclear under what criteria any of the exemptions were granted. EPA UIC regulations include a set of criteria under which a USDW must fall in order to qualify for an aquifer exemption.[6]

Process: Difficulty in Delineation of Underground Sources of Drinking Water Using the Base-of-Treatable Water

Base-of-treatable water (BTW) maps were created by the state to define the zones of 'fresh' and 'saline' water. According to a presentation by OCC,[7] BTW was defined as "the base of fresh/usable groundwater, approximately 10,000 mg/L total dissolved solids (TDS)." BTW depths were established by using electric resistivity (ER) well logs. ER well logs were used from "at least one well per mile in gently dipping areas" and "density is higher in steeply dipping faulted and complex areas" *(see previous reference)*. BTW well logs were used to create a contour surface map and published the file for public use *(Figure 1)*.

Obtaining groundwater quality values for salinity from electrical resistivity logs is a relatively complicated calculation with multiple assumptions about the aquifer formation and physical characteristics. According to an EPA presentation from 2002,[8] EPA has recognized two approaches to using electrical resistivity logs to estimate groundwater quality data. Examples of both methods are discussed in the previously cited presentation, but either method is highly dependent upon user inputs and assumptions. Several sources of error are related to 1) incorrect assumptions about fitting coefficients, 2) not considering the cation/anion composition of the groundwater, which can influence TDS, and 3) salinity gradients between the well fluids and the groundwater.[9]

Other research has demonstrated that the relationship between bulk measured resistivity and water quality can be influenced by a host of factors, including clay content, soil and mineral properties, and water composition.[10] In any event, substantial caveats must be accounted for to correlate and interpret these results, even with intimate knowledge about localized conditions in the aquifer. Still, it is unclear which method and assumptions were used to create the BTW in Oklahoma. According to a OCC presentation, the BTW maps were commissioned in the 1980s by the OCC based on roughly 75 years of resistivity logs from oil and gas wells,[11] and BTW maps were subsequently updated around 2009.[12]

Methods: Domestic, Public Supply, and UIC Well Depth Compared to BTW

Groundwater wells and BTW shapefiles were downloaded from the Oklahoma Water Resources Board (OWRB).[13] According to the OWRB database, there were a total of 69,918 domestic wells and 2,739 public water supply wells in the State. The BTW contour was the relative depth to the assumed boundary of the USDW, therefore it can be compared directly to the well depth at a given latitude and longitude. UIC well locations and depths were from data publicly available through the Oklahoma Corporation Commission, Oil and Gas Division.[14]

In ArcGIS, the 'Topo to Raster' tool was used to convert and interpolate various BTW polylines to a raster. The corresponding BTW depth raster was compared to well depth database to understand relative locations of wells to the BTW. This may represent some source of error as the contour values representing each polyline were interpolated to create a raster.

Furthermore, there may be some variability with the establishment of the well latitude longitude

