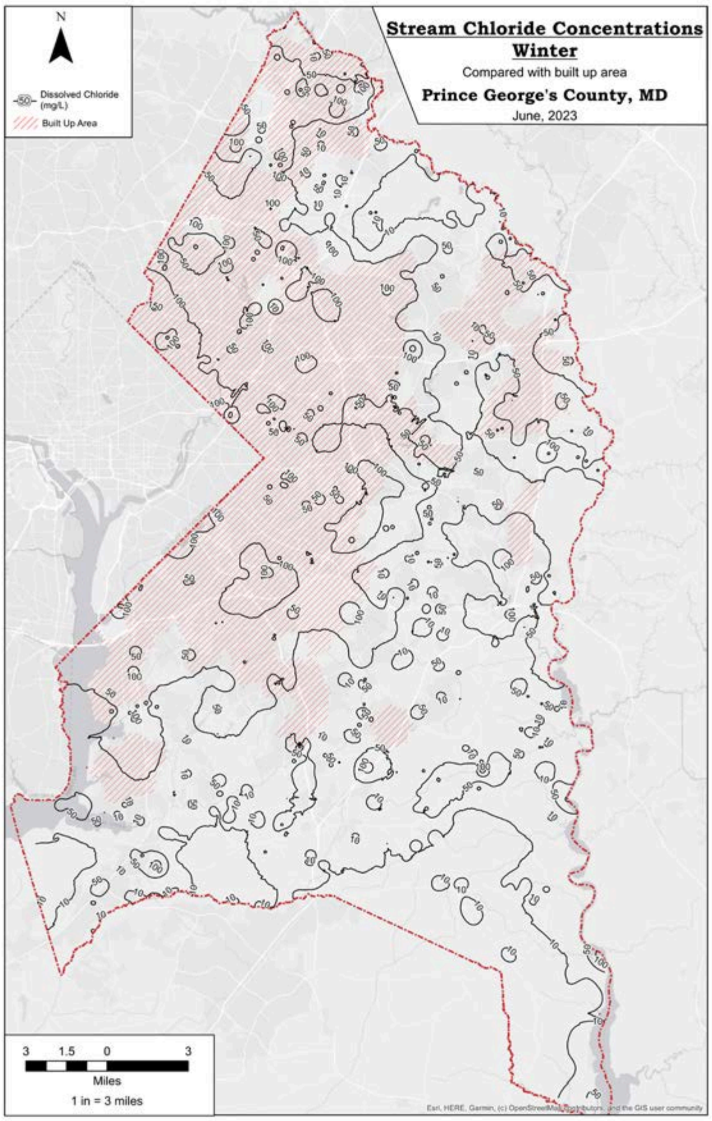
Salt Management Requirements and Recommendations

March 19, 2024



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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ANOVA	analysis of variance
BIBI	benthic index of biotic integrity
AASHTO	American Association of State Highway and Transportation Officials
AVL	automated vehicle location
BMI	benthic macroinvertebrate
BMP	best management practice
Ca^{2+}	calcium ion
CCME	Canadian Council of Ministers of the Environment
Cl^{-}	chloride ion
CO_3^{2-}	carbonate ion
D.C.	District of Columbia
°C	degrees Celsius
°F	degrees Fahrenheit
DCA	Ronald Reagan International Airport
DNR	[Maryland] Department of Natural Resources
DoE	[Prince George's County] Department of the Environment
DPIE	[Prince George's County] Department of Permitting, Inspections and Enforcement
DPW&T	[Prince George's County] Department of Public Works and Transportation
EMS	emergency medical services
EPT	ephemeroptera, plecoptera and pulmonate
FHWA	Federal Highway Administration
FOM	facilities operation and management
HCO_3^{-}	Bicarbonate ion
ICPRB	Interstate Commission on the Potomac River Basin
IDW	inverse distance weighting
K^{+}	potassium ion
lbs	pounds
MARWIS	Mobile Advanced Road Weather Information Sensors
MBSS	Maryland Biological Stream Survey
MD	Maryland
MDSD	Maryland Division of State Documents
MDOT	Maryland Department of Transportation
MDSS	Maintenance Decision Support System
mg/L	milligrams per liter
Mg^{2+}	Magnesium ion"
M-NCPPC	Maryland-National Capital Park and Planning Commission
µS/cm	micro siemens per centimeter
MPCA	Minnesota Pollution Control Agency
MS4	municipal separate storm sewer system
MWCOG	Metropolitan Washington Council of Governments
NVRC	Northern Virginia Regional Commission
NWIS	National Water Information System
Na^{+}	sodium ion

NaCl	sodium chloride
NCEI	National Centers for Environmental Information
NWIS	National Water Information System
NWQMC	National Water Quality Monitoring Council
OCR	Office of Community Relations
OCS	Office of Central Services
OEM	Office of Emergency Management
PSA	public service announcement
R^2	correlation coefficient
RA	relative abundance
RWIS	road weather information system
SaMS	salt management strategy
SBI	salinity biotic index
SC	specific conductance
SDC	sensitivity distribution curve
SHA	State Highway Authority
SMP	salt management plan
SO_4^{2-}	sulfate ion
SSAt	Smart Salting Assessment tool
STORET	STOrage and RETrieval
S.T.O.R.M.	Statewide Transportation Operations Response Map
TITAN	Threshold Indicator Taxa ANalysis
TMDL	total maximum daily load
TV	tolerance value
U.S.	United States
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WATERS	Watershed Assessment, Tracking & Environmental Results System
WIP	watershed implementation plan
WSSC	Washington Suburban Sanitary Commission

1.0 INTRODUCTION AND BACKGROUND

Increased chloride (equivalently, salinity) concentrations in surface water are a growing concern in Prince George's County (the County) due to winter salt annual applications leading into accumulations in the watershed. The County has five watersheds (Anacostia, Mattawoman, Piscataway, Upper Potomac tidal, and Upper Patuxent) on Maryland's (MD) list of impaired waters due to chloride. Winter deicing operations are believed to be a principal cause of chloride impairment.

The purpose of this memorandum is to quantify the chloride levels in the County waters, provide a review of best salt management practices from other areas around the Country, and develop materials for winter deicing education and outreach. This memorandum covers five topics:

- a description of stream chloride concentration patterns and the benthic macroinvertebrate (BMI) community structure as a function of winter deicing salt application;
- identification of salinity hotspots by subwatershed;
- an outline of the current state of salt management in the County;
- suggestions based on experiences in other counties in the state of Maryland and beyond for better salt management; and
- suggestions for using outreach materials, partner channels, and distribution methods for sharing information and educating the public.

1.1 THE NEED FOR SALT MANAGEMENT

A study in Minnesota found that over 70 percent of salt applied to roads remains in the local watersheds (Stefan et al. 2008). Rock salt is the most applied deicing agent in the United States. Rock salt is predominantly sodium chloride, which increases soil alkalinity over time and causes cumulative damage to plants, macroinvertebrate communities in soil and water, and degraded water quality. Maryland Department of the Environment (MDE) states that the accumulation of chlorides in the soils, streams, and groundwater has serious deleterious effects to human and natural systems (2023).

These include stream ecosystems effects that:

- are detrimental to aquatic macroinvertebrates, impair the osmoregulation and growth of native freshwater fish, and degrade the spawning habitat of migratory anadromous fish such as perch and herring,
- poison native animals, birds, and plants by high chloride content that reduces the oxygenation of soils and contacting waters (sometimes leading to anoxia), and
- become corrosive and detrimental to soil and biotic communities when brine (a liquid solution of sodium chloride and magnesium chloride) is used to pre-treat surfaces and remove the potential for bond formation between ice and road surfaces.

In addition to human health effects that:

- degrade water quality at residences,

- increase the rate of human health concerns including risk of cardiovascular illness, hypertension, and electrolyte imbalances in high-risk demographics such as children, the elderly, and people with heart, liver and kidney ailments, and
- restrict the use of salt-impaired stream- and groundwater usage in critical health services such as dialysis.

The application of chloride-based deicers can also have deleterious effects on infrastructure including:

- the corrosion of steel in reinforced concrete structures, as well as oxidization of the concrete, causing deterioration and cracks in roads, sidewalks, bridges, culverts, and stormwater drainage pipes,
- spray from salted roads leading to vehicle rust,
- the corrosion of stormwater conveyance pipes causing metals to leach into drinking water, damaging stormwater retention infrastructure while diminishing their effectiveness, and
- corrode home water pipelines and appliances.

Therefore, there is a need for the County to effectively manage salt application operations to maintain public safety priorities while providing for the protection of public waterways and drinking water supplies. The County is currently implementing a variety of best practices for salt management and has additional improvements earmarked for the coming years (PGC DPW&T 2014). For example, In the winter of 2021/2022, the County had substantially reduced its salt usage to 14,911 tons, a reduction of 14 percent from the previous year, by treating only hills, cold spots, and bridges during a subset of storm events (PGC DoE 2022). The subsequent sections in this memorandum provide data and approaches useful for augmenting these practices further.

1.2 SALT LEVELS IN THE COUNTY

In the County, areas with substantial impervious cover are associated with increased levels of biological degradation. Figure 1 shows the chloride concentration contours (black lines) and the salinity biotic index (SBI; color levels)—a metric of stream benthic ecosystem health—in winter superimposed on a map of the subwatersheds (dashed blue lines) and built-up impervious areas (green hatch). A detailed explanation of how these quantities were derived is presented in Section 2 of this document. Briefly, the SBI is a relative score between 0 (comparatively pristine streams) and 10 (comparatively degraded streams) indicating biological habitat quality.

The SBI values are lower than 5 along the Potomac River and Patuxent River, along with certain pockets in the north and south. These lower SBI values indicate elevated stream health (low degradation) and a higher number of salt-sensitive macroinvertebrates taxa. However, over large parts of the County, the SBI ranges from 5 to 7.5 indicating moderate stream degradation. In areas with significant development (northern portion of the County and inside the Beltway) and high chloride concentrations, there are small areas of SBI values greater than 7.5, indicating elevated rates of biological degradation in the invertebrate community that has become dominated by salt-tolerant taxa. In Figure 1 the more urbanized areas are a surrogate for areas where winter deicing salt application likely occurs. The patterns indicate that better management of winter deicing salt application is needed to prevent further environmental degradation and, potentially, reverse the current effects.

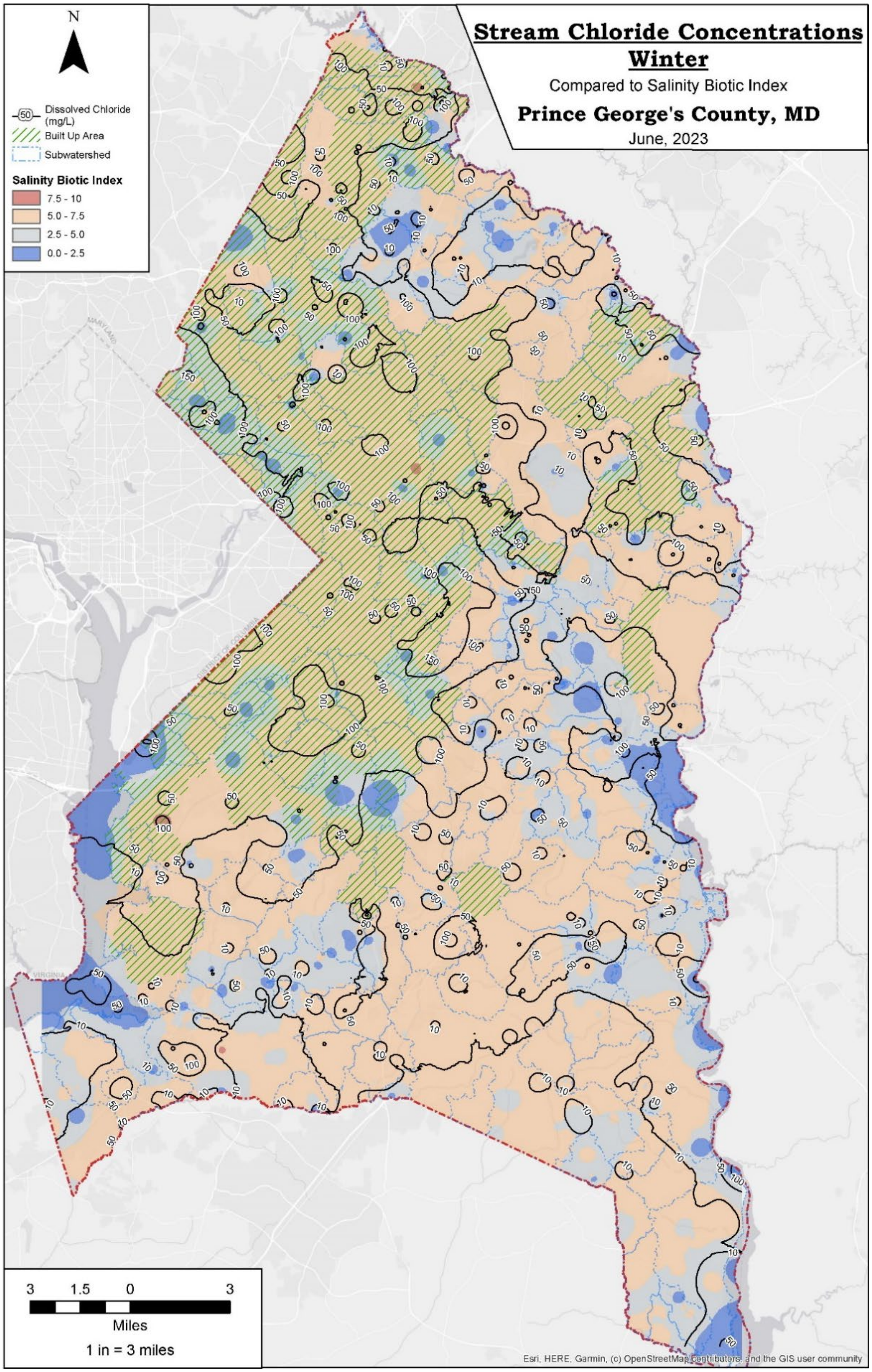


Figure 1. Chloride levels above background versus salinity biotic index shows biological degradation in built-up areas.

1.3 WATER QUALITY CONCERNS WITHIN THE COUNTY

The County has five watersheds listed as impaired due to chloride in *Maryland's Integrated Report of Surface Water Quality* (MDE 2022a). These watersheds are the Anacostia River, Mattawoman Creek, upper Patuxent River, Piscataway Creek, and the tidal upper Potomac River. Through a biostressor analysis, MDE determined that chlorides were a major stressor to biological integrity of the stream. These watersheds were placed on the Maryland 303(d) list of impaired streams as Category 5s. This category indicates that waterbody is impaired due to chlorides from road salts. These waters are a low priority for total maximum daily load (TMDL) development, but a high priority for pollutant control measures and restoration to address the listing.

Additionally, Maryland has designated Tier II high-quality waters, which are waterbodies with existing water quality that is significantly better than water quality standards. Therefore, it is critical for the County to ensure that winter deicing salt application does not degrade streams further.

1.3.1 Designated Uses and Water Quality Standards

Maryland's General Water Quality Criteria [Code of Maryland Regulations (COMAR) 26.08.02.03B(2)] states that the State waters should not be polluted by any materials to the extent that perceptible sensory and aesthetic aspects of the water are affected. The pollution must also not cause nuisance or interfere with the designated uses (see below) of the waterbodies (MDSD 2024). However, an explicit numeric water quality standard does not exist for chlorides in the State's waters.

The MDE assigns designated uses to the State waterbodies depending on the ecological function they serve (MDE 2022). A designated use is a goal for water quality based on the intended use by humans and/or aquatic life. While the designated uses may not be met currently, they should be, nonetheless, attainable. In Maryland these designated uses are grouped into "use classes" for each water body. Details on how designated use classes are assigned are available in the COMAR sections on designated uses (26.08.02.02) and anti-degradation policy (26.08.02.02-1) [MDSD 2024]. The County streams have the following designated use classes (COMAR 26.08.02.08 O) [see Table 1]:

- I: water contact recreation, fishing, and protection of nontidal warmwater aquatic life including fish (other than trout), agricultural and industrial water supply,
- I-P: water contact recreation, protection of aquatic life, and public water supply,
- II: support of estuarine and marine aquatic life and shellfish harvesting (tidal reaches only),
- II-P: support of estuarine and marine aquatic life and shellfish harvesting (tidal reaches only), and public water supply,
- III: nontidal cold water,
- III-P: nontidal cold water, and public water supply,
- IV: recreational trout waters, and
- IV-P: recreational trout waters, and public water supply.

Table 1. Designated water uses in the County based on MDE use-class groupings (Source: MDE 2022).

Designated Uses	Use Classes							
	I	I-P	II	II-P	III	III-P	IV	IV-P
Growth and propagation of fish (not trout), other aquatic life, and wildlife	X	X	X	X	X	X	X	X
Water contact sports	X	X	X	X	X	X	X	X
Leisure activities involving direct contact with surface waters	X	X	X	X	X	X	X	X
Fishing	X	X	X	X	X	X	X	X
Agricultural water supply	X	X	X	X	X	X	X	X
Industrial water supply	X	X	X	X	X	X	X	X
Propagation and harvesting of shellfish			X	X				
Seasonal migratory fish spawning and nursery use			X	X				
Seasonal shallow water submerged aquatic vegetation use			X	X				
Open-water fish and shellfish use			X	X				
Seasonal deep-water fish and shellfish use			X	X				
Seasonal deep-channel refuge use			X	X				
Growth and propagation of trout					X	X		
Capable of supporting adult trout for a put-and-take fishery							X	X
Public water supply		X		X		X		X

1.3.2 Anti-Degradation Regulations

Maryland has designated Tier II high-quality waters, which are waterbodies with existing water quality that is significantly better than water quality standards. Per federal regulations (Title 40 of the Code of Federal Regulations section 131.12 [40 CFR 131.12]), these waters must be maintained at their high-quality level. As shown in Figure 2, very few streams within the County have been designated as Tier II high-quality waters, whose watersheds cannot assimilate any more pollution without violating antidegradation regulations. Additionally, several miles of streambanks along the Potomac, Anacostia, and Patixent River are designated as critical areas by the United States Environmental Protection Agency (USEPA). Finally, there are a few wetlands within the County as well. These are all areas vulnerable to pollution and habitat degradation. It is imperative that winter deicing salt management should protect the water quality of these areas, the Tier II high-quality waters, and other streams in the County.

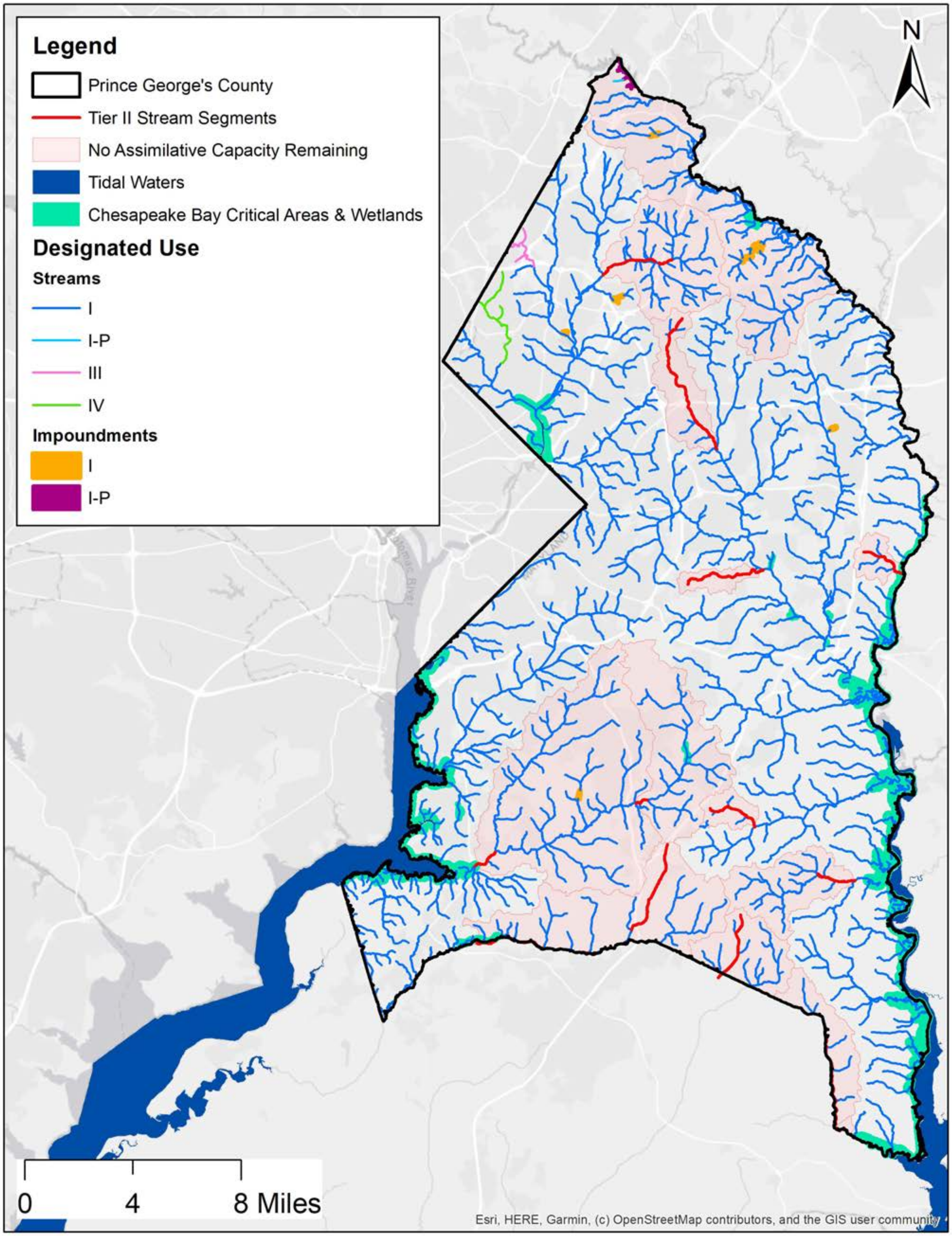


Figure 2. Designated water uses in Prince George's County.

1.4 REGULATORY LANDSCAPE FOR SALT MANAGEMENT

Tetra Tech is supporting the County's Department of the Environment (DoE) in developing suggestions for better management of its winter deicing to meet the obligation of its fifth-generation National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) permit, which was received in December 2022 (see permit Part IV.D.4.d below). This permit requires the County to reduce use of deicers and anti-icing materials. The permit states that the County is required to develop a salt management plan (see permit text below.) Additionally, the five degraded watersheds identified in Section 1.0 are on the Maryland list of impaired waters listed for chlorides (e.g., salts). This document will both advance progress towards meeting the latest permit obligations and addressing specific water impairments.

Permit Text: Part IV.D.4.d

The County shall reduce the use of winter weather deicing and anti-icing materials, without compromising public safety, by developing a County Salt Management Plan (SMP) to be submitted to the Department in its third year annual report and implemented thereafter. The SMP shall be based on the guidance provided on best road salt management practices described in the Maryland Department of Transportation, State Highway Administration's Maryland Statewide Salt Management Plan, developed and updated annually as required by the Maryland Code, Transportation §8-602.1. The County's SMP shall include, but not be limited to:

i. *A plan for evaluation of new equipment and methods, and other strategies for continual program improvement;*

ii. *Training and outreach:*

- *Creating a local "Salt Academy" that annually provides County winter weather operator personnel and contractors with the latest training in deicer and anti-icer management, or the participation of County personnel and contractors in a "Salt Academy" administered by another MS4 permittee or State agency; and*
- *Developing and distributing best salt management practices outreach for educating residents in the County.*

iii. *Tracking and reporting:*

- *Starting with the fourth year annual report, during storm events where deicing or anti-icing materials are applied to County roads, track and record the amount of materials used, and snowfall in inches per event, if applicable; and*
- *Report the deicing or anti-icing application by event or date, and the monthly and annual pounds used per lane mile per inch of snow.*

1.5 SALT MANAGEMENT RESPONSIBILITIES IN THE COUNTY

Salt management in the County occurs through various agencies with different focuses (Table 2 and 3). The County has many agencies that have programs focused on different aspects of winter deicing that include DoE, the Department of Public Works and Transportation (DPW&T), the Office of Community Relations (OCR), the Health Department, County Fire/Emergency Medical Services (EMS) Department, the Office of Emergency Management (OEM), the Department of Permitting, Inspections and Enforcement (DPIE), and the Police

Department. In addition, the Maryland State Highway Administration (SHA); and the Washington Suburban Sanitary Commission (WSSC) have programs that focus on winter deicing in the County.

Table 2. County agencies managing salt in Prince George's County.

Agency	Program	Focus	Resources	Reference
Office of Central Services (OCS)	Facilities Operation and Management (FOM) Division	Deicing treatment and snow removal at all County-owned buildings and leased facilities	Operations	PGC 2023
Department of Public Works and Transportation (DPW&T)	VisionZero	Safe driving	Public outreach and educational materials	PGC 2022
	Snow fighting equipment	Contractor trucks and County fleet of winter deicing and plowing equipment	Vehicle maintenance and operations	
	Snow Portal	Automated vehicle location (AVL)	Online tracking system	
	County Snowplow Tracker	AVL	Online tracking system	
County Fire/Emergency Medical Services (EMS)	Winter fire safety	Fire safety and smoke alarms	Educational materials	PGC 2022
Health Department	Emergency preparedness	Kidney dialysis patients	Educational materials	PGC 2022
	Snow operations	Snowplow operations and staffing	Operations	PGC 2018
Office of Emergency Management (OEM)	Emergency preparedness	Road safety, snow preparedness, and home safety	ALERT service	PGC 2022
		Educational materials and online resources	OEM Mobile app	PGC 2021
Department of Permitting, Inspections, and Enforcement (DPIE)	Sidewalk snow and ice removal inspection program,	Private and commercial sidewalk snow and ice removal enforcement	311 mobile app	PGC 2022
Office of Community Relations (OCR)	PGC311 Call Center	Community snow hazard reporting system	311 mobile app	PGC 2021
Police Department	Emergency response	Emergency response during accidents	911 call response	PGC 2018

Table 3. State agencies managing salt in Prince George's County.

Agency	Program	Focus	Resources	Reference
Maryland Department of Transportation (MDOT) State Highway Administration (SHA)	Maintenance shops	Winter deicing and plowing equipment	Facility and vehicle maintenance and operations	PGC 2022
	Snowplow tracking	Snow plowing operations tracking	Statewide Transportation Operations Response Map (S.T.O.R.M.)	
Washington Suburban Sanitary Commission (WSSC)	Report a Problem	Reporting water mains breaks	Emergency call center	PGC 2022
	Customer Notification System	Informing residents of water mains breaks	Emergency alert system	
	Winter Ready	Home protection against ice	Educational materials	
	SaltWise	Public outreach on residential salt management	Educational materials	

1.5.1 Winter Deicing Operations Within the County

The County adopts a tiered, multi-agency approach to tackle winter deicing operations to minimize salt application and maximize safety. This tiered approach involves some agencies managing responsibility for certain paved surfaces and other agencies working with the public through enforcement and education programs to maintain clear surfaces. Specific program details include the following (PGC DoE 2022):

- SHA operates two maintenance shops with 324 vehicles including five brine trucks, multiple dump trucks, and V-box salt spreaders. The two maintenance shops also house two salt domes and seven salt barns. During heavy snow, six teams (state employees and contractors) per shop direct winter vehicle operations round-the-clock to ensure deicing of all the state highways. The movements and operations of the snowplows are tracked in real time using the Statewide Transportation Operations Response Map (S.T.O.R.M.), and automated vehicle location (AVL) system.
- DPW&T owns and operates 135 trucks and coordinates with an additional 160 contractor trucks. In addition, DPW&T owns seven salt dump trucks and coordinates the efforts of 206 MDE and DPW&T snowplow operators and route inspectors across five snow districts (Figure 3).
- DPW&T first pretreats primary and collector roads with a brine solution prior to snow events, which are then plowed during snowfall. Plowing and treating of residential roadways, followed by dead-ends, happen after snowfall ends (Figure 3). An AVL system using the Snow Portal, an online tool, is used to manage the operation of snow vehicles.
- DPIE sidewalk snow and ice removal inspection program enforces residential and commercial property owners to remove accumulated snow and ice of thickness greater than two inches from abutting sidewalks in 48 hours after snowfall. The areas enforced include sidewalks adjacent to commercial establishments and apartment complexes, along roadways in 1.5 miles of schools, state highways, County primary roads, and major public gathering places.

1.5.2 Winter Deicing Salt Sources Within the County

Figure 3 demonstrates how above background chloride levels correlate with biological degradation in built-up areas within the County. However, not all areas and roads in the County borders are owned or managed by the County. Figure 4 presents areas and roads managed by the County and non-County entities.

Particularly in the north and central portions of the County, there are lands and roads under State or Private jurisdiction. Additionally, locations such as airports, helipads, and landing strips (Figure 4) are not typically managed by the County.

This indicates that although chloride levels due to winter deicing are generally high in the western and northern parts of the County, there are likely multiple sources of salt entering the County streams:

- Both County- and State-managed road salting activities,
- Residents using deicers on a small scale, but often over applying deicing agents on sidewalks,
- Commercial property owners improper applying salting practices, with salt pile on commercial properties and parking lots, and
- Aircraft and runway deicing operations on small local airfields.

The impairment to County streams due to these sources of salt is analyzed subsequently in Section 2.

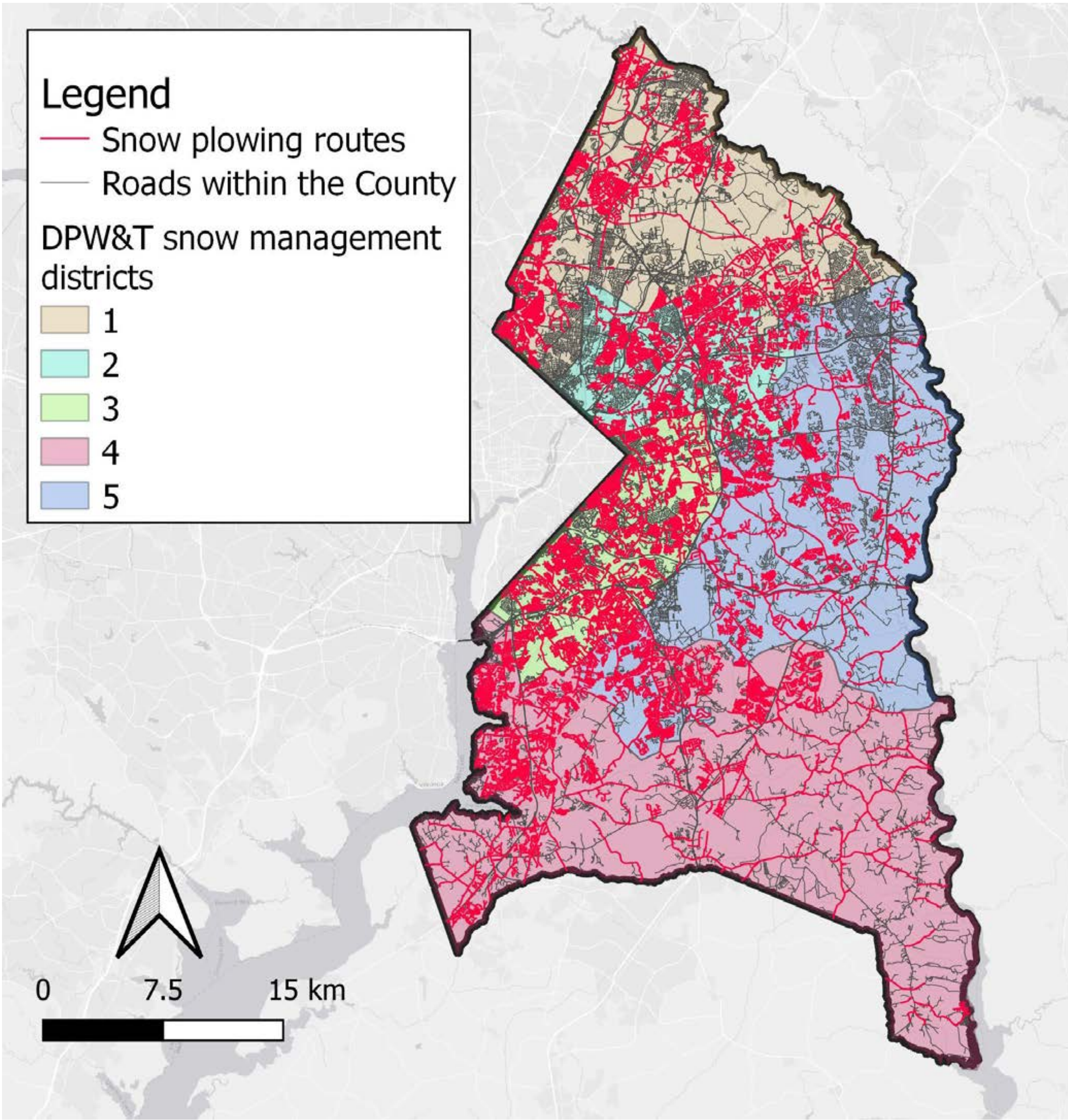


Figure 3. Department of Public Works and Transportation snow management districts (PGC 2022).

