Harmful Algae Blooms (HABs) Occurrence within counties with differing land use and population trends within Virginia, USA

May 4, 2018

GEOG 574
Mary Mahoney

Introduction and Background

Algae growth has long been a common problem for drinking water suppliers utilizing surface water; however, harmful algae blooms (HABs) are phenomena that have recently become a cause for concern for water utilities. HABs are defined as "…colonies of algae—simple photosynthetic organisms that live in the sea and freshwater—[that] grow out of control while producing toxic or harmful effects on people, fish, shellfish, marine mammals, and birds" (National Oceanic and Atmospheric Administration). These events can cause low oxygen environments within the water column, creating "dead zones" and sicken animals and humans with dangerous toxins produced by the organisms. HABs also can negatively impact industries that rely on water, such as increasing treatment costs for waterworks or companies involved in water recreation or tourism (Environmental Protection Agency, 2017). The causes for algae blooms are typically slow-moving water, sunlight, and nitrogen and phosphorus availability in the water column (Environmental Protection Agency, 2017).

While ocean and saltwater-related HABs have been studied and recognized as a recreational hazard, freshwater blooms became a larger concern due to blooms on Lake Erie causing the shutdown of the water treatment facility for several days in Toledo, Ohio (Environmental Protection Agency, 2017; Jochem, 2017). This portion of Lake Erie is relatively shallow which allows sunlight to fuel HAB growth. In addition, this portion of the Lake Erie watershed (the Maumee River watershed) has a large nutrient input from agricultural land uses (Heisig, 2018). This, combined with the slow-moving water of the lake, created the perfect environment for a HAB event.

In this report, the Commonwealth of Virginia is the main area of concern regarding HABs occurrence. Virginia is a state with wildly varying landscapes and census data. This point was considere when choosing localities of interest for this report. The counties used to research were determined by population size, differing land uses, and knowledge of public water intakes serving the population within Virginia. Counties used were Albemarle County (hilly landscape with some large mountains, medium population density, river and reservoir public water intakes), Dickenson County (mountainous, low population density, and public water intake within a reservoir environment), and Fairfax County (relatively flat and highly urbanized, densely populated, river and reservoir public water intakes).

Multiple research questions are considered:

1. How many public surface water intakes exist in each county,
2. Where are reported HABs within public surface water intake watersheds, if any,
3. What the land use, in percent, is within the counties of each target intake,
4. What population change occurred within each locality between 2017 and in 2010,
5. What the median household income is within each watershed.

Methods

Database Design

This database contains 6 entities represented as tables: water source data intake locations (wsd), surface water intake watersheds within five miles of the intake (sw_zone_1), algae reports from 2017 and 2018 (algaerpt), Virginia localities (va_counties), median household income for 2016 for Virginia localities (mhi2016), population data for the localities of Virginia (popdata), and land use acreages by Virginia locality (countylu). These entities had several attributes which can be seen in the Entity-Relationship Diagram in Figure 1 and are described below. From this attribute information and Entity-Relationship Diagram, a logical schema was created and is shown in Figure 2.

