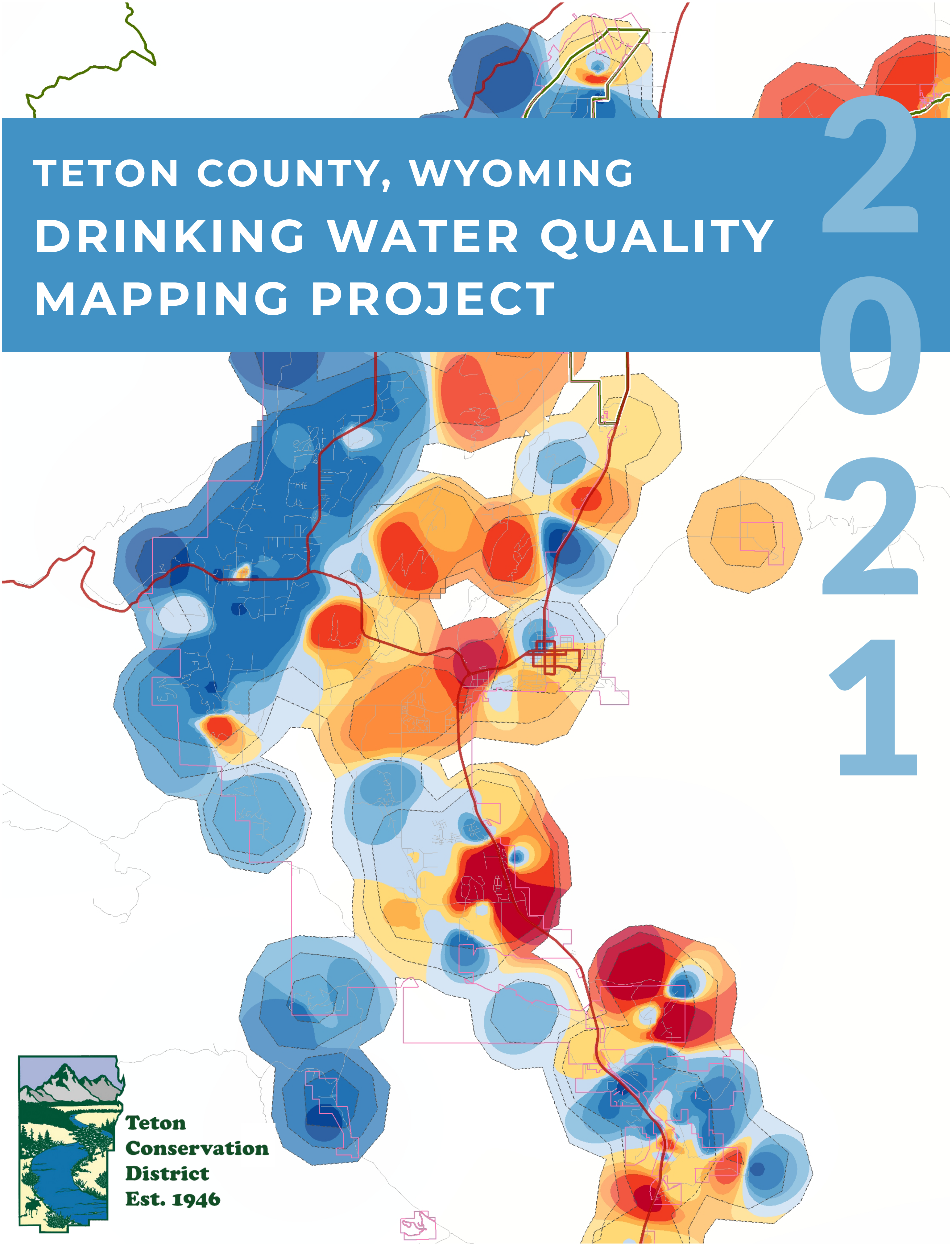

TETON COUNTY, WYOMING
DRINKING WATER QUALITY MAPPING PROJECT

2021

Teton
Conservation
District
Est. 1946

Teton County, Wyoming

Drinking Water Quality Mapping Project

January 20, 2021

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For more information regarding this report or the Teton Conservation District—a political subdivision of the State of Wyoming—please contact 307-733-2110 or visit www.tetonconservation.org.

Cover Image: Depiction of the Maximum Sulfate Values Map. See full map under Maps section.

Suggested Citation:
Girard, C.E., Smith, E.P., Coburn, P.T., and Graham, M.W. 2021. Teton County, Wyoming Drinking Water Quality Mapping Project. Teton Conservation District, Jackson, WY. URL https://www.tetonconservation.org/drinking-water-quality-mapping

ABSTRACT

Teton Conservation District assembled data for eight water quality parameters from 360 groundwater locations in Teton County, Wyoming, which included samples from both public water system and private drinking water wells. The parameters sampled were chloride, fluoride, nitrate, pH, sodium, sulfate, total dissolved solids, and total hardness. Some sites had repeated sampling events, which were summarized so that one value per parameter was created for each site. The summary statistic for each parameter was chosen based upon the primary reason it is analyzed in drinking water. For each water quality parameter, an Inverse Distance Weighting model was used to create an individual spatial interpolation layer. Models were assessed and individual maps were created for each model. A density overlay was created based on the number of samples collected within a one-mile radius of modeled cell values to spatially depict the relative confidence of the model result in space. Eight individual maps present the modeled groundwater concentration of each parameter, and this narrative provides an overview of the process, project outcomes, and intended uses.

