Capstone Project May 2013 David Marquardt

Distributing records by zip code polygons to augment farm location models

Executive Summary

For studies where the exact location of a record is not known or can't be disclosed, a random point distribution serves as a useful tool for visualization and analysis. This project looks at the potential benefits of changing the boundary from county data to zip code level data for a manure spreading model in the Chesapeake Bay Watershed (CBW).

The CBW is encouraging manure trading between Animal Feeding Operations (AFOs) and farmers that need fertilizer. The model seeks to estimate the manure hauling distance from AFOs to available cropland. It uses a linear coefficient to generate this distance, based on the excess manure produced in a county. This capstone project compares the coefficient based on a county distribution of AFOs, to a distribution based on zip code level counts.

Since this study involves proximity analysis, the random point distribution comes with some inherent issues. The clustering result for any one distribution may not represent a robust figure.. This study repeats through the point distribution 70 times, to better understand the variance.

Even with this variance, results for many counties were meaningfully different between zip code and county coefficients. For 114 of 157 counties in the CBW, the difference was statistically significant at the 95 percentile (using Welch's t-test). Of these, 97 had a medium to strong effect size using Glass Delta (difference between means, compared to the standard deviation). By using zip code data in the full model, the hauling costs increased by about $625,000.

The findings show that there are benefits to using zip code level data and highlight the need to account for variance in random point distribution analysis.

Introduction

This study analyzes the benefits and challenges of using a random point distributor tool for estimating manure hauling costs. It compares results when the distributor tool is based on county and zip code level data. The potential difference between these two scales of analysis can be confounded, though, by the variance in the statistical distribution of the resulting values. Randomly distributing points 70 separate times illustrates the variation range, and illustrates whether the signal (difference in county vs. zip code level data) can be distinguished from the noise (variation in the random point distribution).

Background

The Chesapeake Bay Watershed (CBW) includes the largest estuary in the United States. It is at the confluence of many waterways, including the largest river on the Atlantic Seaboard, the Susquehanna. The Chesapeake Bay (Bay) itself supports a variety of flora and fauna; over 2,700 plant and animal species live there. Many animals rely on the estuary's intermixing of fresh and saltwater to survive. About 500 million pounds of seafood are harvested from the bay each year (Chesapeake Bay Program, 2009).

This diversity is threatened by the increase in nutrients flowing in from rivers. While nitrogen and phosphorus are essential for life, too much of it can destabilize the ecological balance. About 300 thousand tons of nitrogen are flushed into the Bay each year (Chesapeake Bay Program, 2012). High nutrient concentrations in the water can create algal blooms (Chesapeake Bay Program, 2012). When the algae die, they decompose deep beneath the surface, using up the limited oxygen found in the Bay floor. This leads to hypoxia, or oxygen free dead zones.

The Environmental Protection Agency (EPA) found that the voluntary standards of the Clean Water Act (Clean Water Act of 1972, 2002) alone are not reducing nutrient amounts to sustainable levels. Along with Delaware, Maryland, New York, Pennsylvania, Virginia and West Virginia, they enacted a mechanism of increased accountability using the Total Maximum Daily Load (TMDL) regulations (U.S. Environmental Protection Agency, 2010) It established how much pollution the Bay can take and still meet the requirements for the Clean Water Act “fishable” and “swimmable” area requirements (Congressional Research Service, 2012).

The Chesapeake TMDL was conceptualized in 2000, with a final version ratified in 2010. Its goals are mandated to be met by 2025, with 60% reduction expected by 2017. Each state in the CBW is divided into hydrologic units specified by a Hydrologic Unit Code (HUC), and is responsible to meet these standards.

A variety of human activities, both urban and rural, have greatly increased the nitrogen load in the Bay. One activity contributing nitrogen that is relatively easier to mitigate is agricultural runoff, especially in comparison to urban inputs such as storm water drain retrofitting and wastewater treatment plant upgrades (Jones, 2010).

According to the Chesapeake Bay Program (2012), agricultural runoff accounts for over 40% of excess nitrogen inflow. Most of this runoff comes from livestock farms of varying sizes. The largest, officially known as Confined Animal Feeding Operations (CAFOs), have over a thousand head of livestock. Their manure production is monitored by the states in the CBW. Smaller operations are known as Animal Feeding Operations, or AFOs. These have, at least 12 animal units on the farm (an animal unit allows comparison among species and is 1000 lbs.: about one dairy cow, or about 350 chickens (Kellogg, 2012) , This report looks at all potential AFOs and CAFOs, as long as the animals are confined to a small space for a majority of the year (Ribaudo, 2003).

In the CBW, most of the feed is shipped in from the Midwest, which the animals turn into manure. From a nutrient perspective, it’s like taking nitrogen from the Midwest and moving it to the Chesapeake region. This is more nitrogen than the region has traditionally handled, destabilizing the Bays environment.

When there is too much manure for the topsoil plants to absorb, the excess is sloughed off as runoff. Every plant has a different agronomic rate of intake of nitrogen. Maryland sets a limit of 50 lbs. of nitrogen per acre, in order to stay below agronomic rates and assure that much of the available nitrogen in the manure does not end up as runoff (State of Maryland Department of Agriculture, 2010).

Manure contains nitrogen. Its concentration in manure varies by animal; poultry tend to have a higher proportion of nitrogen vs. other livestock. Depending on the makeup of the manure, this can mean a limit from one to five tons of manure per acre (Aillery, 2013).

Many AFOs, though, produce more manure than they have land available for its application. If all the nitrogen was applied to cropland at the proscribed agronomic rate, over 40% of agricultural land in the CBW would be covered. There's enough phosphorus in manure produced in the CBW to cover almost 75% of its cropland (Ribaudo, 2003).

Manure comes with inherent costs (e.g. associated pests, high runoff, transportation costs). Since manure is not the only choice for fertilizing plants, many farmers don't want it. This and the abundant supply of manure would imply that AFOs would have to travel farther to find cropland for their manure, further increasing transportation costs.

Maryland is helping them by subsidizing transportation costs and matching large livestock operators with farmers who use the manure. This program to transfer manure is a new market; establishing the behavior of and costs to both manure producer and receiver is crucial. Maryland currently monitors only CAFOs. If this plan is expanded from CAFOs to AFOs (a much larger group of farmers), how will this affect the market? Will competition between AFOs increase travel costs, as an increasing list of manure producers competes for a limited number of receiving farmers?