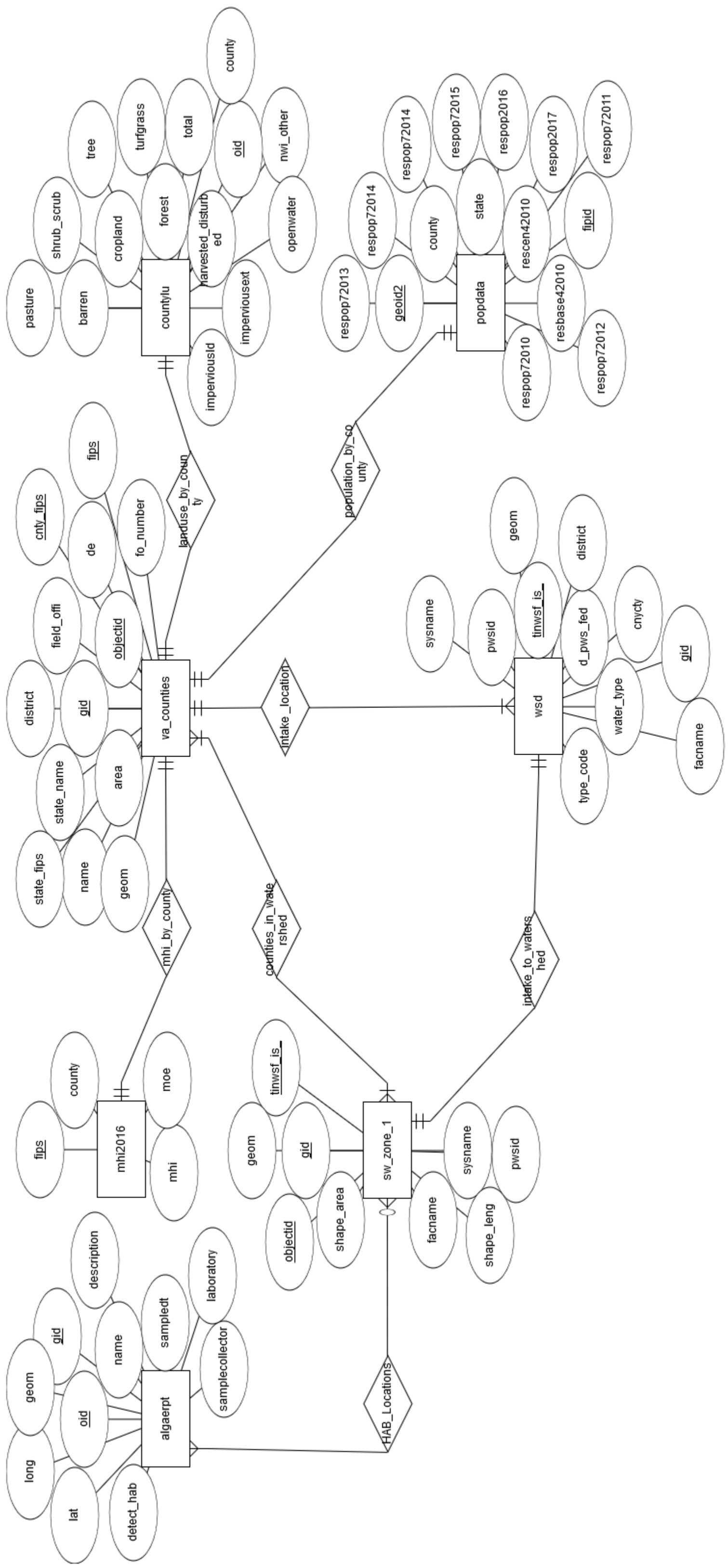

Figure 1. Entity-Relationship Diagram

WSD

The water source data locations include public water sources including wells, springs, and intakes. For this database, the focus is on the surface water intakes, since these locations are the most vulnerable to HAB events. Attributes included are the public water system ID numbers (pwsid), a unique source identifier created by the original database system (tinwsf_is_), the federal code type (d_pws_fed) which identifies if the USEPA identifies the utility as a Community or Non-Community waterworks, the water type, such as surface water (water_type), the type of structure (type_code), the Office of Drinking Water district (district), the principle county or city served (cnycty), the facility name (facname), the system name (sysname), the derived population (d_populatio), and the geometry fields added in PostGIS (geom and gid). This entity includes a unique identifier (tinwsf_is_) and primary key of a geographic ID (gid).

SW_Zone_1

The watershed data in this entity was delineated in ArcGIS and transformed in PostGIS to include geographic information in the database. This portion of the watershed is within 5 miles of the intake and most HAB impacts to a waterworks would occur within this area. Attributes include an object identification field (objectid), public water system ID numbers (pwsid), a unique source identifier created by the original database system (tinwsf_is_), the facility name (facname), the system name (sysname), a shape length field (shape_leng), a shape area field (shape_area), and the geometry fields added in PostGIS (geom and gid). Unique fields are the tinwsf_is_ and objectid fields, and the primary key is the gid field. This entity includes a unique identifier (tinwsf_is_) and primary key of a geographic ID (gid).

Algaerpt

In the Commonwealth of Virginia, research on HABs occurrence is limited, but HAB reports have been recorded by the HAB Task Force. This database includes data from 2017 and reports as of April 25, 2018 derived from a csv file. Attributes include object identification (oid), the name of the bloom (name), the sample date (sampledt), the agency collecting the sample (samplecollector), the lab analyzing the data (laboratory), a general description (description), if

HAB toxins were detected (detect_hab), the latitude and longitude (lat and long, respectively), and the geometry fields added in PostGIS (geom and gid). The algae reports entity's primary key is oid and gid is a unique field.

VA_counties

This entity represents Virginia cities and counties. The attributes include object identification (oid), the name of the locality (name), the state (state_name), Federal Information Processing Standards (FIPS) identification number for the state, the county, and a combination of the two (state_fips, cnt_fips, and fips, respectively), area in square meters (area), Office of Drinking Water assigned service areas (field_offi, DE, and FO_number), and the geometry fields added in PostGIS (geom and gid). The primary key is the fips attribute. Additionally, the va_counties entity has a unique gid field for its spatial information.