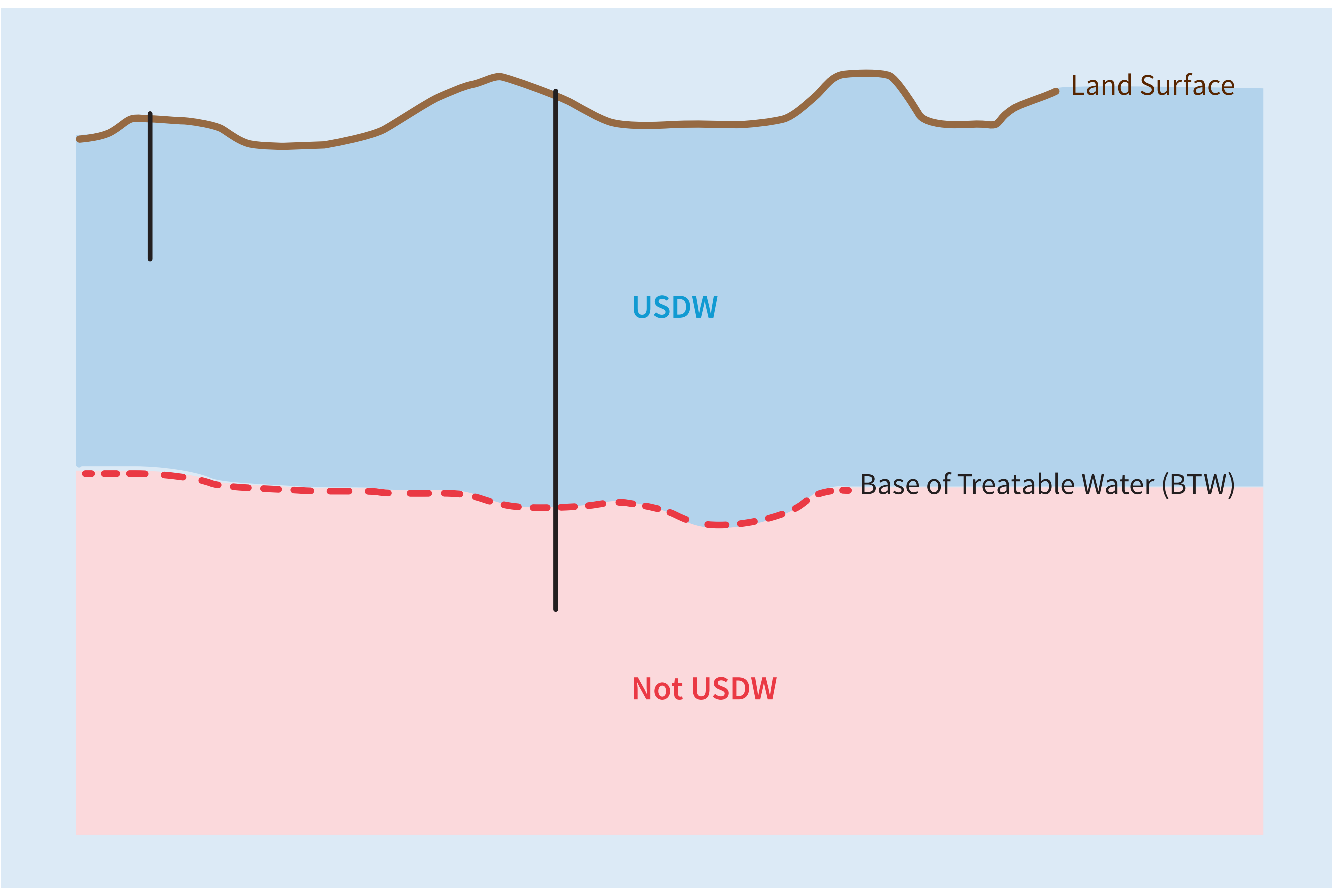

Figure 2. *Cross section displaying the separation between an underground source of drinking water (USDW) and non-USDW by the base of treatable water (BTW). Note that the BTW varies laterally and vertically across the state of Oklahoma.*