DEFINITIONS

Inverse Distance Weighing Tool: A spatial interpolation tool that calculates values for unsampled location values using values from nearby weighted locations. Sampled locations are weighted according a power coefficient, which controls the relative importance of points that are closer or farther away.

Kernel Density: Calculates a magnitude-per-unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline.

Pearson Correlation: A statistical analysis to assess the relationship between two datasets, which produces a coefficient value between -1 and 1. A value of 1 implies a linear relationship between the datasets, where the y value increases equally to the x value.

Polygon Feature Class: A spatially attributed dataset that holds polygon data within an ArcGIS datatype format.

Public Water System: A drinking water conveyance system that provides water for human consumption to at least 15 service locations, and is thus overseen by the Environmental Protection Agency in the State of Wyoming.

R-squared value: Also known as the coefficient of determination and often denoted as R^2, this is the proportion of variance for the dependent variable that is predictable from the independent variable. This is a standardized metric used to assess a model's predictive capability.

Raster: A matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information.

Spatial Interpolation: A mathematical modeling technique that uses sampled data values from known locations to estimate values for unsampled locations.

CONTENTS

1 - INTRODUCTION

This project seeks to display interpolation models built using empirical chemical concentration data from drinking water sources in Teton County, Wyoming. Prior to this project, there were few accessible sources of information that summarize the significant body of drinking water well data that is available for this region. This project assembles these data and seeks to present them in a format suitable for public use.

Teton Conservation District (TCD) works with private well owners, public water systems (PWS), and managing agencies to address groundwater problems. TCD provides assistance and a cost-share program for private drinking water well testing and drinking water treatment; this has made TCD aware of regional water issues in Teton County, WY. There is enough empirical data to characterize groundwater water quality and shed light on the scope and scale of potential issues. TCD hopes to begin creating a common understanding among property owners, health practitioners, and resource managers of where and to what extent drinking water quality issues occur.

This document serves as the narrative portion of an analytical exercise to model and display groundwater quality parameters using numerical and spatial analyses. The overarching goal of this mapping project is to display existing data. We used spatial interpolation techniques to expand the spatial extent of the study area and honed model inputs to help create products that reflect the primary reason for interest in each water quality parameter.

2 - METHODS

Study Area

The study area for the Teton County, WY Drinking Water Quality Mapping Project encompasses all portions of Teton County, WY where drinking water wells are present. Teton County, WY is unique in that 97% of the 4,216 mi^2 total area is federal land. This analysis is focused on the roughly 1,051 mi^2 of land that occurs within a one-mile radius of water systems that have available data. Higher concentrations of drinking water wells are found on private lands.

The Town of Jackson is the only municipality within Teton County, WY and operates the largest drinking water system within the study area. There are numerous other smaller water systems that vary in size. Drinking water in Teton County, WY is almost exclusively sourced from groundwater. The valley floor, also known as Jackson Hole, contains a relatively shallow alluvial aquifer that is highly productive and generally of adequate drinking water quality. The private lands that are positioned on the periphery of the valley—along the foothills and bedrock formations of the mountains—access different aquifers, which can be influenced by limestone or metamorphic geology depending on location.

Drinking Water Data Sources

Drinking water data is required to be collected by PWS at regular intervals. The Environmental Protection Agency (EPA) retains drinking water records for all of the PWS that it oversees in the State of Wyoming. Using a Freedom of Information Act Request, we obtained all PWS data within Teton County, WY for the parameters listed in Table 1. The data table consisted of 8,208 rows of data for the eight parameters analyzed, attributed to 143 PWS locations. In some cases, PWS data dated back to 1993, and for PWS still in operation, data ends in mid-2019, which is when the EPA provided the data included in this analysis.

PWS point locations were mapped individually by hand in ArcGIS. Of the 143 PWS locations with drinking water data, we excluded four because we were not able to identify their locations. Most of the public water systems are found on private land, however, we also included water systems on public land.

Table 1: County-wide summary statistics for the water quality parameters included in the Drinking Water Quality Mapping Project. Data originates from EPA regulated PWS locations and private wells that used well test kits provided by TCD. Sampling dates ranges from 1991 to 2019, in Teton County, WY.

Parameter	Minimum	Maximum	Average	Median	Number of Tests	Units	Site Count	Modeled Statistic
Chloride	0	310	15	5.6	275	mg/L	233	Maximum
Fluoride	0	23.1	0.59	0.3	784	mg/L	305	Average
Nitrate	0	59.4	0.58	0.13	4827	mg/L	360	Maximum
pH	5.5	9.7	7.71	7.7	339	s.u.	247	Average
Sodium	0	620	18.67	7	762	mg/L	303	Average
Sulfate	0	257	31.1	11.4	668	mg/L	298	Maximum
Total Dissolved Solids	11	1000	295	264	282	mg/L	234	Average
Total Hardness	0	860	179.0	150	271	mg/L	234	Average

Private drinking water wells do not have monitoring requirements. TCD has collected water quality data for eight chemical parameters through a drinking water well test kit cost-share program since 2013.

Private drinking water data was spatially attributed using the Teton County, WY ownership shapefile (https://www.greenwoodmap.com/tetonwy/mapserver/download/download.html, accessed 02/18/2020). Using ArcGIS, a point location was assigned for each property with water quality data by creating a centroid of each parcel polygon. In total, 268 of the 326 Teton County, WY well test kit data sets (that had not opted out of the study) were complete and able to have spatial coordinates applied. This resulted in 230 well test kit locations, with 38 of the well test kits locations having one or more sampling events.