MHI2016

The median household income data was retrieved from the U.S. Census Bureau as a csv file. Attributes include the FIPS code (fips), the locality name (county), the median household income for the locality in 2016 in U.S. dollars (mhi), and the margin of error in U.S. dollars (moe). The primary key is the fips attribute.

Popdata

The population data for Virginia was retrieved from the U.S. Census Bureau as a csv file. The attributes include the FIPS code (fipid), a unique identifier (geoid), a unique field of the locality name (county), the state (state), the 2010 census population and base estimate (rescen42010, resbase42010) and population values from 2010 to 2017 (respop72010, respop72011, respop72012, respop72013, respop72014, respop72015, respop72016, respop72017). The primary key is the fipid attribute.

Countylu

The county land use data originated as a csv file from the Virginia Information Technology Agency. Though there is raster GIS data of this information, it was far too large to include in the database. The entity has an “oid” attribute as the primary key and a “county” unique attribute. All other attributes are the amount of a land use type in acres (barren, cropland, forest, harvested_disturbed, imperviousext, imperviousld, nwi_other, openwater, pasture, shrub_scrub, tree, turfgrass, total).

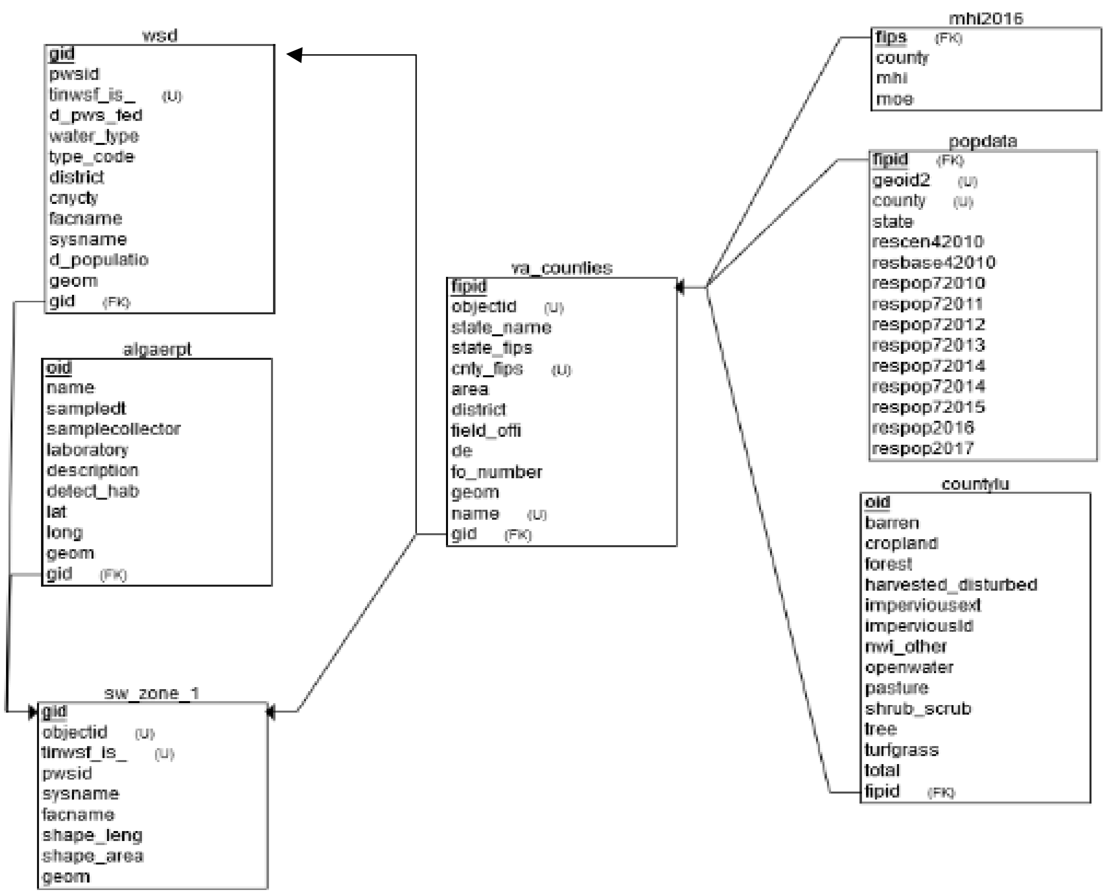

Figure 2. Logical Database Schema

SQL Queries

To determine what intake facilities within or .01 decimal degrees from the target counties:

```
select w.facname, w.sysname from wsd as w
join va_counties as c
on ST_DWithin(w.geom, c.geom, .01)
where (w.water_type='SW')
and (c.name='Dickenson' or c.name='Albemarle' or c.name='Fairfax')
group by facname, sysname;
```