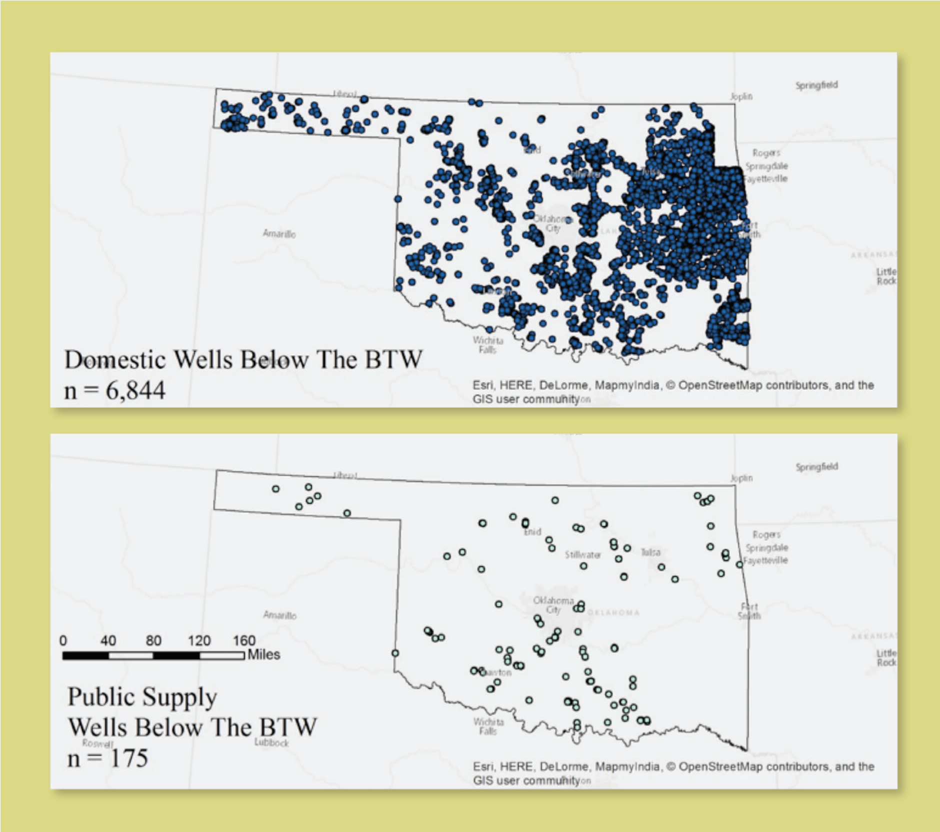

Figure 3. *Spatial locations of each well drilled below the assumed BTW; top: Domestic wells – 6,844 and bottom: Public Supply Wells = 175.*

Note: Wells inside of counties without an established BTW were not included in the analysis.

Clean Water Action generated maps.

locations which may affect the relative relationship with the BTW. For example, as stated in the meta-data of the OWRB database: *"For the computer calculate latitude and longitude locations, the location of each well is within a 10, 40, 160 or 640 acre area of land. These could be anywhere inside the described area. For the GPS collected well locations, the point is as accurate as the device it was collected with. See the 'LL_METHODS' field for type of collection."* While increased precision about well locations could potentially alter the numbers presented in this report, it is unlikely that the conclusions would be altered, due to the magnitude of wells in question. Certainly, if more information becomes available, or is updated, then the findings in this report could be modified to reflect those changes.

In the OWRB database, 'USE_CLASS' was used to organize the different types of water wells, specifically, 'Domestic' and 'Public Water Supply'. The 'Extract Values to Points' tool was used to extract lat/long coordinates of wells with the corresponding z-value depth to the BTW.

Results: Comparison of BTW and Water Well Depths

Based upon the relative latitude and longitude and the corresponding well depths, the public supply, domestic, and UIC wells were compared with the BTW to examine the relative depth of the well. Recall, the BTW depth assumes that any water below that depth is >10,000 mg/L TDS and not considered a federally protected USDW. When a domestic or public supply well depth was less than the BTW, the well was assumed to be operating in a USDW *(See Figure 2)*. Conversely, when a domestic or public supply well was located below the BTW, the well was operating in a non-USDW.

The statewide analysis results suggest a relatively large number of domestic and public supply wells are operating below the BTW *(Figure 3; Top and Bottom)*. In order for a public supply well to extract water from a non-USDW aquifer (>10,000 mg/L TDS), it would require significant water treatment to lower the TDS to levels acceptable for human consumption. In other