Economic Research Service (ERS), part of the United States Department of Agriculture (USDA), analyzes the costs of manure transport as the willingness to accept manure changes. The model used in this analysis takes into account variations in transport costs based on animal origin and the physical condition of the manure (dry, slurry or wet manure). It also acknowledges the spatial relationships within and among counties (Ribaudo, 2003).

The competition among AFOs relies not only on the number of AFOs in a county, but the overall shape and distribution of cropland/pastureland. For example, if two counties have the same amount of cropland acres, with cropland dispersed and segmented in one county, and contiguous and compact in the other, AFO operators would have to travel farther in the county with segmented cropland.

In addition, the position of AFOs affects their proximity to cropland. For example, if a county has evenly distributed AFOs, it would economize the distance from AFOs to cropland. On the other hand, if all AFOs in the county are clustered together, cropland at the opposite end of the county would be farther away from the AFOs. The relative location of the AFO points to cropland (measured by getting the AFO centroid compared to the cropland centroid), also affects the resulting hauling distance.

Due to disclaimer issues with the Census of Agriculture, the location of AFOs is not recorded. While the model is unable to include accurate locations of these AFOs, it seeks to match spatial distributions as best it can with the limited locational information available. It uses a function that relates available acres to the proximity to cropland, called a cumulative area to distance function. This function incorporates the cropland shape, clustering effects and AFO location into account.

These are some assumptions used in the model:

- The initial place to begin spreading manure is on the AFO property. In the model, 20% of that land is unavailable for application, (already exceeds the nitrogen limit).
- In addition to cropland, 50% of pastureland is made available to operators for applying manure. The included pastureland is chosen randomly from the Cropland Data Layer (a land use designation created by the National Agricultural Statistics Service (NASS)) (National Agricultural Statistics Service, 2011).
- In this scenario, all AFOs participate in the manure program and seek land to spread their respective manure.
- Since the location of AFOs is not known, specific animal manure amounts cannot be applied. Instead, the total manure amount is calculated for the whole county, and divided evenly among AFOs.
- The county sum nitrogen load of the manure is calculated as well. Each animal has a specific nitrogen concentration in its manure. The manure nitrogen load is weighted by the animal distribution in each county.

Rationale for using a random points tool for distribution AFOs

Providing an accurate area to distance function would be easy if we knew the location of each AFO. Unfortunately, this is not possible. The Census of Agriculture 2007 (Census) is the source of the manure estimates and identification of AFOs. Although it records farm information, location is not provided due to disclosure issues. This could expose a farmer's strategic advantage to competitors.

Instead, the general territorial location can be gleaned from Census questions. Every operator is identified by their mailing address (county and zip code). They're also asked if they've lived on their farm during the last year. If the operator's response is affirmative, his/her address is used as a proxy for the farm. Each county (or zip code) is then assigned a valued for the total count of AFOs within their territory.

The model uses this value to model the distribution of AFOs within each territory. The AFO count is randomly placed on the cropland and pastureland within the territory, and the total manure distributed evenly among the AFOs. While this is not accurate, it's the best input that can be provided for the model. The tool used for this purpose is Esri's ArcGIS tool, Create Random Points. The tool distributes a number of points randomly within a constraining feature (in this case, county or zip code boundary). The number of points to distribute is based on the number of AFOs.

Since the Census itself doesn't define AFOs, the model uses the AFO counts and manure production derived from Census data by the National Resource Conservation Service (NRCS). These figures are provided at the county level.

Objective

The current version of the model takes these assumptions and creates a distribution of AFOs by county. This study looks at augmenting the model by distributing points at the zip code instead of the county level.

This study compares these two levels of constraints (county vs. zip code) for differences in results. In this case, the study focuses on the coefficient of slope of the *area to distance* function (Ribaudo, 2003). This study repeats the comparison with multiple random distributions of points to test for variability, creating two sample groups of 70 random distributions each. Variability becomes the basis for further analysis, measured as a test of means and a test for effect size. Finally, the study looks at the financial difference in results when using zip code vs. county level data.

Methodology

In order to do these comparisons, the study duplicates the AFO identification of the past model, applying it at the zip code level. This is derived from Census animal counts. The study estimates the number of confined animal units on a farm during the year, using a SAS code, based on raw animal counts. Those that have 12 or more confined animals will be considered an AFO. The study then uses these AFO counts to develop a list of CBW counties and zip codes with their corresponding AFO counts.

This list of AFOs is limited to those that have the operator living on the farm, and a zip code located within the recording county. The study measures proximity (Euclidean Distance) using Esri tools and Python scripting to identify the distance of each cropland grid cell (30 m) to the closest AFO. After obtaining this grid and table, the study uses a program written in R to create an area to distance cumulative function (with area as the independent variable).

Like the original model, the study uses a simplified slope coefficient to summarize the relationship between acreage and distance to them from the various AFOs. The study does this for AFOs distributed based on county data and based on zip code data.

The study runs the same tool, for zip code and county dispersal methods, various times to get a better idea of the range of potential distributions, and an idea of its central tendency. Certain counties have more variance than others, and it is important to identify them. Others might have such limited variance that one run would be enough to get a representative value.

The study iterates through this process 70 times. This involves 140 AFO placements for each county (70 using the zip code data for allocation and 70 using county data). These zip code and county method runs are first paired together, to get a comparison between the two methods (zip code coefficient – county data coefficient). This gives me an idea of the variation in the difference *between* the two methods. The study also looks at the variance *within* each of the two methods, and whether this interferes with finding significant results *between* the two methods (using a Welch's t-test for statistical significance and a Glass Delta to test for effect size).

Cumulative Area to Distance Function

The cumulative area to distance function converts these AFO distributions into a function to estimate the total manure hauling distance needed to apply all manure in a county. The study uses one county as an example (Rockingham County, in Virginia's Shenandoah Valley). Due to disclaimer issues, this study can't report derived Census counts.

Figure 1 shows the initial setup of the tool with false AFO counts. In the actual study, AFO counts determined from the Census. To account for edge effects, counties within a 90 km buffer are included as well. The resulting list contains 12,697 farms that are considered AFOs.