To find algae reports within any intakes:

```
select sw.facname, sw.sysname, a.name, a.sampledt, a. description, a.detect_hab from
sw_zone_1 as sw
join algaerpt as a
on ST_Within(a.geom, sw.geom)
group by sw.facname, sw.sysname, a.name, a.sampledt, a. description, a.detect_hab;
```

To find the landuse percentages for the target watersheds:

```
select w.facname, w.sysname, ((l.forest/l.total)*100) as forestpct,((l.tree/l.total)*100)as
treepct, ((l.barren/l.total)*100) as barrenpct,
(((l.imperviousext+imperviousld)/l.total)*100) as imperviouspct,((l.cropland/l.total)*100) as
croppct,((l.pasture/l.total)*100) as pasturepct,
((l.harvested_disturbed/l.total)*100) as harvestpct, ((l.nwi_other/l.total)*100) as wetlandpct,
((l.shrub_scrub/l.total)*100) as shrubpct, ((l.openwater/l.total)*100) as
openwaterpct,((l.turfgrass/l.total)*100) as grasspct, l.county from countylu as l
inner join va_counties as c on c.name=l.county
join sw_zone_1 as w
on ST_Intersects(w.geom, c.geom)
```

```
inner join tasource as t
on w.tinwsf_is_  = t.tinwsf_is_ ;
```

To find the population change for the counties within the target intakes, a view (tasource) was created to isolate those intakes and their watershed:

```
select w.facname, w.sysname,SUM((p.respop72017)-(p.respop72010)) as changepop from
sw_zone_1 as w
join va_counties as c
on ST_Intersects(w.geom, c.geom)
inner join popdata as p on p.fipid=c.fips
inner join tasource as t
on w.tinwsf_is_  = t.tinwsf_is_
group by w.facname, w.sysname;
```

And, to find the median household income for each county:

```
select * from mhi2016
where county like 'Albemarle%' or county like 'Dickenson%' or county like 'Fairfax%';
```

Results and Discussion

Utilizing the SQL queries in the pgAdmin database, tables were created with the desired information. These tables can be seen below. Additionally, a graph was developed to illustrate land use percentages between watersheds. Maps were also developed to show land use as well as intake locations throughout the target counties.

<u>Intake Locations, HAB Reports, and Land Use/Land Cover</u>

Table 1. Intakes within the Target Counties

Facility Name	System Name	County
BEAVER CREEK RESERVOIR	CROZET WTP	Albemarle

Facility Name	System Name	County
JOHN FLANNAGAN RESERVOIR PUMP STATION	JOHN FLANNAGAN WATER AUTHORITY	Dickenson
NORTH FORK RIVANNA RIVER	NORTH RIVANNA WTP	Albemarle
OCCOQUAN RESERVIOR INTAKE	FAIRFAX COUNTY WATER AUTHORITY	Fairfax
RAGGED MOUNTAIN RESERVOIR	OBSERVATORY WTP	Albemarle
SOUTH FORK RIVANNA RESERVOIR	SOUTH RIVANNA WTP	Albemarle
SUGAR HOLLOW RESERVOIR	OBSERVATORY WTP	Albemarle
TOTIER CREEK INTAKE	SCOTTSVILLE WTP	Albemarle
TOTIER RESERVOIR INTAKE	SCOTTSVILLE WTP	Albemarle

Suspected HAB reports submitted to the Commonwealth were located within two surface water intake watersheds, with the bloom at John Flannagan Reservoir in Dickenson County being a recurring bloom that does not always contain toxin-producing cells (Table 2). Comparing these incident locations to land use within the county in Figure 3, you can see that forest is the dominating land cover within both Albemarle and Dickenson County intakes, with pasture being the second largest land cover in these watersheds. Forest cover can be positive within a watershed, because this land cover does not allow for as much erosion as bare or agricultural land covers. However, Virginia has an established logging industry (Barrett, Chandler, Bolding, & Munsell, 2012), and some of these forests may be owned by logging operations, which would increase the amount of erosion within the watershed. Impacts in Dickenson County from logging are more intense, as the area is within the high-relief area of the Blue Ridge Mountains and any logging activity could rapidly increase erosion. Additionally, connections have been made to agricultural land uses and an increase in algae blooms. A study of the Maumee River Watershed land uses and its relationship to Lake Erie algae blooms noted an increase in algae activity as the watershed converted land from wetland land cover to agricultural lands (Berardo, Formica, Reutter, & Singh, 2017). This report's results further support this theory as these intakes with bloom have significant agricultural lands. It is worth noting that Albemarle County had additional blooms that were not within surface water intakes, which may correspond with the amount of agricultural lands within the county. Albemarle County public surface water systems are aware of the increase of blooms and should consider mitigation and response protocols for when a bloom occurs within their watershed.