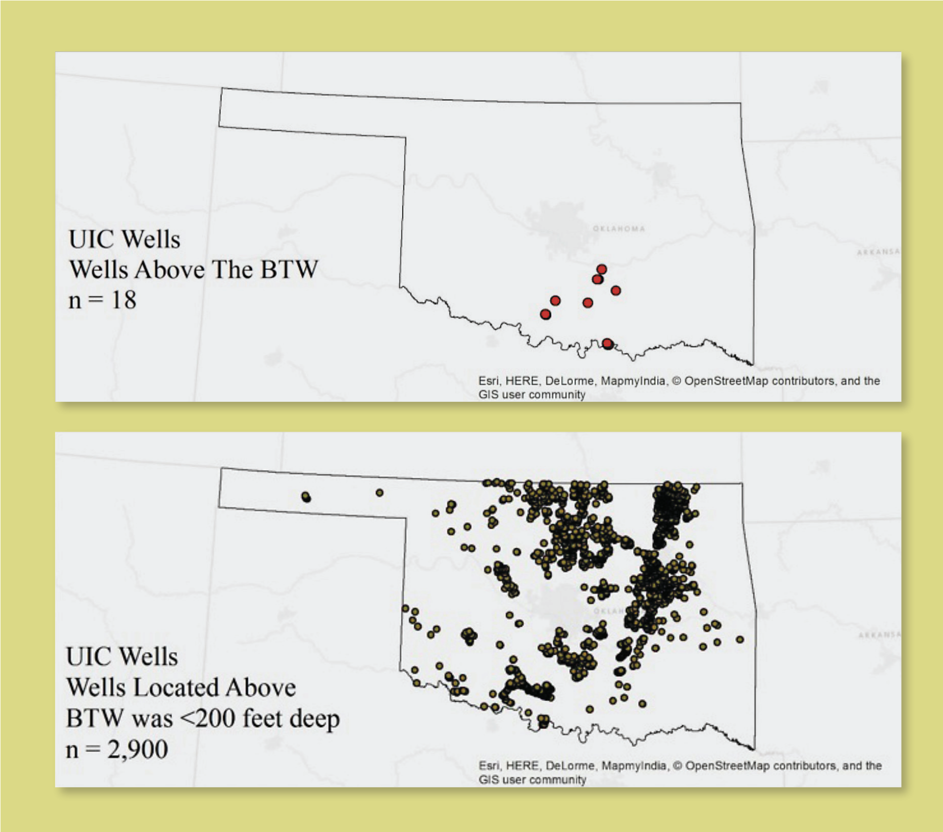

Figure 4. *The results from the UIC well comparison to the BTW. The top figure shows UIC wells above the BTW. Of those 18 wells identified, there were 4 wells identified as '2DNC' and 14 '2Rin'.*

Note: several wells are in close proximity and cannot be distinguished at this scale. The bottom figure shows where UIC depth was below the BTW, however the BTW was <200 feet deep.

Clean Water Action generated maps.

words, this groundwater would be non-potable, as is, due to the high salt content.[15] This finding further calls into question the accuracy of the BTW for determining USDWs.

UIC Wells Compared to the BTW

The publicly available information for UIC wells were also compared to the BTW across the state, in the same manner as the public supply and domestic water wells. However, any UIC wells operating above the BTW, would not be in compliance with SDWA, unless an aquifer exemption had been granted. The results suggest that 155 UIC wells may be operating above the BTW. The original database reports that 132 of the 155 wells were listed as either "0" or "1" feet deep, suggesting potential errors or an incomplete database. However, there remain 18 UIC wells which were found above the BTW and it's unclear if an aquifer exemption has been granted for these operations *(Figure 4; top)*. It is unlikely that the aquifer exemptions discussed in the earlier section were granted for these wells, as the total depth for the 18 UIC wells above the BTW ranged from 195'–1,560', while the aquifer exemptions above were both granted at deeper intervals.

Furthermore, 2,900 UIC wells were found operating in locations where the BTW was shallow,[16] or less than 200 feet deep *(Figure 4, bottom)*. From the BTW raster histogram, the mean depth to BTW throughout the entire state was 340 feet deep.

Oklahoma Groundwater Quality

Oklahoma groundwater quality varies highly by aquifer, location, depth, and is highly dependent on localized geochemical conditions in the aquifer. The Oklahoma DEQ has found the mean TDS was 384 mg/L and the maximum was 1,791mg/L, from 481 public supply well samples.[17] The previous report indicates the vast majority of public supply wells are pumping from aquifers that contain higher water quality groundwater, those with significantly less TDS than 10,000 mg/L. Similarly, a USGS report studied groundwater samples from the Central Oklahoma aquifer and