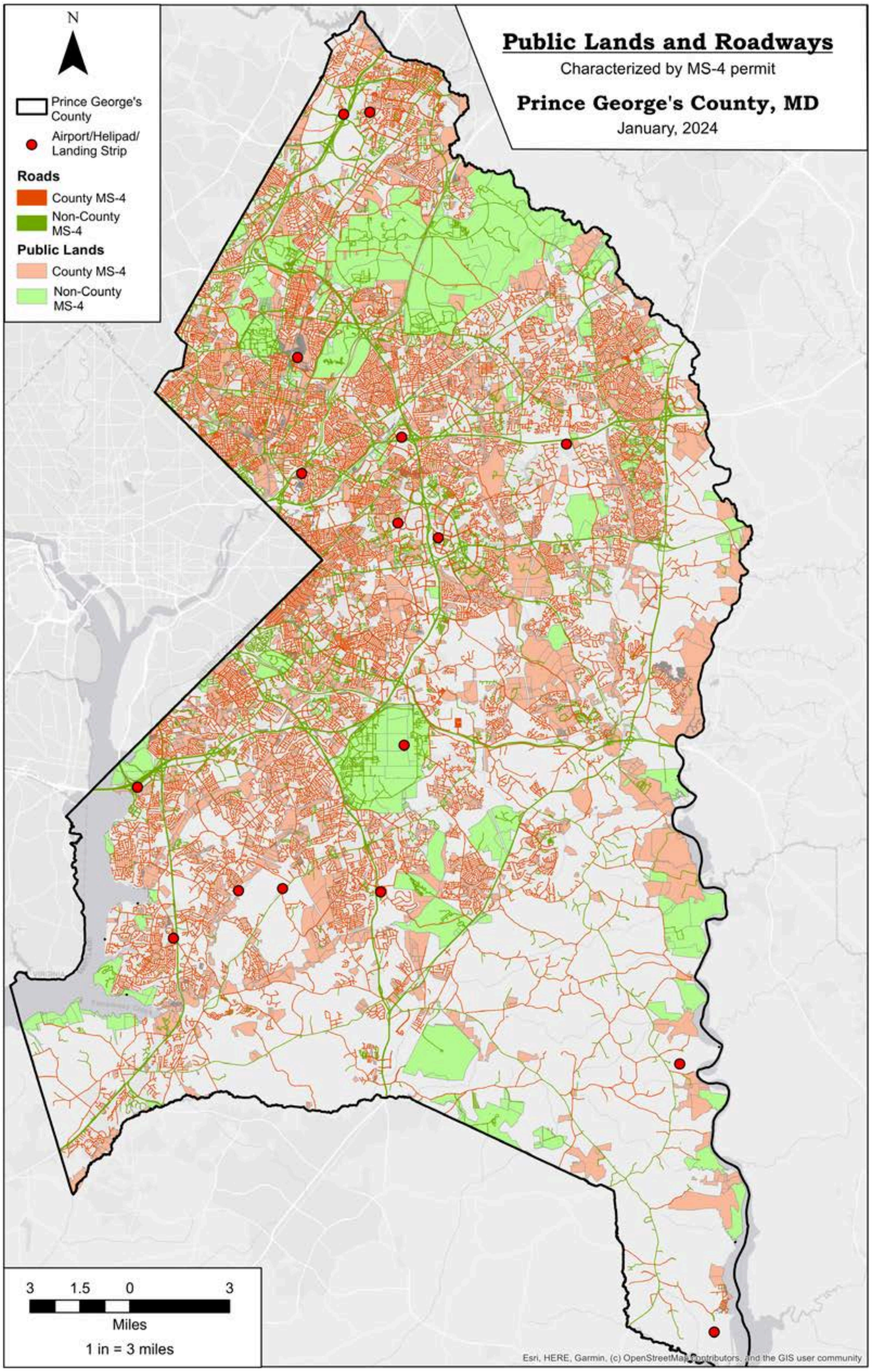


Figure 4. Potential sources of salt in County streams.

2.0 DATA ANALYSIS

This section outlines the analysis of stream chloride concentration patterns and the BMI community structure as a function of winter deicing salt application in the County. In the County, many biological subbasins contain moderate to severely biologically degraded streams, as demonstrated in Figure 5. Apart from chloride levels, there are other biological factors such as degradation of physical habitat quality, altered hydrology, lack of leaf litter and woody debris (diminished allochthonous input), low dissolved oxygen. elevated water temperature, pH imbalance, elevated conductivity, and increased numbers of invasive species that could contribute to these patterns.

One approach to quantifying the impacts of high chloride levels is by measuring how many indicator BMI genera have become extirpated (i.e., killed off) due to various environmental factors, including increasing salinity levels in the streams. This information can be used by the County to identify areas that are most vulnerable to salt accumulation, target winter deicing salt reduction approaches spatially, and focus efforts on ecosystem restoration in key areas that have become the most degraded over time.

Several analyses are presented here to better understand how the distribution of chloride-related salinity (caused by the primary anion used in winter deicing operations) concentrations in the County above background levels relates to biological degradation:

1. A **temporal trend analysis** of long-term salinity datasets from two rivers to study how salt accumulation has evolved over time (Section 2.1). This analysis will set the context of the winter deicing salt application reduction effects being undertaken by the County to protect its environment.
2. A two-step geospatial analysis to develop **quantitative maps of the spatial variation** of chloride levels in the County above the baseline at the subwatershed-scale (Section 2.3). This analysis will allow the County to better correlate potential sources of salt with the outcome of increased salinity and to quantify the role of snowfall and precipitation on salt levels in streams. To further refine the patterns observed in this coarse-scale spatial analysis, a finer-scale spatial analysis was also performed. The finer-scale analysis compared the spatial patterns of monthly chloride data collected at streams near different types of built-up areas to provide insight into how specific salting operations can lead to salinity in the County's freshwater streams.
3. A **seasonal precipitation and snowfall analysis** (Section 2.4) to better understand how stream salinity varies by season and across precipitation events, and to elicit the mechanisms by which salt enters the County's streams. This analysis will allow the County to better manage its winter deicing operations.
4. The principal biological degradation analysis involving the **development of the SBI** (Section 2.5.2), which is an abundance-weighted average of taxonomic composition and salt tolerance of BMIs; this SBI work was then paired with stream chloride levels due to salt application.

This memorandum also includes a literature review that characterizes the response of BMI communities to salinization of watersheds (Appendix A). This literature review is intended to establish the scientific basis for justifying the use of the SBI (described above) as a proxy for salinity-related environmental degradation. More broadly, this literature review guided this work and analysis to help the County understand how accumulation of salt in streams affects the environment.

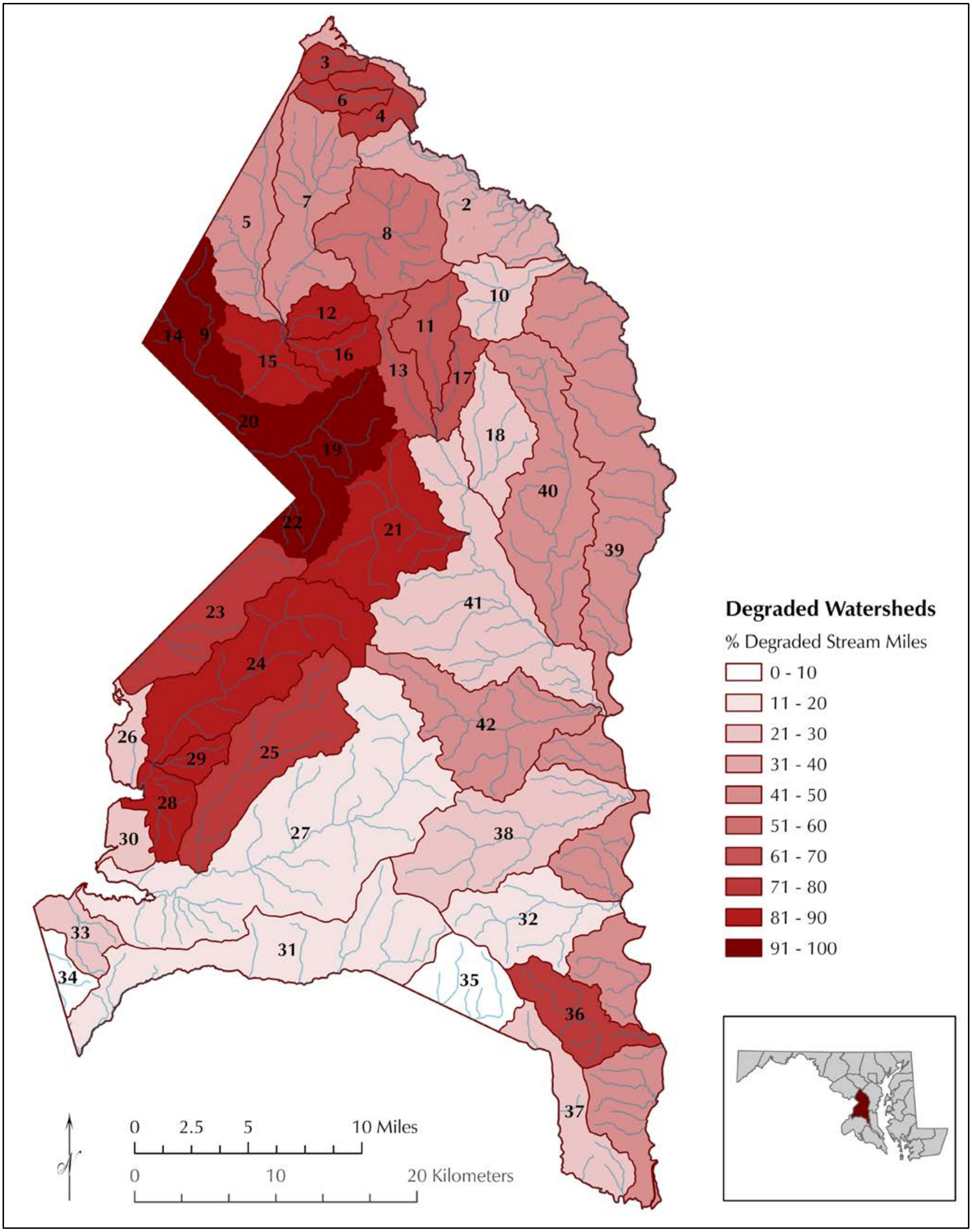


Figure 5. Percent biological degradation of streams in Prince George's County (Maryland) subbasins.

Together, these four analyses and accompanying literature review present the County with a scientific understanding of how winter deicing salt application affects the biological condition of the County's subwatersheds and identifies those areas that should be targeted for additional winter salt management activities.

2.1 CHLORIDE, BENTHIC MACROINVERTEBRATE, AND WEATHER DATA

Clean Streams, LLC conducted a literature review to characterize the response of BMI communities to watershed salinity to establish the central hypotheses that winter deicing causes salinization of the County streams (Appendix A). This literature review documented studies on the impacts of salinization on BMI communities and case studies relating winter salt application to biological degradation of streams. The key ideas are presented subsequently.

Osmoregulation in highly saline streams has been identified as a key stressor of BMIs (Roy et al. 2003). Freshwater salinization, or the accumulation of ionic salts over time in freshwater streams, degrades both water quality and biological conditions. The literature review documented this effect, particularly in relation to salinization due to chloride ions, the principal salt ion in winter deicing operations. See Appendix A for a more detailed discussion.

Winter deicing has been known to increase freshwater stream salinity over the past decade in the mid-Atlantic region. In Maryland, Moore et al. (2020) suggest that a 4-day average specific conductance (SC) (conductivity at 25^{o}C) value of 227 micro siemens per centimeter (µS/cm) could be considered detrimental to BMIs; and that a value of 300 µS/cm could be a cutoff for good stream biological health. Using the MDE-approved formula (Moore et al. 2020) for estimating chloride concentrations from SC readings, these two thresholds translate to chloride concentrations of 30.7 mg/L and 48.3 mg/L (See Section 2.1.2 for how SC is converted to dissolved chloride concentration). Daily exposure to chloride concentrations higher than 30.7 mg/L could result in biological degradation and a subsequent shift in the BMI community from mostly salt sensitive taxa to a few taxa that are largely salt tolerant (Moore et al. 2020). Typically, in Maryland, stream SC values between 227 and 243 µS/cm—resulting in estimated chloride concentrations between 30.7 and 34.6 mg/L—result in a 5 percent extirpation of BMIs (Moore et al. 2020). Chloride concentrations greater than 190 mg/L resulted in substantial degradation of biological condition (MD DNR 2013; Cormier et al. 2018). By comparison, the United States Environmental Protection Agency (USEPA) recommends limiting exposure to chronic (4-day average) chloride concentrations of 230 mg/L and acute (1-hour average) concentrations of 860 mg/L (USEPA 1988). These values are substantially higher than the thresholds reported above for biological stress. To avoid ambiguity, in this document only, a value of 48.3 mg/L (the higher end of literature reported values for biological stress of stream health) is used as a threshold to compare chloride concentrations with to illustrate potential effects.

The broad literature review found that, in Maryland, a strong correlation existed between road density and chloride concentrations in streams according to Morgan et al. (2012) and Moore et al. (2020). Furthermore, Moore et al. (2020) found that chloride concentration spikes were common in the winter. These two findings indicate that winter deicing salt applications are related to stream chloride concentration spikes in areas with a high impervious cover fraction.

The literature review also found that while chloride is the dominant ion contributing to freshwater stream salinity, other metal ions such as sodium, calcium, and magnesium, as well as heavy metal ions liberated under high salinity conditions also lead to habitat degradation (Morgan et al. 2020).

Not many studies have been conducted specifically in Maryland, its ecoregions, or physiographic provinces with respect to salt tolerance of freshwater BMIs. However, the subject-relevant literature is applicable to Maryland freshwater BMI analysis. Seven papers pertaining to BMI response to salt content in the watershed were reviewed in detail and 64 references therein were briefly summarized (See Appendix A). The seven primary papers summarized included regional studies from Maryland, Missouri, the Eastern United States (U.S.), multiple U.S. states, Toronto (Canada), and one global study. While the studies from the other geographical regions do not directly impact the findings of this analysis, they nonetheless provide context for which species are most at risk for extirpation. The results of the literature review are used to motivate the discussion around the subsequent analysis discussed below.

2.1.1 Data Sources

Salinity and benthic data were obtained by combining three data sources:

1. The USEPA STOrage and RETrieval (STORET) database (NWQMC 2023). This database contains chloride concentrations, conductivity, temperature, and SC from 475 stations in the County.
2. The United States Geological Survey's (USGS's) National Water Information System (NWIS) database of stream gages (USGS 2023). This database contains chloride concentrations, conductivity, temperature, and SC from 202 stations in the County.
3. Tetra Tech's long-term County macroinvertebrate survey database. This is a long-term program through which 1,228 conductivity samples were collected in the spring between 1994 and 2022. Since 1999, BMI surveys have also been routinely performed each year in March and April along with paired conductivity and stream temperature monitoring. This resulting database contains data from 1,067 sites randomly visited across the 41 subbasins in three major basins (Patuxent River, Anacostia River subbasin, and Potomac River subbasin, which includes Piscataway and Mattawoman Creeks) and one ecoregion (Middle Atlantic Coastal Plain) across the County (Figure 6). Of these sites, conductivity samples were observed at 1,062 sites, and in total, 1,003 sites contained both conductivity and benthic data. In the benthic sampling, 719 genera were identified with 654 taxa paired with conductivity data.

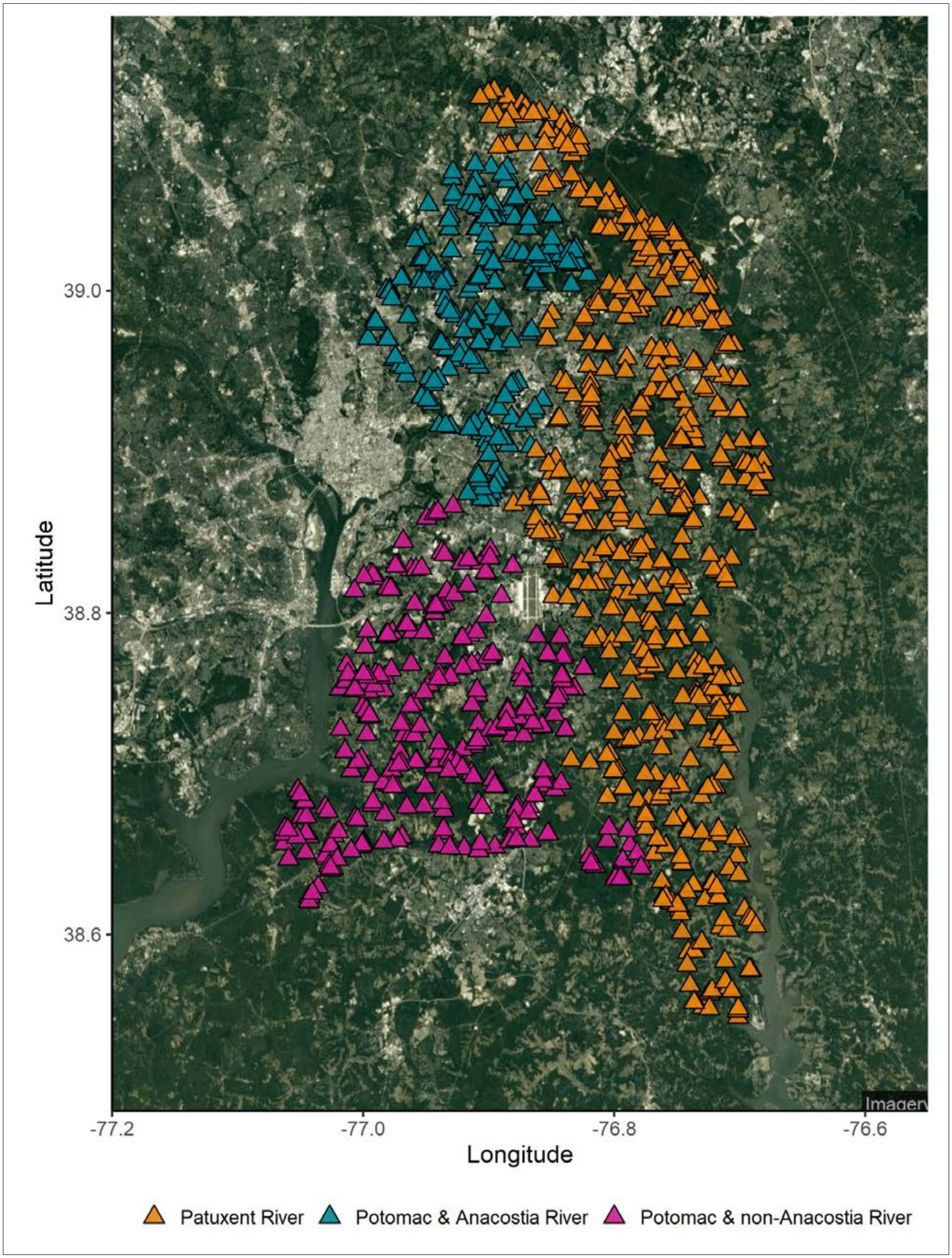


Figure 6. Map of Tetra Tech sampling locations by major basin.

2.1.2 Calculating Chloride Concentration Values

The three datasets contained chloride, conductivity (C), water temperature (t) and SC data. Since the principal salt associated with winter deicing is sodium chloride, dissolved chloride concentrations in mg/L were calculated at different points in the County by combining the chloride, conductivity, and SC data. To generate a uniform dataset, conductivity values were converted to SC by applying the formula (USGS 2019):

$$SC = \frac{C}{1 + 0.019(t - 25°\mathrm{C})}$$

These SC values (in µS/cm) were then converted to chloride concentrations ($[Cl^-]$) by adopting the MDE-approved formula (Moore et al. 2020):

$$[Cl^-] = 0.24 \times SC - 23.75$$

This formula was obtained from the supplementary table (S10) of Moore et al. (2020), which lists the slopes, intercepts, and number of samples for 20 mid-Atlantic region sites where regressions were performed between chloride and SC data. Researchers then weighted averaged (by number of samples) the slopes and intercepts of these 20 regression fits. If the chloride concentration estimated by the equation was less than zero, the concentration was set to zero; however, such instances were fewer than 1 percent of all records. If logarithmic transformations of the chloride concentrations were needed, a very small number (typically 10^{-6} mg/L) was added. This offset is several orders of magnitude below the minimum detection limits for chloride and miniscule enough to not affect any inferences concerning chloride patterns and still allow logarithms to be taken, to allow key differences in the data to be visualized.

2.1.3 Precipitation Data

Local precipitation data was collected to analyze how stream salinity levels are impacted by antecedent wetness. Hourly rainfall and daily snow depth data collected between 1999 and 2023 at Ronald Reagan International Airport (DCA) weather stations were obtained from the National Centers for Environmental Information (NCEI) database (NCEI 2023). The hourly rainfall from the same day were summed to capture the total daily rainfall. The daily total rainfall and daily snow depth data were matched with conductivity and chloride data, by date.

The antecedent rainfall conditions were assigned to each chloride concentration data point from the existing dataset by matching recent precipitation data with the sampling times, allowing the samples to be classified as wet, normal, or dry weather samples. In this approach, chloride concentration records were assigned the hourly rainfall corresponding to the sampling times. Next, the accumulated rainfall in 24 hours and 72 hours prior to the chloride datapoint time stamp event for each datapoint was calculated. Dry data were defined as datapoints without precipitation in the 72-hour period prior to the datapoint time stamp. Normal (relatively dry) weather data were defined as less than 0.5 inches accumulated rainfall in the 24 hours prior to the datapoint time stamp but with some rainfall in 72 hours prior to the datapoint time stamp. Wet data were defined as greater than 0.5 inches of rainfall in the 24-hour period prior to the datapoint time stamp.

The number of days since the last rainfall was calculated for each datapoint to explore the chloride concentration changes before and after precipitation. Similarly, daily snow depth data on the previous day was subtracted from the current day to account for accumulated snow on the day the data was collected. The days with accumulated snow were considered as snow days. The number of days since the last snow day was counted for every datapoint.

2.1.4 Salinity Biotic Index

BMI surveys were conducted during the months of March and April, to measure the relation between stream salinity and genus richness in each subwatershed in the County. The SBI is a relative score between 0 and 10 calculated from each stream benthic sample indicating the biological quality of streams.

To develop the SBI, benthic tolerance values for chloride were developed. First, the 95th percentile of chloride values for each taxa were calculated. This value is also referred to as the extirpation concentration (*XC95*). The *XC95* indicates the chloride concentration beyond which a given taxon is unlikely to be found in nature and, thereby, represents a biological threshold for the survival of that taxon. The *XC95* was calculated for taxa with at least 16 samples, so that rare taxa would not overly influence the salt tolerance values. In total, 257 taxa had sufficient data to calculate an *XC95*. Next, the *XC95* values were divided into 11 tolerance values (TV; 0 to 10). Small TVs indicate taxa that have a relatively low salt tolerance threshold, while large TVs indicate taxa that have a relatively high salt tolerance threshold, in the set of taxa sampled.

Next, a sensitivity distribution curve (SDC) for chloride was generated by plotting the cumulative distribution of taxa as a function of *XC95* values. SDC plots can be used to identify what proportion of taxa would be expected to be removed from the observed population as a biological stressor (here, chloride) levels increase.

The SBI was then developed using relative abundance (RA) of each taxon and the chloride tolerance values. The SBI is based on the Hilsenhoff Biotic Index (Hilsenhoff 1977), which is a weighted average of TVs for each sample ID (Site-Date combination), weighted by RA:

$$SBI_i = \sum(RA_j * TV_j)$$

Here, RA_j is the fraction of the number of individuals of taxon j found in the ith sample compared to the total number of individuals of that taxon. SBI values are associated with a given sample ID (site-date combination), whereas TVs are associated with a given taxon. SBI were calculated for each site-date combination. However, for each site the SBI were aggregated across time, before being used in this analysis.

SBI values can range from 0 to 10, indicating low and high salinity conditions, respectively. Values close to 0 are observed when one or both TV and RA are low. However, as the *XC95* values were only calculated for samples with at least 16 individuals, the likelihood of low SBI values occurring due to small TVs is substantially higher. Thus, low SBI values indicate stream conditions where chloride concentrations are low and the benthic assemblage is dominated by salt-sensitive taxa. Conversely, SBI values closer to 10 are observed when TVs are large and the benthic sample is dominated by salinity-tolerant taxa, that is, those able to survive in the presence of elevated salinity.

The SBI is a relative score indicating the number of salt-tolerant genera of BMI at each location. The SBI is 0 for survey points with the smallest number of salt-tolerant macroinvertebrate genera and 10 for survey points with the largest number of salt-tolerant genera. Small values of the SBI indicate greater variety of salt-sensitive macroinvertebrates, while high values indicate that most taxa are extirpated (killed off), and only highly salt-tolerant taxa are remaining. The intention is to protect salt sensitive species as well as salt tolerant species. Therefore, smaller values indicate areas where salt levels are not affecting stream health.

To make SBI maps, the SBI values during all the surveys at a location were first averaged and plotted. Then, an inverse distance weighting (IDW) interpolation was performed. In IDW, the data are weighted inversely based on a quadratic function of distance, so that the observed data near an interpolated point have a greater weight than data located further away. To perform the IDW, the raster cell size was set at 200 square feet for both chloride and SBI data, with the 12 closest neighboring points used in the interpolation.

2.1.5 Data Processing and Reporting

Data cleanup and harmonization of the three salinity data sources was undertaken according to standard methodology. Data processing was performed using Excel and R (Core Team 2023). Data analysis was performed using Excel and R by Tetra Tech, and map creation was performed using ArcMap by AB Consultants, Inc. The STORET and NWIS data sources contain records dating to 1919 and include both stream gage and well sites.

Since only surface water salt accumulation was considered in this study, all well sites were removed from the subsequent analysis. To study the long-term accumulation of salt in the County streams, two USGS stream gages with the longest series of records were selected, shown in Figure 7.

Only records from a recent period (1999 to 2022) were retained to perform a spatial and seasonal analysis of chloride patterns and the biological degradation analysis in the County. The chloride data were split into summer (May–October) and winter (November–April). All chloride data from the STORET, NWIS, and Tetra Tech databases were merged. Data was directly measured or calculated according to the process described in Section 2.1.2. BMI data are only collected in March and April, so SBI values are only available for this period. For each datapoint spatial location, the dissolved chloride and calculated chloride concentrations from all datasets over the entire 1999–2022 summer and winter months were then averaged into single summer and winter records. Similarly, the SBI values were also collapsed into a single average value at each location. This data harmonization resulted in 309 observations of average chloride concentration in the summer, and 1,057 coupled observations of chloride and SBI in the winter. The 1,057 matched winter records contain gaps in both the chloride concentration and the SBI values because some chloride concentrations do not have SBI values (particularly locations in the STORET and NWIS databases), and some locations have SBI values but no matching conductivity measurements.

The stream condition results are reported across the 41 subbasins as these are the units over which the sampling was distributed. However, the more recent County subwatershed delineation demarcates 267 subwatersheds for restoration planning. The chloride concentrations, when averaged over larger spatial scales, could mask finer-scale spatial patterns and are, therefore, reported at the subwatershed scale.

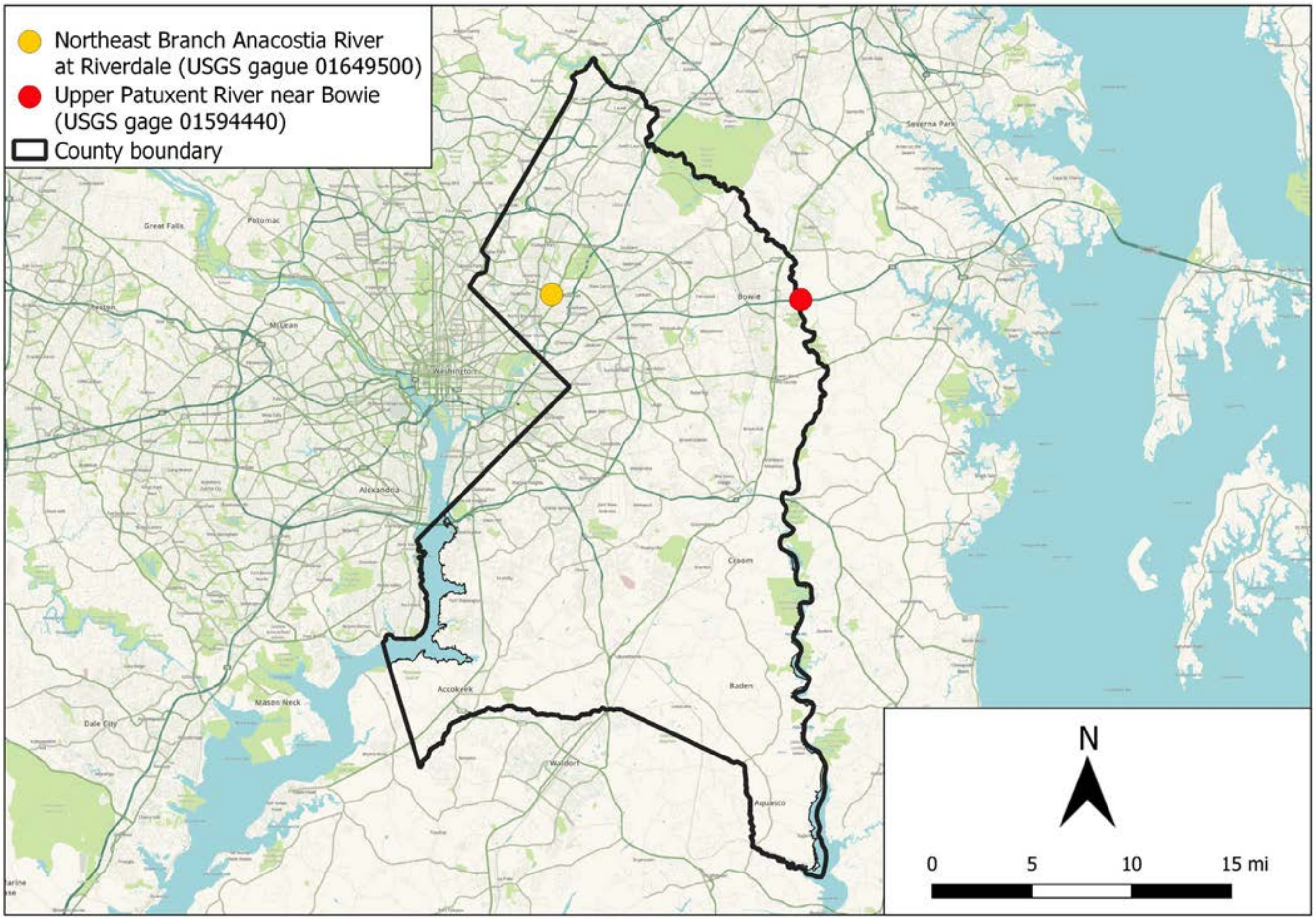
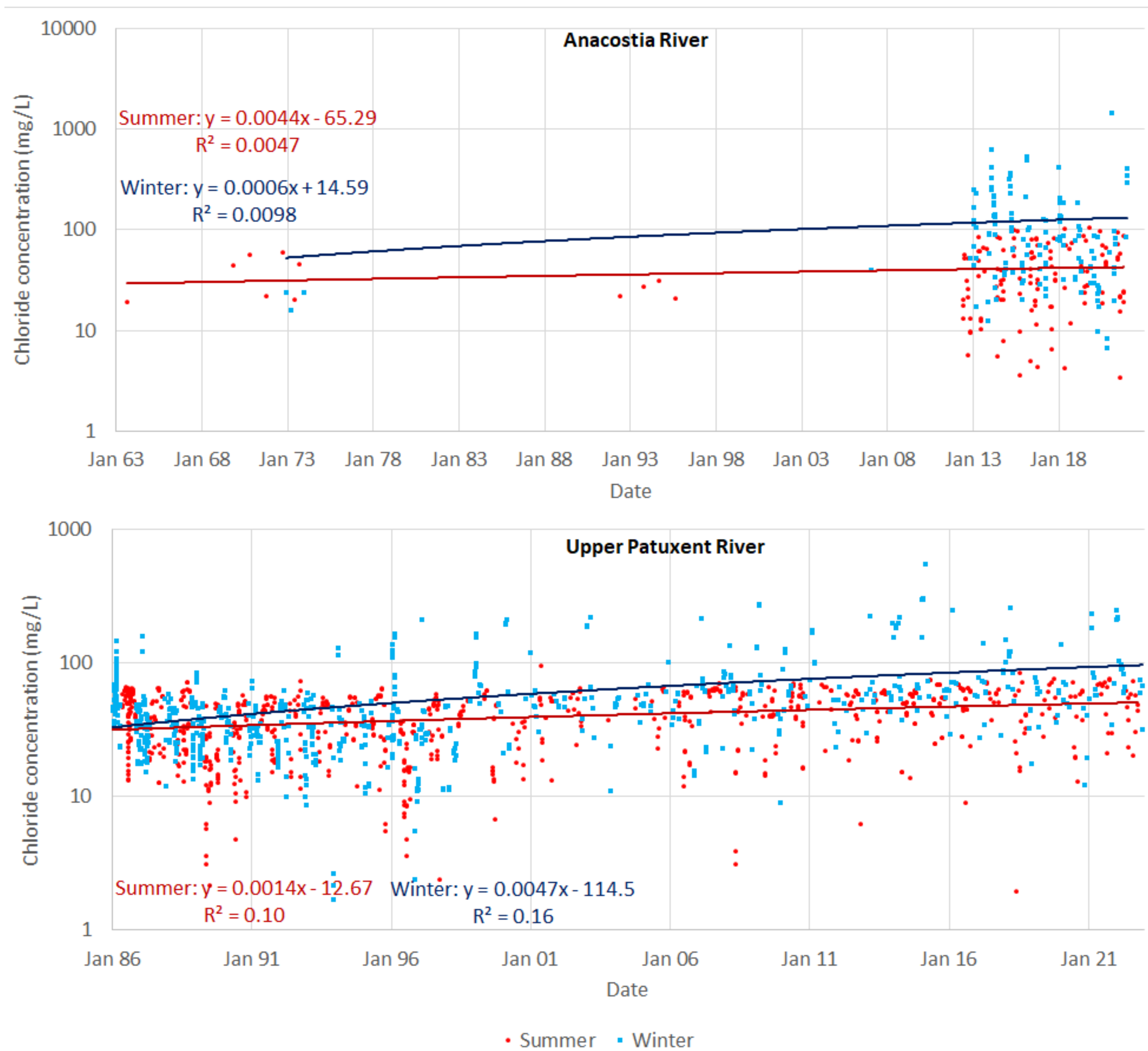


Figure 7. Anacostia River and Upper Patuxent River USGS stations.