Since most of the data for the SQL database originated from an ArcGIS database, maps were created showing the land use within the target intakes (Figures 4, 5, and 6).

Table 2. Reported HAB Events within Target Intakes

Facility Name	System Name	Bloom Name	Sample Date	Description	HAB Toxin Detected?
JOHN FLANNAGAN RESERVOIR PUMP STATION	JOHN FLANNAGAN WATER AUTHORITY	Flannagan at Cranesnest River subsurface	2/6/2018	A new sample collected by VDH staff on 2/6/18 and analyzed by ODU indicates No harmful algal bloom present and Mcrocystin toxin below detected level	N
JOHN FLANNAGAN RESERVOIR PUMP STATION	JOHN FLANNAGAN WATER AUTHORITY	Flannagan Lake	2/1/2017	Sample collected by VDH staff indicates presence of harmful algal bloom	Y
JOHN FLANNAGAN RESERVOIR PUMP STATION	JOHN FLANNAGAN WATER AUTHORITY	Flannagan Boat Ramp next to water intake subsurface	2/6/2018	A new sample collected by VDH staff on 2/6/18 and analyzed by ODU indicates No harmful algal bloom present and Mcrocystin toxin below detected level	N
JOHN FLANNAGAN RESERVOIR PUMP STATION	JOHN FLANNAGAN WATER AUTHORITY	Flannagan Lake	1/26/2018	Sample collected by VDH staff on 1/26/18 indicates presence of harmful algal bloom at a cell counts of 732,800 cells/ml which exceeds the safe cell counts threshold, while the microcystin toxin found at (2.6725ppb), below threshold. No advisory would be issued at this time, since microcystin at a low concentration and the weather condition is limiting human recreational. As an exception for a few fishermen, an educational sign with how to avoid harm including from fish consumption or from direct contact are posted.	Y

Facility Name	System Name	Bloom Name	Sample Date	Description	HAB Toxin Detected?
NORTH FORK RIVANNA RIVER	NORTH RIVANNA WTP	Chris Greene Lake	7/1/2017	Recent weather has caused the harmful algal bloom of the blue-green Aphanizomenon spp.	Y