Figure 1: County AFO count (example)

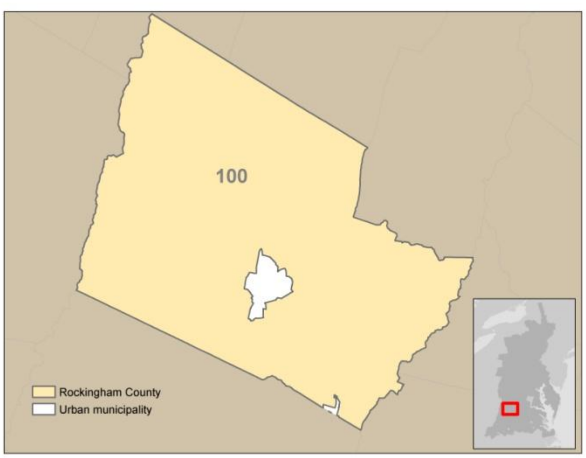
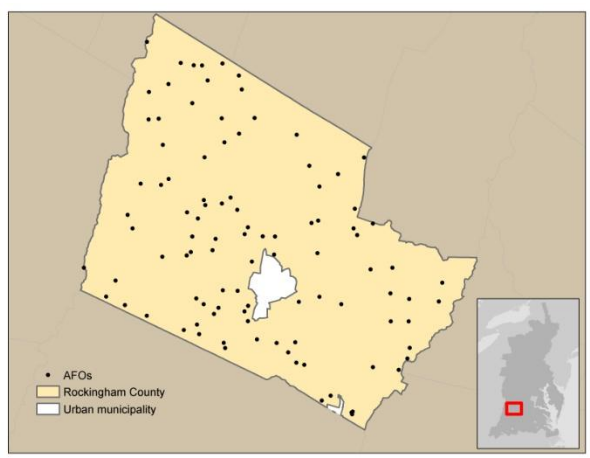


Figure 2: Random distribution of AFO count



In order to compare to the original model output, the study distributed the AFOs by county and then by zip code. For both methods, I used cropland to further constrain likely locations of AFOs. If there is any underlying clustering in the AFO zip code counts, it should result in even more clustering. Figure 1 and Figure 2 show a hypothetical number of AFOs in Rockingham County. The 100 AFOs in the county could be further split up by zip code. Figure 3 and 4 show that both distributions limit the results to the cropland, but Figure 4 is also constrained by zip code boundaries.

Figure 3: AFO distribution w/in cropland

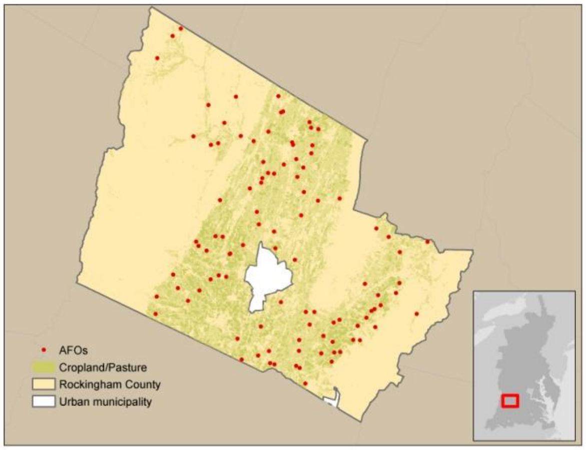
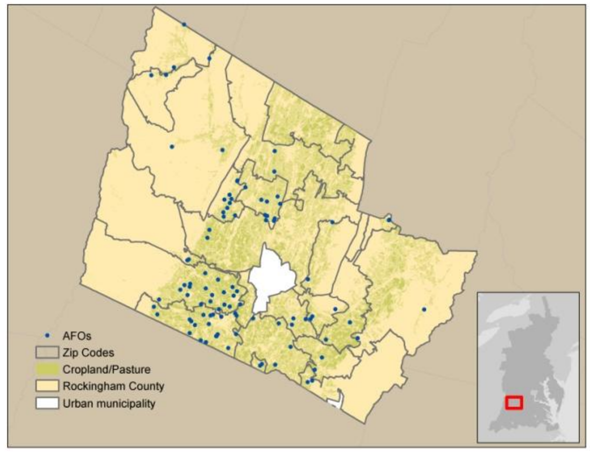


Figure 4: AFO distribution w/in zip codes



The next step relates AFOs to the surrounding cropland. Each grid cell of cropland is assigned a value, the number of meters to the closest AFO (Euclidean distance). Figures 5 and 6 color the cropland grid cells based on these values.   This creates a best case scenario, given the shape of the cropland and the distribution of AFOs. Figure 6 shows the distribution of grid cells by these distance values in the upper right hand corner.

Figure 5: County Euclidean distance

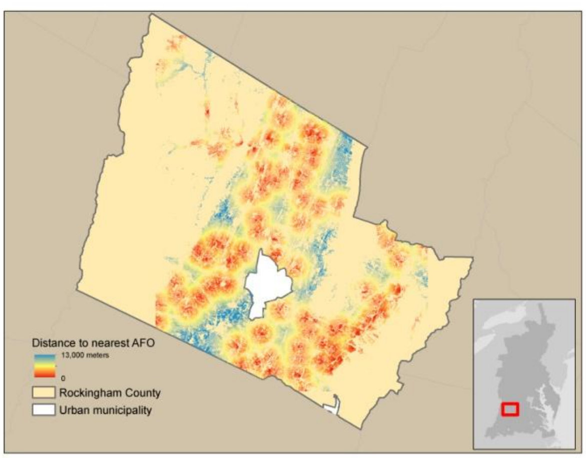
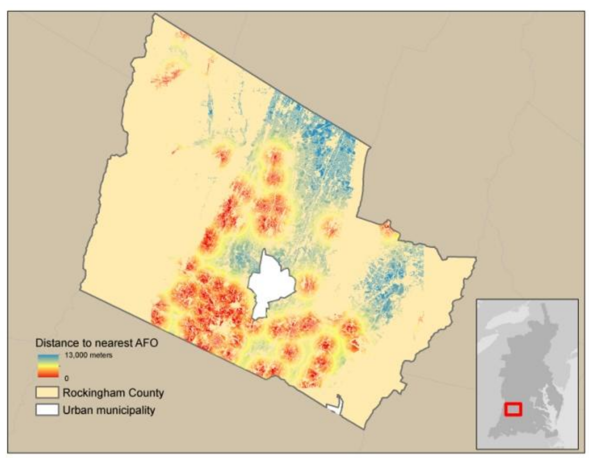


Figure 6: Zip code Euclidean distance



By transposing meters on the y axis and the number of grid cells (which can be converted to acres) on the x, or independent axis, the model is able to find out the minimum travel distance, given a set amount of acres necessary to spread the total manure in the county. This is what we see in Figures 7 and 8.