2.2 LONG-TERM SALINITY TREND ANALYSIS

This section presents a trend analysis of long-term datasets to study salt accumulation in the County streams. Over the past six decades, salt has been accumulating in the County streams. This indicates that as deicing salt applications have increased over time, so too has the salt accumulation in the environment. Generally, weak trends in the instantaneous chloride concentrations are observed (**Figure 8**), from long-term water quality monitoring timeseries of chloride concentrations in the Northeast Branch Anacostia River at Riverdale, MD (281 records) and SC in the Upper Patuxent River near Bowie, MD (1700 records). These two locations were selected due to their continuous long-term records. These trends for the two rivers are more pronounced in the winter than in the summer (Figure 8). While most of the trends in the instantaneous chloride concentrations are statistically insignificant, the Upper Patuxent River winter trend is statistically significant with a *p* value of 0.013 (less than 0.05).

However, salt accumulation in streams is a long-term process. The annual average chloride concentrations at these two locations show much more significant trends, although with better winter deicing salt management practices over the past seven years, this trend has been reversing (Figure 9). The 5-year moving average annual chloride concentrations indicate the increasing chloride content in the County streams very clearly, with the increase faster during the winter than the summer (Figure 9).



Note: Dark red lines and text indicate summer trends and dark blue lines and text indicate winter trends. Vertical scales are logarithmic.

Figure 8. Instantaneous chloride concentrations and weak linear trends in the Anacostia and Upper Patuxent Rivers.

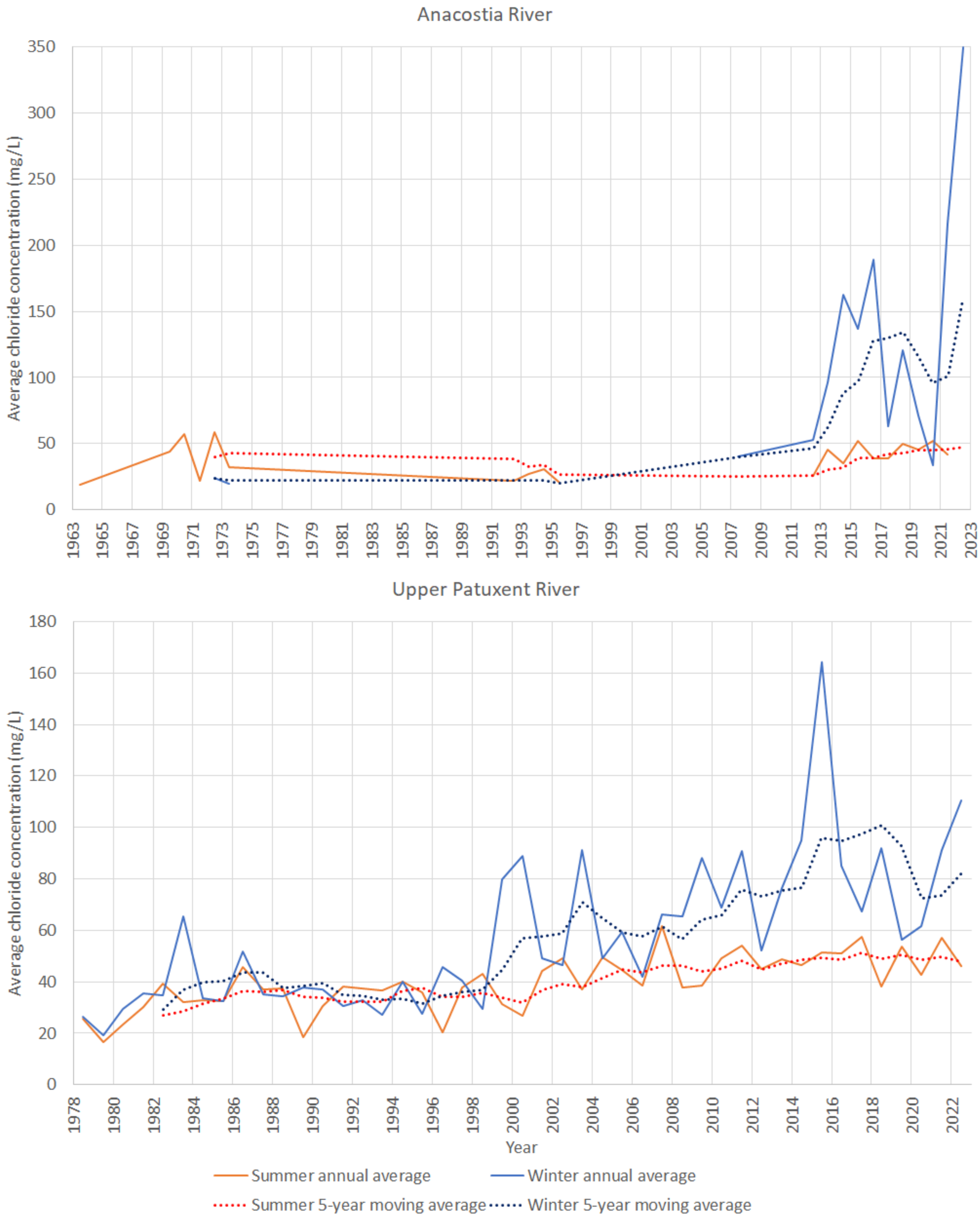


Figure 9. Average annual chloride concentrations in the Anacostia and Upper Patuxent Rivers with 5-year moving average trends.

2.3 GEOSPATIAL CHLORIDE VARIABILITY ANALYSIS

Chloride concentration data were used to visualize potential chloride *hotspots* across the county. Chloride concentration values for summer and winter are plotted in the figures below (Figure 10 to 15). To make the subwatershed chloride maps, all chloride concentrations in each subwatershed were averaged. To remove the effect of background chloride levels due to the tidal influence of brackish water inflow in the Patuxent River along the eastern boundary of the county, chloride concentrations greater than the 95th percentile of average winter levels (183 mg/L) and average summer levels (142 mg/L) were removed before generating the concentration contours. The impervious cover was used as a proxy for the intensity of salt applications to evaluate the relationship between chloride levels and deicing practices. The impervious cover (M-NCPPC 2023) in each subwatershed was summed and subwatersheds that contain more than 20 percent of impervious cover were classified as built-up areas.

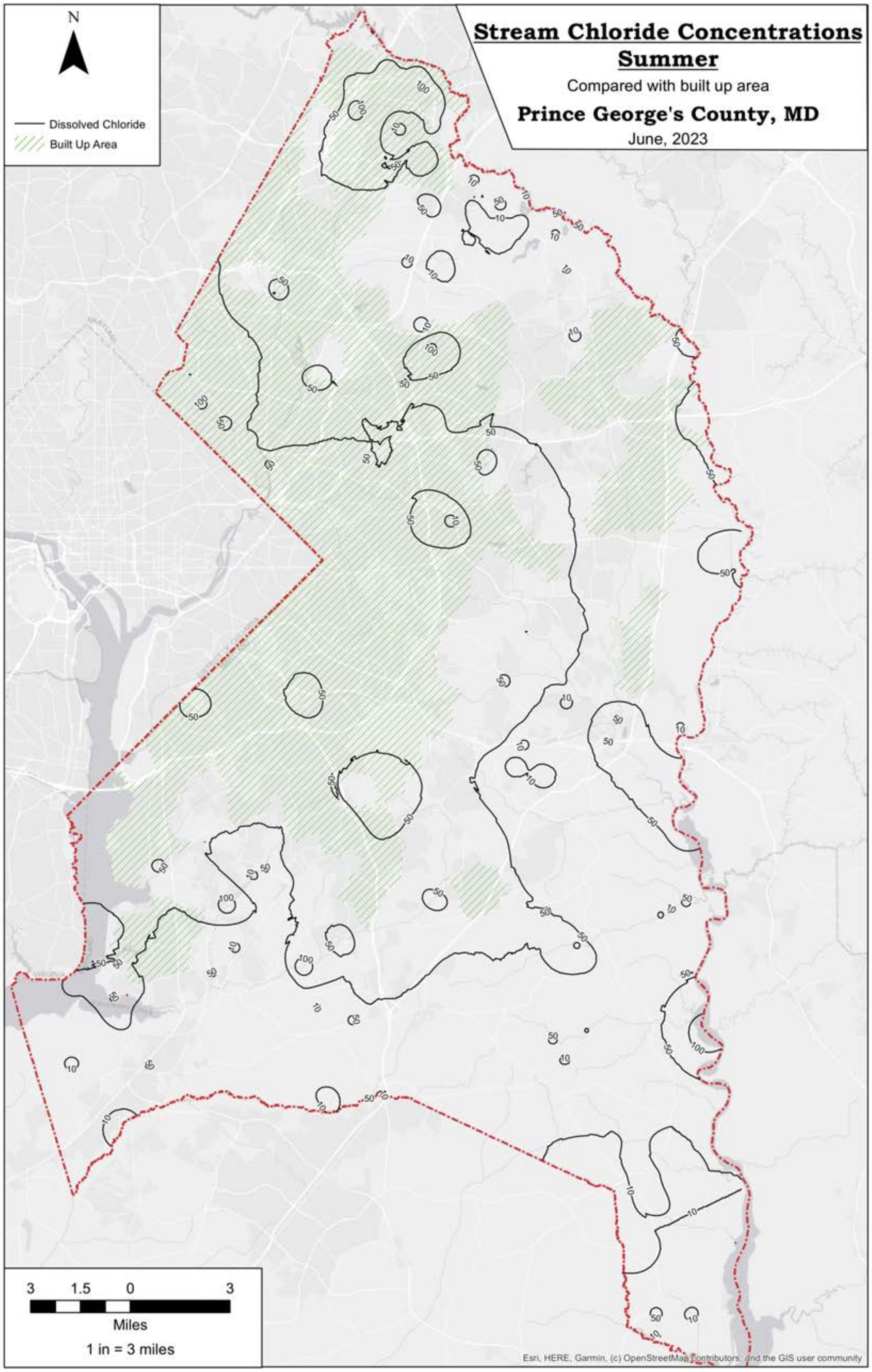
2.3.1 Coarse-scale spatial analysis

Figure 10 indicates that subwatersheds with high fractions of built-up areas have larger average chloride concentrations compared to areas with more pervious cover. These figures show chloride concentration contours averaged over the summer and over the winter between 1999 and 2022.

Figure 10 shows that in the summer, chloride levels are generally lower than about 10 mg/L in the eastern part of the County, except in areas near the tidal Patuxent River, and are generally higher than 50 mg/L in the built-up western and northern parts of the County, which is inside the Beltway bordering Washington, D.C. In the winter, Figure 11, chloride levels spike to well above 100 mg/L in the built-up areas in the County. This means that the built-up parts of the County are generally above the threshold for biologically healthy Maryland streams, or 48.3 mg/L (Moore et al. 2020).

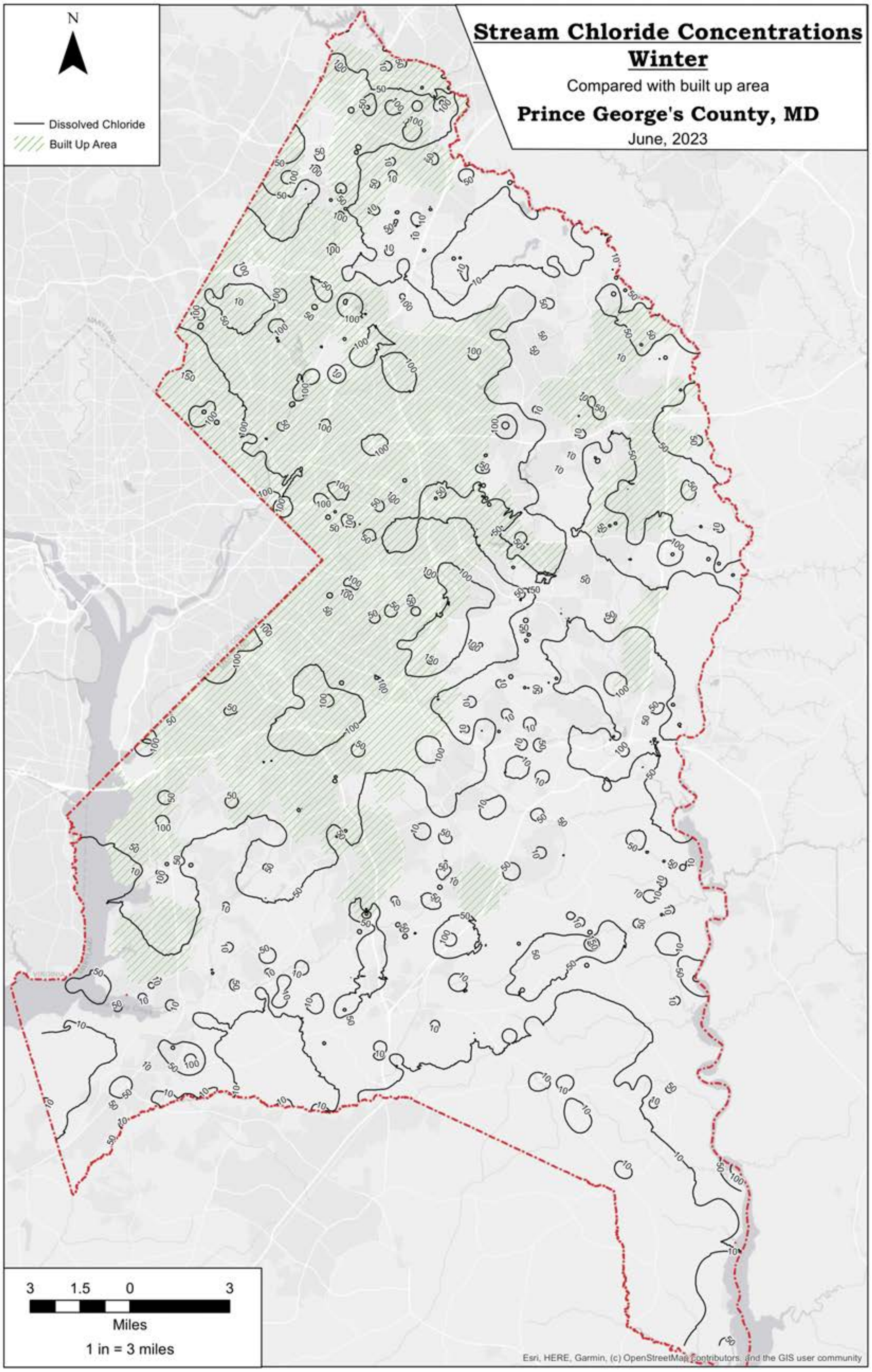
Figure 12 and Figure **13** suggest higher chloride concentrations in the north and western portions of the County and low to moderate concentrations in the eastern and southern rural parts of the County. To make these subwatershed by chloride color maps, the chloride values in each subwatershed were averaged. In these and subsequent maps, subwatersheds without any color indicate that no datapoints were available in them to average over. These maps suggest that chloride concentrations appear greater in the winter, especially in developed areas. This pattern is to be expected, since more road salt is applied in the winter and more road salt is applied in urban areas compared to rural areas. These patterns are corroborated by the chloride concentration contour maps in Figure 10 and 11.

Figure 14 and Figure **15** show chloride concentration contours, along with different types of impervious area, as well as eleven road salt dome locations associated with the County Department of Public Works and Transportation (DPW&T) [five domes] and the Maryland State Highway Authority (SHA) [six domes]. The Countywide chloride contours do not suggest surges in chloride concentrations adjacent to the salt dome locations. However, increases in chloride concentrations associated with salt domes could be higher at a more localized, spatial scale.



Note: Hatching represents subwatersheds with ≥20% impervious area.

Figure 10. Long-term chloride concentration contours in the summer.



Note: Hatching represents subwatersheds with ≥20% impervious area.

Figure 11. Long-term chloride concentration contours in the winter.

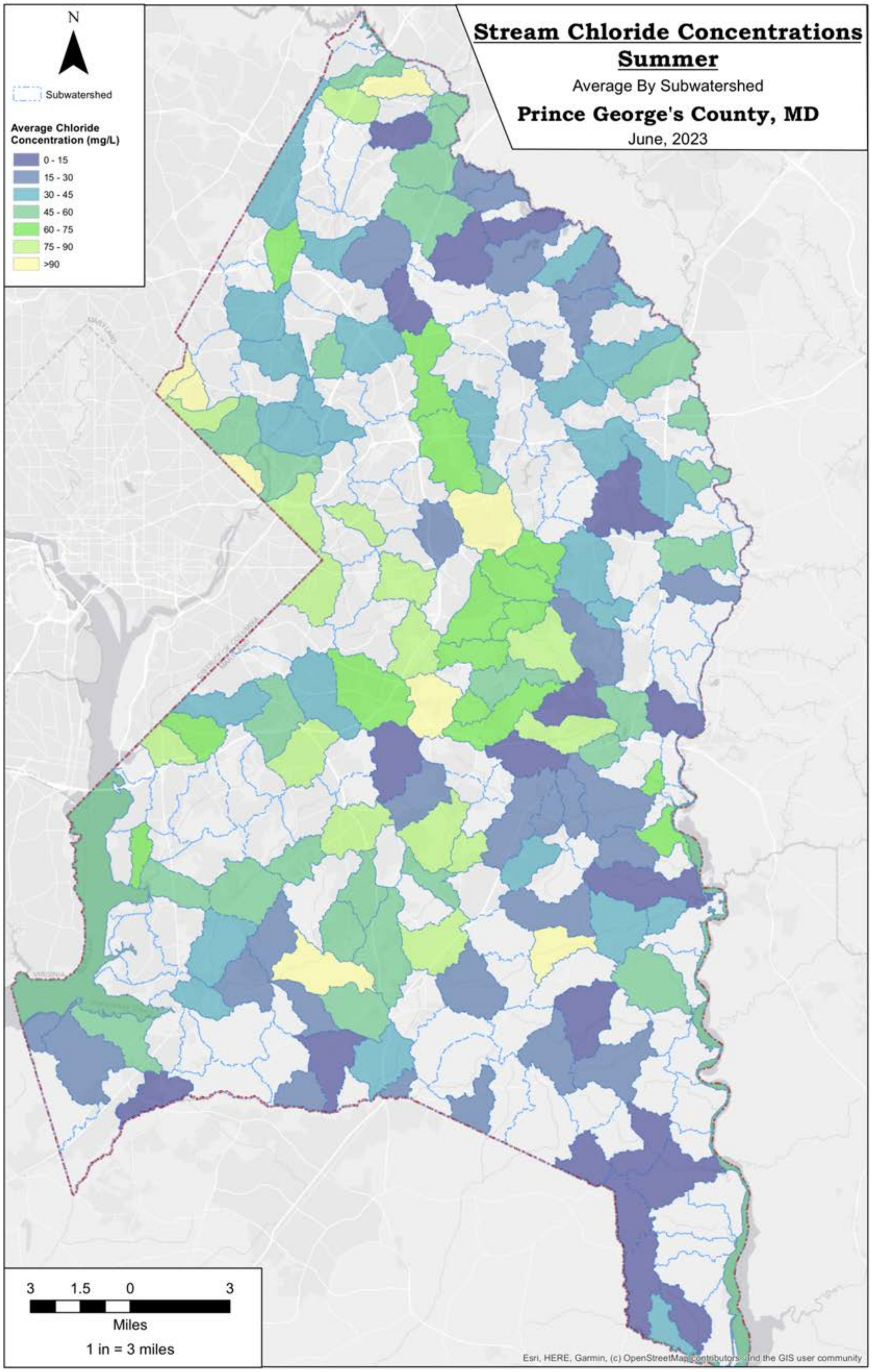


Figure 12. Long-term calculated chloride concentrations during the summer by subwatershed.

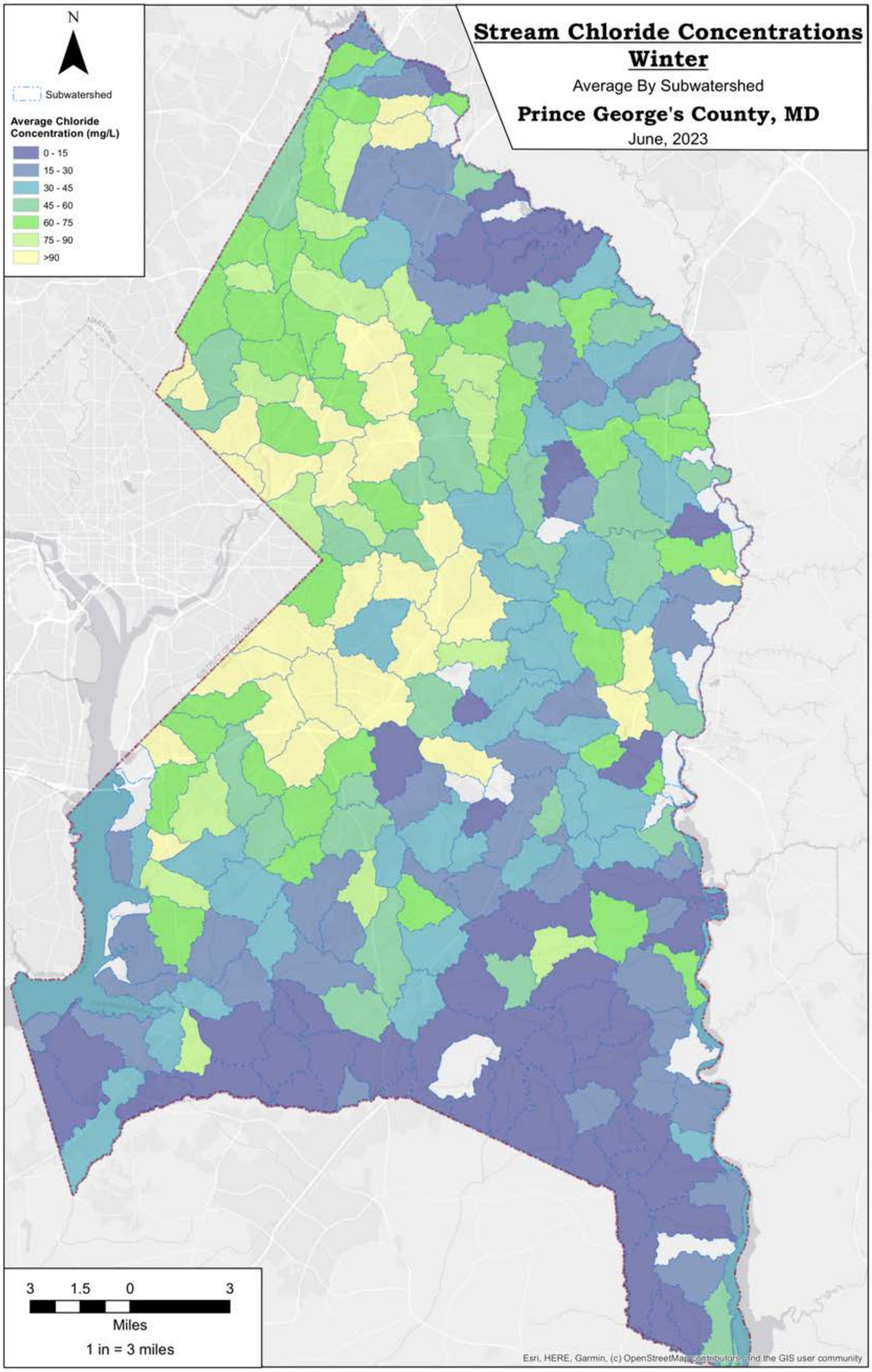
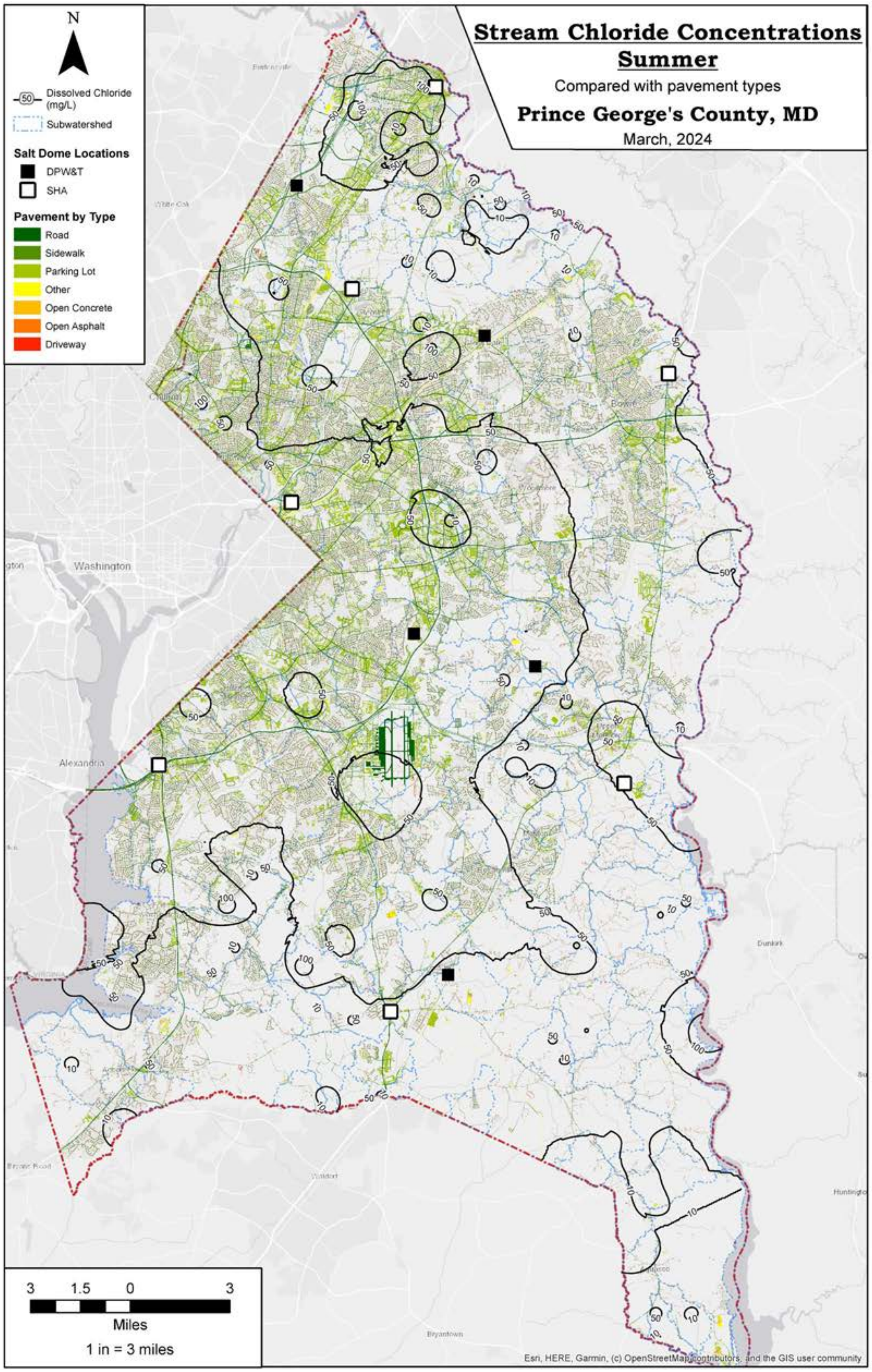
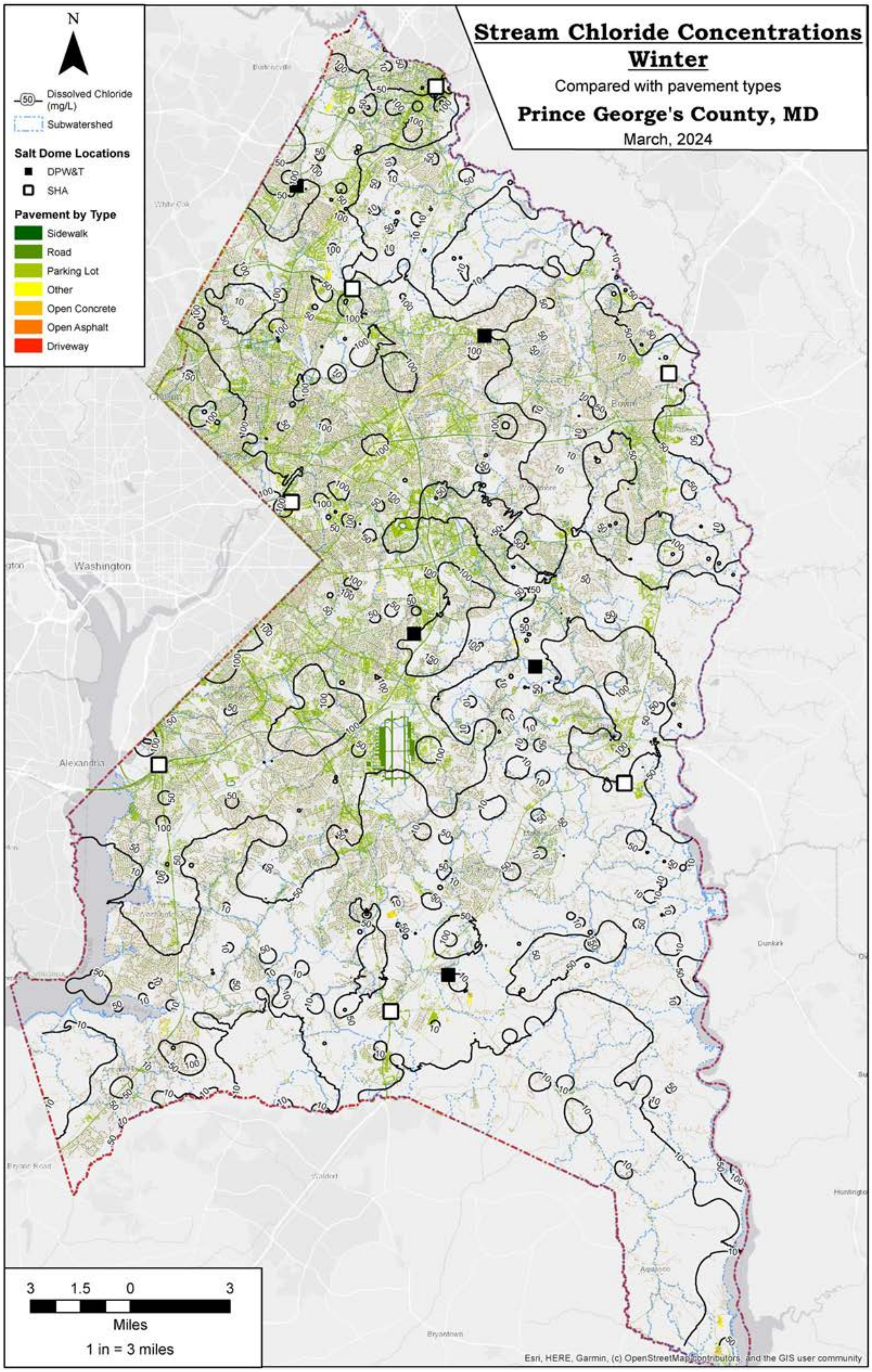


Figure 13. Long-term calculated chloride concentrations during the winter by subwatershed.



Note: Impervious type denoted by color.

Figure 14. Long-term chloride concentration contours in the summer.



Note: Impervious type denoted by color.