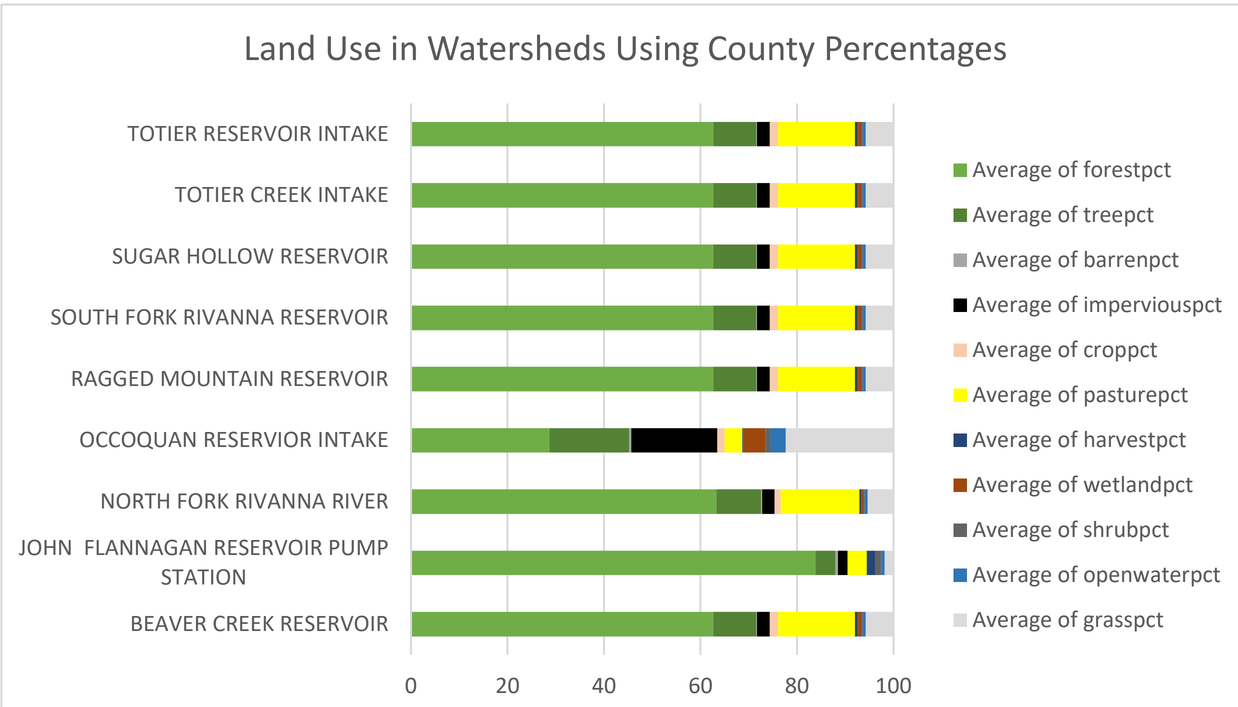

Figure 3. Land Use in Watersheds Using County Percentages.