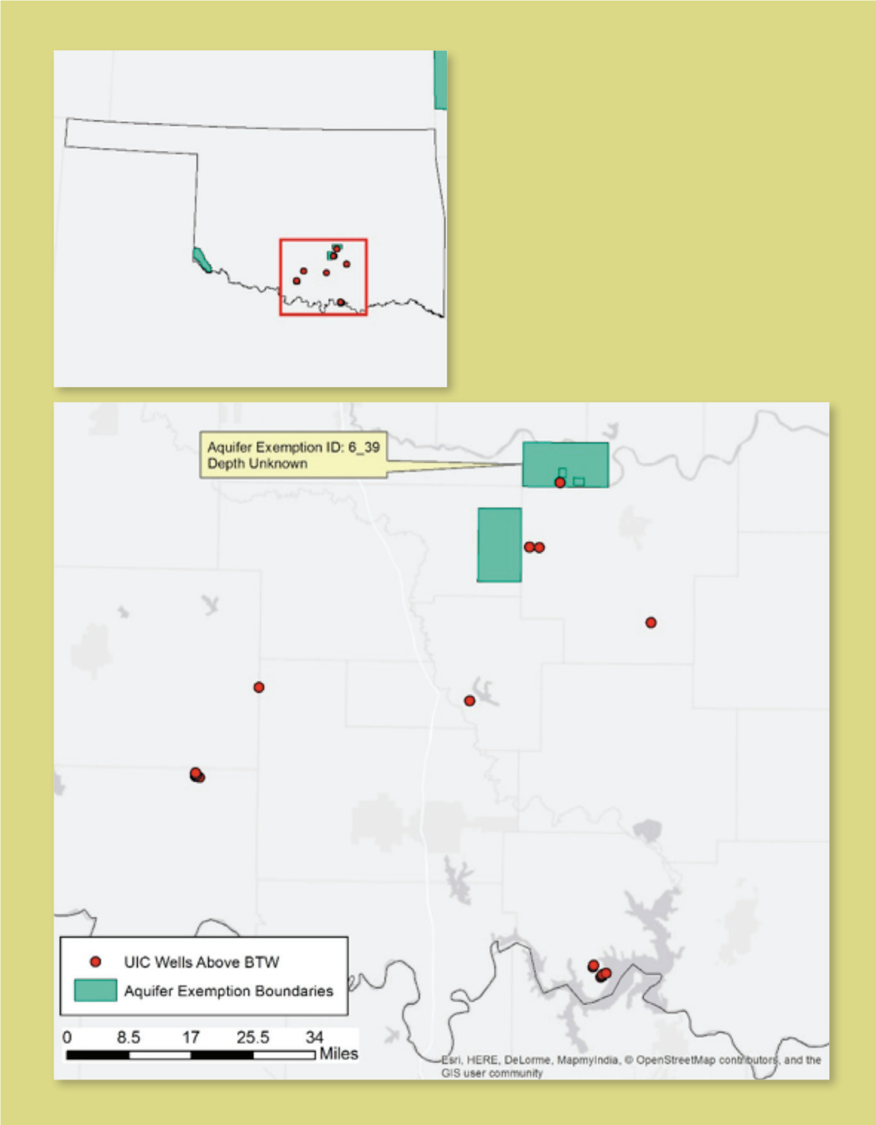

Figure 5. *EPA approved aquifer exemption boundaries compared to UIC wells above BTW. One UIC well (API: 3512304891) and aquifer exemption (ID: 6_39) spatially overlapped, however the aquifer exemption did not have specific depth information. Therefore, more information is needed to confirm whether this UIC well is injecting into the approved geologic formation for this aquifer exemption. The UIC well listed a total depth as 740 feet.*

Clean Water Action generated map.

found the median TDS concentration was 380 mg/L, and the maximum was 1,270 mg/L.[18]

Discussion and Suggestions

The results of the analysis suggest BTW depth does not adequately identify the presence of potential USDWs. This is supported by the finding that roughly 175 public supply wells and 6,844 domestic wells were found to be located deeper than the BTW (where groundwater was assumed >10,000 mg/L), throughout Oklahoma *(Figure 6)*.

Furthermore, this research found that 18 UIC wells are injecting fluids above the BTW, potentially into USDWs and it is unclear whether aquifer exemptions were granted for these wells *(Figure 5)*.[19] The report also suggests a large number of UIC wells (~2,900) were drilled where the BTW was shallow (<200 feet deep). This is significant because having roughly half of the total UIC wells located over a very shallow BTW seems to suggest that there's little confidence in the adequate characterization of the potential drinking water quality groundwater reserves located below that line and specifically in the aquifer being injected into.

The findings of this research raise serious questions about the ability of the BTW, determined by electric resistivity logs, to be