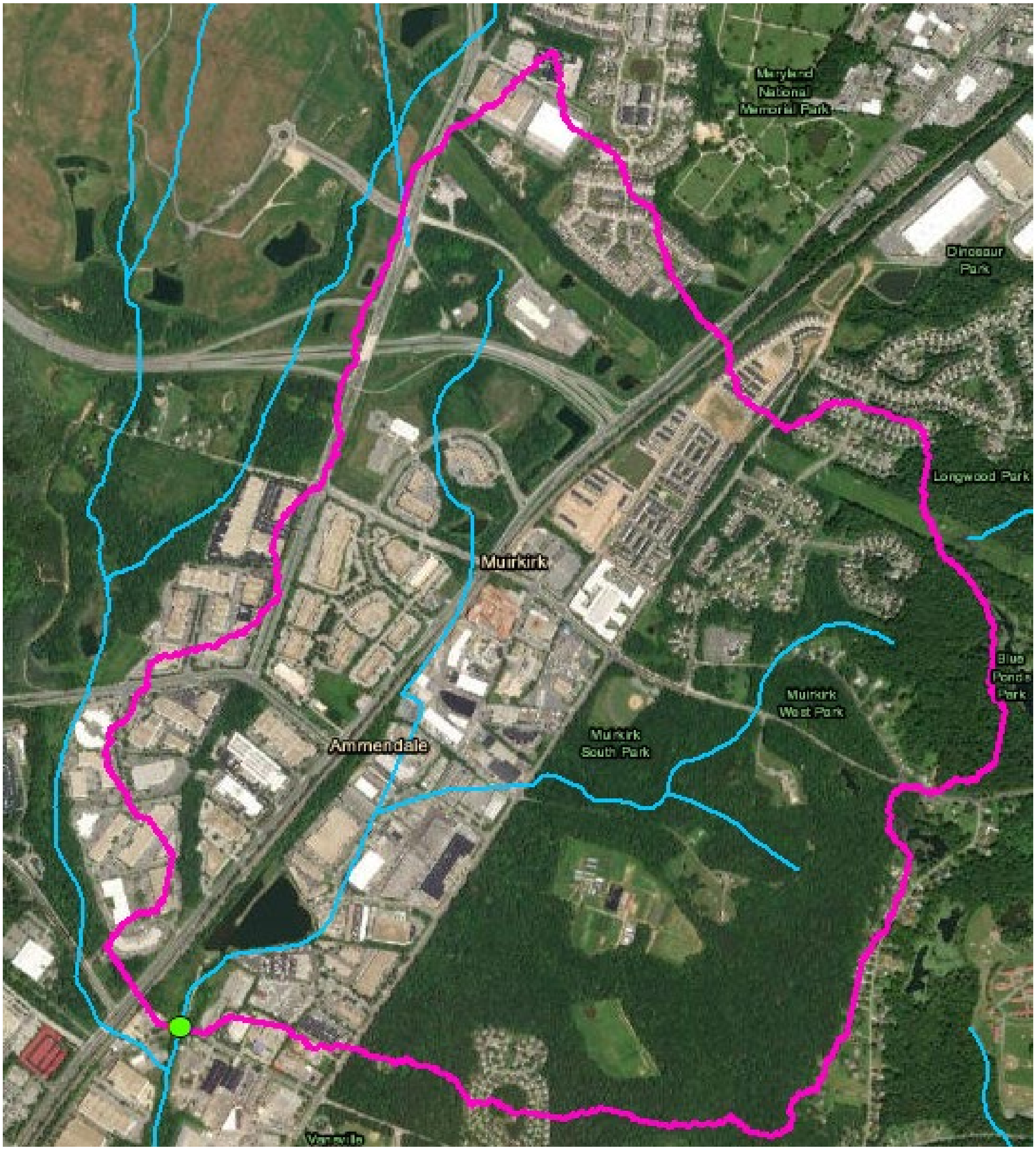
Figure 15. Long-term chloride concentration contours in the winter.

These patterns in the subwatershed-scale chloride variability displays indicate that salinity has accumulated in the County watersheds over time due to winter deicing salt application; further, the observed winter spikes in chloride concentrations are directly related to salt application and subsequent runoff due to rainfall and snowmelt. This finding indicates that the fine-scale spatial application of salt in areas with different types of impervious cover could demonstrate how the chloride concentration in the nearby streams respond in areas with different types of land use.

2.3.2 Fine-scale Spatial Analysis

To study the effects of localized salt application on stream chloride levels, monthly water samples were collected from September 2022 to June 2023 at six stream locations. These locations include a commercial site, an industrial site, a forested site, a rural/agricultural site, a high-density residential neighborhood, and a low-density residential neighborhood. The samples were collected approximately at the same time each month, regardless of weather conditions (unless hazardous). This work helps determine if there is a spatial pattern as a function of the land use and offer insight on the seasonality of chlorides. The various sites are described by maps below (Figure 16 to Figure **21**).

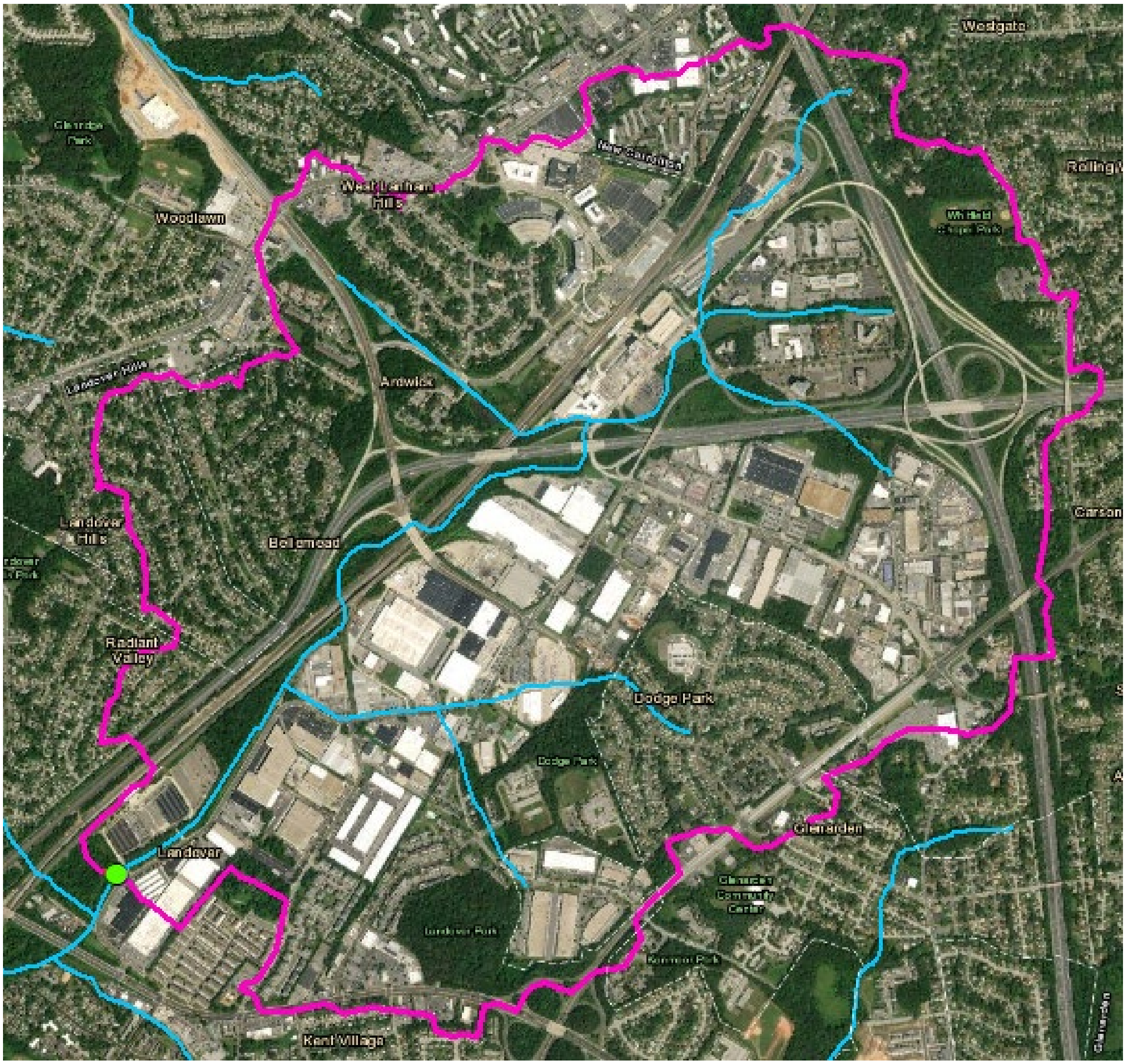
The commercial site was near 6401 Ammendale Road in Beltsville, with a developed area size of 1,102 acres (Figure 16). Matched precipitation over the three days (72 hours) prior to the sampling events are obtained from the nearby Weather Underground station in Beltsville (Weather Underground 2023a).



Note: basin boundary (pink), streams (blue), and sampling point (green dot).

Figure 16. Aerial image of the commercial site.

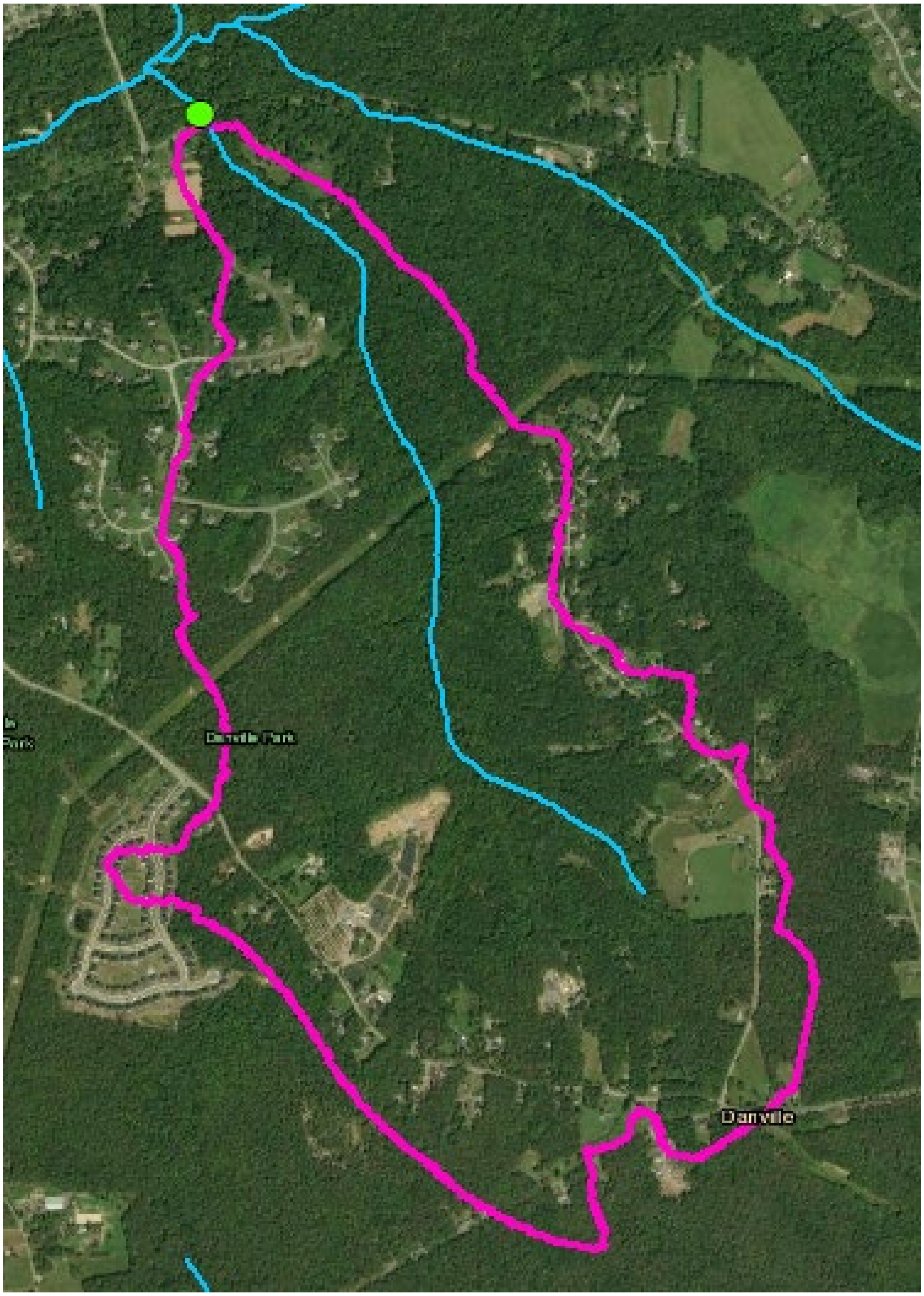
The industrial site was near 2929 Pennsy Drive in North Englewood, with a developed area size of 1,970 acres (Figure 17). Matched precipitation over the three days prior to the sampling events are obtained from the nearby Weather Underground station at Mile High East in Cheverly (Weather Underground 2023b).



Note: basin boundary (pink), streams (blue), and sampling point (green dot).

Figure 17. Aerial image of the industrial site.

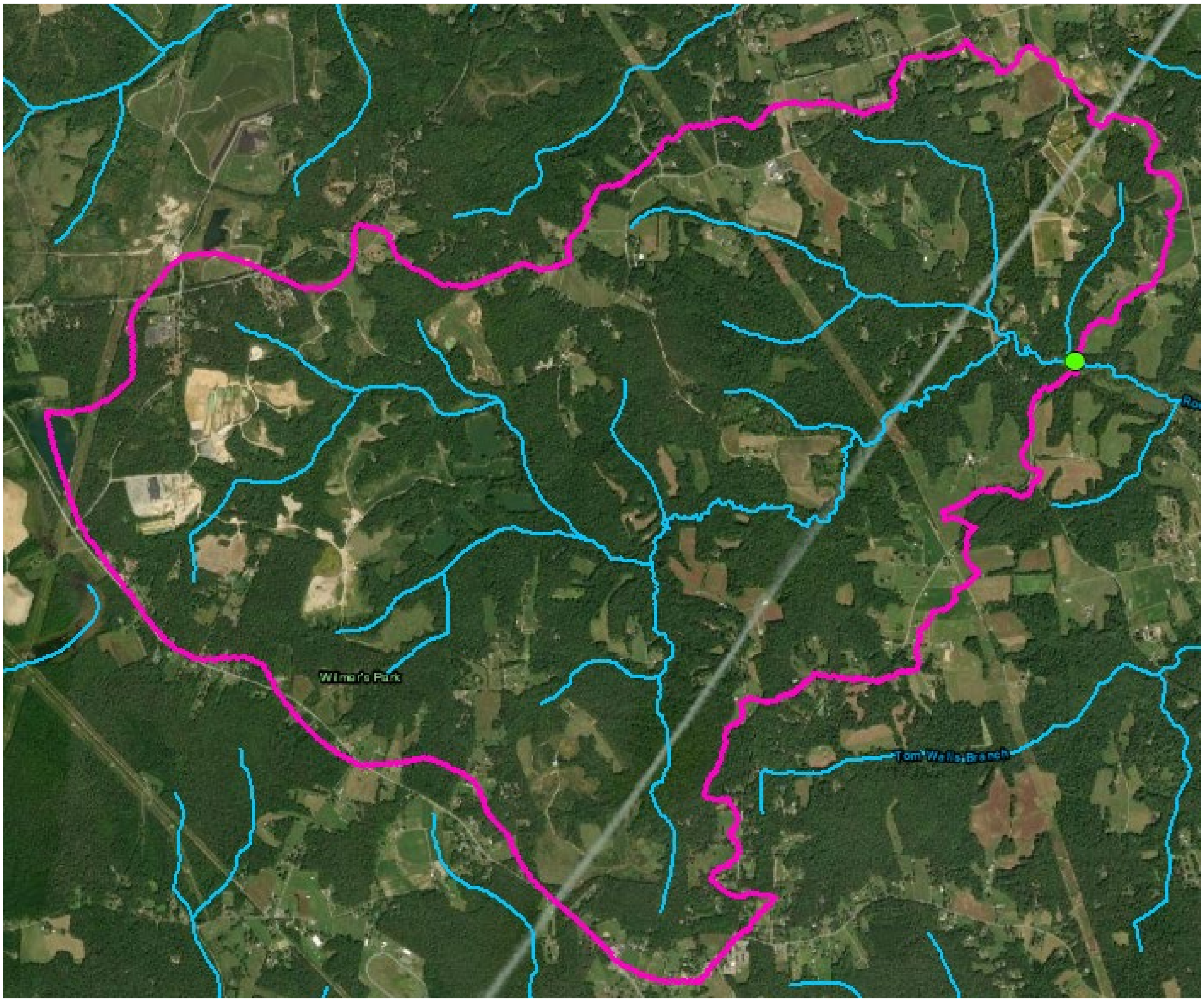
The forest site was near 4021 Floral Park Road in Brandywine, with a developed area size of 682 acres (Figure 18). Matched precipitation over the three days prior to the sampling events are obtained from the nearby Weather Underground station at The Ridges in Brandywine (Weather Underground 2023c).



Note: basin boundary (pink), streams (blue), and sampling point (green dot).

Figure 18. Aerial image of the forest site.

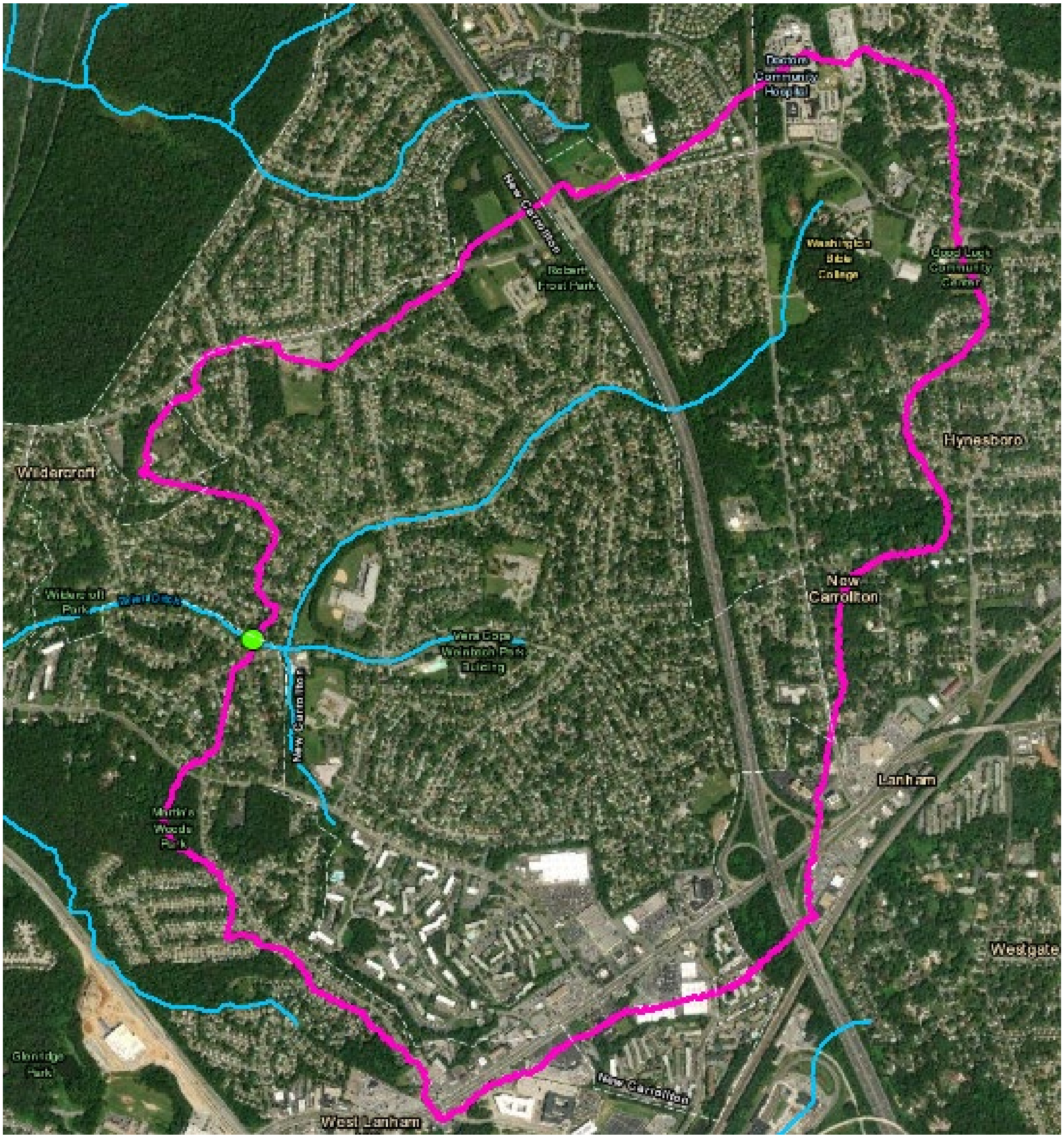
The rural site was located near 14450 Molly Berry Road in Brandywine, with a developed area of 4,810 acres (Figure 19). Matched precipitation over the three days prior to the sampling events are obtained from the nearby Weather Underground station in Upper Marlboro (Weather Underground 2023d).



Note: basin boundary (pink), streams (blue), and sampling point (green dot).

Figure 19. Aerial image of the rural site.

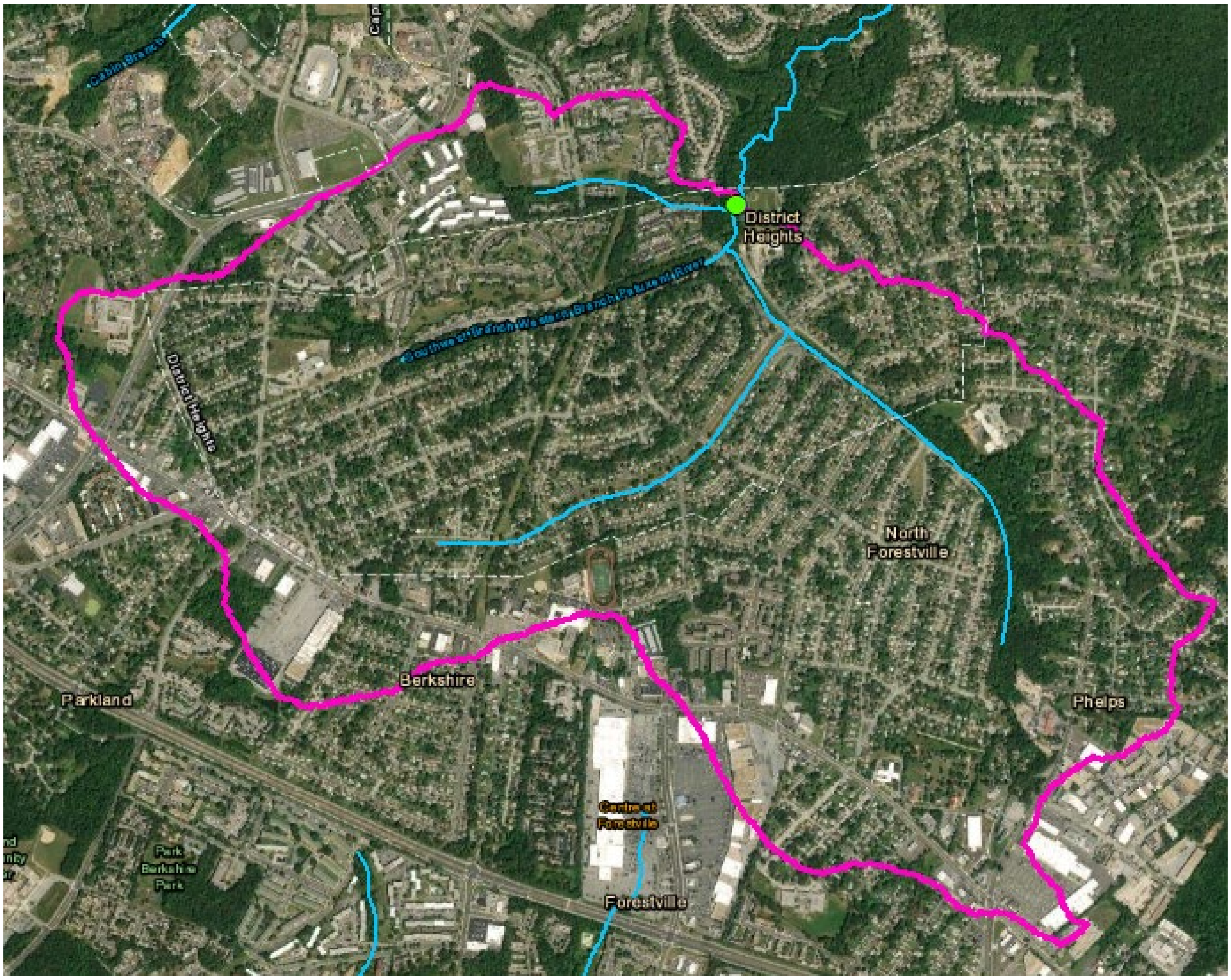
The high-density residential site was near 6318 Westbrook Drive in New Carrollton, with a developed area size of 1,360 acres (Figure 20). Matched precipitation over the three days prior to the sampling events are obtained from the nearby Weather Underground station at Larry Fox in Lanham (Weather Underground 2023e).



Note: basin boundary (pink), streams (blue), and sampling point (green dot).

Figure 20. Aerial image of the high-density residential site.

The low-density residential site was near 7177 Marbury Court in District Heights, with a developed area size of 1,135 acres (Figure 21). Matched precipitation over the three days prior to the sampling events are obtained from the nearby Weather Underground station at WxOne in District Heights (Weather Underground 2023f).



Note: basin boundary (pink), streams (blue), and sampling point (green dot).

Figure 21. Aerial image of the low-density residential site.

From this smaller scale study, initial sampling from September 2022 to June 2023 indicates that chloride concentration in the nearby streams is a function of the built-up area in the region. The industrial and high-density residential areas with substantial built-up areas have the highest chloride concentrations, respectively 99.1 mg/L and 105.3 mg/L on average. The low-density residential and commercial areas with a significant amount of forest cover have on average about 54.4 mg/L concentration of chloride. The rural and forested areas with virtually no development have only a small background chloride concentration, respectively 15.6 mg/L and 21.6 mg/L, which is about 80-90 mg/L lower than the high-density residential and industrial areas (Figure 22).

Antecedent rainfall conditions appear to dilute chloride concentrations in the high-density residential and industrial areas, with a decrease from about 120 mg/L to 85 mg/L, and 130 mg/L to 65 mg/L on average respectively, as rainfall decreases from more than 0.2 inches to less than 0.1 inches. Antecedent rainfall conditions do not seem to have a measurable effect on chloride concentrations in the areas with less development (Figure 23). These trends indicate that salt application causes chloride accumulation in nearby rivers and streams and that rainfall events have the potential to dilute the chloride concentrations.

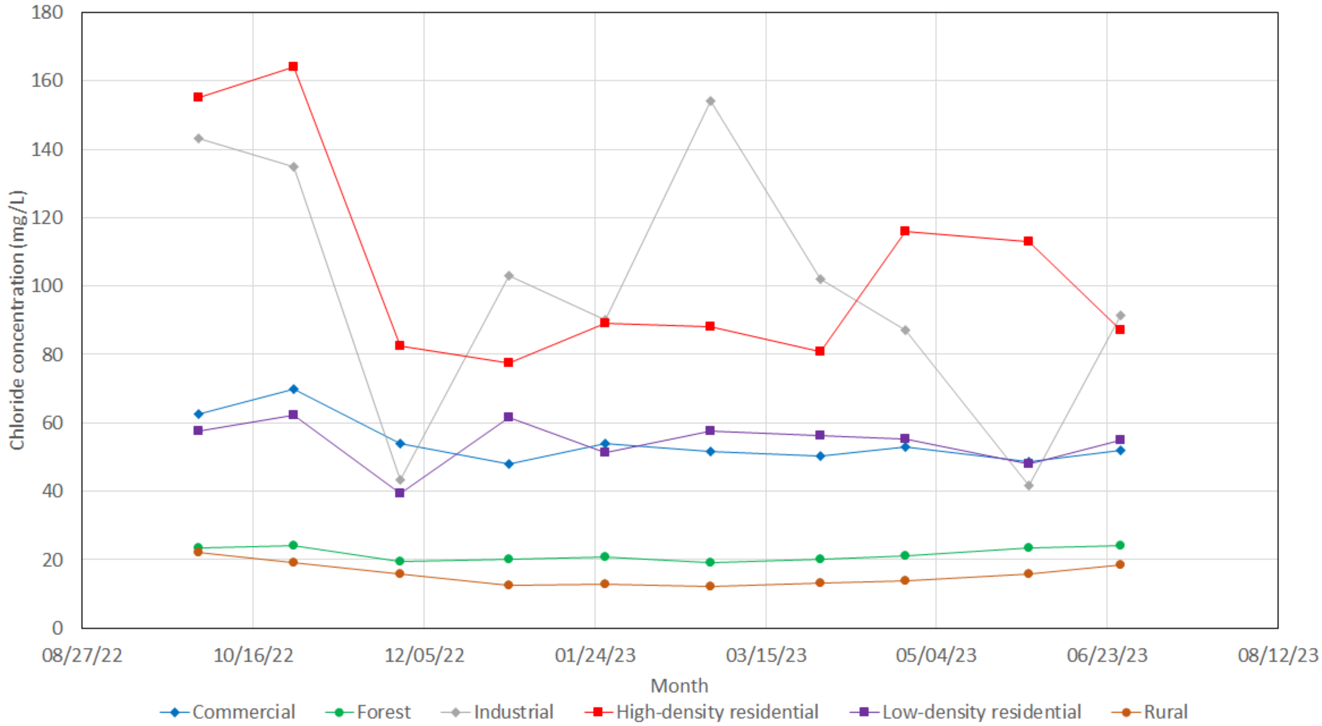


Figure 22. Time series of chloride concentrations at six sampling locations in the County.

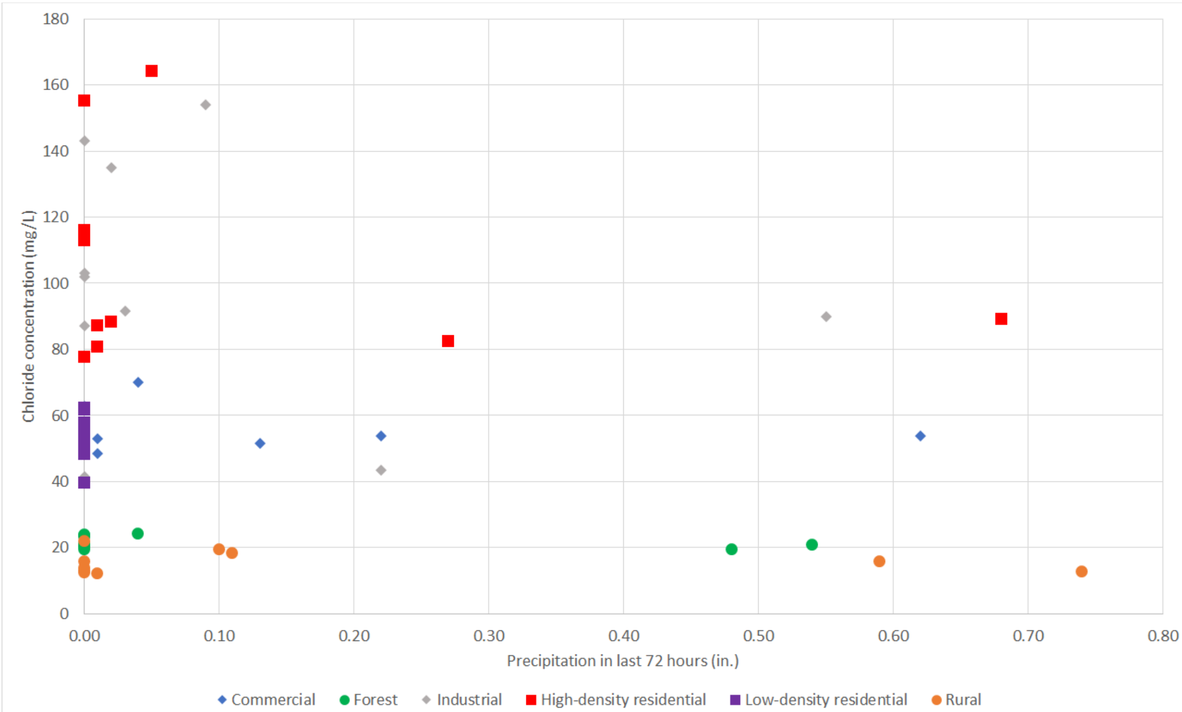
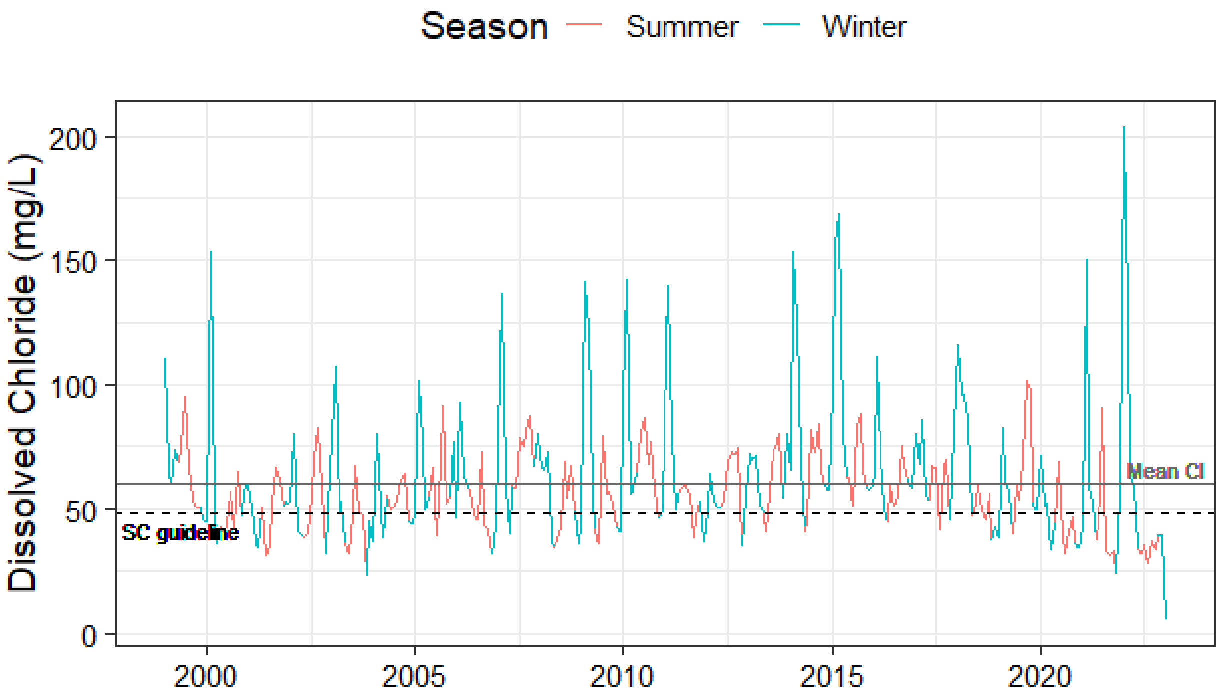


Figure 23. Chloride concentration versus antecedent precipitation at six sampling locations in the County.