Data Summary

To establish a dataset suitable for spatial analyses, data were manipulated and summarized in Program R (Version 4.0.2) using RStudio (Version 1.3.959). Data was summarized for each parameter and site so that the spatial analyses for each parameter could be fed a point dataset of well locations, with each location containing one record per parameter. Each water quality parameter was summarized and evaluated, based on the primary reason for interest in that water quality parameter (Table 1). For example, the human health concerns posed by nitrate increase as nitrate concentrations in drinking water increase; therefore, the maximum recorded nitrate value from each sample location was used. In contrast, we used average values as the summary statistic to model groundwater pH and hardness because these parameters are foundational characteristics of the groundwater and less associated with health risks. For these parameters, we assumed users of this product are most interested in what they are likely to encounter at a given location and not the maximum.

Spatial Analysis

Drinking water data was analyzed in ArcMap (10.3.1) using a spatial model selected for the type of data being used. In all cases, chemical data was numerical and continuous, and the output was an interpolated raster file.

Each chemical parameter was analyzed individually using the Inverse Distance Weighting (IDW) tool. The IDW tool was run individually for each of the eight water quality parameters at all spatial locations with available data.

Once final IDW models were created, model assessment was completed for each individual IDW model output by comparing empirically-collected water quality data at a given location to the modeled cell value extracted at that same location. For each parameter, empirical and modeled values were brought into Program R, plotted, assessed visually, assessed using a Pearson's correlation, and fitted with a linear model to establish a slope, y-intercept, and R-squared value (Table 2).

Map Visualization

In all cases, symbology was chosen to help emphasize the innate water quality considerations of each chemical. For instance, if established human health thresholds existed for a chemical, such as nitrate and fluoride, color spectrums were used to help depict relevant breaks in the data (i.e., red was used when a drinking water standard was exceeded; Table 3).

Spatial interpolation can easily produce erroneous predictions in areas without data. To address this potential issue, we created a density overlay for each water quality parameter map, which displays the relative spatial density

Table 2: Analyses of ArcMap 10.3.1 Inverse Distance Weighting interpolation model for each chemical parameter, assessing the accuracy of each model against the data collected at each survey location in Teton County, WY.

Parameter	Slope	Intercept	R-squared	Pearson Correlation
Chloride	0.96	0.42	0.96	0.98
Fluoride	1.06	0.00012	0.97	0.98
Nitrate	1.14	-0.14	0.74	0.86
pH	1.02	-0.14	0.92	0.96
Sodium	1.03	1.06	0.86	0.93
Sulfate	0.95	0.98	0.94	0.97
Total Dissolved Solids	1.01	-1.07	0.94	0.97
Total Hardness	0.98	2.08	0.81	0.90

Table 3. Relevant and recommended concentrations for the water quality parameters and potential human health effects if above or below the recommendation. The recommendations are derived from EPA water quality standards, maximum containment levels, secondary maximum containment levels, and USGS designations.

Parameter	Relevant Concentrations and Potential Effects
Chloride	Salty taste above: 250 mg/L[†]
Fluoride	Dental recommendation, to help protect against tooth decay: 0.7 mg/L[‡] Tooth Discoloration above: 2.0 mg/L[δ] Health issues including bone disease & mottled teeth in children above: 4.0 mg/L[†]
Nitrate	Health issues including causing severe illness and possibly death in infants above: 10mg/L[†]
pH	Bitter taste & corrosion if below, while slippery feel, soda taste and deposits if above acceptable range: 6.5-8.5 mg/L.[δ]
Sodium	Salty taste above: 60 mg/L[⸙]
Sulfate	Odor and bacteria increase above: 30 mg/L Salty taste and stomach issues above: 250 mg/L[δ]
Total Dissolved Solids	Water quality decreases with the possibility of hardness, deposits, colored water, staining & salty taste above: 500 mg/L[δ]
Total Hardness	Soft: 0-60 mg/L; Moderately hard: 61-120 mg/L; Hard: 121-180 mg/L; Very hard: Above 180 mg/L[⸾]

Sources (URLs, full references at end):
[†] www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations
[‡] www.ncbi.nlm.nih.gov/pmc/articles/PMC4547570/ (journal article)
[δ] www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals
[⸙] www.epa.gov/sites/production/files/2014-09/documents/support_cc1_sodium_dwreport.pdf, page 3
[⸾] www.usgs.gov/special-topic/water-science-school/science/hardness-water?qt-science_center_objects=0#qt-science_center_objects

of data points that were available for that water quality interpolation model. The final map product for each water quality parameter includes its own unique density overlay because each water quality parameter is associated with a unique dataset (number of samples collected and location of water sources where samples were collected).

For each water quality parameter, point locations were input into the Kernel Density tool only for drinking water wells where data for that parameter existed (link). We ran the Kernel Density Tool on a count field (column), which tallied the number of samples per site available for that given parameter.

Once the kernel density surface was created for each parameter, the raster symbology was classified into four classes of equal size. This symbology decision produced the following result: all cell values that were '0', which equates to no points within a one-mile radius, were one class; and then all cells with a density value were split into three bins of roughly equal size. The kernel density surface was converted into a polygon datatype to facilitate our desired visual and symbolization goals.

Visualization of the polygon feature class that was created from the kernel density estimate was identical for each water quality parameter. The output polygon feature class for each water quality parameter had four polygon types that matched the raster classification of its kernel density surface. Polygons with a '0' density value were depicted with 0% transparency of a white background, obscuring underlaying data and intended to indicate no confidence in the underlaying interpolated map. The three remaining classes were differential using stippling and polygon boundary differences to depict areas of low, medium, and high levels of confidence in the underlying interpolation map.