Figure 7: Area to distance function, county example

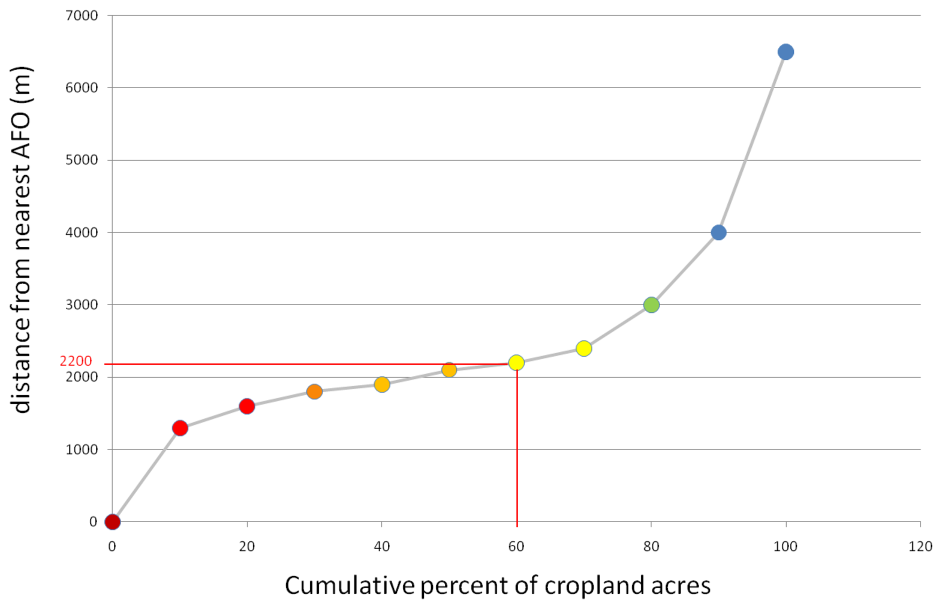
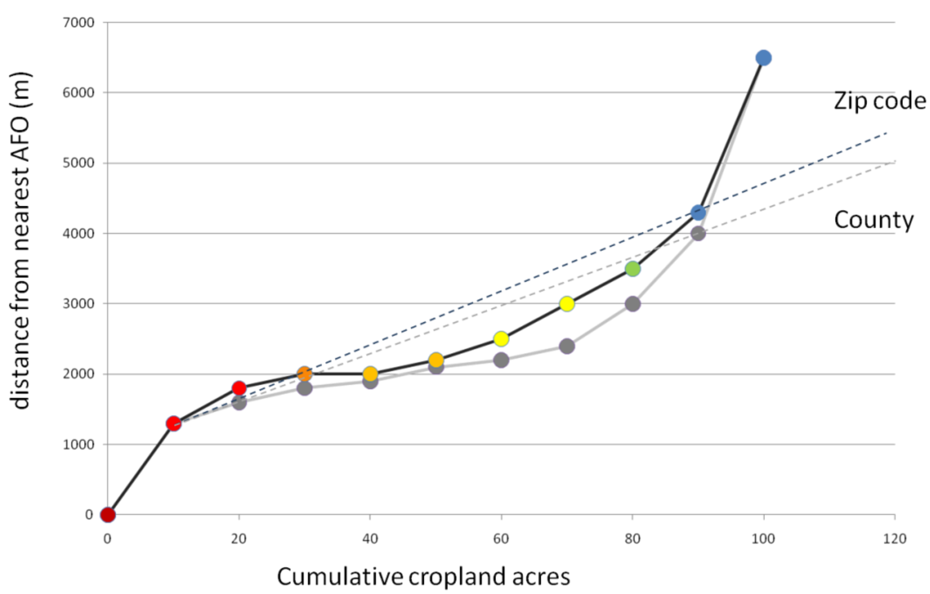


Figure 8: Area to distance function, zip code and county, with summary coefficients



This function becomes a best case scenario, given the distribution of the cropland in the county, and the location of the AFOs. For example, if a county needs to get rid of 30,000 tons of manure, the best case scenario would be that the marginal distance at that point is 220 meters from the AFO centroid (Figure 7). The original model takes a summary value from this function: the coefficient value of the slope from the 10th through the 90th percentile acre in the county (Figure 8).

Results compare the coefficient with and without zip code information, subtracting the zip code method from the county method of distributing AFOs. The comparison is only within counties, since the number of AFOs, and shape of the county cropland varies across the CBW.

Results

Figure 9: Difference between coefficients (zip code - county), ordered from low to high for all CBW counties