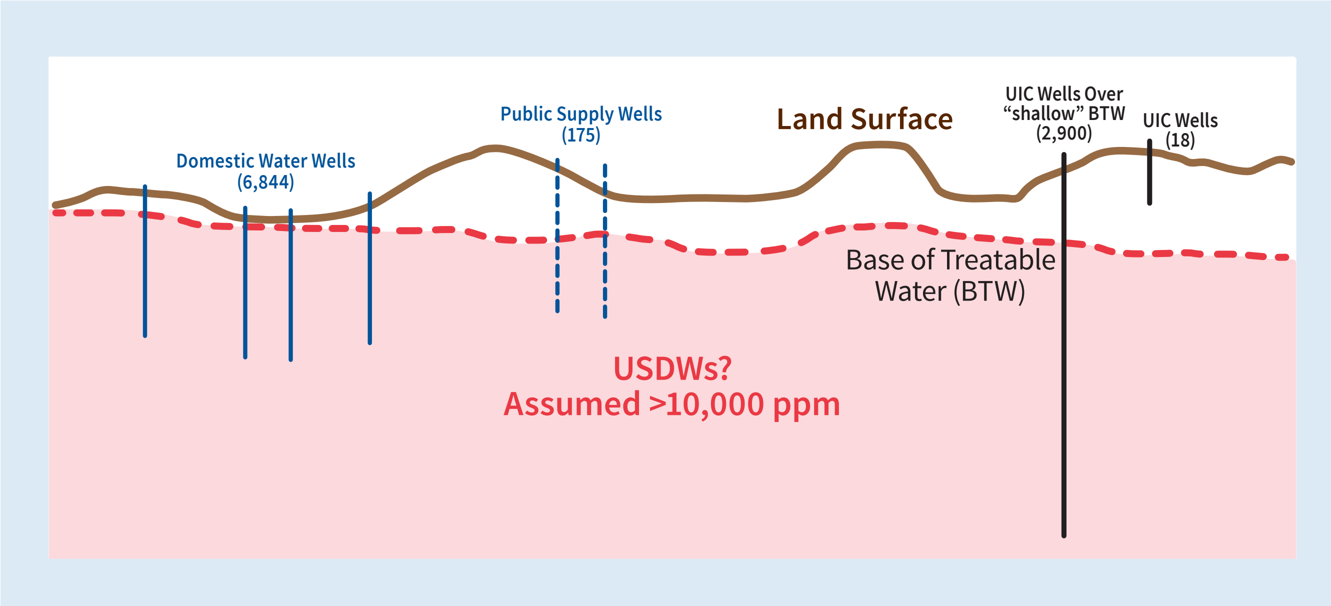

Figure 6. *Cross section displaying the separation between an underground source of drinking water (USDW) and non-USDW by the base of treatable water (BTW), including examples of BTW inaccuracies. Note that the BTW varies laterally and vertically across the state of Oklahoma.*

used as an adequate predictor of the depth and location of USDWs at the state scale. By extension this calls into question if the state aquifer exemption process is based on adequate and dependable USDW locational and water quality information. Therefore it is reasonable to suspect the aquifer exemption process may not be implemented in an appropriate and consistent manner.

Accurately determining depth and location of USDWs is critical to the UIC permitting process under SDWA. The best option would be for the state to require groundwater sample(s) at depth intervals where UIC permits are proposed, to confirm no USDWs are present. If groundwater quality sampling demonstrates USDWs, then the applicant must apply for an aquifer exemption, and satisfy the appropriate criteria under 40 CFR 146.4.

Creating a More Protective and Transparent Aquifer Exemption Process

The UIC program was created to protect underground sources of drinking water from injection activities. Yet aquifer exemptions provide a way around these protections and hand over groundwater to the oil and gas industry.

The rules for exempting aquifers are more than 30 years old, and do not reflect current and future water shortages, population shifts and evolving water treatment and well drilling technologies. Surface water resources are projected to decline in many areas of the US, including Oklahoma.[20]

As a result certain oil and gas producing states will increasingly have to rely on groundwater in order to meet the public's needs.[21] Indeed, some states have already had to turn to lower quality and or brackish water sources.[22] At the same time, the outdated exemption criteria opens up vital sources of groundwater to pollution.

In addition to the longstanding oversight concerns at the federal level, state agencies, as reported here, have fallen short in basic regulatory duties. This includes ensuring USDWs are

protected and the processes and protections afforded by the SDWA are followed regularly. Understanding these concerns will help move agencies towards positive reforms necessary to protect vulnerable sources of drinking water.

Notable improvements in oversight include EPA's interactive mapping tool which provides maps of available data on aquifer exemptions nationwide.[23] This centralized data repository is a tremendous step forward and provides a level of transparency and accountability that was missing prior.

Still, long term reforms are needed in order to properly safeguard drinking water from oil and gas contamination as the industry evolves. A practice as important as lifting federal protections for a water source requires rigorous oversight. The public deserves to know that its drinking water is given the protections the Safe Drinking Water Act demands. Clean Water Action calls on EPA and Oklahoma to go further and demonstrate the willingness to adequately protect our most precious and shared resource: drinking water.