For additional details regarding the methods used in the project, see Appendix 1.

3 - RESULTS

We created eight separate IDW raster outputs, one for each water quality parameter. These maps were symbolized to display relevant health thresholds and provide more detail in the portion of the data range where most values occurred. Spatial extents of the maps are somewhat dependent on whether PWS and well test kits included the modeled water quality parameter of that given map, or if the data predominantly originated from well test kits.

Overall, the model's ability to accurately convey chemical concentrations in areas with empirical data was confirmed by the strong Pearson correlations between known parameter concentrations and the IDW modeled values at survey locations. Chloride and fluoride had the strongest correlations with Pearson values of 0.98, and while nitrate was least, it was still strongly correlated with a Pearson value of 0.86 (Table 2). While there was some deviation between the sampled and modeled values, the slopes, y-intercepts, and R-squared values of the linear models all indicate that there was no overarching bias (Figure 1; Table 2). The slopes ranged from 0.95 for sulfate to 1.14 for nitrate, while Total Dissolved Solids (TDS) had the best slope alignment with 1.01. Linear model R-squared

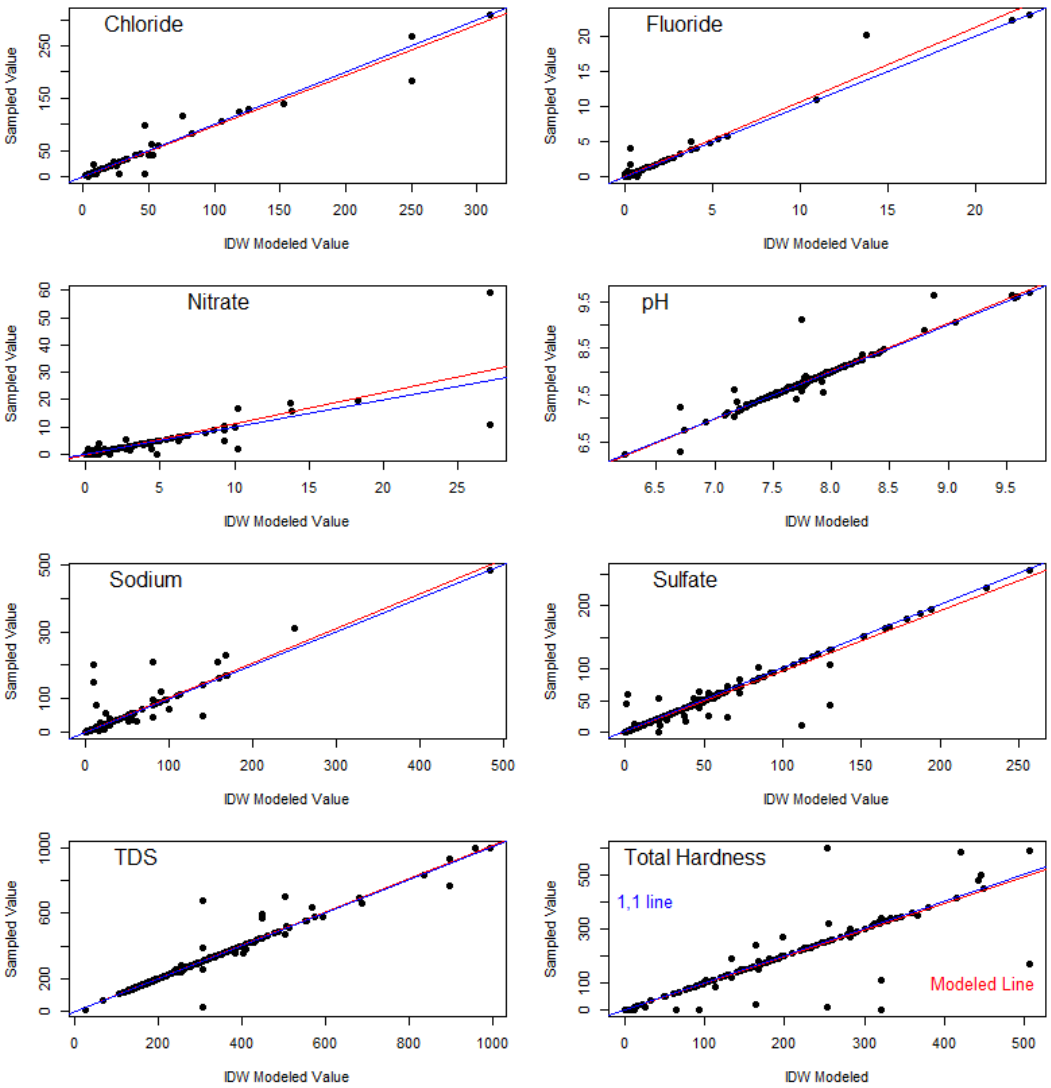

Figure 1. Scatter plots and linear models of extracted ArcMap 10.3.1 Inverse Distance Weighting (IDW) modeled values for each of the chemical parameters in Teton County, WY regressed against the collected drinking water parameter concentrations at the same location (red line). The blue line has been added for comparison, and has a slope of 1 and a y-intercept of 0, which would indicate a perfect model fit.

values ranged from 0.74 for nitrate to 0.97 for fluoride. No outliers were removed in these analyses because these models were only used as an assessment of IDW accuracy, not in a predictive capacity. Retaining outliers likely led to weaker model fits and correlation strengths.