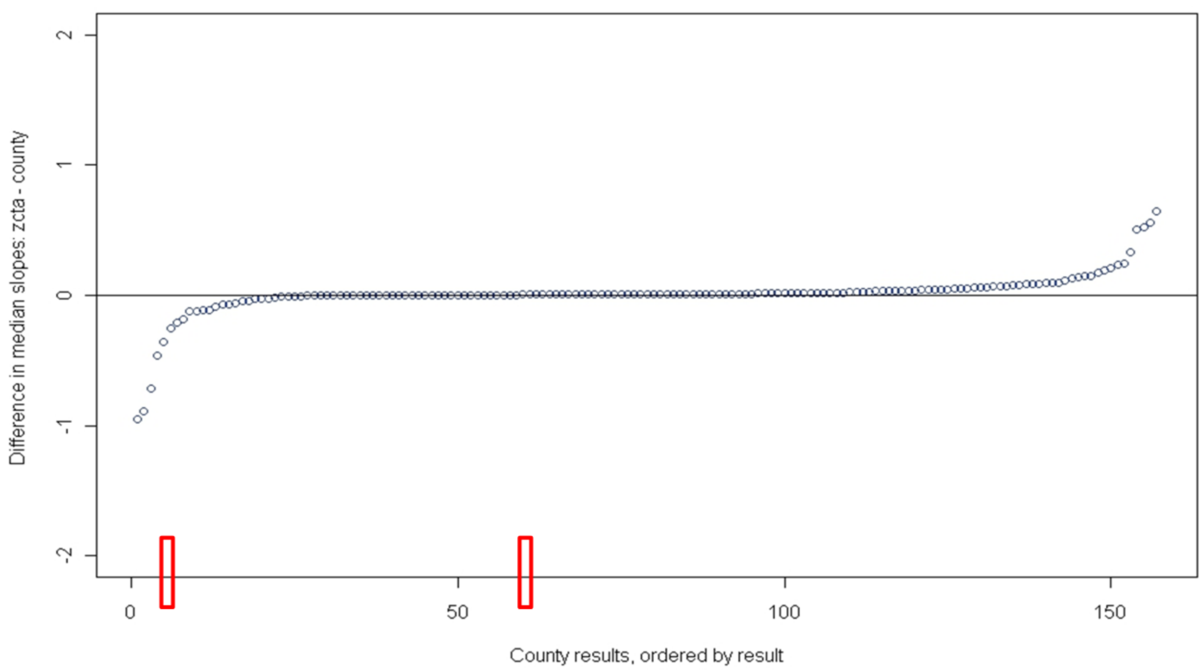


Figure 9 shows the range of the differences between coefficients when AFO points are distributed with zip code level data versus county. This is from a first iteration (one of 70). The figure orders county coefficients by this difference (zip code method coefficient – county method coefficient). Some counties on the left side of the chart (about 40) have a higher county coefficient than zip code coefficient (negative values of y in Figure 9); indicating county distribution is more clustered than the zip code distribution. These counties tend to have fewer AFOs or few croplands, where an inaccurate location of AFOs would have significant effects on the proximity to cropland. The graph highlights two counties for further analysis (the red boxes point to their position in the county ranking). These two counties (Rockingham County in Virginia and Allegany County in Maryland) illustrate the effect of variance in the results.

Figure 10: Median difference (zip code – county) and standard deviation of CBW counties, for 70 iterations

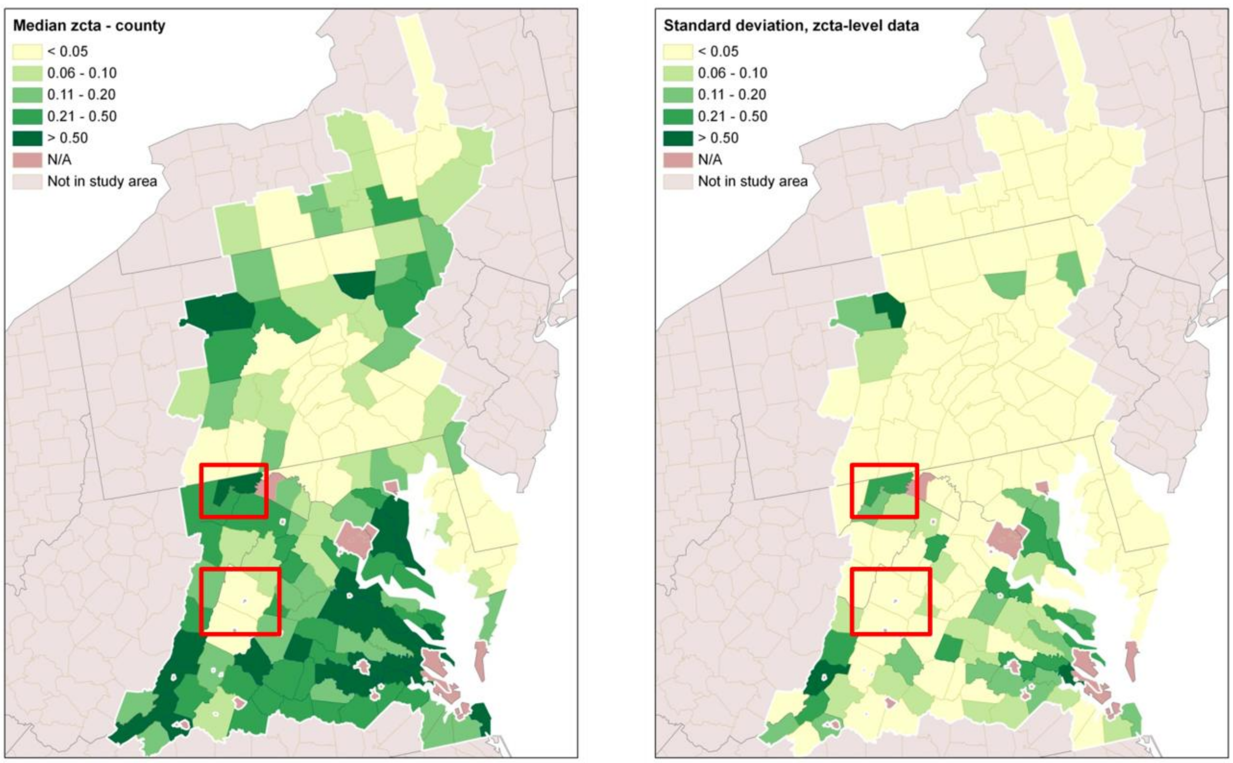


Figure 10 shows the statistical results when looking at all 70 iterations. The map on the left shows the median difference of all iterations (zip code coefficient – county code coefficient). The figure uses absolute values to highlight the size of the difference, rather than the actual value. Those in dark green had the largest difference. To the right is a map showing the standard deviation of these 70 iterations.

The counties with the largest difference between coefficients from county and zip code methods appear to coincide with larger standard deviations. The two counties highlighted in red on these maps are indicated with red rectangles in Figure 9, 11 and 12 to further illustrate these differences. The northern example in red is Allegany County, Maryland. It has fewer AFOs (< 50) and is has sparsely distributed cropland. Rockingham County, in the Shenandoah Valley in Virginia, has more AFOs (> 100) and produces some of the greatest amounts of manure in the CBW.