Oklahoma Corporation Commission Recommendations

- Full program review of all UIC wells to determine if any additional wells are injecting into USDWs.
- Immediately halt injection activity at any wells injecting into USDWs.
- Review methods for determining USDWs including reevaluating the use of the BTW. This could include coordinating data and methods with other state agencies to identify the locations and quality of groundwater, such as the Oklahoma Department of Environmental Quality and/or Oklahoma Water Resources Board.
- Conduct a full assessment of impacts to water quality and supply of any injection that has occurred into a USDW.
- Provide a clear process for all future injection well permit applications to ensure that injection into USDWs does not occur without an aquifer exemption.
- Develop a process for submitting future aquifer exemption applications to EPA that includes public notice and a public hearing and opportunities for public comment.
- Map all current, past and future oil and gas production fields and wastewater disposal fields to determine if these areas contain USDWs.
- Improve the transparency in the aquifer exemption approval process and post all available information on current aquifer exemptions online.
- Develop a transparent process for residents, water districts, and other interested stakeholders to be informed about and comment on aquifer exemption applications.
- Until these protections are put in place, there should be a statewide moratorium on approving any injection well that meets the criteria for an aquifer exemption.

Federal Recommendations

- EPA must update the regulatory exemption criteria and required analysis in order to reflect changing circumstances and be more protective of potential drinking water sources.
- Impose an immediate moratorium on granting any new exemptions until new rules and clarifying procedures are put in place, including full and transparent opportunities for public notice and ability to comment on each aquifer exemption application.
- Commit to updating the Interactive Aquifer Exemptions Mapping Tool in real time if aquifer exemptions continue to be approved.
- Continue to work with states and regions to fill gaps in the national aquifer exemption inventory.
- Investigate whether a streamlined approval process for states to implement UIC programs related to oil and gas activity under SDWA Section 1425 has played a role in the aquifer exemption program oversight and management problems.

NOTES

1 Freeman, Bill. Arthur, Daniel. Aquifer Exemptions: Wise Use of Environmental Protection Resources. Society of Petroleum Engineers, SPE 29760. 1995. Available at https://assets.documentcloud.org/documents/537118/spe-article-aquifer-exemption-00029760.pdf.

2 Noel, John. Texas Aquifer Exemptions: Ignoring Federal Law to Fasttrack Oil and Gas Development. Clean Water Action. August 2016. Available at http://www.cleanwateraction.org/sites/default/files/docs/publications/Texas%20Aquifer%20Exemptions%20-%20Clean%20Water%20Action%20August%202016.pdf.

3 Murray KE (2014) Class II Underground Injection Control Well Data for 2010–2013 by Geologic Zones of Completion, Oklahoma. Oklahoma Geological Survey Open-File Report (OF1-2014). Norman, OK. pp. 32.

4 United States Environmental Protection Agency. Underground Injection Control (UIC), Aquifer Exemptions Map. https://www.epa.gov/uic/aquifer-exemptions-map

5 Class V wells are used to inject non-hazardous fluids underground. EPA's regulations define Class V wells as injection wells not included in other well classes. https://www.epa.gov/uic/class-v-wells-injection-non-hazardous-fluids-or-above-underground-sources-drinking-water

6 40 CFR 146.4. https://www.law.cornell.edu/cfr/text/40/146.4

7 Lord, C. and Billingsley, P. Protecting Groundwater, Base of Treatable Water Maps and EM Surveys.

8 United States Environmental Protection Agency. Introduction to UIC Permitting. Drinking Water Academy Presentation, April 2002.

9 The EPA presentation goes so far to state: *"What is the net result of these common errors? They can result in overstating USDW salinity by 100 percent! Know your method and know its drawbacks."*

10 Friedman, S. P. (2005). Soil properties influencing apparent electrical conductivity: a review. *Computers and electronics in agriculture, 46 (1)*, 45-70.

11 Billingsley, P. Two Oklahoma Corporation Commission Programs to Protect Water Supplies. Presentation, Oklahoma Corporation Commission, Oil and Gas Conservation Division.

12 Lord et al. 2009. Using Geological Data and GIS to Make Base of Treatable Water Maps that Protect Fresh Water Aquifers. Abstract.

13 http://www.owrb.ok.gov/maps/pmg/owrbdata_GW.html

14 http://www.occeweb.com/og/ogdatafiles2.htm

15 Note: 10,000 mg/L TDS groundwater is roughly one-third as salty as seawater.

16 "Shallow" is defined as <200 feet deep. This was similar to the USGS paper: Becker, C.J., 2006, *Comparison of Ground-Water Quality in Samples From Selected Shallow and Deep Wells in the Central Oklahoma Aquifer,* 2003–2005: U.S. Geological Survey Scientific Investigations Report 2006–5084, 55 p.