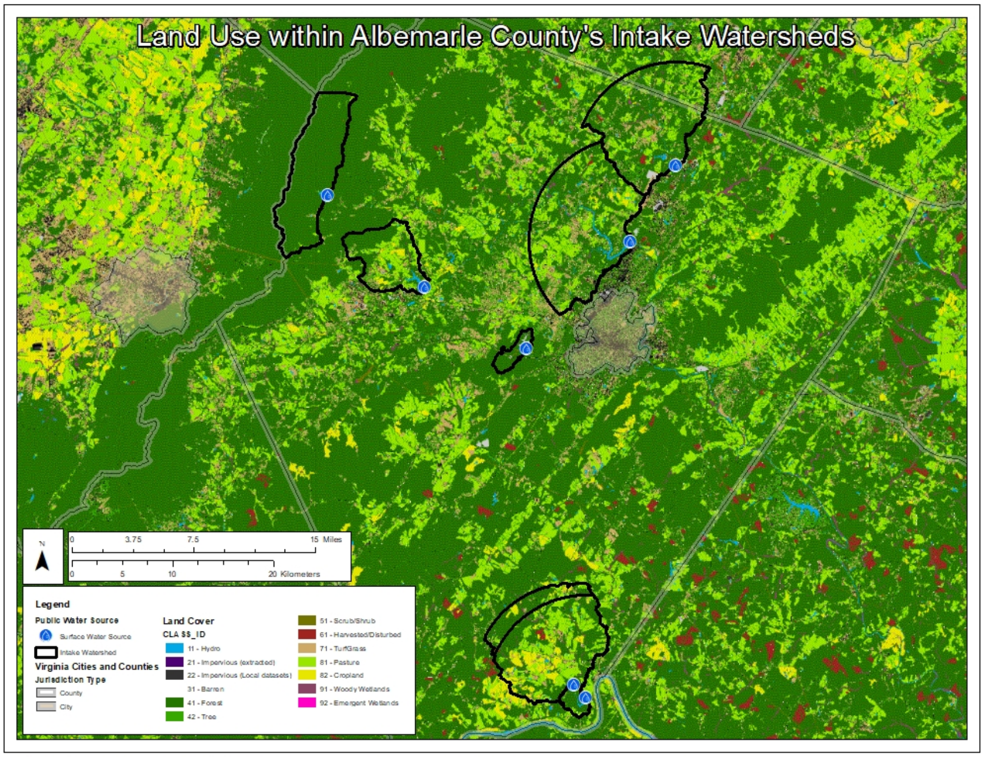

Figure 4. Land Use within Albemarle County's Intake Watersheds

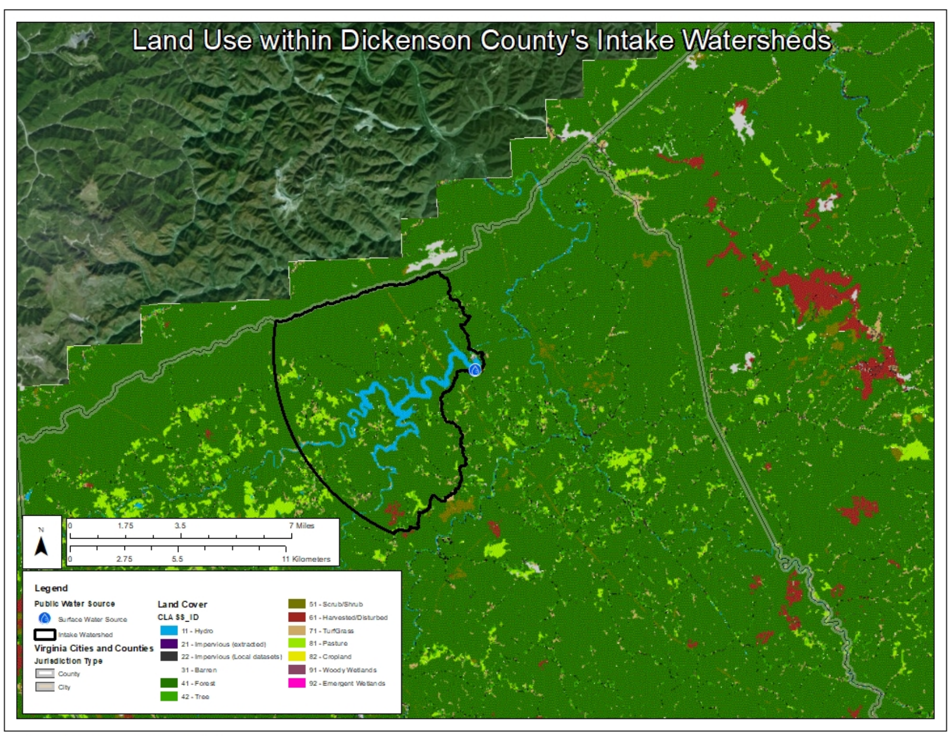

Figure 5. Land Use within Dickenson County's Intake Watersheds

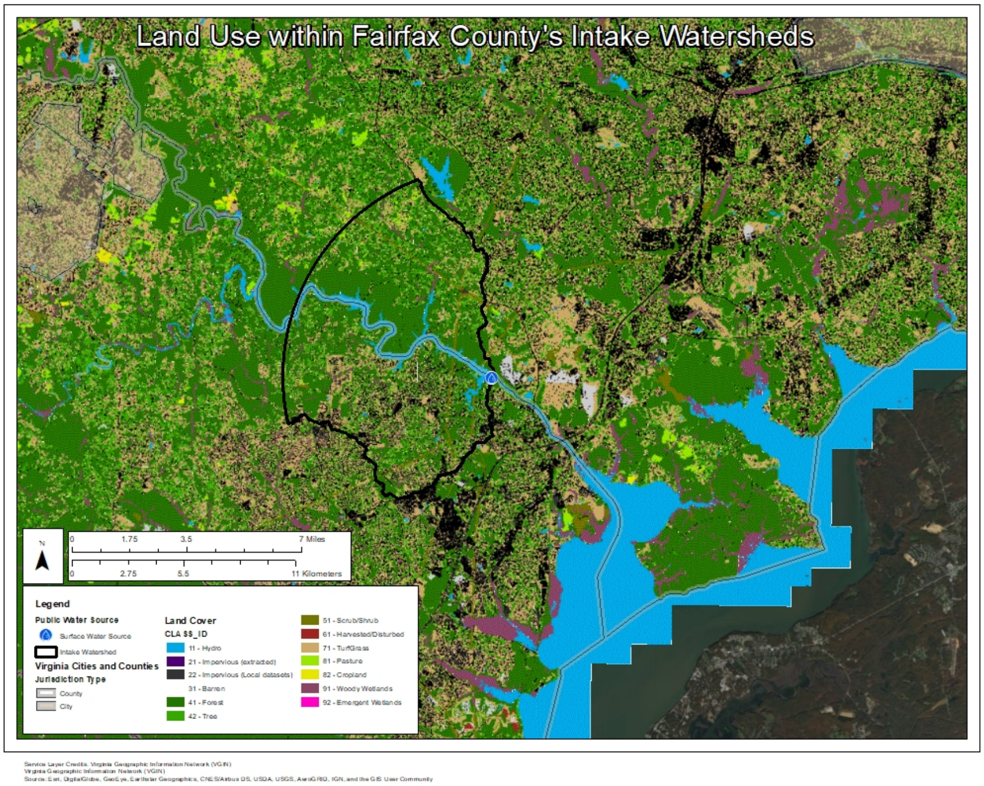

Figure 6. Land Use within Fairfax County's Intake Watersheds

Population and Median Household Income

The additional population and median household income tables derived from the SQL queries can be seen in Tables 3 and 4. The only intake where the population dropped and the median household income is below the U.S. 2017 average of $59,039 is the John Flannagan Reservoir in Dickenson County. The population in southwestern Virginia has been steadily dropping with the reduction in coal demand, as much of the industry in the area is coal mining. Both having a reduced customer base and having a customer base with a low median household income can impact the utility's financial ability to respond to an expensive HAB event response or for local governments to provide economic incentives to reduce non-point source pollution in the community (National Science and Technology Council Subcommittee on Ocean Science and Technology, 2017). The population change and median household income may also help explain the bloom report distribution. Fairfax County is considered a suburb of Washington D.C. and has exploded in population and in high-paying jobs due to the proximity to our nation's capital.