Chloride

Chloride concentrations were available for 233 locations, the majority of which were well test kits provided by TCD, with only five being PWS locations. The concentrations ranged from 0 to 310 mg/L, but average chloride concentration was relatively low (14.95 mg/L). The majority of the sample concentrations were below 20 mg/L, with 35 locations having concentrations exceeding this concentration. Only eight had concentrations over 100 mg/L, indicating a low background concentration of chloride in Teton County, WY. Only two locations (both located in southern Teton County, WY) had maximum values over the limit for potable water recommended by the EPA (Table 3).

Fluoride

Fluoride concentrations were available at 305 sampling locations and ranged from 0 to 20.2 mg/L, with the average of all values being 1.19 mg/L. The majority of the locations, however, had internal site average concentrations ranging from 0 to 0.6 mg/L, which is below 0.7 mg/L, the recommended concentration established to help protect against tooth decay. Eighteen sampling locations recorded higher than the 2 mg/L secondary recommended limit (nuisance standard), while nine recorded higher than the 4 mg/L EPA recommended maximum containment limit (health standard; Table 3). The majority of these locations were located in the southern portion of the county, in the vicinity of Red Top Meadows (south of Wilson) and Hoback, but some locations in and around Yellowstone also show elevated fluoride.

Nitrate

Nitrate provided the most spatially complete dataset available for this analysis, with 360 locations having available data (including Yellowstone National Park) and many of these sites containing duplicate records. The median value for the 4,827 sampling events for nitrate was 0.13 mg/L and is a testament to the low background concentrations typically found in the region. Eight locations have nitrate concentrations that exceeded the 10 mg/L recommended limit for potable water, and 34 locations exceeded 3 mg/L, which is above typical background concentrations and can indicate human influence.

Nitrate appears to be elevated above background concentrations in isolated locations, with exceedances of drinking water criteria of 10 mg/L found only in the vicinity of Hoback. Of note, EPA sampling and reporting requirements for nitrate on systems that have nitrate reduction treatment in place do not include raw water, and therefore, PWS data does not necessarily depict groundwater concentrations of nitrate once treatment is in place. Similarly, if treatment was installed prior to exceeding the 10 mg/L drinking water threshold, this data would not necessarily reveal whether groundwater concentrations continued to rise beyond this value. Sufficient data availability in the locations where nitrate is above background levels allows users of this product to have confidence in the visual representation of these areas.

pH

Most of the 247 sampling locations containing pH data originated from well test kits, with 19 PWS locations sampled. The EPA recommends a range of 6.5 to 8.5 for the pH of drinking water (Table 3). pH was sampled at 247 locations with values ranging from 6.23 to 9.70 and an average value of 7.76. Only two locations registered pH levels below 6.5, while eight had values above 8.5. These ten survey locations were located in Red Top Meadows (south of Wilson) and Hoback areas. The majority of Teton County, WY recorded pH values between 7.75 and 8.0, well within the recommended range.

Sodium

At the 303 locations where sodium was sampled, the concentrations ranged from 0 to 485 mg/L, with an average value of 24.9 mg/L. The EPA recommends sodium concentrations below 30 to 60 mg/L due to salty taste (Table 3). This was determined to be the threshold for taste-sensitive segments of the population, although many won’t be able to taste it at those levels. The majority of sampling locations registered average concentrations below 30 mg/L, but 54 locations had concentrations over 30 mg/L, while 34 recorded over 60 mg/L. A large number of these locations are in southern Teton County, WY while the rest are spread throughout the county with locations in Alta, Moran, and the north-end of the Gros Ventre Buttes. This indicates that while the typical background levels for sodium are below the 30 mg/L recommendation for potable water, there is a distinct probability of having higher concentrations throughout the county, especially in the southern portion.

Sulfate

At the 303 sampling locations where sulfate data was collected, the concentrations ranged from 0 to 257 mg/L with an average value of 31.12 mg/L. The majority of the sulfate concentrations recorded were below 50 mg/L, which is below the threshold for adverse health effects, but above the concentration where sulfur bacteria can become problematic locally. Only one location (located in the South Park area, south of Jackson) recorded a maximum sulfate concentration above the 250 mg/L recommended limit.

Total Dissolved Solids

TDS concentrations ranged from 11 to 1,000 mg/L across the 234 sampling locations, which predominantly originated from well test kits. Average TDS was 284.38 mg/L. The majority of the locations had concentrations between 150 and 350 mg/L, while 20 locations recorded concentrations greater than the 500 mg/L secondary limit as determined by the EPA (Table 3). These samples were all found from Melody Ranch (south of Jackson) to the southern extent of the county. The majority of the sampling locations where TDS data was recorded were well test kits, with only five being PWS locations.

Total Hardness

Total hardness ranged from 0 to 860 mg/L across the 234 locations sampled, the vast majority of which were from well test kits. The U.S. Geological Survey (USGS) classifies water hardness into four categories: soft, moderately hard, hard, and very hard (Table 3). In Teton County, WY, 30 locations had total hardness concentrations that register as soft, 50 with moderately hard, 54 with hard, and 100 with very hard water, indicating a trend towards hard water in the county. There were 26 locations with total harness concentrations over 300 mg/L and seven locations with concentrations over 400 mg/L. There are sampling locations with water categorized as very hard throughout the county, with values over 300 mg/L recorded in the Kelly, Jackson, Wilson, and Hoback areas, as well as areas south of Jackson. The locations with 400 to 600 mg/L were all located in the southern portion of the county.