Figure 11: Box plots for difference in coefficients, all CBW counties, with ordering based on Figure 9

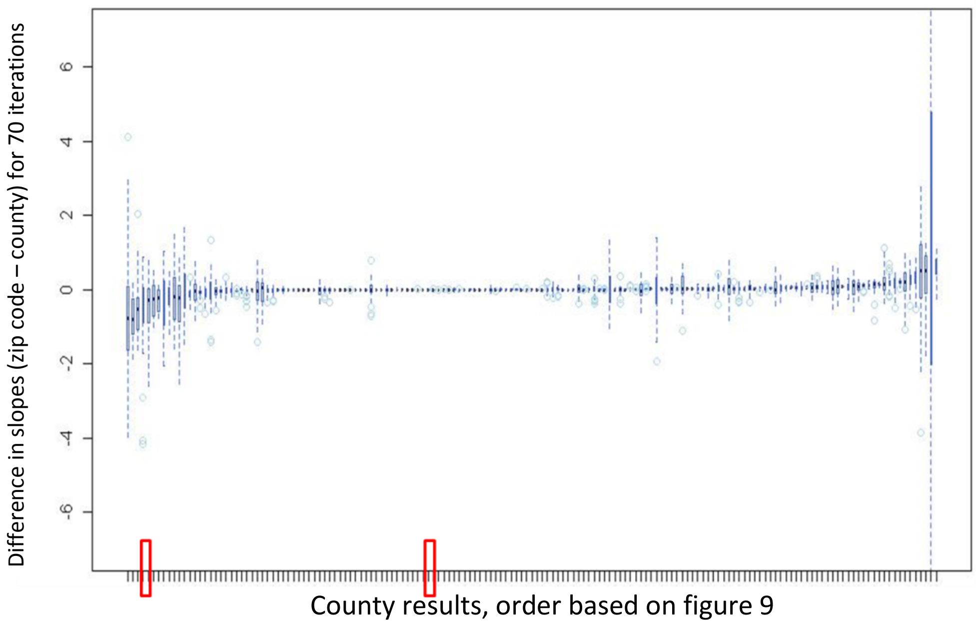
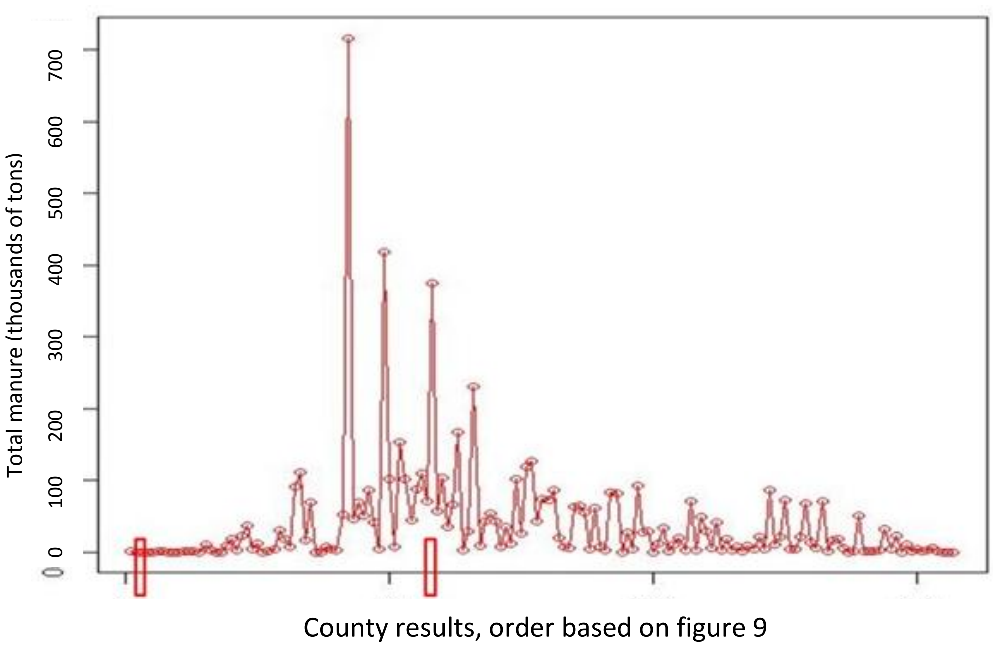


Figure 12: Total excess dry manure, all CBW counties, with ordering based on Figure 9

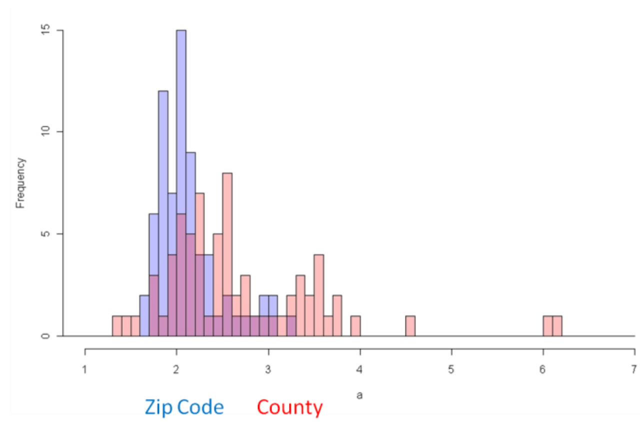


Ties in with variance

The high standard deviations seem to correspond to counties with large differences between zip code and county results. Ordering the counties in Figure 11 and 12 the same as shown in Figure 9 reveals the most extreme values, both positive and negative, are in counties that have the most variance (such as Allegany). Those in the middle, with little difference between zip code and county coefficients, have little variance, such as Rockingham. The middle is also contains the counties with the largest manure production.