The waterworks in this area have the finances to monitor, respond, and mitigate the impacts of a HAB event. The utility also provides water to many high-profile locations and is more proactive to maintain public trust in their ability to provide clean water. Albemarle County also has had an increase in population and has an above-average median household income. Additionally, the City of Charlottesville and the University of Virginia border Albemarle County, and resources from the college and the city help to provide support for algal monitoring as well. This increase in finances and population may help explain why there were fewer bloom reports near intakes compared to Dickenson County even though the county has more agricultural influences.

Table 3. Population Change within the Counties of Target Watersheds

Facility Name	System Name	Population Change 2010-2017
SOUTH FORK RIVANNA RESERVOIR	SOUTH RIVANNA WTP	8,488
TOTIER RESERVOIR INTAKE	SCOTTSVILLE WTP	8,488
BEAVER CREEK RESERVOIR	CROZET WTP	8,488
SUGAR HOLLOW RESERVOIR	OBSERVATORY WTP	13,875
NORTH FORK RIVANNA RIVER	NORTH RIVANNA WTP	9,638
OCCOQUAN RESERVIOR INTAKE	FAIRFAX COUNTY WATER AUTHORITY	118,427
RAGGED MOUNTAIN RESERVOIR	OBSERVATORY WTP	8,488
TOTIER CREEK INTAKE	SCOTTSVILLE WTP	8,488
JOHN FLANNAGAN RESERVOIR PUMP STATION	JOHN FLANNAGAN WATER AUTHORITY	-1,071

Table 4. Median Household Income within the Target Counties.

FIPS Code	County	Median Household Income (U.S. Dollars)	Margin of Error (U.S. Dollars)
51003	Albemarle County	70,342	1,896
51051	Dickenson County	31,226	3,132
51059	Fairfax County	114,329	1,028

Future Research

Additional research should be done on other sources of nutrients beyond land use, such as the sewer vs. septic system use in watersheds. Education levels within watersheds as well as research in outreach specifically on HAB events could also provide insight. Quantifying the benefits of financial assistance from federal, state, and local governments to reduce nutrient loading should also be studied. Ultimately, HABs are a complex subject of interest and of increasing public concern, so extensive research is needed for years to come about the causes, human impacts, and mitigation, response, and future prevention.

References

Barrett, S. M., Chandler, J. L., Bolding, M. C., & Munsell, J. F. (2012). *Forest Harvesting in Virginia.* Blacksburg, Virginia: Department of Forest Resources and Environmental Conservation.

Berardo, R., Formica, F., Reutter, J., & Singh, A. (2017). *Impact of Land Use Activities in the Maumee River Watershed on Harmful Algal Blooms in Lake Erie*. Retrieved 5 1, 2018, from http://cse.ucpress.edu/content/early/2017/06/13/cse.2017.sc.450561

Environmental Protection Agency. (2017, April 7). *Harmful Algae Blooms*. Retrieved from USEPA: https://www.epa.gov/nutrientpollution/harmful-algal-blooms

Environmental Protection Agency. (2017, November 9). *Harmful Algal Blooms & Drinking Water Treatment*. Retrieved from https://www.epa.gov/water-research/harmful-algal-blooms-drinking-water-treatment: https://www.epa.gov/water-research/harmful-algal-blooms-drinking-water-treatment

Heisig, E. (2018, April 12). *Judge chastises Ohio, U.S. EPAs in lawsuit over Lake Erie's algal bloom-covered western basin*. Retrieved from Cleveland.com: http://www.cleveland.com/court-justice/index.ssf/2018/04/judge_chastises_ohio_us_epas_i.html

Jochem, G. (2017, November 9). *Algae Toxins In Drinking Water Sickened People In 2 Outbreaks*. Retrieved from NPR: https://www.npr.org/sections/health-shots/2017/11/09/563073022/algae-contaminates-drinking-water

National Oceanic and Atmospheric Administration. (n.d.). *Harmful Algae Blooms*. Retrieved from NOAA: https://oceanservice.noaa.gov/hazards/hab/

National Science and Technology Council Subcommittee on Ocean Science and Technology. (2017). *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation.* Wasington, D.C.: National Science and Technology Council Subcommittee on Ocean Science and Technology.