4 - DISCUSSION

Overview

Between private well owner well test kits and PWS reporting, available drinking water quality data in Teton County, WY is extensive. However, reviewing this data is challenging, due to the complexity of the datasets and the different places and condition in which the data is stored. We assembled available data, summarized it by unique location, and used spatial interpolation to extend the point data into a continuous surface for visual display.

The water quality parameters that were used in this analysis were chosen, quite simply, because they were available, being some of the most common parameters collected in drinking water systems. These basic parameters are also relevant to characterizing the groundwater chemistry from both a potability and palatability standpoint. Furthermore, there is potential for spatial autocorrelation of groundwater characteristics, due to the large degree of geologic influence. When possible, there is also a logical priority to highlight areas where drinking water parameters are outside of the preferred range, or exceed established human health water quality standards.

Nitrate is of particular interest, as it is a known human health hazard, and in Teton County, WY occurs above naturally occurring concentrations. While there are multiple known sources of nitrate contamination locally, there has been an increasing focus on wastewater sources. Anecdotally, the IDW map for nitrate appears to show that the areas where nitrate exceeds background concentrations have some degree of overlap with areas of development that use septic systems. Nitrate concentrations that occur above background levels are found in smaller, outlying communities such as Hoback, Kelly, Wilson, Buffalo Valley (near Moran), and Alta. However, Hoback is the only region where nitrate occurs above the drinking water human health limit, even though areas around South Park (south of Jackson) are not far below the 10 mg/L drinking water human health threshold established by the EPA.

Of note, the nitrate map clearly depicts the spatial isolation of areas with elevated nitrate concentrations. This supports the assumption that the occurrence of multiple areas with high nitrate are not linked by an underground nitrate plume, and instead, are likely due to isolated instances of nitrate contamination, which are separated by areas of normal background concentrations.

Beyond nitrate, sulfate is of interest because it is one of the most common problems that well owners need to address, due to the development of sulfur reducing bacteria, which produce odiferous hydrogen sulfide. While treatment systems exist, they are often costly and problematic, with increasing challenges as sulfate concentrations increase. Our mapping efforts help define the areas of concern for sulfate, which appear to be focused in the eastern and southern portions of the county. With little exception, sulfate is at much lower concentrations and below the thresholds that tend to generate adverse drinking water impacts in areas west of the Snake River, which runs north to south, roughly dividing the county on an east-west basis.

Hardness, which is comprised primarily of calcium carbonate, is unquestionably one of the largest dissolved components of drinking water in Teton County, WY. Geologically, the limestone bedrock found extensively throughout the region is readily dissolved by water, and produces the ‘hard’ water found almost everywhere in the region. Small pockets of soft water do exist, but more commonly, pockets of hard to extremely hard water are encountered. Water softeners are installed often on residential water systems and in some cases may be required for the preservation of household appliances.

While TDS (a measure of all dissolved material) is largely driven by hardness, it is also associated with sodium and chloride. Southern Teton County, WY appears to have particularly high TDS, as well as both sodium and chloride. Not surprisingly, areas with very high TDS also tend to have challenges with abundant hardness, sulfate, chloride, and sodium, and thus, poor tasting water. Southern Teton County, WY and Buffalo Valley are two regions where TCD and local commercial treatment companies have regularly worked with homeowners seeking resolution to challenging water issues.

Low concentrations of fluoride are found throughout Teton County, WY with a small portion meeting the dental recommendation of 0.7 mg/L. But, in some cases, such as in Red Top Meadows (south of Wilson) and Hog Island (north of Hoback), we see concentrations well above recommended levels.

Looking at the collection of available data, the area west of the Snake River in Teton County, WY appears to have some of the best drinking water in the county. While hardness may be above some individual's preference, the somewhat contiguous area west of the Snake River appears to have relatively low TDS. This is not surprising, given the fact that one of the area's PWS (the Aspen/Pines Water System) has won several national drinking water taste competitions. This good water quality is coupled with a generally productive water supply.

Challenges and Constraints

The constraints of this final product are very important to consider, depending on its use. Primarily, this tool is intended to provide a spatial assessment of existing data, so that well owners, water managers, planners, public works departments, and decision-makers have a broader context than just the data available for an individual well or tabulated records. However, direct testing of the water source of interest is by far the best way to assess conditions of drinking water.

We used a direct comparison of existing data with modeled data to assess model accuracy. However, this assessment method does not account for error in model interpolation where no data exists. This could have been addressed by withholding a portion of the data from each model (validation dataset), and comparing the withheld data to modeled values. This was not done, because our priority was incorporating as much data and sampling locations as possible into each model.

There was a wide date range for the data collected, and therefore, this project does not present a snapshot in time. It is important to acknowledge that map values might relate to samples or specific events dating back years or even decades.

There is no way to discern whether results were produced following some type of water treatment. In PWS that require water treatment (nitrate reduction for instance), they publish the treated result, not raw water results. Similarly, if a well test owner has chosen to test the resulting water from a reverse osmosis or water softener treatment system, this study would not reflect the source water quality.

This assessment only includes a handful of water quality parameters, which were available at a level possible for spatial analysis. There are known water quality issues that result from parameters not included in this assessment, and that are not associated with these parameters. Examples of toxic chemicals that have been found in local groundwater but were not presented here include: arsenic, benzene, and per- and poly-fluorinated alkyl substances (PFAS).

If you have questions about how this product was created or is best used, please contact the authors.