2.4 SEASONAL PATTERNS IN CHLORIDE VALUES

This section presents the timeseries of countywide average chloride values and subwatershed-specific average chloride values to better understand the seasonal patterns in chloride values in the County. Chloride concentrations in the County between January 1999 and January 2023 range up to 540.3 mg/L, with 90 percent of the samples having concentrations between 7.5 mg/L (5th percentile) and 144.7 mg/L (95th percentile). The average is 60 mg/L. The average value is above the SC threshold of degraded biological condition in the eastern U.S. of 300 µS/cm (48.3 mg/L chloride) [Moore et al. 2020]. This means the average chloride concentration in the County is at risk of threatening the biological condition of its freshwater non-tidal streams and watersheds. However, it is noted that the 300 µS/cm (48.3 mg/L chloride) threshold is based on a 4-day average stream salinity exposure, while the chloride concentrations in this analysis are either instantaneous values or seasonal averages. Therefore, inferences from this analysis should be considered preliminary. Figure 24 presents the monthly average countywide chloride concentration, along with the overall average countywide concentration and the concentration related to biological degradation.



Note: Solid line is the mean chloride concentration of 60.04 mg/L. Dashed line is the guideline concentration of biological degradation at 48.3 mg/L from Moore et al. (2020).

Figure 24. Monthly average countywide chloride concentration between January 1999 and January 2023.

Overall, the countywide chloride concentration is slightly higher in winter than in summer, as expected (Figure 25). The mean chloride concentration in summer is 57.3 mg/L, which is 5.9 mg/L lower than the winter mean chloride concentration of 63.2 mg/L. A one-way analysis of variance (ANOVA) test was conducted to compare these findings statistically. The *p* value of 7×10^{-7} is statistically significant, indicating that the winter chloride concentration is likely higher than the summer chloride concentration.

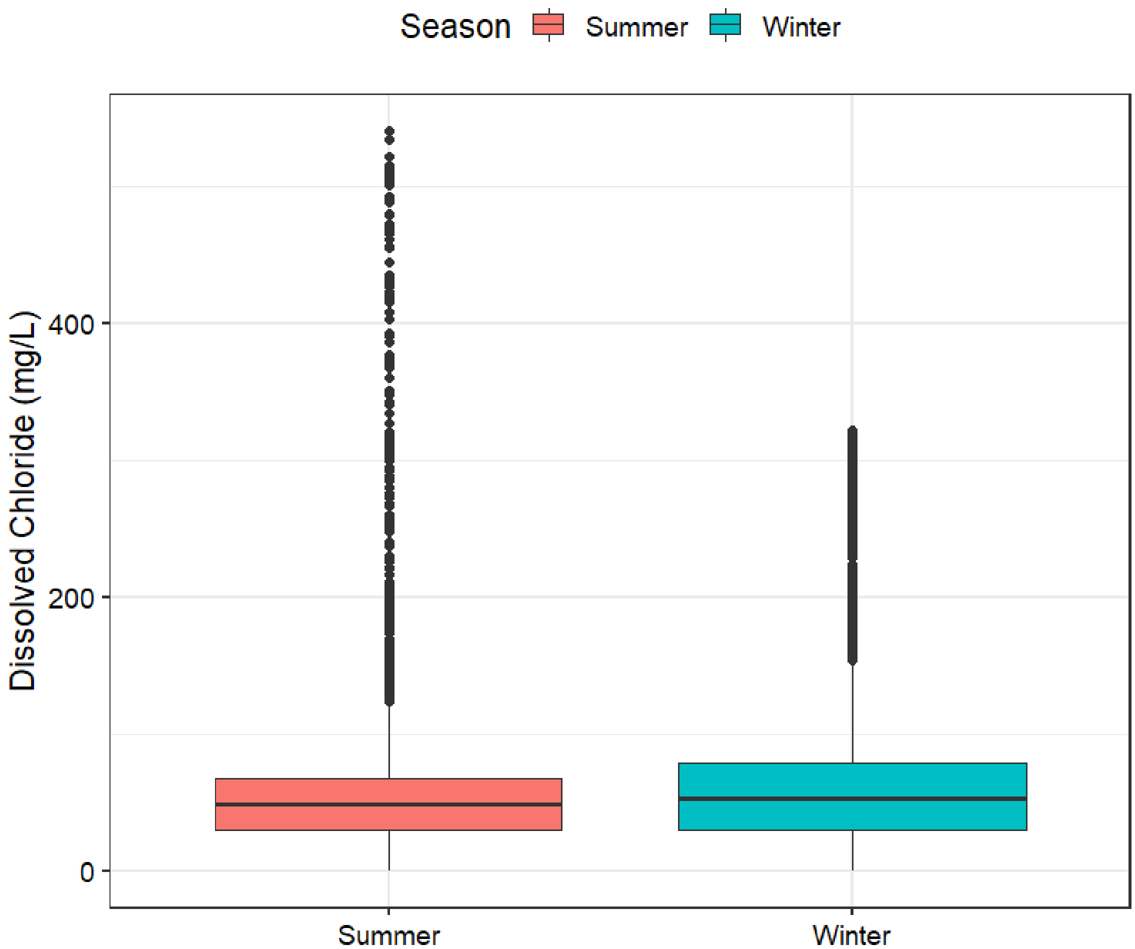


Figure 25. Countywide summer and winter chloride concentrations.

To better understand these seasonal patterns as a function of precipitation, two representative subwatersheds in the Anacostia and Patuxent River watersheds were chosen. The representative subwatersheds considered were AR-10 in the Anacostia River watershed and PR-18 in the Patuxent River watershed as they each have more than 100 records and represent more developed areas of the County (Figure 26).

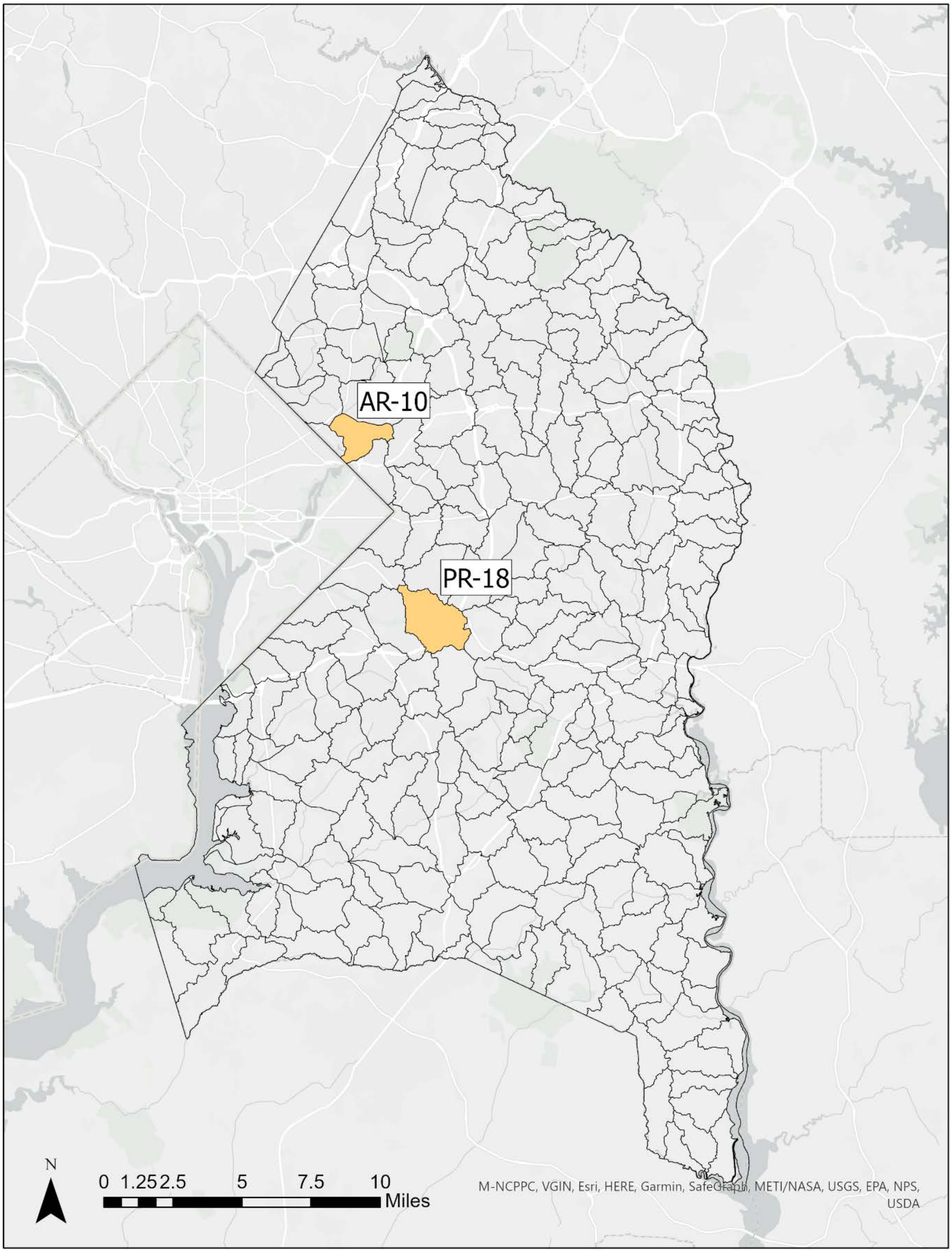


Figure 26. Selected representative subwatersheds AR-10 and PR-18.

In the more developed subwatersheds AR-10 and PR-18, the chloride concentration increase in winter is more pronounced than the County average (Figure 27), which could be due to their high development level and pavement ratio.

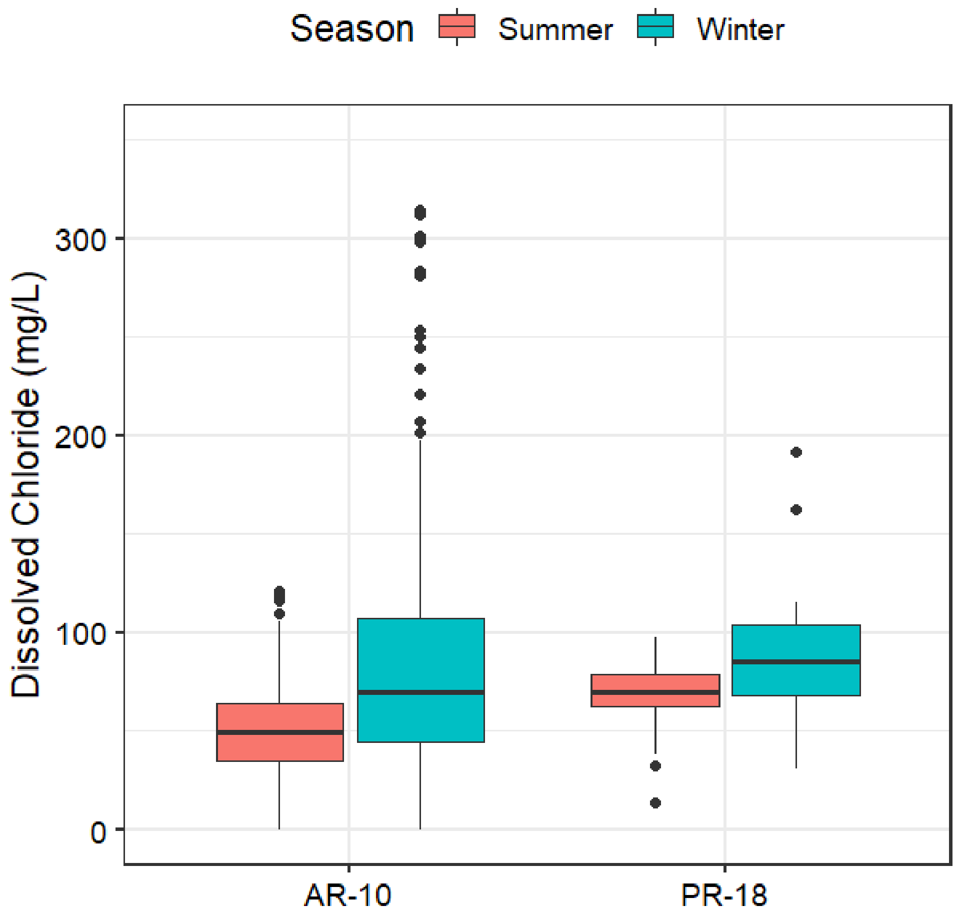


Figure 27. Summer and winter chloride concentrations in sub-watersheds AR-10 and PR-18.

2.4.1 Effect of Rainfall on Stream Chloride Concentration

Rain significantly reduces the concentration of chloride due to dilution. The countywide average chloride concentrations under different antecedent rainfall conditions are compared (Figure 28). The mean chloride concentrations under dry, normal, and wet conditions are 66.04 mg/L, 57.98 mg/L, and 32.70 mg/L, respectively. The average chloride concentration in wet conditions is only about half of the average concentration in dry conditions. The same conclusion is supported by a statistically significant negative correlation between rainfall and chloride concentration ($p < 0.01$) [Figure 29].

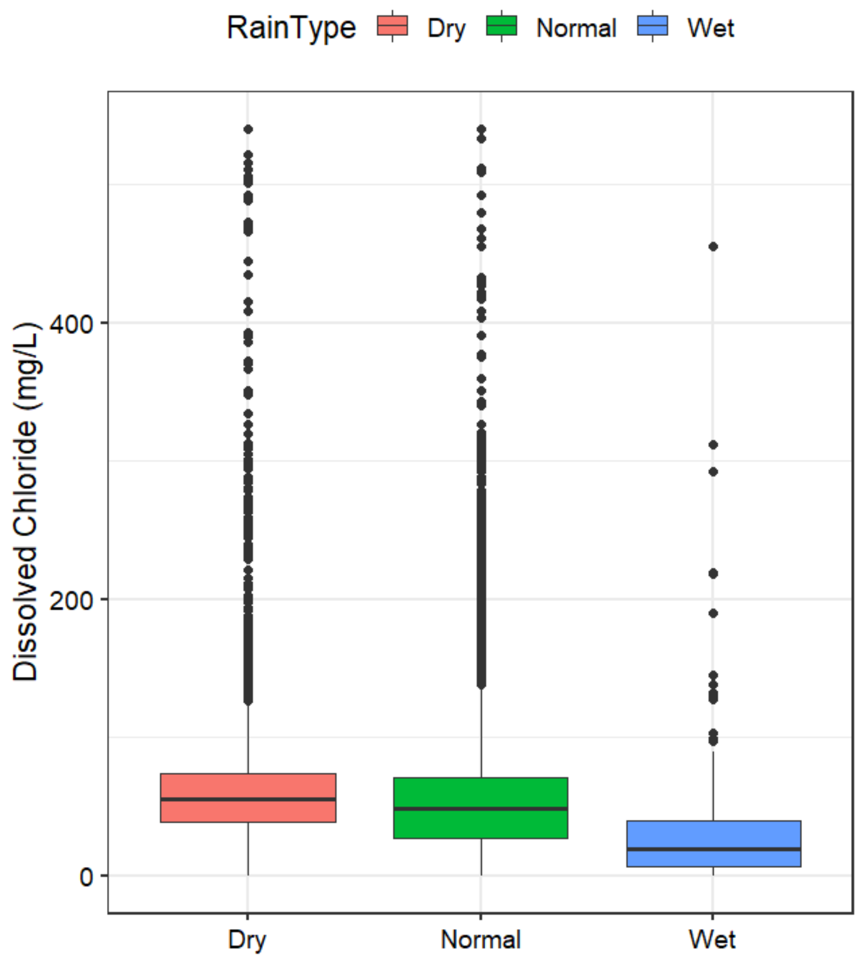


Figure 28. Chloride concentrations during different antecedent rainfall conditions.

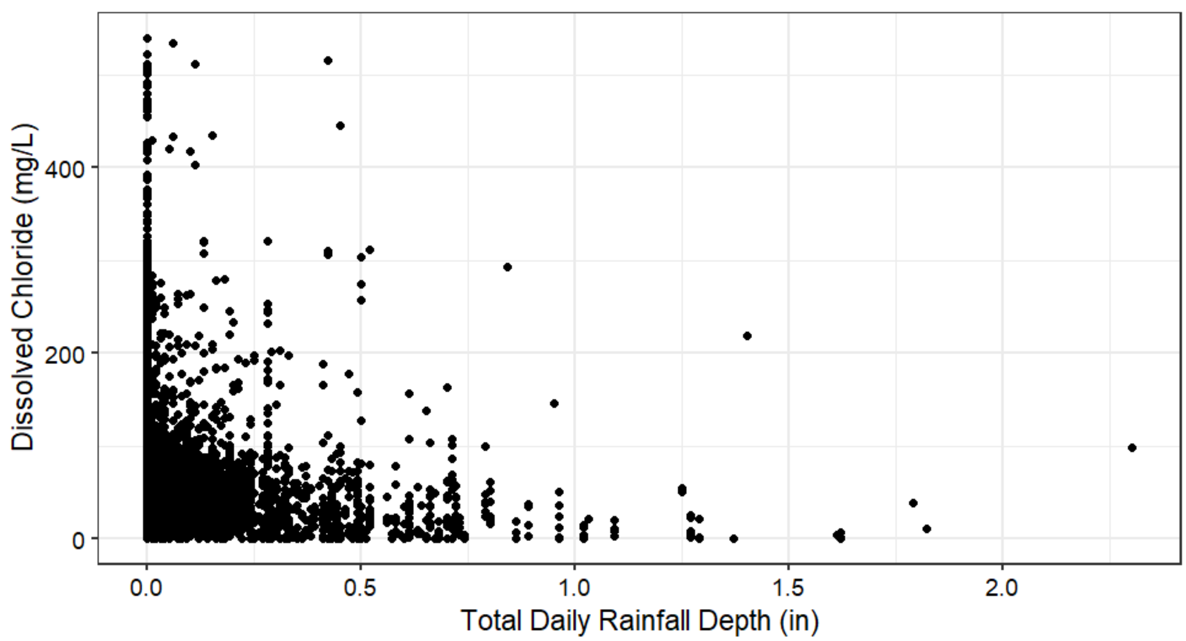


Figure 29. Relationship between rainfall and chloride concentrations.

Figure 30 to Figure **32** show summer and winter average chloride concentrations during dry, normal, and wet antecedent rainfall conditions respectively. In subwatersheds bordering northeastern Washington, D.C., for example, the chloride concentrations are 60 mg/L in both normal and dry conditions, dropping to less than 15 mg/L in wet conditions. The greatest differences in chloride concentrations are seen under normal antecedent conditions.

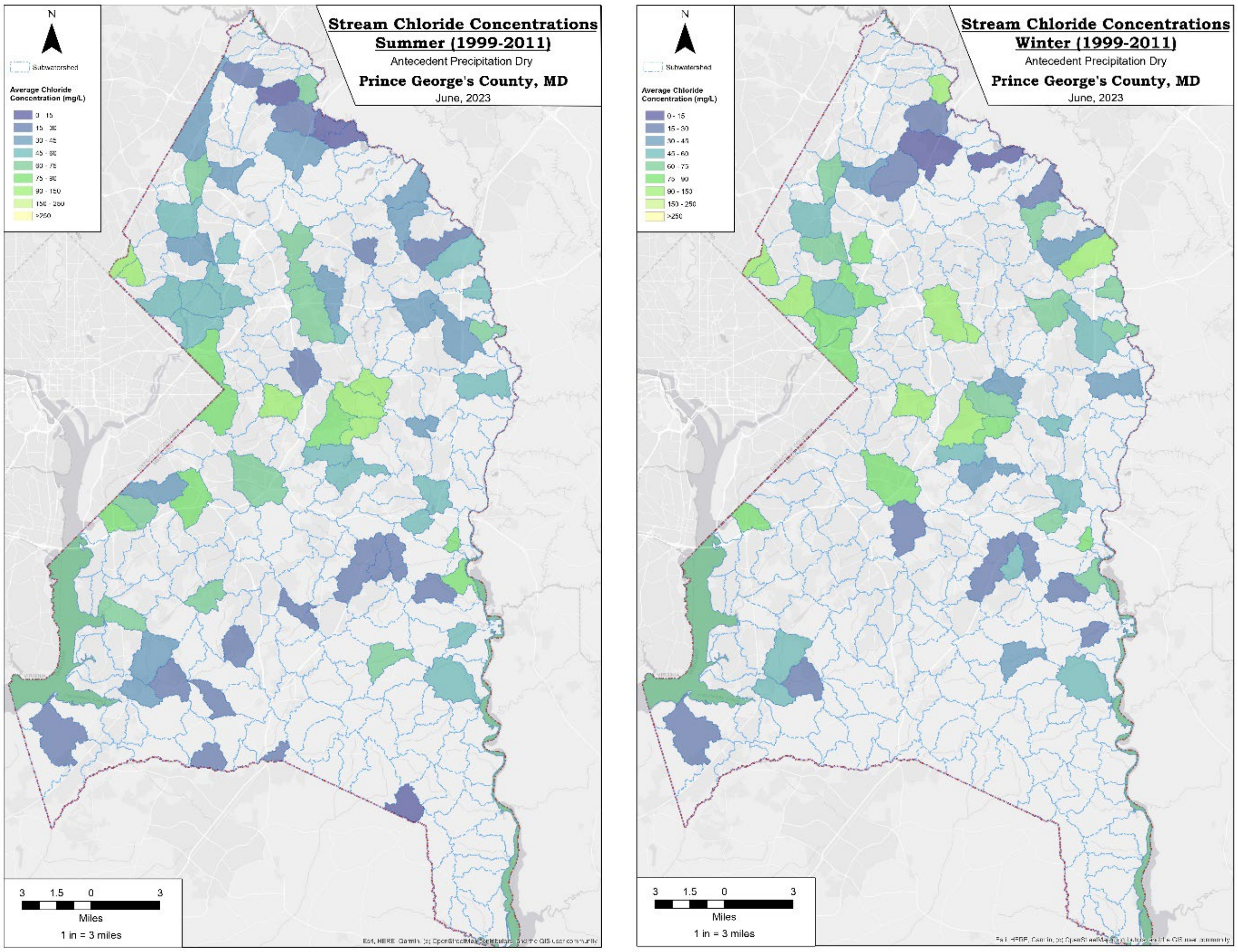


Figure 30. Summer (left) and winter (right) chloride concentrations in dry conditions.

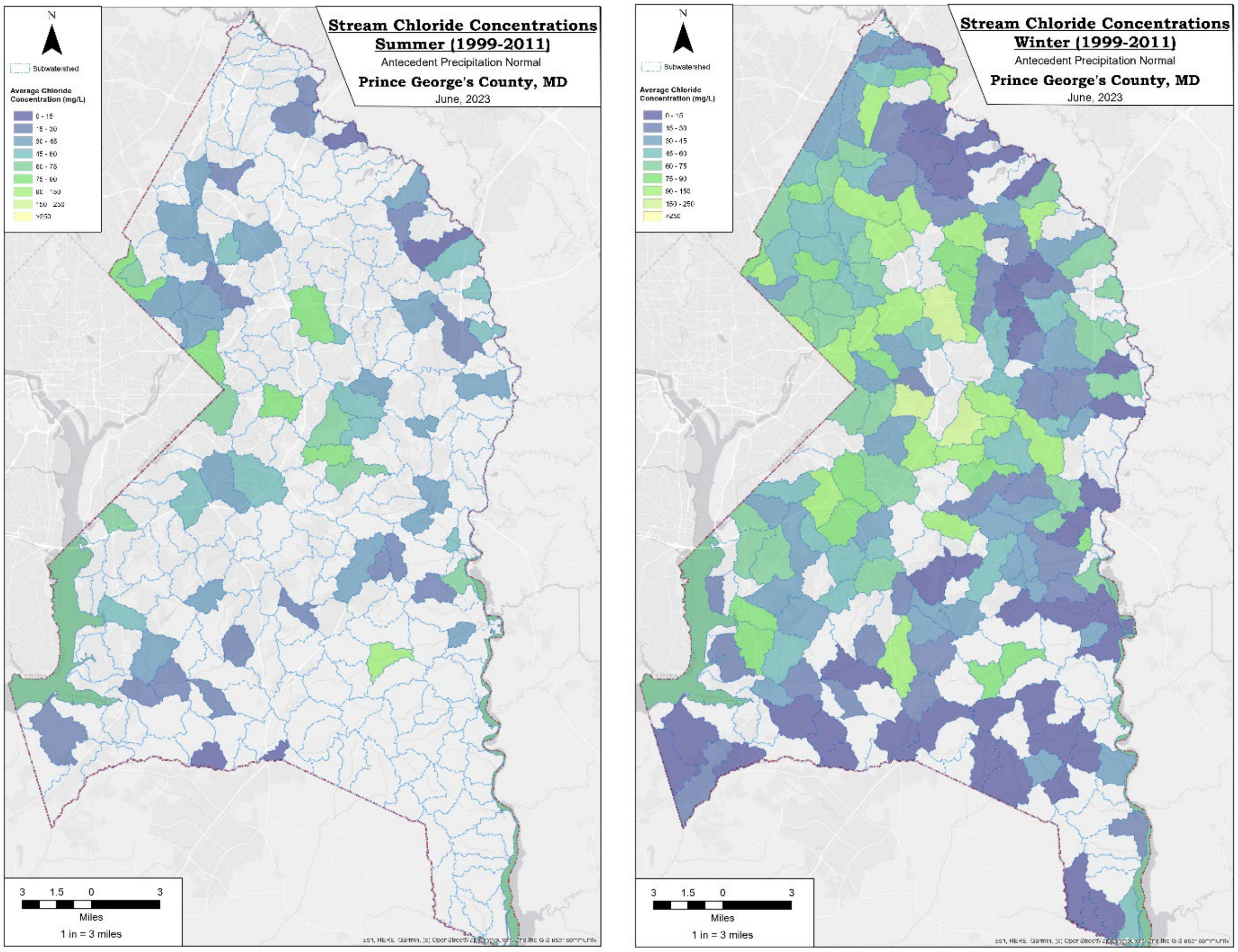


Figure 31. Summer (left) and winter (right) chloride concentrations in normal conditions.

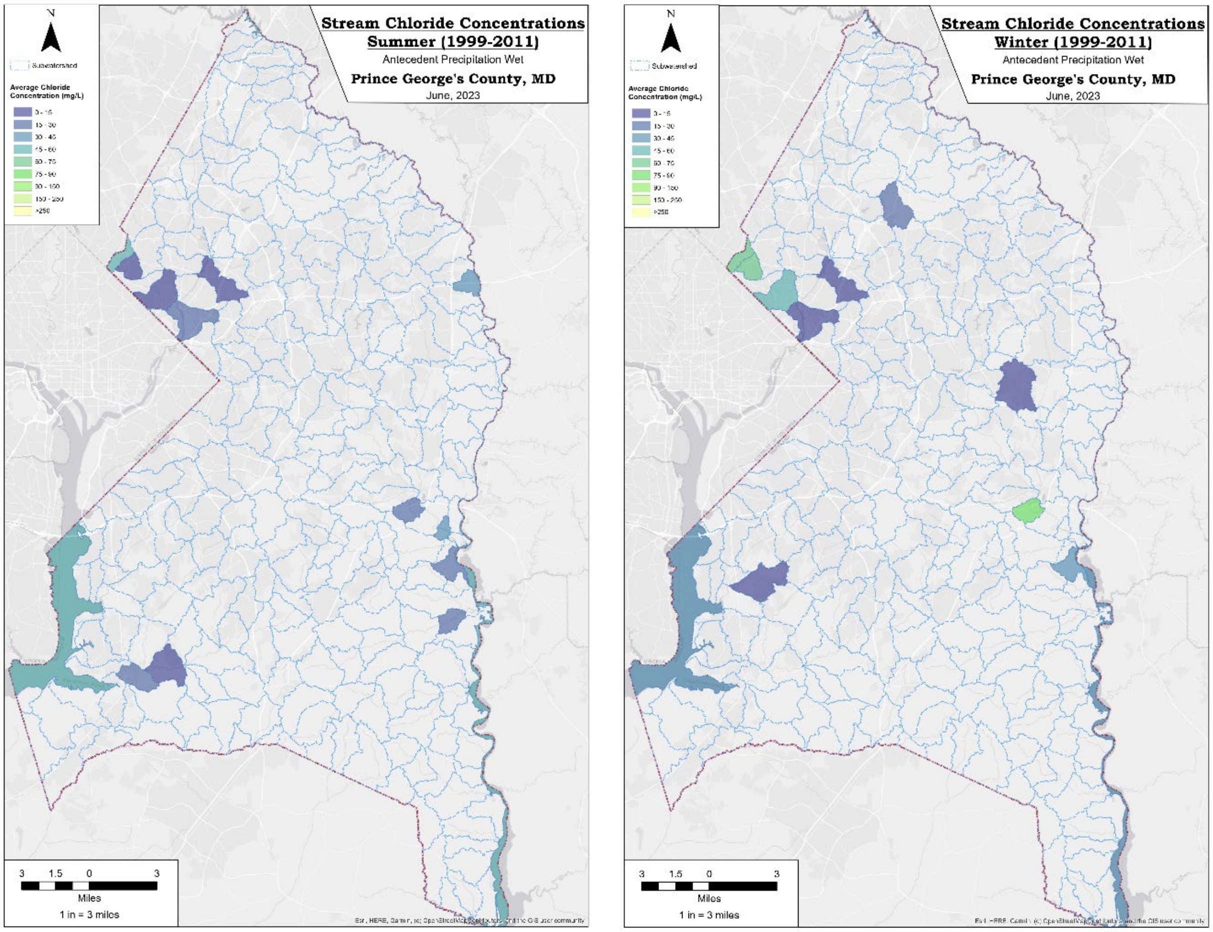


Figure 32. Summer and winter chloride concentrations in wet conditions.

While subwatershed PR-18 does not have samples collected in wet conditions, it is important to note that the chloride concentration in wet conditions is lower than that observed in dry and normal conditions in AR-10 (Figure 33).

Stormwater runoff due to rainfall and snowmelt are the principal sources of chloride to the freshwater streams. Runoff and snowmelt create a *flushing effect*, whereby rainfall carries chloride from impermeable surfaces such as roads into the water system, causing the chloride concentration to rise. The rain also creates a *dilution effect* where the condition of rainfall bringing more water into the water systems reduces the chloride concentration. Flushing and dilution effects – and their interactions – in streams can be observed by comparing the data before and after rainfall events. Often, the flushing effect of chloride due to stormwater runoff is overwhelmed by the dilution effect. In Figure 34, the boxes from left to right show the distribution of chloride concentrations for the day before, the day of, the day after, and more than 1 day after a rainfall event. The mean value of chloride concentrations sampled on the day before a rainfall is 51.61 mg/L, which drops to 44.25 mg/L on the rainy days. After rainfall, the chloride concentrations rise gradually, averaging at 48.01 mg/L on the day after and 54.13 mg/L longer from the rainfall. These post-precipitation increases indicate the flushing effect of stormwater runoff. The significant drop in chloride concentration on the days of rainfall and the gradual rebound after a longer period after the rainfall in both summer and winter suggest that here, the dilution effect is greater than the flushing effect.

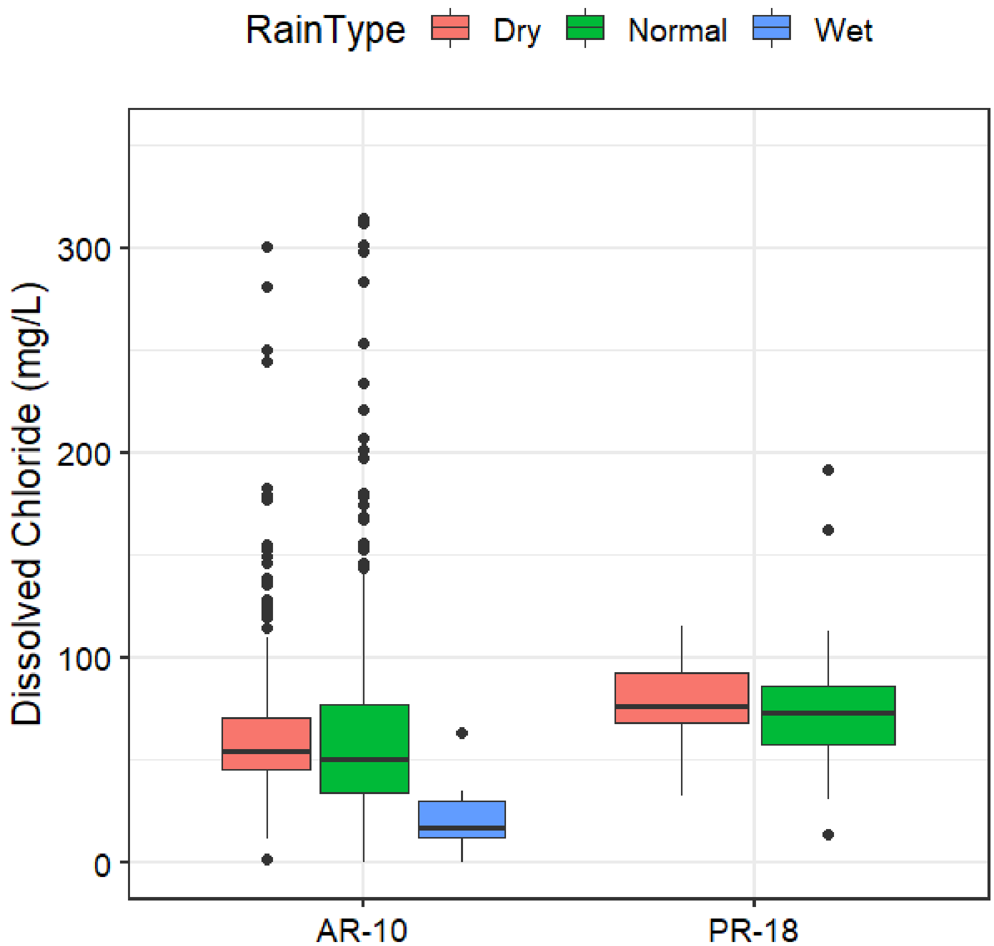


Figure 33. Chloride concentrations in subwatershed AR-10 and PR-18 during dry, normal, and wet antecedent rain conditions.