Figure 13: Histogram of zip code and county coefficients, Rockingham County

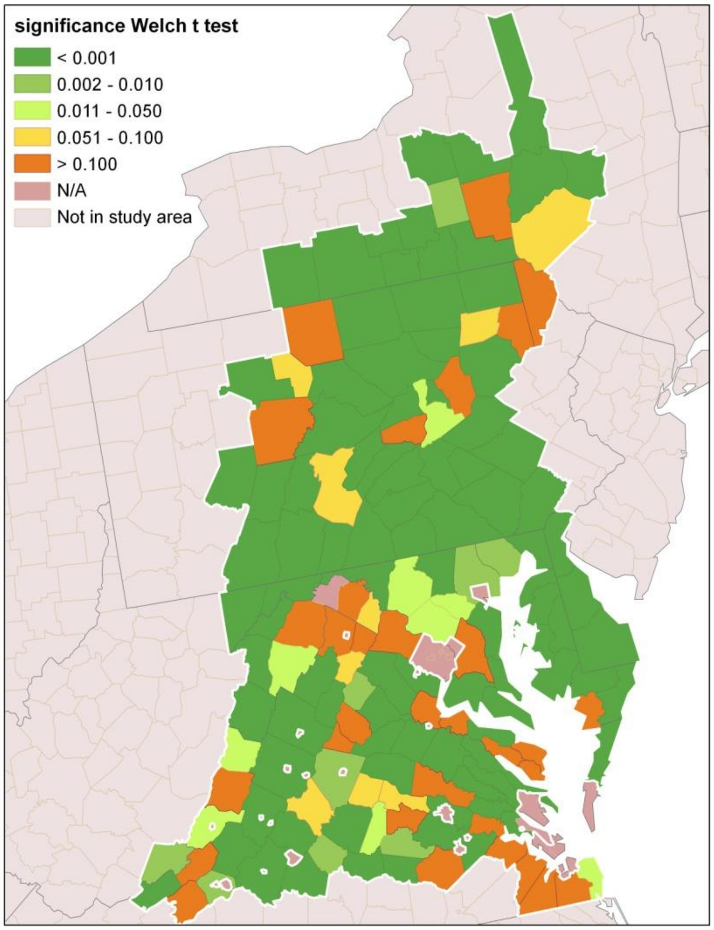
Figure 14: Histogram of zip code and county coefficients, Allegany County



This is confirmed when looking at the variation *within* the two methods (zip code and county) separately as histograms of the coefficient values in Figures 13 and 14. The difference between coefficient values (x axis) for Rockingham County is very small; the median of the zip code population in blue is about 0.004 larger than that of the county method (in red). Yet, they show two distinct distribution curves. Comparing this to Allegany in Figure 14, the variance of within county (red) and zip code (blue) values is much larger. The distribution curve is much wider, especially for the county iterations.

T-test

Figure 15: P value from Welch t test, for CBW counties



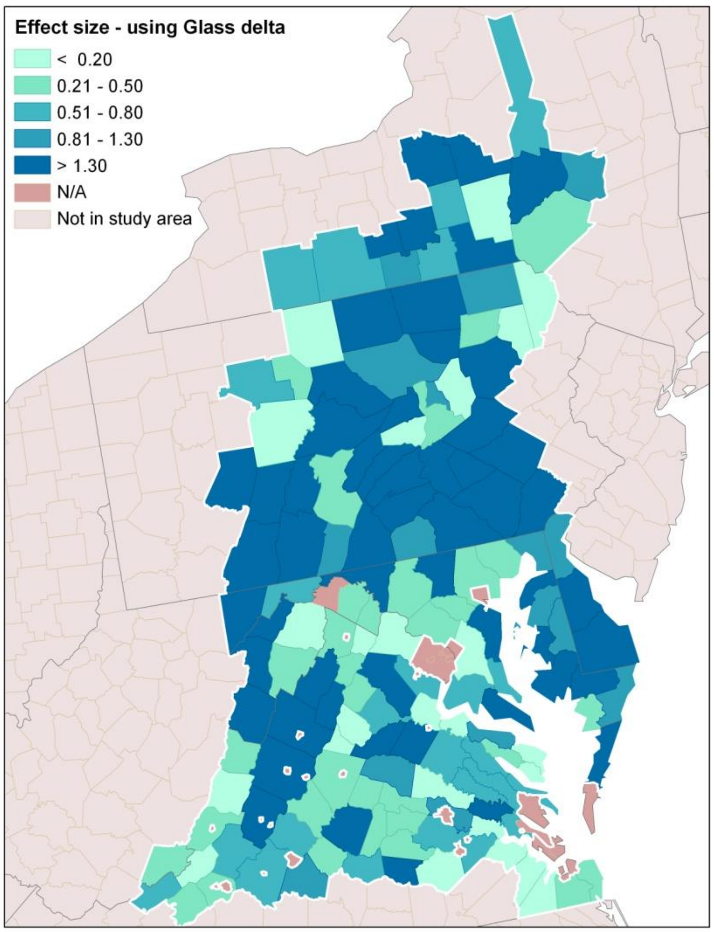
It's worth considering if noise (variation caused when randomly distributing AFOs) is masking the signal (measuring the difference between the zip code and county results). A variant of the t-Test (Welch) compares means t-test of the compared means from the 70 county iterations against the 70 zip code iterations. The null hypothesis is that there is no difference between the two sample means, using a 95% confidence level.

The study uses Levine's test to confirm that there are significant differences in the variance in about 2/5ths of the counties, making the Welch t-test appropriate. The results of the t-test showed a significant difference at the 95% percentile, and a rejection of the null hypothesis, for 114 of 157 counties in the study. In Figure 15, counties in the top 3 categories (in green) met this significance test. Those in the next two categories (in yellow and orange) did not.

Cohen's D, using Glass Delta

While the t-test shows significant differences in some counties, the level of significance varied in size and effect. The study uses a variant of the Cohen's D, which measures effect size, to account for differences in variance. It looks at the differences in means, normalized by the standard deviation of the control sample. Since t-test statistical significance includes sample size as well as the difference between the groups, the study includes Cohen's D. I want a better test to see if the size of the difference is meaningful as well. Since I have no established scale of meaningful difference for my coefficients, I rely on tests that used the distribution of potential values as the reference scale (Coe, 2002).