17 Prepared by: Michael S. Houts. *Statewide Groundwater Monitoring Project for Oklahoma Year 1 Report.* Clean Water Act, Ground Water 106 Grant No. I-006400-03. Project 2, Task 200.3 – Fiscal Year 2003-04 Report.

18 Note: These concentrations were established from the 'shallow wells' (<200 feet deep). While the 'deep wells' (>200 feet deep) were found to have a similar median and maximum; 300 mg/L and 1,900 mg/L respectively. Becker, C.J., 2006, *Comparison of Ground-Water Quality in Samples From Selected Shallow and Deep Wells in the Central Oklahoma Aquifer,* 2003–2005: U.S. Geological Survey Scientific Investigations Report 2006–5084, 55 p.

19 One UIC well, found above the BTW, may be injecting into an approved aquifer exemption; however more information would be needed to confirm.

20 Kristen Averyt et al., *Sectoral contributions to surface water stress in the coterminous United States,* 2013 Environ. Res. Lett. 8 035046, at 2 (2013) ("Average surface water supplies are decreasing, and are expected to continue declining, particularly in the southwestern US."), available at http://iopscience.iop.org/article/10.1088/1748-9326/8/3/035046/pdf.

21 Timothy R. Green et al., *Beneath the surface of global change: Impacts of climate change on groundwater,* 405 Journal of Hydrology 532-560, 554 (2011) available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.465.3292&rep=rep1&type=pdf Vincent C. Tidwell et al., *Mapping water availability, projected use and cost in the western United States,* Environmental Research Letters 9:064009 (2014), attached as Exhibit A21 and available at http://iopscience.iop.org/article/10.1088/1748-9326/9/6/064009/pdf

22 LBG-Guyton Associates prepared for Texas Water Development Board, *Brackish Groundwater Manual for Texas Regional Water Planning Groups,* (2003), available at http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/2001483395.pdf The Kay Bailey Hutchison Desalination Plant, the largest inland municipal desalination plant in the world, is located in El Paso Texas. http://www.epwu.org/water/desal_info.html

23 With the exception of California which is in the process of organizing and submitting data in the aftermath that state's oversight problems within the program.

24 http://www.owrb.ok.gov/maps/pmg/owrbdata_GW.html, http://www.occeweb.com/og/ogdatafiles2.htm

Data Limitations: The data is based on information located on various public websites, provided by Oklahoma Water Resources Board and Oklahoma Corporation Commission.[24] About the databases, the BTW shapefile disclaimer states: *"The data represent the results of data collection and/or processing for the specific OWRB activity or purpose described above. As such, the data are valid only for their use, content, time, and accuracy specifications determined or intended by, or acceptable to, the OWRB. These data are not guaranteed to be useable, timely, accurate, or complete. The user is responsible for any use of these data other than their use by the OWRB, and for the results of any application of the data for other than the purpose intended by the OWRB. Although these data have been processed successfully on a computer system at the OWRB, NEITHER THE STATE OF OKLAHOMA NOR THE OWRB NOR ANY OTHER AGENCY THEREOF, NOR ANY OF THEIR EMPLOYEES, CONTRACTORS, OR SUBCONTRACTORS, MAKE ANY WARRANTY, EXPRESS OR IMPLIED, NOR ASSUME ANY LEGAL LIABILITY OR RESPONSIBILITY FOR OR AS TO THE ACCURACY, COMPLETENESS, USEFULNESS OR MERCHANTABILITY OF ANY DATUM, SOFTWARE, INFORMATION, APPARATUS, PRODUCT, OR PROCESS DISCLOSED, NOR REPRESENT THAT ITS USE WOULD NOT INFRINGE ON PRIVATELY OWNED RIGHTS. NOR SHALL THE ACT OF DISTRIBUTION CONSTITUTE ANY SUCH WARRANTY. THIS DISCLAIMER APPLIES BOTH TO INDIVIDUAL USE OF THE DATA AND AGGREGATE USE WITH OTHER DATA. Conclusions drawn from, or actions undertaken on the basis of, such data and information are the sole responsibility of the user. Users are cautioned to consider carefully the provisional nature of these data and information before using them for decisions that concern personal or public safety or the conduct of business that involves substantial monetary or operational consequences."* Please visit either website for information about further limitations with data and accuracy.

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