Study Applications and Further Information Needs

This study does not seek to empirically assess the underlaying causes of the water quality gradients it presents. TCD intends to use these spatial datasets to directly compare water quality characteristics to hydrological, geological, and human development parameters. Using existing geological data would likely produce strong correlation for parameters like hardness, TDS, sulfate, sodium, and chloride. It could also be useful to analyze Wyoming State Engineer's Office well completion logs and develop a spatial interpolation of pump tests, thereby inferring aquifer productivity and flow rates. This could be very useful in assessing human caused issues, like increasing nitrate concentrations, and allow for further refinement of 'sensitive areas' for wastewater discharges to groundwater in Teton County, WY.

It is the authors' hope that this tool is used to help identify areas where human health concerns are present, or could be developing. The nitrate map could be easily incorporated into wastewater planning, drinking water protection planning, and development planning.

Further refinement of the presentation of this data is intended. Ideally, we hope to produce a web mapping application, hard copy maps for handout to medical and dental professionals and their clients, and full-size prints for those who would like them.

5 - CONCLUSION

Drinking water quality is an underlying factor in development planning, and when mismanaged can result in human health problems or constrain future community development. The products that have resulted from this study portray existing data so that residents and water managers in Teton County, WY have more information in hand as they use, manage, and try to protect drinking water resources.

6 - ACKNOWLEDGEMENTS

TCD wants to acknowledge the hard work of numerous people who supported the completion of this project, who were not cited as authors. This includes assistance with data acquisition and development from Elyce Gosselin, Abigail Karrin, and Alex Clark. We also want to thank Ronna Simon, Michael MacDonald, Ted Van Holland, and Justin Scott for reviewing the spatial modeling approach. Finally, we want to thank all of the participants in the TCD Well Water Test Kit Program who volunteered their data for this study.

7 - DISCLAIMER

The Teton County, WY Drinking Water Quality Mapping Project maps and the associated narrative report are available for public use. Please cite Teton Conservation District (TCD) as the author. End user assumes all responsibility for interpretation or misinterpretation of these products.

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8 - MAPS

The following Teton County, WY Drinking Water Quality Mapping Project final maps were produced by inputting available water quality data from eight parameters sourced from private drinking water well data from the Teton Conservation District (TCD) well water test kit cost-share program and public water system (PWS) monitoring. All maps were created using the ArcMap 10.3.1 Inverse Distance Weighting (IDW) tool. All maps include their own density overlay, which depicts areas with more or less underlying data, and therefore the level of confidence users can have in the model results at any given location.

List of maps:

1) Chloride
2) Fluoride
3) Nitrate
4) pH
5) Sodium
6) Sulfate
7) Total dissolved solids
8) Total hardness

Teton County Water Quality, Maximum Chloride Values

Teton County Water Quality, Average Fluoride Values

Teton County Water Quality, Maximum Nitrate Values

Teton Conservation District Est. 1946

Teton County Water Quality, Average pH Values

Teton County Water Quality, Maximum Sulfate Values

Teton County Water Quality, Average Sodium Values

Teton County Water Quality, Average Total Dissolved Solids Values

Teton
Conservation
District
Est. 1946

Teton County Water Quality, Average Total Hardness Values

9 - REFERENCES

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10 - APPENDIX 1: DETAILED METHODS SECTION

Study Area

The study area for the Teton County, WY Drinking Water Quality Mapping Project encompasses all portions of Teton County, WY where drinking water wells are present. Teton County, WY is unique in that 97% of the 4,216 mi^2 total area is federal land. This analysis is focused on the roughly 1,051 mi^2 of land that occurs within a one-mile radius of water systems that have available data. Higher concentrations of drinking water wells are found on private lands.

The Town of Jackson is the only municipality within Teton County, WY and operates the largest drinking water system within the study area. There are numerous other smaller water systems that vary in size. Drinking water in Teton County, WY is almost exclusively sourced from groundwater. The valley floor, also known as Jackson Hole, contains a relatively shallow alluvial aquifer that is highly productive and generally of adequate drinking water quality. The private lands that are positioned on the periphery of the valley—along the foothills and bedrock formations of the mountains—access different aquifers, which can be influenced by limestone or metamorphic geology depending on location.

Drinking Water Data Sources

Drinking water data is required to be collected by PWS at regular intervals. The Environmental Protection Agency (EPA) retains drinking water records for all of the PWS that it oversees in the State of Wyoming. Using a Freedom of Information Act Request, we obtained all PWS data within Teton County, WY for the parameters listed in Table 1. The data table consisted of 8,208 rows of data for the eight parameters analyzed, attributed to 143 PWS locations. In some cases, PWS data dated back to 1993, and for PWS still in operation, data ends in mid-2019, which is when the EPA provided the data included in this analysis.

Based on local knowledge of the water systems and their names, PWS point locations were mapped individually by hand in ArcGIS. Of the 143 PWS locations with drinking water data, we excluded four because we were not able to identify their locations, due to their age, naming convention, and/or obscurity. Most of the public water systems are found on private land, however, we also included water systems on public land, including Yellowstone and Grand Teton National Parks and the Bridger-Teton and Caribou-Targhee National Forests.

Private drinking water wells do not have monitoring requirements. TCD has collected data through a drinking water well test kit cost-share program since 2013. This program has amassed a significant body of drinking water data with a standard set of water quality parameters, which were analyzed by a professional water quality laboratory in Riverton, WY. All participants in the drinking water well test kit program were contacted and allowed the opportunity to request that their data be excluded from this analysis, with seven participants opting to be excluded.