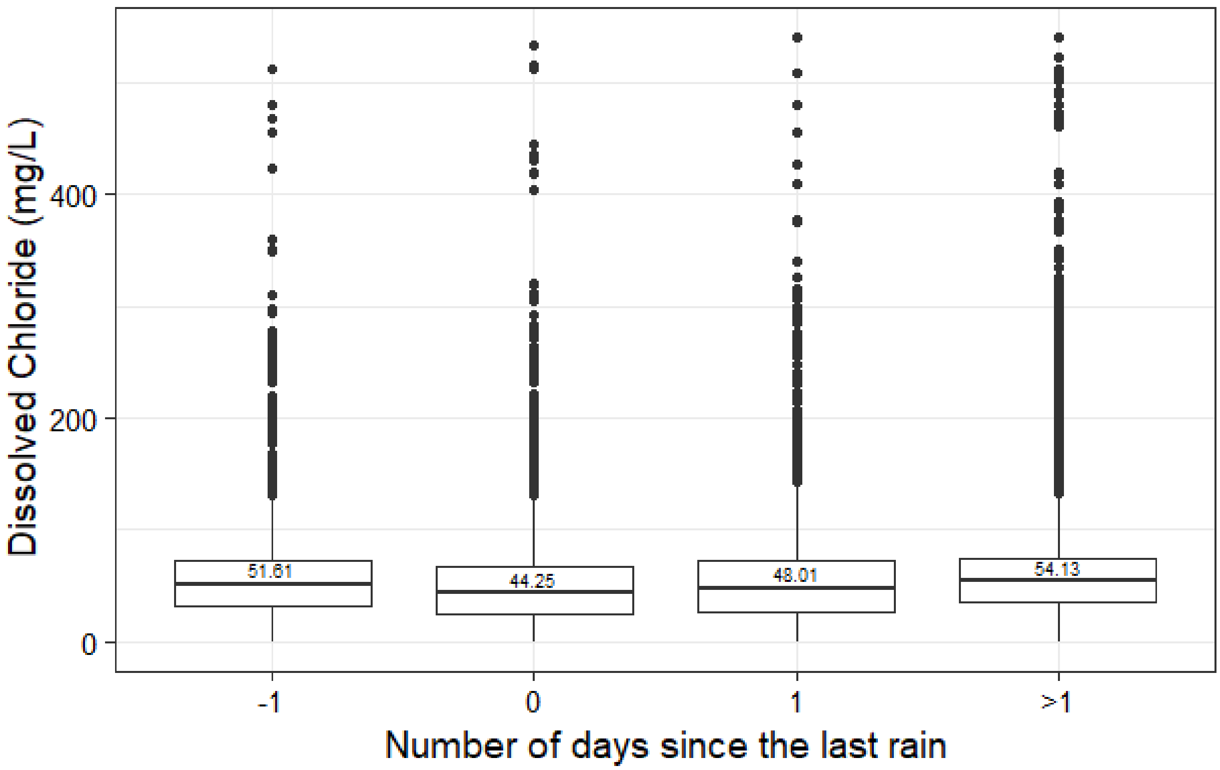


Figure 34. Chloride concentration on the day before, the day of, the day after, and more than 1 day after a rainfall event, labeled by the mean values.

2.4.2 Effect of Snowfall on Stream Chloride Concentration

The number of days from the last snowfall, referred as "no snow days," is used to explore the relationship between chloride concentration and snowfall, because the number of days of snowfall is relatively small and cannot correspond to the days on which chloride sampling was conducted. The no snow days and chloride concentrations have a negative relationship, which means the closer to the last snowfall, the higher the chloride concentration. Using linear regression, the predicted average chloride concentration is 67.79 mg/L on the day of snowfall and decreases by 0.05 mg/L for each additional day without snowfall thereafter (Figure 35). High post-snow chloride concentrations are more pronounced in the developed urban areas on the western side of the county. The chloride concentrations sampled in 5 days after snow (Figure 36) in highly urbanized watersheds can exceed 250 mg/L, while the average chloride concentrations in these same subwatersheds with more than 5 days since the last snowfall snow (Figure 37) are only 60-90 mg/L. These patterns indicate the direct correlation between winter deicing salt application and stream chloride concentration.

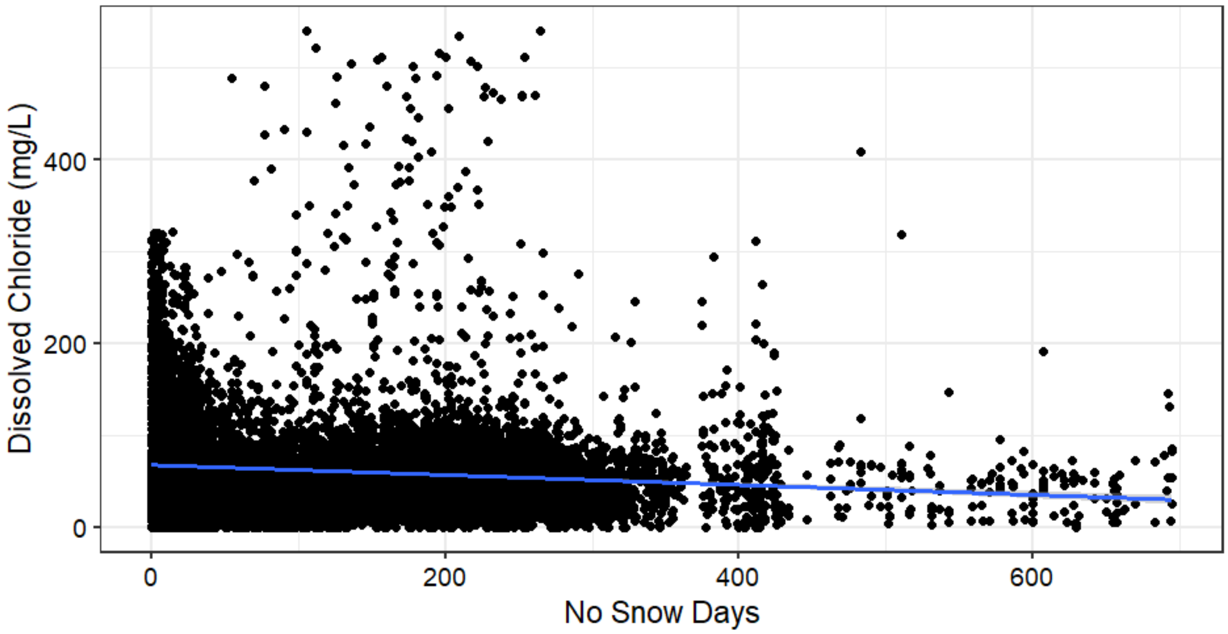


Figure 35. Relationship between no snow days and chloride concentrations.

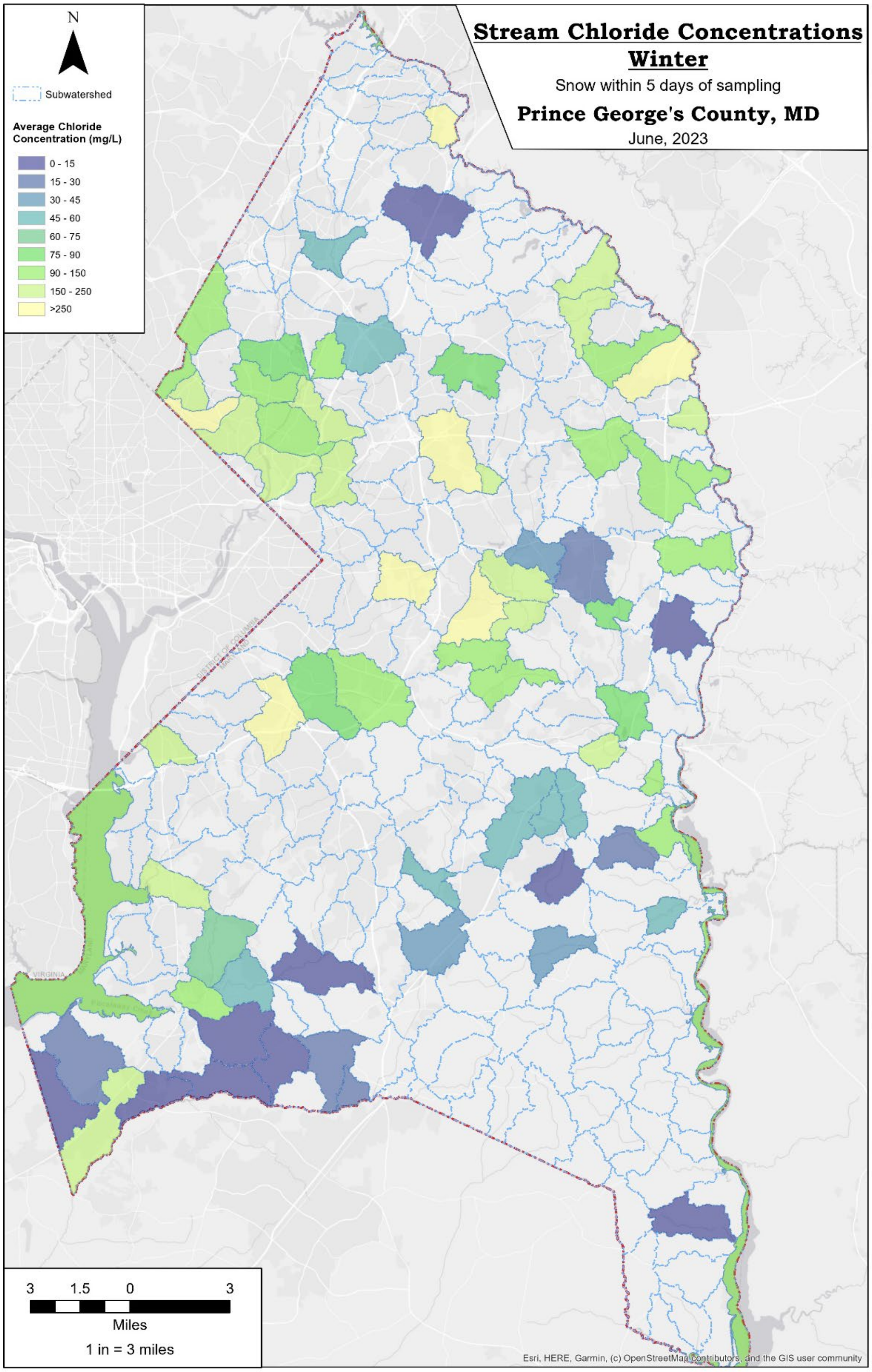


Figure 36. Chloride concentrations sampled in 5 days of a snow event.

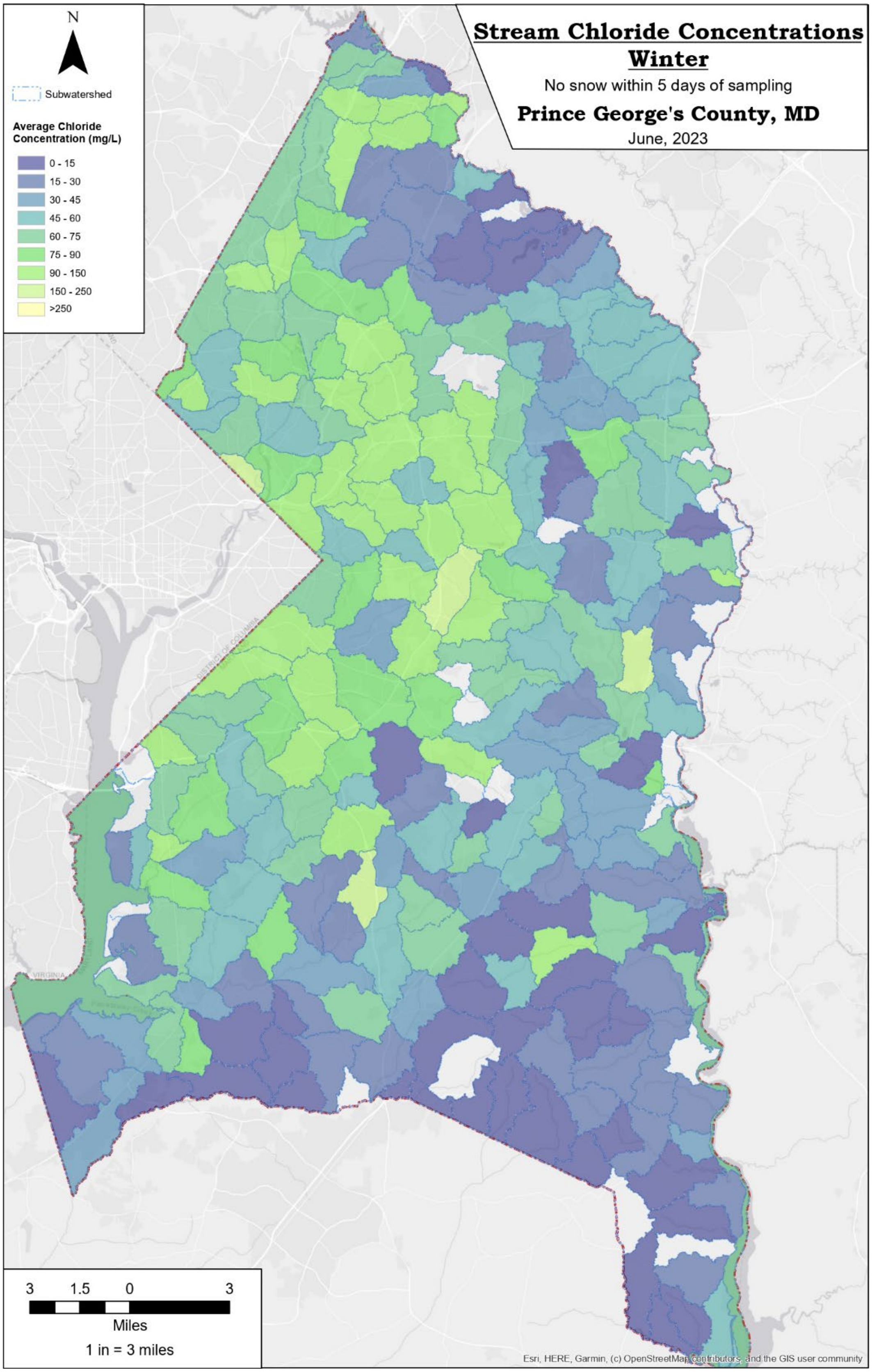


Figure 37. Chloride concentrations with no snow in 5 days of sampling.

The average chloride concentration in 5 days of snow in subwatershed AR-10 is 100 mg/L higher than when more than 5 days have passed since the last snowfall, while in PR-18, it is 20 mg/L higher (Figure 38). This difference could be because AR-10 has more urban development.

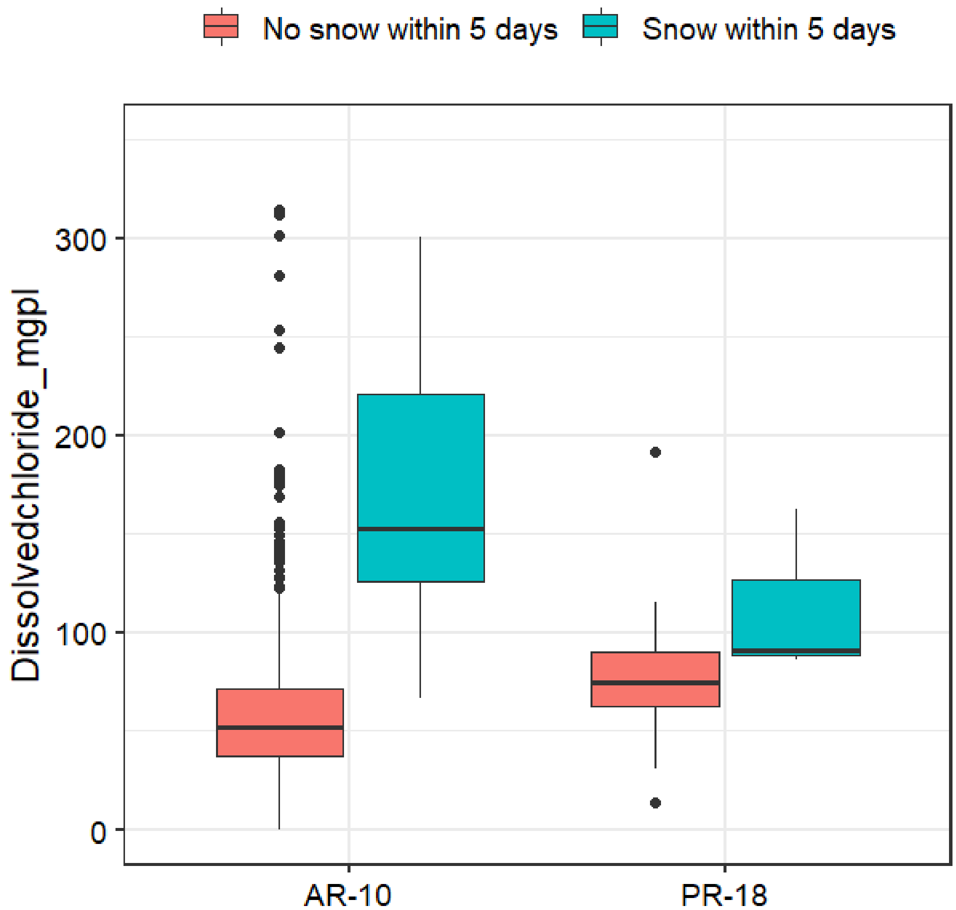


Figure 38. Chloride concentrations in sub-watersheds AR-10 and PR-18 with or without snow in 5 days of sampling.

These spatial and seasonal patterns in chloride concentrations in the County can provide valuable insights into where water quality degradation problems are localized and how intense they are throughout the year. The next analysis indicates how increased chloride concentrations can affect the environment for MBIs using the SBI.

2.5 BIOLOGICAL DEGRADATION ANALYSIS

The biological degradation analysis completed to describe stream biological quality involved analyzing the SBI. This involves multiple steps beginning with the development of the SDC, followed by the SBI (see Section 2.5.2). Below, the quantitative findings related to the development of the SBI are presented.

2.5.1 Chloride Tolerance Values (TV) and Sensitivity Distribution Curve (SDC)

First, the *XC95* and TVs were quantified for each taxon. The vast majority of *XC95* values ranged from 38.7 to 286.2 mg/L, with only three taxa having an *XC95* greater than 287 mg/L. Therefore, TVs 0 to 9 were defined as equally-spaced groups between log(38) and log(300). The relationship between *XC95* and TV is presented in Figure 39. Most taxa received a TV between 5 and 7 (Figure 40). These figures indicate that around 60% of all taxa (number of taxa between TV values of 5 and 7 in Figure 40) are able to survive chloride levels of 100-200 mg/L (see Y-axis chloride concentrations on the ordinate in Figure 40 between TV values of 5 and 7).

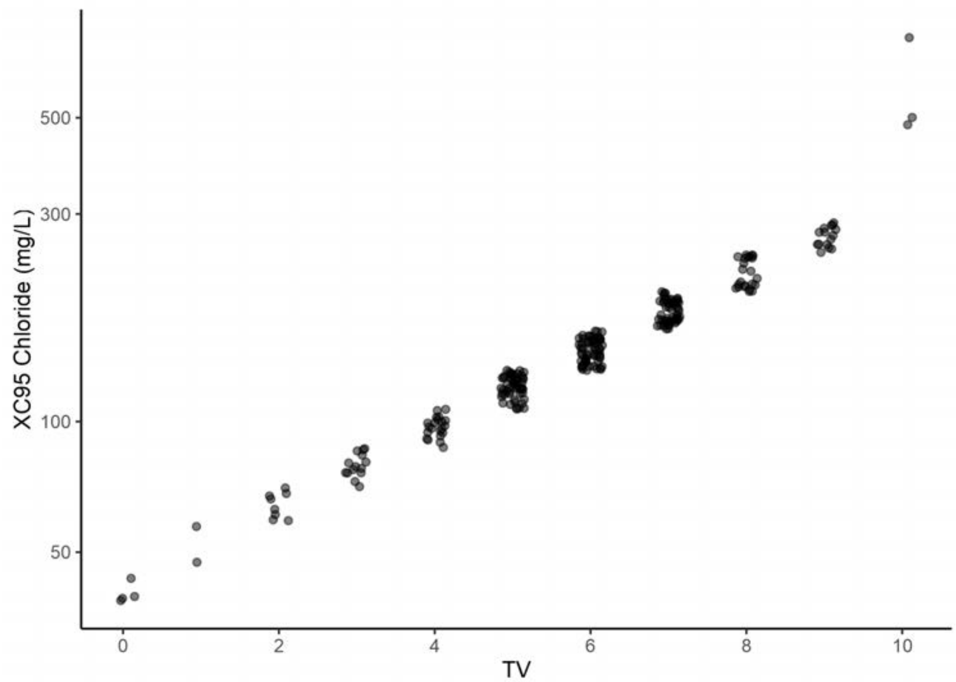


Figure 39. Scatterplot of extirpation concentrations vs tolerance values. Each point represents a unique taxon.

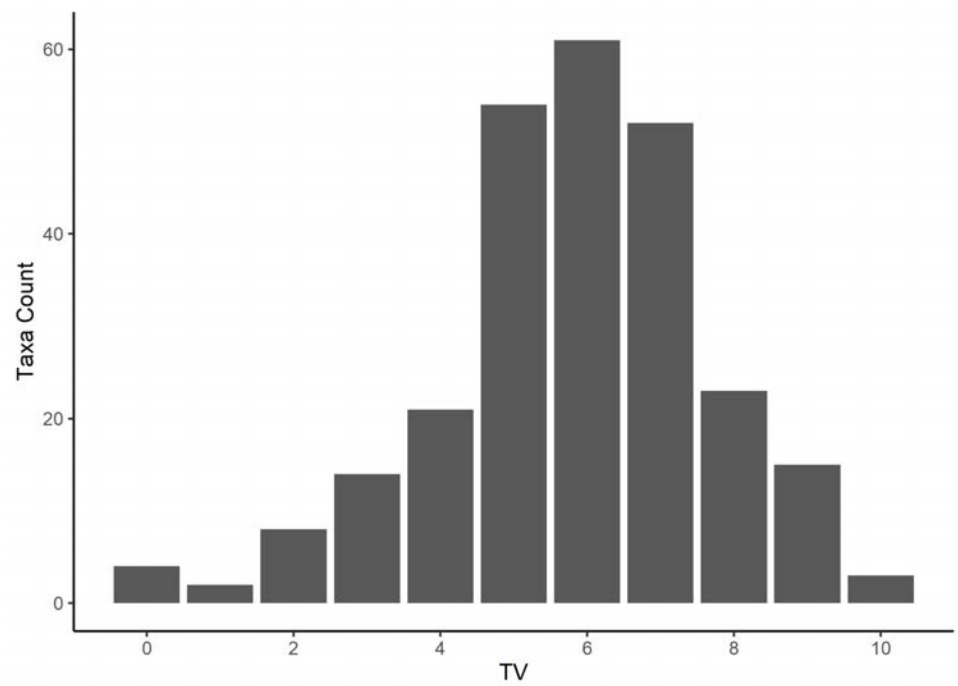


Figure 40. Barplot of chloride tolerance values.

Next, the SDC for chloride for the county was generated using the *XC95* values as shown in Figure 41. From Figure 41, 25% of the observed taxa in this dataset cannot tolerate chloride values above 116 mg/L. Therefore, 25% of taxa richness could potentially be lost if the minimum chloride concentration at every sampling location across the county were greater than 116 mg/L. At about 290 mg/L chloride concentration, nearly all the taxa could potentially become extirpated.

The SDC developed for the County, in conjunction with the chloride distribution maps in Figure 10 to Figure 13, indicates that in the Western and Northern parts of the County, there is a probability that approximately 17% of the BMI genera have become extirpated. While the average chloride concentration along the Patuxent River is high, this water is predominantly tidal salinity in nature; these areas could have physiologically different genera that are intertidal or more salt tolerant than in the Western part of the County.

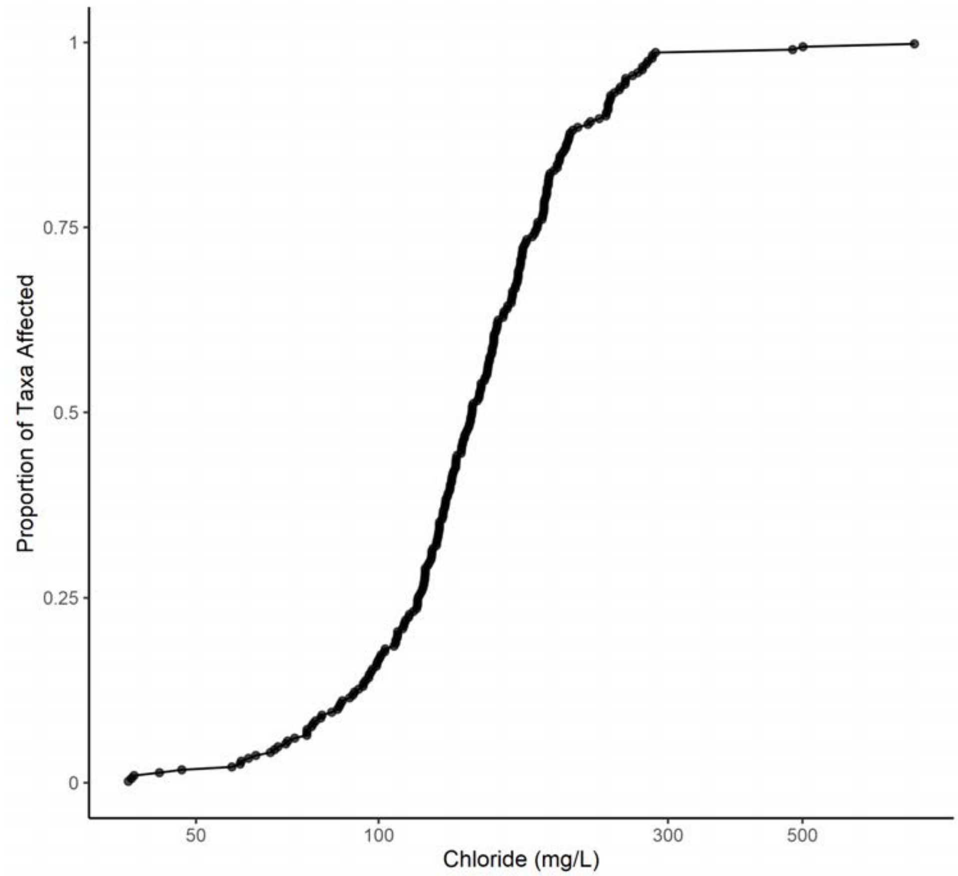
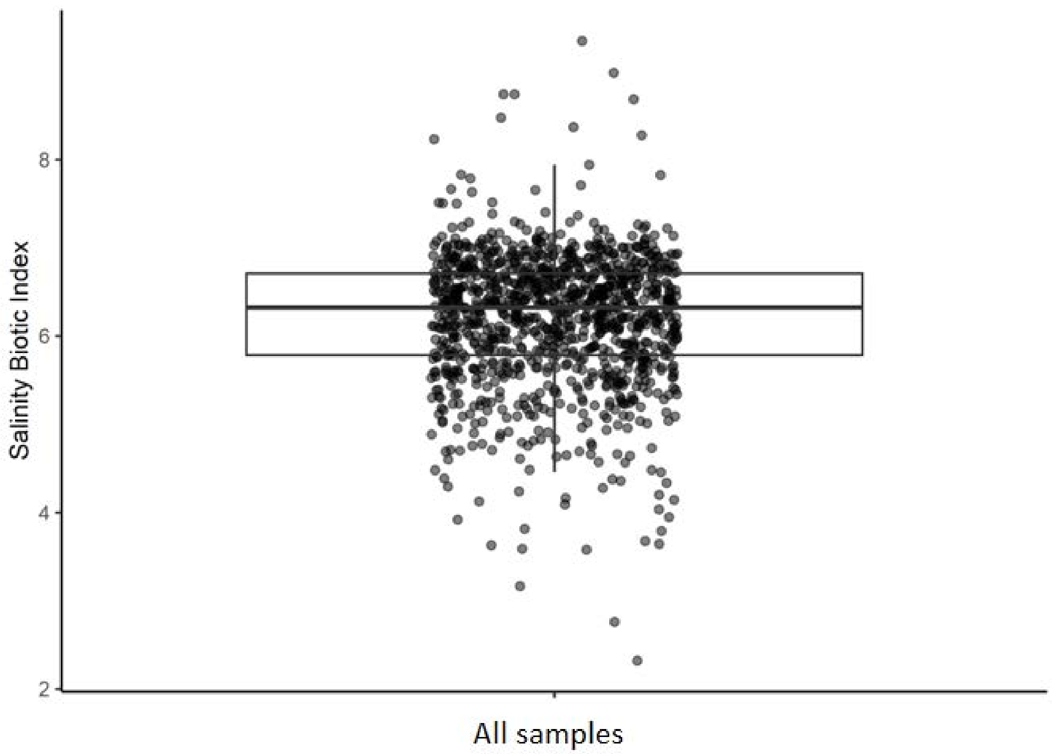


Figure 41. Sensitivity distribution curve for chloride.

2.5.2 Salinity Biotic Index (SBI)

SBI values ranged from 2.3 to 9.3, with most falling between 5.8 and 6.7 from the BMI and salinity data (Figure 42 and Figure **43**). Low SBI values indicate low salinity conditions and high SBI values indicate high salinity conditions. Values close to 0 are observed when one or both tolerance value (TV) and relative abundance (RA) are low. These SBI distributions suggest that most stream locations in the County are facing some level of biological degradation from elevated stream salinity.



Note: Values are from 1,081 non-tidal freshwater streams in the mid-Atlantic coastal plain (Prince George's County, MD), and each point represents an SBI value from a single stream location.

Figure 42. Percentile distribution of salinity biotic index values.