Figure 16: Effect size, for CBW counties

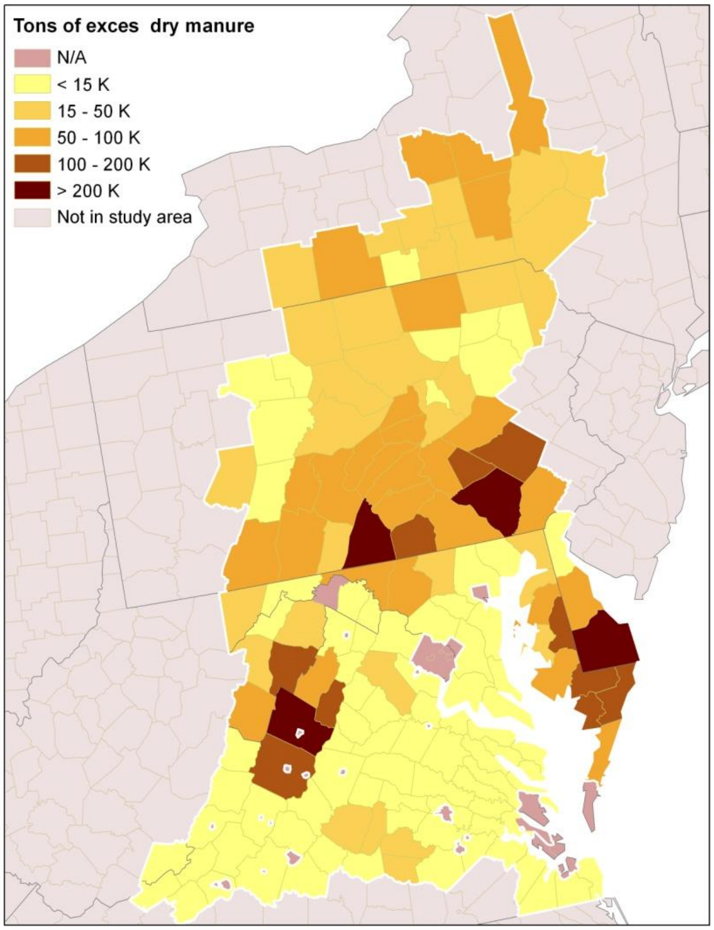


Of the 114 counties that have a significant difference in their means, 97 have a medium effect size or better (>=0.5). These are the three darker blue categories in Figure 16. This means that there's a 64% probability that that a random coefficient from the zip code method will be higher than the county method. For counties in the highest group on the map, with a very large effect size of 1.3 or greater, there's an 82% chance it will be higher.

Looking at areas with high amounts of manure

The top 15 manure producing counties not only are significant, but have a large effect size between zip code and county methods for distributing AFOs. These are the counties in Figure 17 that are in the two

Figure 17: Total tons of excess manure, CBW counties



darkest brown categories. Not all counties in the CBW have the same impact on study results. If counties that produce a large percentage of manure don't have significant or meaningful difference between zip code and county, the practical utility of this study is diminished. The study looks at manure output by county, finding that manure outputs of the largest producers (in dark brown in Figure 17) also have a high effect size shown by the dark blue color class in Figure 16 (> 1.3). This also resonates with Figure 12; the counties with the least variation in results (in the middle of the x axis) include the larges manure producing counties.

How does this affect model?

To further evaluate the effect of zip code level data, I put each county's median zip code coefficient into the model, keeping all other variables at a best case scenario. Table 1 shows the results if AFOs can accept 80% of their load within their own land, 50% of cropland/pasture is available for application and all AFOs with excess manure applied them to outside cropland. The model calculates county distribution simultaneously with other forms of manure application (on farm, and county – county hauling of excess manure). The coefficient has a direct effect on within-county hauling, and an indirect effect on county-county transfers and on farm hauling of manure. When modeling the hauling of manure, the monetary benefit of zip code level allocation is modest (2.5% for within county trading). This results in a total increase of $625,000.000 in hauling costs.

Table 1. On farm distribution of manure

Level of distribution	Zip code method (millions of dollars)	County method (millions of dollars)	Difference (millions of dollars)
On farm distribution of manure	166.35	166.33	.02
Within county distribution of manure	23.06	22.51	.55
Inter county distribution of manure	25.39	25.32	.06
Total distribution	214.80	214.16	.625

Next steps

The results lead to various questions:

- Are there some common characteristics of counties that have high variability of results?
- Which of these characteristics have the strongest relationship with effect size?
- How might someone distinguish between the spatial characteristics that are measured with area to distance function, shape characteristics of croplands, AFO clustering and AFO mean location?

Preliminary correlations relating effect size (Glass Delta) with various county characteristics (AFO count in a county , standard deviation of the zip code AFO count within a county, cropland area, ratio of cropland perimeter to area), show all are statistically significant at the 95 percentile, but only the first two have a strong relationship (> 0.3). Effect size and AFO count have a positive correlation of 0.5, and effect size and standard deviation of AFO counts have a positive relationship of 0.62. This second value means that as number of AFOs vary (some zip codes have more AFOs than other zip codes) the effect size tends to increase as well. Conversely, in counties with a more homogenous AFO count across zip codes, it provides no further information about clustering than the county data.

Limitations of the current method include the area to distance function not distinguishing between the three spatial characteristics of interest: cropland distribution, AFO clustering and location of AFOs relative to county cropland centroids. It may be necessary to develop three different indicators that separate these factors for further study.

It might also be helpful to center on a more explicit variables, such as nearest neighbor to better assess clustering and placement.

Conclusion

While the results varied by county, over half of counties (114 of 157) shows a statistically significant difference between the two methods for distributing points (by zip code and by county). Seventy-two percent of counties have a significant difference at the 95% confidence level using the Welch t-test. There is a medium to large effect size using a deviant of Cohen's D (Glass Delta) - in 61% of counties. Total hauling costs increase by 625 thousand dollars, and most of this is felt within the county of origin (500K), a 2.5% increase in the within-county distribution of manure.

It is important to note that many of the counties that do not have a statistically significant difference have high variation with 70 iterations through the AFO placement tool. Figure 15 shows the location of these counties (in orange and red). This highlights a potential weakness of past model runs, where the coefficient for the model was based on only one AFO point allocation (rather than multiple iterations).

Reference

"Clean Water Act Section 303(d): Water Quality Standards and Implementation Plans. Regulations Concerning Listing of Impaired Waters and Development of TMDLs", 40 CFR 130.7 (Code of Federal Regulations 10 18, 2001).

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