Private drinking water data was spatially attributed using the Teton County, WY ownership shapefile (https://www.greenwoodmap.com/tetonwy/mapserver/download/download.html, accessed 02/18/2020), which is a parcel polygon dataset. Where we were able to do so with a high level of confidence, water quality data was joined to the parcel ownership layer using property owner information (PIDN) and physical address. Using ArcGIS, a point location was assigned for each property with water quality data by creating a centroid of each parcel polygon. In total, 268 of the 326 Teton County, WY well test kit data sets (that had not opted out of the study) were complete and able to have spatial coordinates applied. This resulted in 230 well test kit locations, with 38 of the well test kits locations having one or more sampling events.

Data Summary

To establish a dataset suitable for spatial analyses, data were manipulated and summarized in Program R (Version 4.0.2) using RStudio (Version 1.3.959). Data was summarized for each parameter and site so that the spatial analyses for each parameter could be fed a point dataset of well locations, with each location containing one record per parameter. Each water quality parameter was summarized and evaluated, based on the primary reason for interest in that water quality parameter (Table 1). For example, the human health concerns posed by nitrate increase as nitrate concentrations in drinking water increase; therefore, the maximum recorded nitrate value from each sample location was used. In contrast, we used average values as the summary statistic to model groundwater pH and hardness because these parameters are foundational characteristics of the groundwater and less associated with health risks. For these parameters, we assumed users of this product are most interested in what they are likely to encounter at a given location and not the maximum.

Spatial Analysis

Drinking water data was analyzed in ArcMap (10.3.1), using a spatial model selected for the type of data being used. In all cases, chemical data was numerical and continuous, and the output was an interpolated raster file.

Each chemical parameter was analyzed individually, using the Inverse Distance Weighting (IDW) tool in the Interpolation folder of Geostatistical Analyst Tools of ArcToolbox. The IDW model was set to prioritize increased predictive capability in places with more data, with less emphasis on areas without data (see Map Visualization section below). The IDW tool was run individually for each of the eight water quality parameters at all spatial locations with available data, with an output cell size of 150 meters, the power set to five, and search neighborhood set to smooth.

This model was chosen based upon a few primary factors. First and foremost, TCD used reference material from ArcGIS regarding spatial interpolation tools, which included a flowchart that guides users through methods based on the input data types, and the desired outcomes (link). TCD also selected IDW because the resulting map can be interpreted literally, with the values shown reflecting interpolated groundwater chemical gradients. In comparison, the output cell values of some spatial interpolation tools create a proxy value that cannot be interpreted literally, which was not desirable. While vetting different interpolation tools, visual assessments of model outputs were completed, using a comparison of actual data overlaid upon the modeled raster output to assess the model's ability to, at the very least, accurately display known groundwater chemical concentrations. IDW was determined to produce an adequate model.

Once final IDW models were created, model assessment was completed for each individual IDW model output by comparing empirically-collected water quality data at a given location to the modeled cell value extracted at that same location. For each parameter, empirical and modeled values were brought into Program R, plotted, assessed visually, assessed using a Pearson's correlation, and fitted with a linear model to establish a slope, y-intercept, and R-squared value (Table 2).

Map Visualization

In all cases, symbology was chosen to help emphasize the innate water quality considerations of each chemical. For instance, if established human health thresholds existed for a chemical, such as nitrate and fluoride, color spectrums were used to help depict relevant breaks in the data (i.e., red was used when a drinking water standard was exceeded; Table 3). Additionally, symbology decisions were chosen to emphasize the portions of the data range for each parameter where the bulk of data exists (i.e., more breaks in colors through the most robust portion of the data range; Table 1).

Spatial interpolation can easily produce erroneous predictions in areas without data. To address this potential issue, we created a density overlay for each water quality parameter map, which displays the spatial density of data points that were available for that water quality interpolation model. The final map product for each water quality parameter includes its own unique density overlay because each water quality parameter is associated with a unique dataset (number of samples collected and location of water sources where samples were collected).

The process to derive the density overlay is standard across water quality parameters and resulting maps, but as is stated above, they differ in the point dataset fed into the density analysis. For each water quality parameter, point locations were input into the Kernel Density Tool in ArcGIS only for drinking water wells where data for that parameter existed (link). Kernel Density produces a moving window average and a raster file output based on the input dataset and customization of the tool's options. The Kernel Density Tool was run independently for each water quality parameter. For each independent analysis, we input all point locations with available data for that water quality parameter. We ran the Kernel Density Tool on a count field (column), which tallied the number of samples per site available for that given parameter. The Kernel Density Tool was toggled to 'Density,' and was specified to have a one-mile search radius and 150-meter output cell size.

Once the kernel density surface was created for each parameter, the raster symbology was classified into four classes using the 'quantile' function, which creates bins of equal size. This symbology decision produced the following result: all cell values that were ‘0’, which equates to no points within a one-mile radius, were one class; and then all cells with a density value were split into three bins of roughly equal size. This classification was chosen for its repeatability and simplicity. The classified raster file was fed into the Raster to Polygon Tool, which inherited the classified symbology breakpoints. Converting the kernel density surface into a polygon datatype was completed to facilitate our desired visual and symbolization goals.

Visualization of the polygon feature class that was created from the kernel density estimate was identical for each water quality parameter. The output polygon feature class for each water quality parameter had four polygon types that matched the raster classification of its kernel density surface. A new field (column) was added to the kernel density polygon and was populated with a transparency value, which allowed for a custom transparency symbology to be applied to each of the four density classes. Polygons with a ‘0’ density value were depicted with 0% transparency of a white background, obscuring underlaying data and intended to indicate no confidence in the underlaying interpolated map.

The three remaining classes were differential using stippling and polygon boundary differences to depict areas of low, medium, and high levels of confidence in the underlying interpolation map.