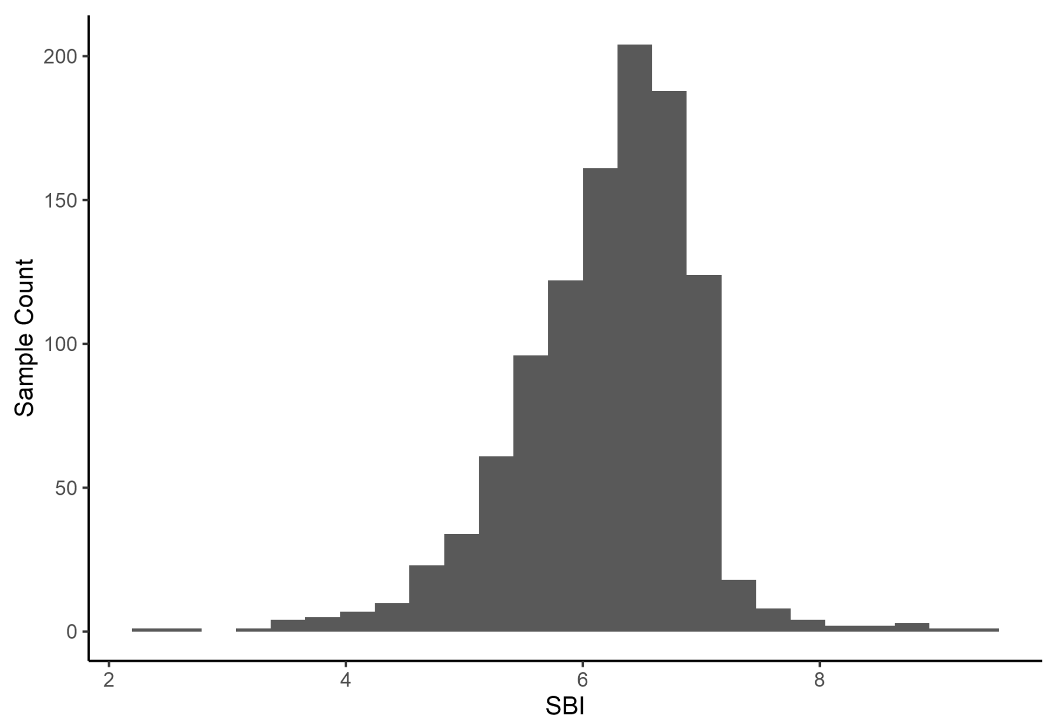
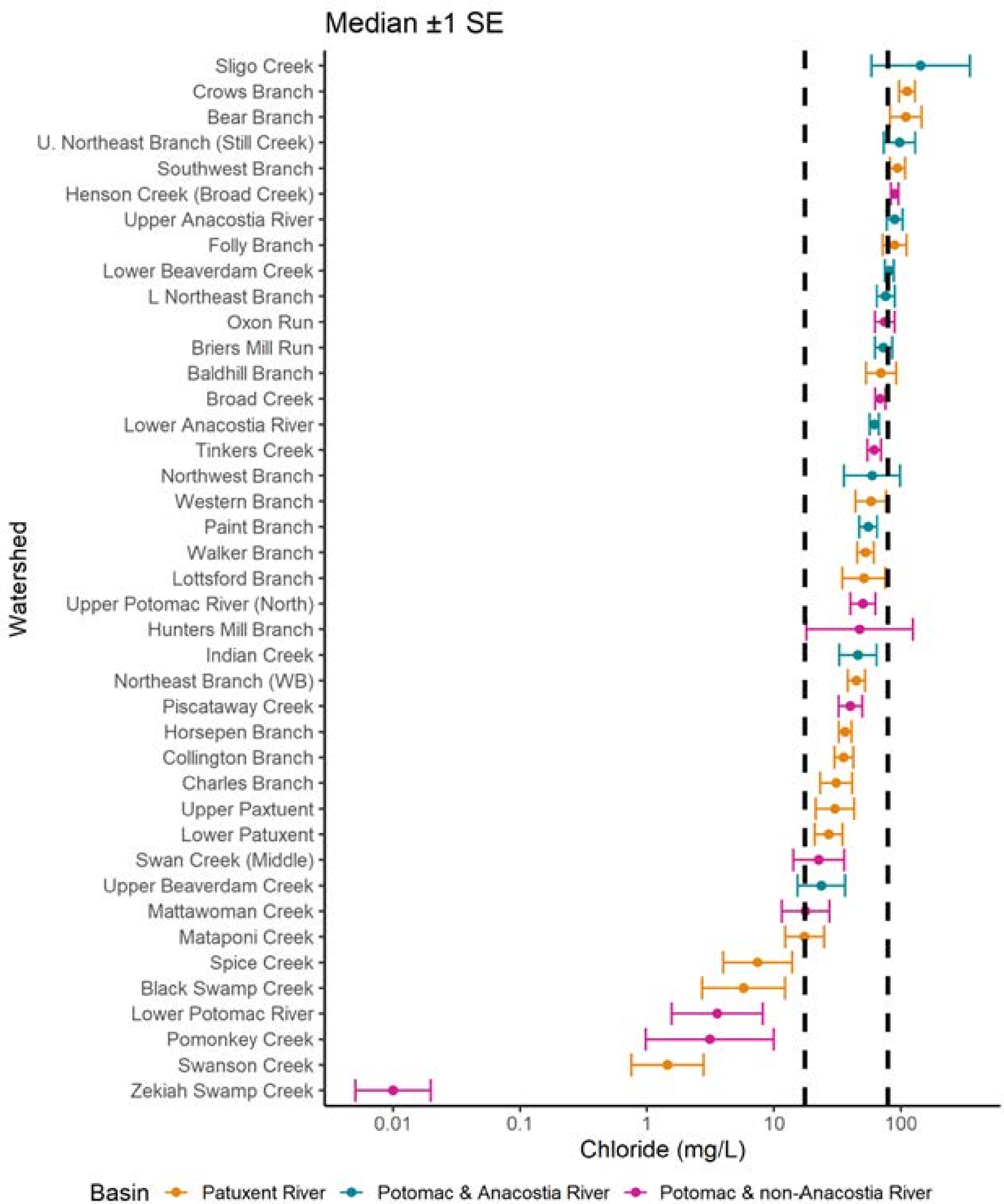
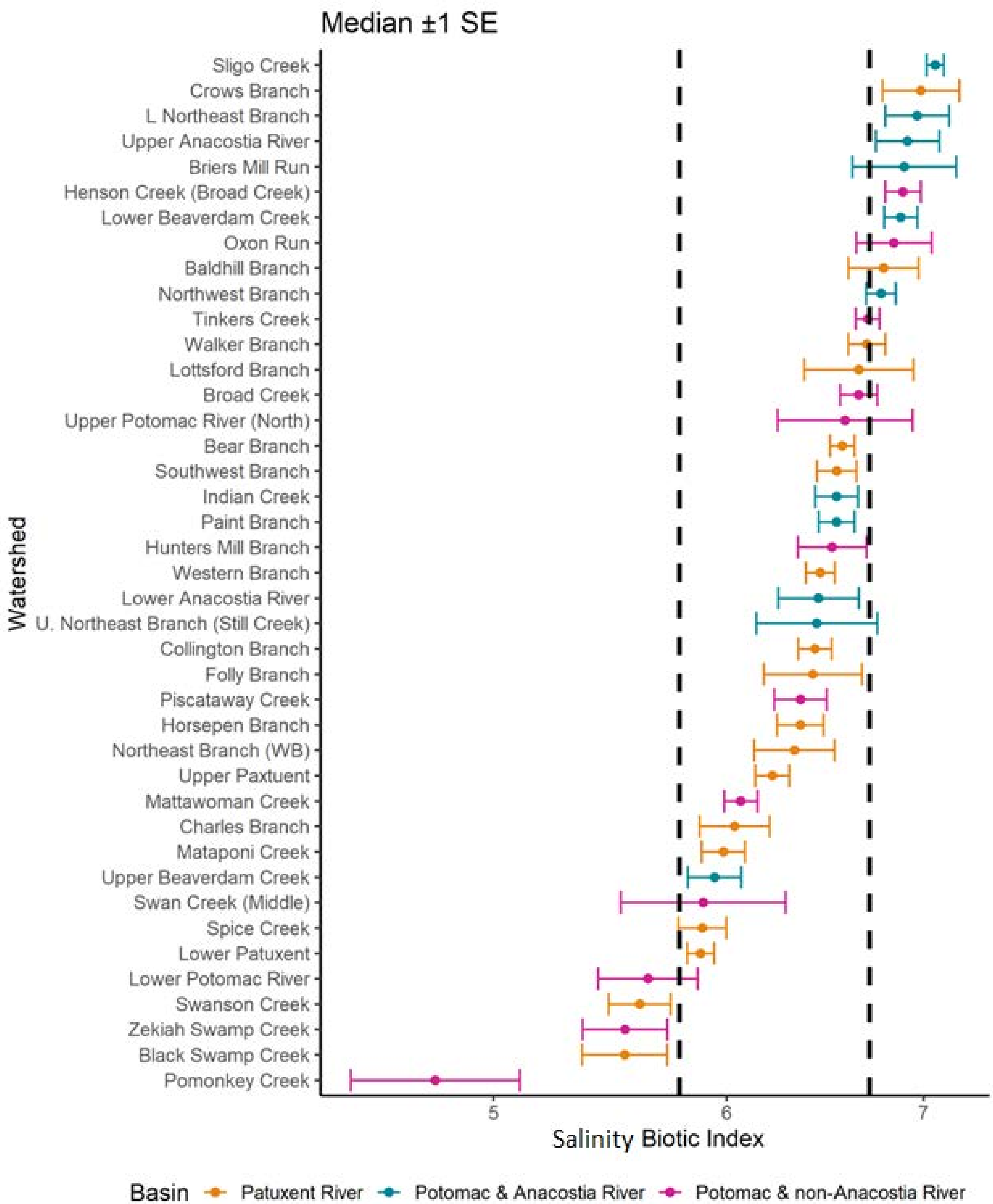


Figure 43. Histogram of salinity biotic index values.

Caterpillar plots partitioned by subbasin (subbasins shown in Figure 5) are used to illustrate the relationship of chloride concentrations and SBI (Figure 44), displaying the long-term median ±1 standard error; the subbasins are ordered by median. The top panel orders watersheds based on their median chloride concentration, whereas the bottom panel orders watersheds by their SBI, which is based on the benthic data. The ordering of subbasins in the two panels is similar but not exact between the two plots. The first panel in Figure 44 indicates that at least 35 subbasins exceed median chloride concentrations of 30 mg/L, and nearly one quarter of all subbasins face median chloride values of about 100 mg/L.

In the second panel in Figure 44, watersheds toward the top of the display have a larger proportion of salt tolerant BMIs; it should be noted, generally, that the benthic community is simultaneously exposed to and potentially affected by other stressors and water quality constituents. Lack of watershed-grouped clustering of SBI and chloride values (Figure 44) suggests that the three major basins are similar regarding these measures.


Median ±1 SE
Sligo Creek
Crows Branch
Bear Branch
U. Northeast Branch (Still Creek)
Southwest Branch
Henson Creek (Broad Creek)
Upper Anacostia River
Folly Branch
Lower Beaverdam Creek
L Northeast Branch
Oxon Run
Briers Mill Run
Baldhill Branch
Broad Creek
Lower Anacostia River
Tinkers Creek
Northwest Branch
Western Branch
Paint Branch
Walker Branch
Lottsford Branch
Upper Potomac River (North)
Hunters Mill Branch
Indian Creek
Northeast Branch (WB)
Piscataway Creek
Horsepen Branch
Collington Branch
Charles Branch
Upper Paxtuent
Lower Patuxent
Swan Creek (Middle)
Upper Beaverdam Creek
Mattawoman Creek
Mataponi Creek
Spice Creek
Black Swamp Creek
Lower Potomac River
Pomonkey Creek
Swanson Creek
Zekiah Swamp Creek
Watershed
0.01
0.1
1
10
100
Chloride (mg/L)
Basin
Patuxent River
Potomac & Anacostia River
Potomac & non-Anacostia River

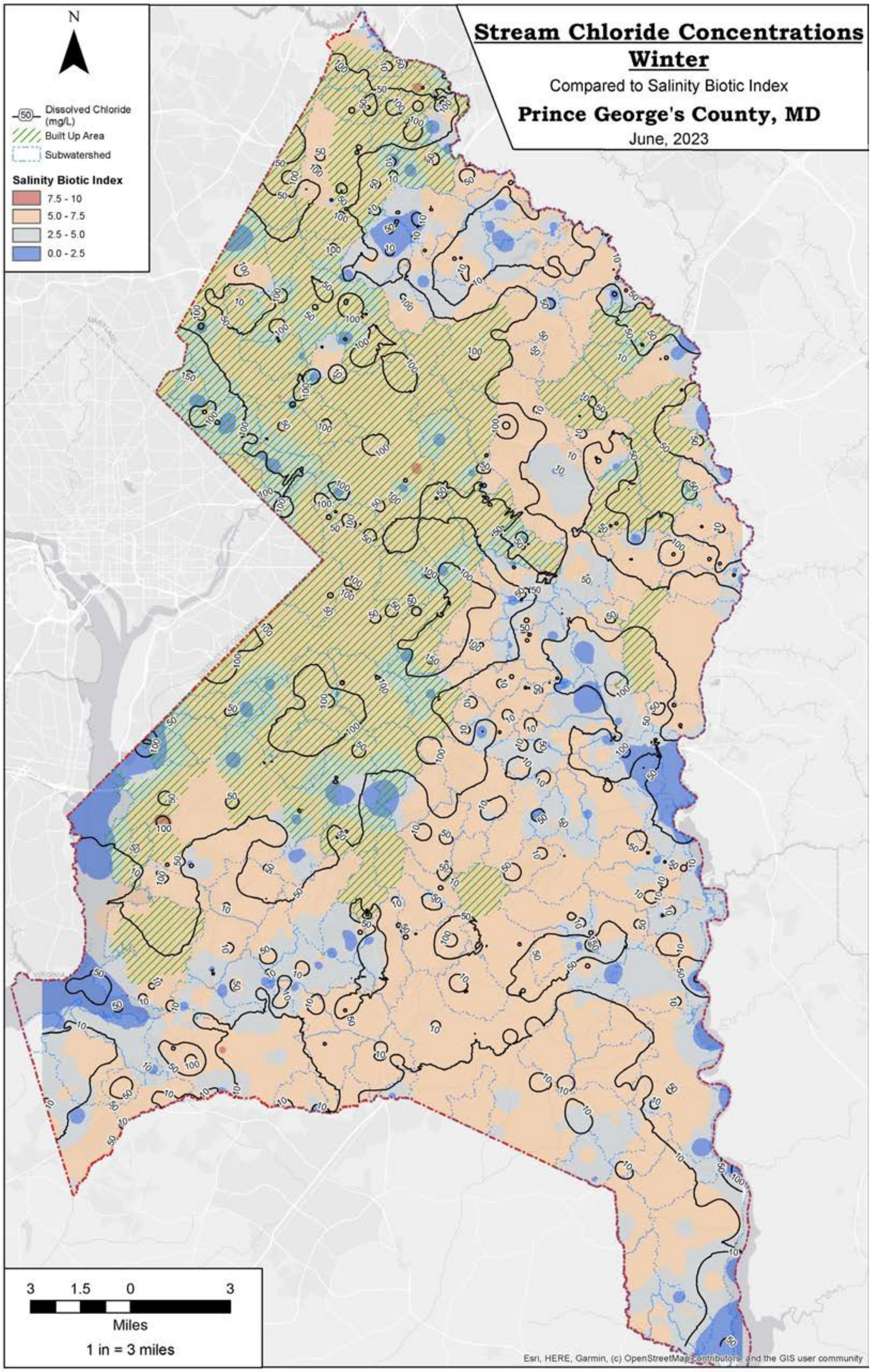


Note: Vertical dashed lines denote the 25th and 75th overall percentiles.

Figure 44. Caterpillar plots of the chloride (top) and salinity biotic index (bottom) medians ±1 standard deviation, for each watershed.

2.5.3 Salinity Biotic Index and Chloride Relationship

Water chemistry and benthic-derived data (here, SBI values) were used to visualize potential hotspots across the county where biological degradation intersected with elevated salinity. Inverse distance weighting was used to spatially interpolate the observed SBI values across the County. The SBI distribution (Figure 45) suggests a patchy pattern, with more salt sensitive taxa located near the Potomac River and the Patuxent River.



Note: Hatching represents ≥ 20% impervious area.

Figure 45. Long-term salinity biotic index contours in the winter.

2.6 DISCUSSION OF DATA

Salinity and biotic conditions in the County's freshwater resources are the primary analysis criteria. Much of this overall technical analysis integrates salinity and biotic conditions to study the status of this local water ecosystem. The main conclusions from the spatial, seasonal, and weather analyses are that:

- elevated chloride concentrations are observed in the developed areas located in the western portion of the County,
- seasonal variations indicate higher chloride concentrations during winter compared to summer,
- rainfall demonstrates a notable dilution effect, resulting in a reduction of chloride concentrations, although a flushing effect that represents the mechanism of transport of chloride from the watersheds into the streams is also present, and
- chloride concentrations tend to be higher directly after snowfall and decrease with time.

In addition to the analysis of temporal and spatial chloride concentrations, biotic analysis also reveals stream health status. TVs for chloride were developed for taxa with sufficient sample size. The distribution of taxa rank-ordered by *XC95* values was plotted to develop the SDC for the County, which indicated that at the typical average chloride concentrations observed, certain regions could experience up to 17% extirpation of the macroinvertebrate taxa. These TVs were combined with taxa relative abundance values to develop a SBI for each sample/stream site. Visualizing the chloride concentrations and SBI values in the watershed can help identify salinity hotspots across the County. The 41 subbasins can also be ranked using these two metrics, to help prioritize locations with high chloride concentrations and high salt tolerant benthos in the county.

This overall analysis reveals general patterns; nonetheless, the work is subject to several caveats:

1. While chloride is the dominant winter deicing-related ion contributing to stream salinization, the literature review indicated that other metal ions, including heavy metals, can lead to stream water quality degradation. These additional effects were not studied in this analysis; hence, additional biological stressors are not included. This means that the correlation between SBI and chloride concentrations could be systematically biased.
2. In this study, instantaneous chloride concentrations and average chloride concentrations by monthly, annual, and multi-decadal intervals have all been used to develop analyses associated with salt accumulation in streams. However, the critical parameter that affects BMIs in streams is the 4-day average ionic toxicity (Tetra Tech 2021). However, continuous monitoring timeseries of ionic constituents in the water do not exist in the County, making an analysis of this quantity impossible.
3. The confounding effects of other environmental stressors, such as stream temperature, pollution, and land-use change are not factored into the SBI calculations. Additionally, the SBI analysis did not include the explicit influence of chlorides versus other ions. Therefore, the effects of chloride due to winter deicing in this analysis may be conflated with other biological stressors.

4. A more sophisticated interpolation scheme such as kriging, compared to the IDW scheme, may yield more realistic SBI field data. However, the basic patterns are not expected to change.
5. The use of the built-up area as a surrogate for areas with likely winter salt deicing application is overly conservative.
6. The censoring of chloride values at the 95th percentile of the seasonal average to remove the effects of the tidal Patuxent River background salinity represents a very simple approach to account for this naturally occurring high salinity. Other, more sophisticated approaches may be possible, but are not expected to change the general patterns of SBI versus chloride concentrations observed here.
7. The precipitation recorded for the low-density residential site associated with the site-specific monthly chloride sampling for the fine-scale spatial pattern analysis is always zero inches. This could most likely indicate a malfunctioning rain gage or an error in Weather Underground's data processing pipeline. It would be useful to obtain an independent comparison from another rain gage for these datapoints.
8. Inferences on the relationship between stream biological health and the many chloride values discussed (instantaneous as well as monthly average, seasonal and annual averages) presented in this memorandum should be considered preliminary.

In conclusion, by using both chloride data and benthic sampling (which can represent longer timeframes based on community level data), potential salinity hotspots across the county can be identified. Chloride and benthic data can also begin to be correlated with land use information. Future work that incorporates confounding factors that impact benthic communities will help increase confidence in isolating chloride salt effects from other stressors.

The identification of salinity hotspots can help generate deicing protocols that take into consideration particular subwatersheds (1) where BMI communities are already highly stressed, (2) where streams have been restored at significant cost and whose BMI populations are targeted for protection, or (3) where BIBI scores are exceptional and where preemptive minimization of deicers can protect those high-quality streams. The following sections consider the state of salt management in the County and what other counties and agencies are doing to address these very concerns.

3.0 SALT MANAGEMENT IN PRINCE GEORGE'S COUNTY

This section explores the current state of salt management in the County and draws from the experiences of other counties in the state of Maryland, and other states to suggest approaches in the following areas of salt management: snow and ice control management protocols, equipment calibration, loading (from salt domes onto trucks) and unloading (from trucks into salt domes) of salt, spreading of salt, storage of salt, handling of salt, best management practices (BMPs) for salt management, and training of County and contractor staff for more efficient salt management that also protects aquatic freshwater ecosystems.

3.1 RESOURCES FOR SALT MANAGEMENT INFORMATION

The suggestions in this section are based on a grey (not published commercially or by academia) literature review of municipal separate storm sewer systems (MS4) permits, salt management plans (SMPs), and other resources developed by the Maryland Department of Transportation (MDOT), other counties in Maryland, and other states that have demonstrated progressive salt management approaches. These suggestions were qualitatively ranked based on three criteria:

1. ease of implementation,
2. cost of implementation, and
3. anticipated salt reduction benefits.

Broadly, these suggestions include:

- the use of new chemical pretreatment solutions other than rock salt to reduce salt application,
- careful detachment of salt sources from stormwater and groundwater flows,
- innovative methods of salt tracking and spreading,
- a variety of nonstructural BMPs for salt management, and
- holistic training for County and contractor staff.

In addition to these suggestions, a selection of national research organizations that could be research collaborators on scientifically-driven salt application optimization and road safety programs are listed.

This section also explores the current state of salt management in the County and draws from the experiences of other counties in the state of Maryland to develop suggestions for better management of its winter deicing program:

- Snow and ice control management protocols,
- Equipment calibration,
- Salt loading and unloading,
- Salt spreading,
- Salt storage,
- Salt handling,
- BMPs for salt management, and
- Training of County and contractor staff for better salt management.

These salt management topics have been taken directly from the subsections of the County's Salt Application Management Plan (PGC DPW&T 2014) to facilitate easy reference to relevant topics.

3.2 CURRENT SALT MANAGEMENT IN THE COUNTY

Over the past seven years, various measures have been implemented in the County to meet the MS4 permitting requirements. These measures have primarily revolved around pretreating road surfaces with a brine solution; enabling better weather forecast-based deicing operation decision making using the AccuWeather service; improving equipment maintenance and calibration; implementation of AVLs; enforcing better handling, loading and unloading, and storage of salt; and adopting various other BMPs. These improvements have resulted in paved surface temperature measurement-based salt application during only the most severe storms and in cold spots, along with a 64 percent reduction in the use of salt from over 41,000 tons in 2015 to less than 15,000 tons in 2022 (PGC DoE 2015; 2022).

Current County salt management, guided by the Salt Application Management Plan (PGC DPW&T 2014), includes the following features:

1. ***Snow and ice control management protocol***: The main arterial roads, bridges, and County-owned parking areas are pretreated with a brine solution to prevent ice-asphalt bonding and to reduce salt usage. To reduce multiple brine applications, the pretreatment step is restricted only to cold, dry weather periods before storm events.

   Salt is applied only as needed, with a sand-salt mixture used to reduce salt usage. Salt application and plowing operations are restricted to the main arterial roads during heavy snow periods; facility sidewalks, curbsides, and entryways are treated only when necessary and only with approved salts such as Ice Melt™.

   Operational goals are set every 12 hours and modified in response to current and forecasted conditions during storm events. All the snow districts participate in conference calls at least three times per 12-hour shift to discuss the real-time conditions, roadway temperatures, and snowfall forecasts to plan subsequent deicing and plowing operations.
2. ***Equipment calibration***: There has been a recent trend in shifting from granular rock salt to liquid products such as brine for salt spreading.

   Most snowplows have been equipped with AVL systems to optimize snow removal operations. Salt dump trucks have been equipped with well-maintained salt-spreaders and spinners to limit wastage. The spreader openings on these trucks are set prior to the onset of winter during annual inspection. Contractor trucks are inspected periodically to ensure that the equipment is functioning properly. Drivers of spreaders are instructed to turn their spinners off at red lights and when salt application is unnecessary to minimize the risk of spraying excess salt.
3. ***Loading and unloading salt***: The County has incorporated several measures to ensure that wastage and accidental spreading of salt does not occur during loading and unloading operations. These measures include restricting loading operations to near salt domes during snow events, and minimizing transloading, or the practice of offloading and reloading salt to transport to another location. Transloading occurences are minimized by the timely ordering of needed salt and ensuring timely delivery of the ordered salt. Excess salt is pushed back into the domes after each loading event. Truck routes are mapped in advance to reduce travel time to-and-from salt domes and to minimize the potential risk of accidental dumping.

   In addition, operators are trained to never overload salt trucks, while drivers are trained to avoid spillage and to minimize both salt spin-off and dumping after each event.
4. ***Spreading of salt***: The County has installed thermometers along various pavements to ensure a temperature-based spreading of salt. This spreading is determined by supervisors based on these pavement temperatures and accumulated depth of snowcover. Unused salt must be returned to the dome where it was loaded to minimize unaccounted losses of salt.

Snow operations personnel are trained on an annual basis on various spreading techniques. In addition, drivers are instructed to never spread salt just to dump loads, while plow operators are instructed to reduce spinner speed to avoid a broadcast of the salt across a wider swath of pavement than required. Plow operators are also instructed to spread salt in one swath, from the center road crown outward to reduce over application and the need to double back on pretraveled lanes and routes.

5. ***Salt storage***: To minimize the risk of excess salt in stormwater runoff and snowmelt, all stockpiles of salt are stored under cover or in the County salt domes. Uncovered salt and abrasive solids stockpiles are allowed during storm events but these materials are required to be placed under cover immediately after the storm.
6. **Handling of salt**: The County recommends using appropriate shop application rates to match specific storm conditions; additionally recommended is the use of appropriate personal protection for the personnel handling the loading and unloading of salt to ensure that excess chloride does not occur to the stormwater and, importantly, to protect the personnel handling the salt.
7. ***Training***: Annual training to all applicable County staff and contractors is provided on proper snow plowing techniques, safety, and the proper application of salt and deicing materials.

In addition to these measures, the County has also planned various improvements in the near future. These include (PGC DPW&T 2014):

- identifying and ranking environmentally sensitive areas in order of vulnerability, such as areas of special concern, including hydrologically connected wetlands and stream systems;
- using more accurate weather prediction to limit salting;
- analyzing salt usage data by truck and route collected after winter storms using software systems such as StormTrak;
- exploring alternative pretreatment methods and chemicals;
- adding more salt loading locations throughout the County, including additional dome locations in the south and on D'Arcy Road to increase capacity and reduce travel time between loading and unloading periods and to minimize risk of salt wastage;
- enhancing salt loading through conveyor apparatuses or hoppers;
- equipping all winter operations vehicles with electronic controllers, infrared thermometers, and pre-wet capabilities;
- ensuring that all new vehicles purchased contain electronic spreading equipment;
- locking-in application rates seasonally to avoid over-application and using independent salting controls on each spreader to reduce operator error;
- performing periodic equipment checks for accuracy during the application season;
- calibrating deicing equipment prior to the start of winter;
- calibrating the spreader systems annually;
- checking the quality of the trucks and equipment of contractors before signing or renewing contractor agreements; and
- implementing BMPs for handling salt and other deicing materials.

4.0 SALT MANAGEMENT PRACTICES AROUND MARYLAND

Apart from the measures already implemented in the County and the areas of improvement identified in Section 3.0, the operations in other counties in Maryland, other states, and other national agencies may provide additional practical knowledge benefits for salt management in Prince George's County. These approaches associated with each area of focus in the County Salt Application Management Plan (PGC DPW&T 2014) are described in this section. Each subsection has a brief description and an evaluation table on the approaches found during a grey literature search.

This section also contains a detailed description of the approaches and tables that include the ease of implementation, cost of implementation, and potential salt reduction benefits, which were qualitatively ranked using best professional judgement. This judgement approach reflects that metrics are likely to vary from county to county based on operational policies, institutional structures, budgets, and resource availability, thus, direct comparison is difficult.

4.1 SNOW AND ICE CONTROL MANAGEMENT PROTOCOLS

Various management protocols could be adopted with varying levels of ease and potential effectiveness based on the experiences of others in the region as listed in Table 4.

Pretreatment of paved surfaces is approached using different chemical mixtures by different counties and states, some more effectively than others. For example, instead of a rock salt-based brine, Montgomery and Frederick counties in Maryland, and the State of Minnesota, use a predominantly sodium chloride brine for pretreatment. This sodium-based brine is more effective than a rock salt brine at low temperatures (down to -6°F versus 20°F). While this approach is useful to prevent ice-asphalt bonding at low temperatures, this brine might not provide much environmental benefit. Alternatively, Frederick County uses Caliber M-1000, a 30% magnesium chloride- and agricultural byproduct-based solution to enhance the effectiveness of magnesium chloride, reduce corrosion, and improve both the rock salt working speed and melting capacity at lower temperatures. Howard County, MD uses Dri-Zorb, a corn cob absorbent, on sidewalks to reduce rock salt usage. Charles County, MD uses Quad-release, a magnesium chloride, potassium chloride, and sodium chloride mixture on pedestrian walkways and parking lots. These chemical approaches could be viable alternatives to rock salt brine to reduce soil and water pollution due to winter deicing.

Excessive salt application could be minimized—as in the case of Carrol County, MD—by having supervisors inspect roads using thermometers to determine road surface temperatures and adjust application rates as needed. Additionally, Carrol County conducts deicing on sidewalks only where there is human footfall year-round.

An attractive strategy to quantify and potentially reverse the environmental impacts of salt application is to adaptively monitor areas to assess the impact of winter deicing, with action plans to reduce salt impact over time through holistic watershed management. Anne Arundel County, MD practices such approaches.

Table 4. Snow and ice control management approaches.

Approach	Ease of implementation	Cost of implementation	Potential salt use reduction	Comments
Sodium chloride brine pretreatment	Easy	Low	Minimal	Rock salt brine also has sodium chloride
Dri-Zorb pretreatment	Easy	Low	Low	Not applicable for roads
Quad-release pretreatment	Hard	High	Medium	Still contains many corrosive chlorides
Caliber M-1000 pretreatment	Hard	High	High	Chemical may be expensive to procure and store
Human footfall-based pavement deicing	Easy	Low	Low	Not all pavements will have year-round human footfall, so effect is likely to be minimal
Supervisor temperature inspection-based salt application	Medium	High	High	Supervisors already travel throughout County periodically, but temperature-based application may be difficult to implement on non-electronically controlled spreaders
Adaptive monitoring and salt management	Hard	High	High	Programmatic implementation through total maximum daily loads (TMDL) or watershed implementation plans (WIPs) may be necessary

4.2 LOADING AND UNLOADING OF SALT

Several best practices for salt loading and unloading used in other areas could be adopted by the County to reduce the accidental spillage of salt and consequential pollution of stormwater runoff (Table 5). These practices include loading salt trucks under cover and out of precipitation, as practiced in Virginia; the installation of loader scales on loaders to account for the salt being loaded onto trucks, as in Carroll County, MD; and the use of salt tracking barcodes at each salt dome to track how much salt is laden from each dome, as in Charles County, MD.

Table 5. Salt loading and unloading approaches.

Approach	Ease of implementation	Cost of implementation	Potential salt use reduction	Comments
Loading and unloading under cover	Easy	Low	Medium	Infrastructure already exists to practice this at County salt domes
Loader scales	Medium	Medium	Low	Likely not a substantial amount of salt lost during loading and unloading
Dome-based salt barcode	Hard	High	Medium	Tracking of salt quantities can help manage accidental spills and dumping, and transloading

4.3 SPREADING OF SALT

While the County uses the S.T.O.R.M. system to track the use of salt, additional benefits could be realized by reducing the use of salt per lane-mile of roadway (Table 6). For instance, in Harford County, MD, only 300 pounds (lbs.) of rock salt are used per lane-mile by using the PreCise^{R} mobile resource management system, as opposed to the SHA's nearly 500 lbs per lane-mile statewide average (Price 2022).

Table 6. Salt spreading approaches.

Approach	Ease of implementation	Cost of implementation	Potential salt use reduction	Comments
Reduce salt use per lane-mile of roadway	Medium	Low	High	Integration with existing S.T.O.R.M. system may be possible

4.4 SALT STORAGE

If the County is not already implementing stormwater runoff contact prevention measures at the DPW&T's salt domes and barns, the approaches of the MDOT and both Anne Arundel and Baltimore Counties, MD to place bulkheads and straw bales at the entryways of these structures (both are structural-based BMPs) could be adopted. Another structural-based BMP approach could be to surround the structures by berms to prevent leakage into the groundwater (Table 7). These are also likely a requirement of the industrial stormwater permits (20-SW) common to County public works satellite yards.

Table 7. Salt storage approaches.

Approach	Ease of implementation	Cost of implementation	Potential salt use reduction	Comments
Bulkheads and straw bales at dome entryways	Easy	Low	Medium	Easy to implement temporary bulkhead measures at minimal cost
Berms surrounding domes	Hard	High	High	Filter-lined berms would require acquisition of land surrounding the domes and extensive earthwork operations

4.5 OTHER BEST MANAGEMENT PRACTICES

Nonstructural BMPs are designed to improve overall salt management in the County across a variety of salt management practices. These practices could be adopted in conjunction with other management protocols to substantially reduce salt application over time (Table 8).

In Charles and Anne Arundel counties, MD, less-used sidewalks and certain parking lots are closed each winter to reduce deicing applications, thereby concentrating vehicle parking in selected areas (Appendix A). These approaches reduce the need to salt all paved areas. Carrol County, MD has posted signs that indicate the limits of salt maintenance and mark jurisdictional boundaries to minimize overlapping salt applications between salt management districts.

If not being done so already, agency managers could be trained by using web-based tools such as the Minnesota Smart Salting Assessment tool (SSAt) to better understand best practices and identify other sources of salt in the water such as water softening operations and fertilizer applications. This technical approach would allow managers to develop more holistic salt management practices Countywide over time.

Table 8. Other best management practices.

Approach	Ease of implementation	Cost of implementation	Potential salt use reduction	Comments
Closure of less used sidewalks	Medium	Low	Low	Sidewalk application is low compared to road surface application

Approach	Ease of implementation	Cost of implementation	Potential salt use reduction	Comments
Closure of certain parking lots	Medium	Low	Medium	Traffic disruptions may be difficult to justify
Limits of maintenance jurisdiction signs	Easy	Low	Low	Most benefits might already be being realized through the SnowPortal and S.T.O.R.M. systems
Web-based tools for holistic salt management	Easy	Medium	High	Substantial benefits to be realized if cross-sectoral salt management happens throughout the County

4.6 TRAINING OF COUNTY STAFF

Apart from training on equipment use, ongoing training for County staff and contractors could include the best elements of programs from other counties, such as Anne Arundel County's Sensible Salting program (Table 9). This program encourages minimizing salt application during late evening and early morning hours. The Minnesota Smart Salting training program builds awareness among town employees on how salt affects the local waterways, in addition to salt application training (see Appendix A).

Table 9. Training approaches.

Approach	Ease of implementation	Cost of implementation	Potential salt use reduction	Comments
Limit salt application to certain times of day	Medium	Low	Medium	Minimizing low temperature salt application could increase effectiveness of rock salt
Environmental awareness education	Easy	Low	Medium	An environmentally aware staff would be better motivated to operate more effectively as a team

4.7 MARYLAND COUNTIES AND STATE HIGHWAY AUTHORITY (SHA)

The following are descriptions of how local municipalities, primarily in the Washington, DC metro area, are practicing salt management relating to road deicing. Some management activities involve pre-treatment in addition to better accounting and tracking of salt use. Most of the information found comes from municipal MS4 permittee annual reports, which provide limited information on the practices employed and do not necessarily highlight pre-treatment practices.

4.7.1 Maryland Department of Transportation (MDOT)

MS4 permit holding municipalities across Maryland have based their SMPs on MDOT's statewide SMP (MDOT 2022). The salt BMPs outlined in this document are summarized below:

1. ***Salt storage***: Placing a barrier across salt barns and domes when not in use will prevent accidental washoff by stormwater runoff (Figure 46).

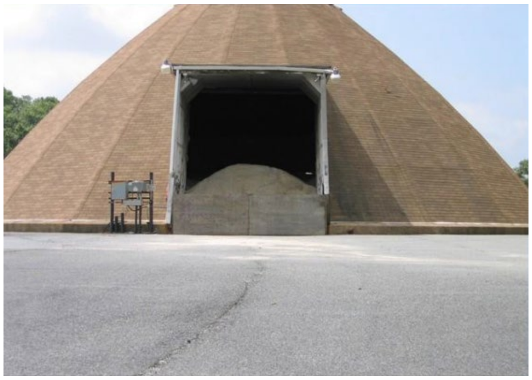


Figure 46. Salt barrier in front of salt dome (MDOT 2022).

2. ***Sand storage***: Storing sand-salt mixtures under cover will help prevent accidental washoff by stormwater runoff (Figure 47).

Figure 47. Abrasives stored under cover (MDOT 2022).

3. ***Brine liquid storage***: Regular inspection and maintenance of brine storage tanks in safe working condition and associated hydraulic fittings will ensure the prevention of accidental leaks.
4. ***Salt handling***: Allowing a sand-salt mixture or salt to wash off into drainage swales and other stormwater BMPs can reduce the BMP's effectiveness (Figure 48).

Figure 48. Stormwater swale affected by salt washoff (MDOT 2022).

- Overflowing trucks, dumping remaining salt after an application trip, and not sweeping spilled salt back into the salt barns or domes can result in accidental pollution (Figure 49).

Figure 49. Salt spillage in truck lanes (MDOT 2022).

5. ***Materials spreading***: Accidental spills from dump trucks should be avoided if possible and mitigated if they happen.
6. ***Equipment preparation and cleaning***: MDOT recommends calibrating all equipment on salt application vehicles prior to the winter season to ensure proper application rates. Clean equipment and the use of an AVL system can also ensure the minimization of inefficient application and accidental spills.
7. ***Managing sensitive areas***: Coordination between the SHA and county agencies can help determine sensitive areas such as wetlands, tier 2 waters that have been designated to protect aquatic life, wellhead protection areas, and streams used by the public. Site-specific plans could be created to adaptively manage such sensitive areas.
8. ***Maintenance Decision Support System (MDSS)***: MDOT SHA's MDSS is based on high-resolution weather and pavement temperature forecasts to ensure a data-based salt application rate.
9. ***Management during severe storms***: During severe storms, plowing could be prioritized over salt application.
10. ***Timing and order of operations of salt operations***: The use of pre-wetting, accurate timing of salt application that ensures is not sprayed to the road edges by traffic, snowplow operations, and traffic-based salt application can all ensure that during very cold conditions, salt usage is limited.
11. ***Equipment***: MDOT recommends the use of modern, electronically controlled loaders, loading scales, spreaders, and salt application machines.
12. ***Contractors***: Contractors should be trained in the proper use and application of salt, and proper maintenance of their vehicles.
13. ***Forecasting weather and pavement conditions***: Pavement condition forecast site networks such as RWIS and Mobile Advanced Road Weather Information Sensors (MARWIS) can be valuable tools for gauging how much salt application would be required.

4.7.2 Anne Arundel County, MD

Anne Arundel County's SMP focuses on the following:

- Winter maintenance policies,
- Trends/data analysis,
- Materials ordering, delivery, storage, handling, and record keeping,
- Equipment upgrading, calibration, and washing,
- Snow and ice control training,
- Weather forecasting,
- Storm response,
- Environmentally sensitive areas,
- Technology review, and
- Public outreach/education.

The Anne Arundel County fiscal year 2022 annual MS4 report describes their SMP, including the initial stages of managing environmentally sensitive areas include identifying and ranking the areas in order of vulnerability (AAC DPW 2022). Next, these areas can be monitored to assess the environmental impacts of Anne Arundel County's winter salt management activities. Lastly, when appropriate, action plans can be developed). No information was provided on specific methods to reduce chloride impacts on environmentally sensitive areas, however, noted are BMP examples is to prevent stormwater runoff from entering salt storage barns. Anne Arundel County added wooden bulkheads and straw bales to the entryways of salt barns. They recommend all winter operations vehicles be equipped with electronic controllers, infrared thermometers, and pre-wet capabilities. Their fleet of snowplows are equipped with AVL tracking hardware as recommended by MDOTs SMP to monitor and optimize snow removal operations. Additionally, Anne Arundel County acquired heavy-duty dump trucks equipped with the latest spreader-controller technology and on-board liquid application capabilities (AAC DPW 2022).

Anne Arundel County provides annual training to applicable staff and contractors. The training includes proper snow plowing techniques and safety, application of salt and deicing materials, and highlights the concept of "Sensible Salting." This concept creates awareness of the need to protect the environment and includes the following lessons: limiting salt during late evening and early morning hours, limiting salt on secondary roads, and proper calibration of equipment.

4.7.3 Baltimore County, MD

According to its latest MS4 report, all snow removal equipment outside Baltimore County's urban-rural demarcation line has been outfitted with independent salting controls, which improve the efficiency and precision of road salting and reduce excess salt use associated with operator error. In addition, more than a quarter of their vehicles have been replaced with new vehicles equipped with independent salting controls. The rest of Baltimore County's crews use manually-adjusted salt spreaders/spinners to restrict salting. The northern portion of the Baltimore County computerized salt-spreading technology, which will be mandated on all new snow removal equipment (BC DEP 2022).

Spreading rates are maintained at between 500 and 600 lbs of salt for each lane-mile compared to Carroll County's 300-500 lbs and Harford County's 300 lbs; higher spreading rates can be more detrimental to environmental health than counties that maintain a lower spreading rate (CC DLRM 2022; HaC DPW 2022; BC DEP 2022). The calibration of spreader technology is checked annually.

To mitigate excess salt application, the Community College of Baltimore County closes certain parking lots to concentrate parking in selected treated areas only. Finally, Baltimore County's full supply of salt is stored under cover, on impervious surfaces, and surrounded by berms or straw bales to deter or prevent leaching (BC DEP 2022). Although no pre-treatment method is consistently used in Baltimore County, in 2022 a trial run of 23 percent rock salt brine solution was used on heavily traveled roads; it is undecided at this point if there will be continued use of this method.

4.7.4 Montgomery County, MD

As detailed in its 2022 MS4 Annual Report, Montgomery County exclusively used sodium chloride brine to treat roads rather than rock salt, which is beneficial due to the ease of manufacturing it and effectiveness at lower temperatures than rock salt, which loses its effectiveness at 20 °F while brine loses effectiveness at -6 °F (MC DEP 2022).

4.7.5 Carroll County, MD

Carroll County reduced salt use by 42 percent in 2022 via these methods. First, Carroll County uses selective deicing at locations when weather conditions affect public/employee safety. Then, they specifically apply deicing chemicals (chemicals not specified) at facilities having year-round usage but not at facilities that are inactive in the winter. Carroll County applies a brine solution to pre-treat roadways before a storm to then apply less granular salt during a weather event (CC DPW 2020).

Carroll County installed "Limit of Maintenance" signs, which mark jurisdictional boundaries to avoid overlap of salt application. Traffic cameras are positioned across Carroll County to monitor weather conditions in real time. Carroll County is divided into 50 snowplow routes that are travelled and plowed by a fleet of dump trucks consisting of single axel units capable of carrying nine tons of salt each and tri-axel units capable of carrying 10-15 tons of salt. Each truck is calibrated annually and equipped with well-maintained plows and electronically controlled spreaders, which apply salt in a pattern that limits material waste.

Carroll County is acquiring loader scales that will be installed on front end loaders to accurately weigh salt being loaded into a truck to track usage by the truck while travelling its routes. Supervisors perform real-time road inspections during winter storm events in vehicles which are equipped with thermometers to monitor air and road surface temperatures to determine if application rates are efficient in terms of cost, effectiveness, and environmental damage.

Carroll County and its co-permittees implement standard operating procedures that include BMPs that cover salt use delivery, storage, handling at storage locations, placement on roadways, and post-storm clean-up procedures (CC DPW 2023). BMPs include:

- residual materials being swept into salt storage structures,

- on-site spill kits available at each salt storage facility in the event of equipment failure during operations, and
- cleaning of salt spreaders and plow blades that have been removed from vehicles occurs so that wastewater does not discharge into stormwater systems or onto the ground.

Deicer that is more effective at lower temperatures and less corrosive has been selected for sidewalks which reduces usage of solid deicers. When appropriate, alternatives to salt are used to remove snow, such as snow blowers and utilization of abrasives (crushed stone or sand) to provide traction on unpaved/gravel roads for motorist safety.

Runoff deicer is not applied to gravel roads to reduce the potential of pollutants entering stormwater and no deicing of aircrafts is performed at the Carroll County Regional Airport. These BMPs and more are reviewed annually at a pre-snow season training which in 2022 was attended by 82 operations staff and 25 government contractors (CC DLRM 2022).

4.7.6 Charles County, MD

According to the latest MS4 report, Charles County uses several methods to increase the efficiency of road salt application and decrease adverse environmental and infrastructural impacts. For example, the Roads Division waits until the storm has nearly passed to plow/spread salt to increase effectiveness and decrease runoff/number of times applied throughout a storm event (CC DPGM 2022).

The Department of Recreation, Parks and Tourism uses Quad-Release, a deicer made from magnesium chloride, potassium chloride, and sodium chloride on pedestrian walkways/parking lots with the following guidelines to reduce its usage as much as possible: shovel prior to applying material, apply only the recommended amount or less, and close lesser-used sidewalks. Following a storm event, sidewalks throughout Charles County are swept to remove excess salt and deicing materials.

Charles County is exploring the option of a salt-tracking barcode which will allow salt taken and returned from its domes to be tracked and if salt is being improperly applied, the contractor responsible can be retrained or removed from the program (CC DPGM 2022).

4.7.7 Frederick County, MD

As described in its latest MS4 permit report, Frederick County dispenses Caliber M-1000, a 30 percent magnesium chloride solution combined with an agricultural byproduct, from 48 of its trucks as a form of pre-treatment when temperatures reach 25 °F or lower (Frederick County 2021). According to EnviroTech Services, the trademark owners of Caliber M-1000, the product is designed to enhance the effectiveness of magnesium chloride by suppressing crystal formation and reducing corrosiveness (Central Salt 2017; EnviroTech 2023). Furthermore, Caliber M-1000 allows rock salt to be used at lower temperatures than without its application and increases both rock salt working speed and melting capacity (EnviroTech 2023). In addition to application of Caliber M-1000, Frederick County pre-treats roads and pathways with a brine solution, allowing for significantly reduced rates of granular road salt application (Frederick County 2021).

4.7.8 Howard County, MD

Howard County uses Dri-Zorb, a single-ingredient corn cob absorbent to reduce rock salt usage on roadways and sidewalks, when appropriate (HoC DPW 2022; The Andersons, Inc. 2020). This product is an eco-friendly alternative, which ideally will reduce the adverse effects of chloride pollution to the environment by substituting biodegradable corn for chloride containing chemicals.

4.7.9 Approaches in Other States

The following salt management practices are employed by Virginia municipalities according to each municipality's latest annual MS4 report:

- Arlington County keeps its stocks of salt and sand in two locations in the county, both of which are covered or inside to reduce potential stormwater runoff due to materials being exposed to rain and other weather events, as is typical of most Virginia counties. One of the locations, the Trades Center, is large enough to allow trucks to be loaded inside under cover, which further reduces potential for polluted runoff (AC DES 2023).
- Fairfax County uses sand as an abrasive in combination with calcium chloride for deicing roadways, and magnesium chloride for walkways. All deicing materials in the county are stored in covered bins at facilities operated by the Maintenance and Stormwater Management Division (FC DPWES 2022).
- Training for applicable employees in the town of Herndon includes standard operating procedures for salt, deicer, and sand usage, for both containment, and clean-up tasks (Herndon DPW 2022).
- The Town of Vienna provides stormwater pollution prevention training for applicable town employees which includes salt BMPs and information on how chloride affects local waterways (Vienna DPW 2022; Figure 50).

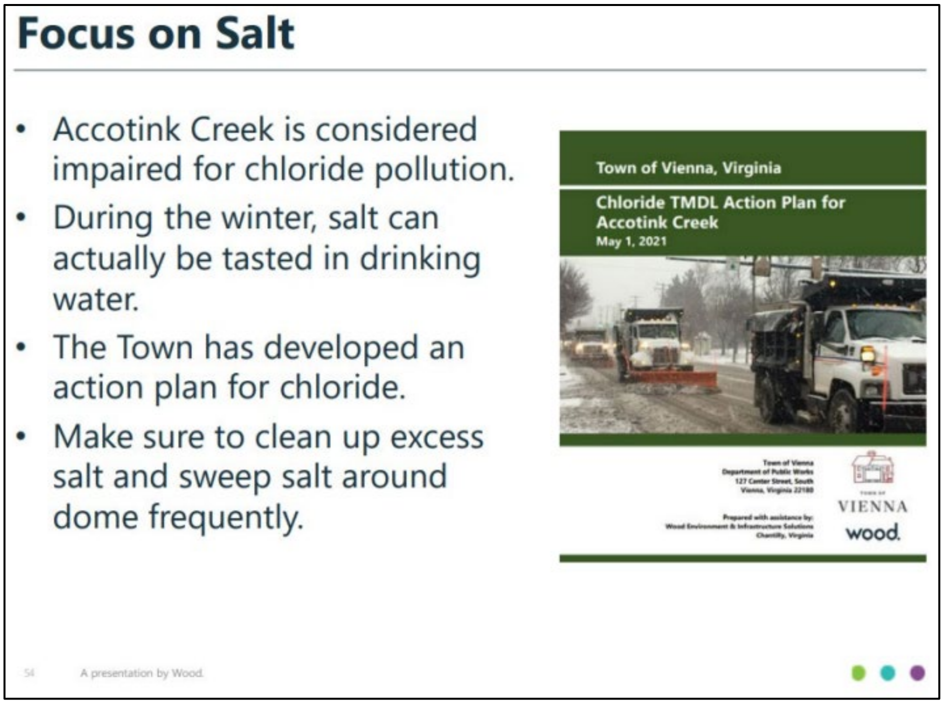


Figure 50. Stormwater pollution prevention training for applicable employees in Vienna, VA (Vienna DPW 2022).

- The New York State based Lake George Association (LGA) has worked with municipalities draining to Lake George to reduce salt usage. In addition to encouraging municipalities and private contractors to certify in a privately-developed Sustainable Winter Management (SWiM®) Program.
    - The LGA also advocates the use of Live Edge plow technology by the Canadian company Metal Pless for more effective snow removal by plows.
- The Minnesota Pollution Control Agency has a 5.5 hour training program for public and private plow operators and anyone responsible for deicing on sidewalks and parking lots that teaches more efficient use of deicers and physical removal to reduce chloride levels. The certificate lasts 5 years. A refresher recertification class is offered as well. Additional tranings exist for property managers, business owners, and environmental professionals and for community leaders.

  The Minnesota Pollution Control Agency (MPCA)'s statewide chloride management plan serves as a reference for municipalities across Minnesota. The document highlights five primary strategies for reducing the use of chloride containing products during the winter, as follows:

  1. Shift from granular products to liquid products,
  2. Improved physical snow and ice removal,
  3. Snow and ice pavement bond prevention,
  4. Training for maintenance professionals, and
  5. Education for the public and elected officials on chloride problems and reduction strategies.

The plan emphasizes the use of a Smart Salting Assessment tool (SSAt) developed by the MPCA which currently can be used voluntarily to understand current practices, identify areas of improvement, track improvement progress, and fulfill MS4 permit requirements for permits with a chloride waste load allocation. The tool is currently being expanded from targeting gravel roads and winter maintenance professionals to include sources of chloride such as water softening, fertilizer, among other improvements (MPCA 2020). Many MS4 permit holding municipalities utilize salt brine as pre-treatment (MPCA 2020). This tool was noted earlier in the main report's section on Best Management practices (Section 2.5).

4.8 COLLABORATION WITH OTHER ORGANIZATIONS

There are many organizations across the Country that perform research on new winter strategies by testing new materials in laboratories and evaluating the effectiveness of new products on highways and bridges. Prince George's County could consider and take advantage of these resources, most of which are free of charge to others in the winter maintenance community. These research organizations include:

1. The Clear Roads pooled fund project provides real-world testing in the field of winter highway operations. This ongoing research program has already attracted 34-member states and is funding practical winter maintenance research (http://www.clearroads.org/).
2. Aurora is an international partnership of public agencies that work together to perform joint research activities in Road Weather Information Systems (RWIS). This website is designed to introduce the program, the partners, and its collaborative research projects (http://www.aurora-program.org/).
3. The Road Weather Management Program, in the Federal Highway Administration (FHWA) Office of Operations, seeks to better understand the impacts of weather on roadways, and promote strategies and tools to mitigate those impacts (http://www.ops.fhwa.dot.gov/weather/index.asp)
4. The Maintenance Decision Support System Pooled Fund Study leads the nationwide effort to provide research, development, and application of computer-based winter maintenance decision support, including route specific weather and pavement condition forecasting, and suggested responses to a winter storm event, based on an agency's rules of practice (http://www.meridian-enviro.com/mdss/pfs/).
5. The American Association of State Highway and Transportation Officials (AASHTO) advocates transportation-related policies and provides technical services to support states in their efforts to move people and goods efficiently and safely. Its Subcommittee on Maintenance provides technical services to support high-level research into preserving and maintaining a world-class highway system. The Winter Maintenance Technical Services Program addresses AASHTO's goals for the snow and ice control community (http://sicop.transportation.org/Pages/About-SICOP.aspx).

4.9 CONCLUSIONS FOR BETTER SALT MANAGEMENT

Salt management for winter deicing operations in the County has resulted in degradation of stream biological condition in the built-up areas in the County. Broadly, the suggestions to help reduce salt loading include:

- using new chemical pretreatment solution alternatives to rock salt to reduce salt application;
- handling best practices to minimize salt wash-off into streams due to stormwater and groundwater flows;
- deploying innovative methods of salt tracking and spreading to minimize excessive salt use;

- considering a variety of nonstructural BMPs to better manage salt; and
- conducting holistic training for County and contractor staff to optimize winter deicing operations.
- consider a certification program for private contractors, commercial property owners, and municipal salt management staff along with limited liability protections for those certified.
- Live-Edge plow technology for future purchases.

In addition to these options, the County could consider collaboration with some of the national research organizations that working on novel scientifically-driven salt application optimization and road safety programs.

5.0 WINTER DEICER OUTREACH FROM AROUND THE DC REGION

Many opportunities exist to educate and engage the County residents and businesses about reducing and effectively managing winter salt use without compromising public safety. Effective outreach and education can raise residents' and property owners' awareness about stormwater runoff and instill behavior changes that will reduce chloride loads in the watershed.

The Maryland Department of Transportation (MDOT) and several Maryland counties have already developed many education and outreach materials discussing salt management. The following is a selection of information and materials that the County can use to inform the public about the impacts of high chloride levels, the benefits of minimizing salt use, and alternative sources of deicing. Many of the materials are available in English and Spanish to help reach a broader population in the community.

5.1 MATERIALS THAT CAN EITHER BE SHARED OR ADOPTED

Many high quality materials already exist, from videos to comic books to pamphlets. With permission of the original creators, much of this educational content could be used as-they-are or with some minor modification. Before using any materials from the list below, the County should contact the product owners to obtain permission. Each organization might have specific protocols to follow for using their materials.

1. **MDOT materials.** Tetra Tech suggests using content already created by MDOT. The information would be a cost-effective approach to meeting the County's goals.
   - An interactive story map explores the effects of salt use on stormwater infrastructure and human and environmental health. Winter Salts (arcgis.com)
   - Fact sheets, such as https://www.roads.maryland.gov/oc/snowfactssheetupdated12-3-21.pdf, present MDOT's strategies for winter operations and the technology available to address winter weather.
2. **Maryland counties**. Several nearby counties have developed materials the County could use as models when creating County -specific resources.
   - ***Informational webpages***. Anne Arundel County provides information to residents, including a Winter Storm Removal page, which describes efficient salt application practices and salt best management practices (BMPs) for residents: https://www.aacounty.org/departments/public-works/wprp/education-outreach/road-salt/index.html.

- ***Informational graphics***. Montgomery County provides residents with resources like informational graphics that visually present the problem and recommend actions. https://www.montgomerycountymd.gov/water/education/winter-salt-management.html
- ***Radio public service announcements (PSAs)***. Charles County released a radio PSA titled "Use Less Salt," which ran in English and Spanish on several radio stations targeting homeowners and businesses. The PSA encouraged homeowners and businesses to use less salt for winter deicing by motivating them to save money and the environment. Specifically, the PSA encouraged measures such as
    - using salt only when storms are imminent and using only the least amount needed by evenly distributing salt and sweeping up any salt piles,
    - storing salt in a dry, covered area, and sweeping up unused salt for later use if the forecasted storm does not occur,
    - using natural cat litter for traction on thick ice, and
    - using chloride-free deicers.

  Additional information from the Charles County Watershed Protection & Restoration Program is available here: www.charlescountymd.gov/watershed and here: https://www.charlescountymd.gov/services/roads/snow-operations
- ***Salt Wise campaign***. Montgomery County and Washington Suburban Sanitary Commission developed a campaign that outlines appropriate salting practices and salt runoff's effect on local waterways: www.wsscwater.com/saltwise. The campaign includes a tip card in English and Spanish and several other relatable graphics. The campaign employs a three-step method:
    - Shovel right away
    - Use less salt
    - Sweep and reuse

3. **Metropolitan Washington Council of Governments** (MWCOG). MWCOG shares salt-related information, impacts, and how to be effective and efficient at home. MWCOG also has a Community Engagement Campaign to raise awareness: https://www.mwcog.org/environment/planning-areas/water-resources/outreach-and-education/winter-salt-smart/.
4. **Salt Smart Collaborative.** The Salt Smart (www.saltsmart.org) is a collaboration of people and organizations working to reduce the amount of salt reaching their local rivers and streams. The Salt Smart Collaborative shares information on BMPs, deicing trainings, and outreach materials, such as the following YouTube video: "More Isn't Always Better | Salt Smart" (https://youtu.be/oZLhdNCrQgs).
5. **Northern Virginia Regional Commission**.
    - The Salt Management Strategy (SaMS) Toolkit provides information on the benefits and the negative impacts of salt use and suggests practices that can minimize the consequences of salt use. The toolkit includes various resources and recommendations that the public can use to implement the practices: https://www.novaregion.org/1498/SaMS-Toolkit.
    - The Commission's webpage provides snow and ice maintenance tips for residents: https://www.novaregion.org/1489/Residential-BMPs.
6. **Animated Movie**. The County created a customized video, "Scoop That Poop," promoting pet waste management: https://youtu.be/AlNCrHhHEA4. The County could develop a similar video on salt management for posting on their website and sharing via social media and with other community organizations.

7. **Fairfax Water**. Fairfax Water, a nonprofit water utility, periodically creates "Water Ninja Adventures," a free online comic aimed at children and young adults to educate them about water pollution issues (Fairfax Water 2020). A feature of these comics is the continuity provided by situating them in a world of superheroes known as the "STEAM Team" – a group of students who are also deeply invested in protecting the environment with special powers. The stories typically begin by a field class of students noticing an issue in their watershed, followed by an inadvertent fall into the river only to discover the problem firsthand. Then, the students use the scientific method to deduce solutions, and use their superpowers to deliver those solutions to the aquatic organism denizens of the river. The comics include graphical info-boxes and pop-up quizzes educating the public and contain useful additional information and contacts at the end. Team Adventure #5 of the comic deals with winter salt: https://www.fairfaxwater.org/comics. The County could either develop similar outreach materials or use these under contract with Fairfax Water.

5.2 COMMUNITY EVENTS

In addition to adopting materials from the resources above, Tetra Tech suggests that the County could conduct various outreach events that discuss the benefits of better salt management by homeowners and commercial property owners. These may include:

- **Children's contests.** The County could host an elementary and middle school art contest. The County could create a children's art contest focusing on the harmful effects of salt and advertise it in all elementary and middle schools. The County could work with the schools to incorporate salt topics into the curriculum as part of the art contest and share the message via various distribution channels.
- **Tabling opportunities.** The County could use existing community meetings or events to increase attendance and reach more people. The following list provides an example of dates and locations for community meetings: https://pgcares.com/site-map/civic-associations-prince-georges-county/. The County could use local events as a venue to connect with a wide audience and promote their resources.
    - ***The Town of Cheverly's Cheverly Day***. This event takes place in Cheverly Town Park, offering many activities for the public and involving local vendors. The town's website provides more information: http://www.cheverlyday.org/2023/.
    - ***Mount Rainier Day***. More than 60 vendors were present at the event held on May 20, 2023. This event offers the opportunity to play children's games and share information with adults about county initiatives: https://www.mountrainiermd.org/residents/mount-rainier-day/mount-rainier-day-2023.
    - ***County festivals and fairs***. Hosting information tables at these events would help reach residents and businesses: https://www.experienceprincegeorges.com/events/festivals/.
- **Giveaways.** The County could offer giveaways that carry an action-related message or slogan and use the County logo. The public is more likely to approach a table giving away free materials. These items will remind each resident to apply the correct amount of salt on their walkway or driveway to save money and protect the environment. If the County distributes the giveaways at an event, county staff could speak to residents directly, which is more likely to spur behavior change. Other staff could lead games for the children, such as the "Scoop the Poop" game, that engages children and teaches them and their parents or guardians about other issues. Example giveaways that are useful and can be reused are:

- A 12-ounce mug that holds enough salt to treat a 20-foot driveway or ten sidewalk squares.
- A scoop that residents use to measure the correct amount of salt to apply (no more, no less).

5.3 SHARING CONTENT

Sharing content is an effective way of reaching many individuals and groups through existing partner distribution channels. The County and their trusted partners could reach more people because partners already have extensive distribution lists and followers on social media. Residents are more likely to open messages and follow information from a trusted source. Through social media, the County could ask partners to share messages about best practices for dealing with winter weather. Shared posts can reach an infinite number of residents in the county.

- **Community organizations** (including civic and homeowner associations). These types of organizations already have membership lists and distribution channels the County could use to share and distribute information: https://pgcares.com/site-map/civic-associations-prince-georges-county/.
- **Social media and blogs**. These include outlets such as the Salt Smart Collaborative: https://saltsmart.org/tools-for-clearing-snow-at-home/; https://saltsmart.org/why-salt-brine-is-better-than-rock-salt/
- **Provide content and PSAs to local news channels and weather applications before and during winter storm events**. These include outlets such as:
  - Prince George's Community Television: pgctv.org.
  - Prepare Prince George's app: https://apps.apple.com/us/app/prepare-prince-georges-md/id1113755509.
  - Daily Voice: dailyvoice.com/maryland/prince-georges.
  - RadioOne: (https://urban1.com/radio-one/.
  - El Zol 107.9: (https://www.audacy.com/elzolradio.
  - Fox 5: fox5dc.tag/us/md/prince-georges-county.
  - WJLA: https://wjla.com/.
  - WUSA9: https://www.wusa9.com.
- **Webinars**. Microsoft Teams and other webinar platforms can be used to actively connect and collaborate in real time with various stakeholders who only need an email address to join. Webinars will allow the County to collaborate with multiple speakers, share content, and record the meeting for posting on community websites for later viewing by those unable to attend. Polls can be used to survey and gauge residents' interest in the topic and their current attitude and activities towards using salt and other deicers. The County could use a webinar venue to first showcase the top three winning art projects focusing on the harmful effects of salt and then close the meeting by announcing the overall winner. A contest-focused webinar would draw in people of all ages and from many schools and local communities.

5.4 OUTREACH AND EDUCATION MATERIALS ON SALT MANAGEMENT

The following is a selection of the outreach and education materials on salt use minimization found in the metro area and beyond. While there is a lot of information for private homeowners, relatively limited information is available targeting commercial property owners.

5.4.1 Prince George's County Department of Public Works and Transportation (DPW&T)

DPW&T sends residential outreach flyers to County residents recommending the use of a 12-ounce deicer cup. This flyer also contains additional advisory information and guidelines for areas homeowners are responsible for. The flyer is circulated in both English and Spanish (Figure 51).

Figure 51. Prince George's County Department of Public Works and Transportation flyer to residents on winter deicing (PGC DPWT 2023).

5.4.2 Maryland Department of the Environment (MDE)

MDE's webpage on Winter Salts uses the same "Attack the Snow like a Pro" graphic offered by Montgomery County MD, also covered in Section 5.4.5 of this document. MDE also links to Minnesota's program already covered in this document, as well as the Izaak Walton League's 2017 Winter Salt Watch, which encourages citizen scientists to monitor salt levels.

5.4.3 Maryland Department of Transportation

MDOT is responsible for producing several online resources to educate Maryland residents on winter safety and operations as well as proper salt management. Most notably, MDOT's statewide Salt Management Plan (SMP) serves as a master document for local permit holding municipalities and information including but not limited to (MDOT 2022):

- guidance on recordkeeping,
- training on snow and salt management practices,
- available technology, and

- strategies and materials for snow and ice removal for relevant state employees, contractors, and the public.

Additional materials MDOT provides include an interactive story map (Figure 52) which explores the effects of salt use on human and environmental health as well as stormwater infrastructure. The story map shows that there are currently 28 Maryland rivers and streams that are impaired by chloride and how that affects the waterways as well as the organisms that live in them. It explains how chloride enters waterways via stormwater runoff and eventually makes its way into reservoirs through groundwater. Additionally, the map explores how chloride impaired drinking water can put residents at risk for a multitude of health problems. The map ends with suggestions of how to reduce chloride impairment in local waterways including preventing overapplication, training, and public engagement as well as some tips for managing salt application at home (MDOT 2024).

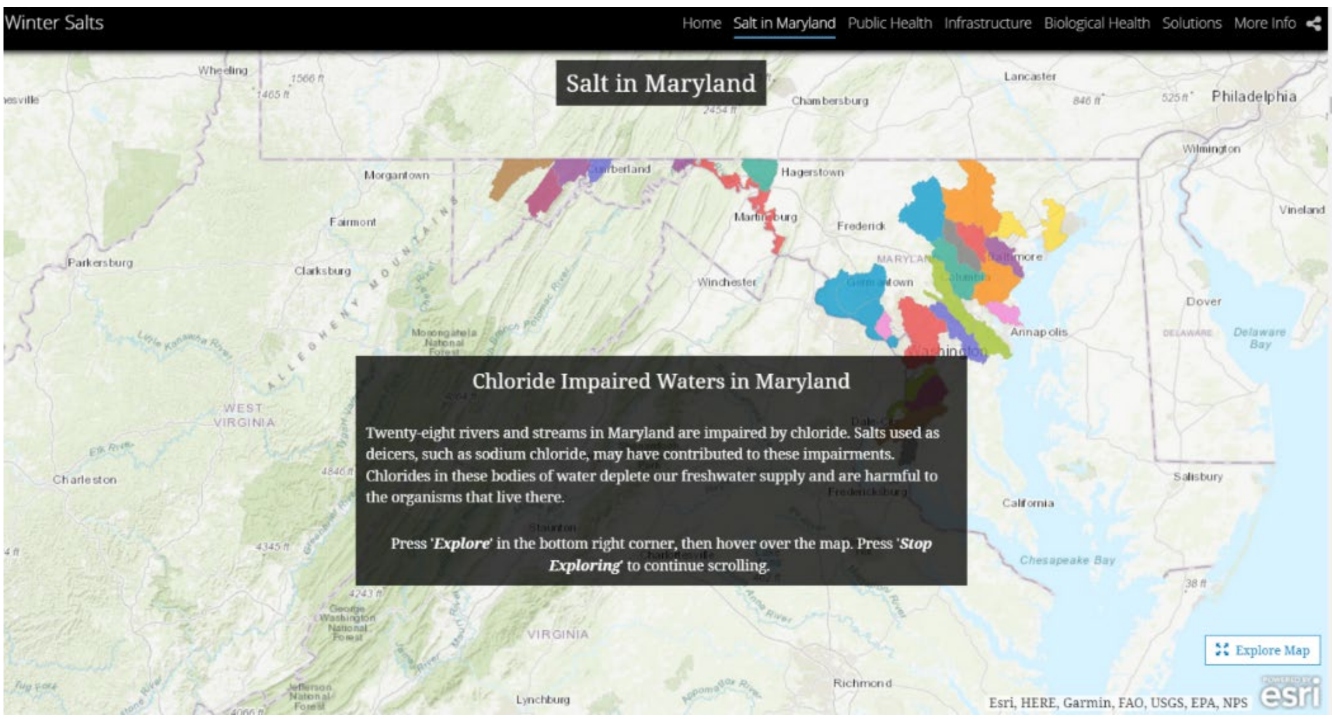


Figure 52. Introduction of the interactive story map "Winter Salts" (MDOT SHA 2024).

MDOT also provides a fact sheet detailing available technology, equipment and materials used for deicing (Figure 53), which are perhaps indirect education on available technologies, methods, and ways to publish data on salt usage which can be emulated by the public and private sectors.

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

WINTER OPERATIONS FACTS AND FIGURES 2021-2022 WINTER SEASON

MDOT SHA maintains most interstate, U.S., and numbered state routes in Maryland. The Maryland Transportation Authority (MDTA) maintains Maryland's eight toll facilities. ***Know Your Roads*** is a great link to ascertain what agency maintains which roads: **https://maryland.maps.arcgis.com/apps/webappviewer/index.html?id=14f27a6cab51422dabdfb168ca603482**

Total Quantities of Materials Available at the Start of 2021-2022 Winter Season

Rock Salt at 93 Salt Facilities:	350,000 tons
Salt Brine at 77 Sites:	1.7 million gallons
Abrasives (Statewide) – Sand and Crushed Stone:	40,000 tons
Magnesium Chloride at 16 Sites:	100,000 gallons
Budget for winter 2021/2022:	$71 million
Lane Miles Maintained by MDOT SHA and MDTA: (Length of roadway times the number of lanes, including ramps)	18,100 miles
Pieces of Equipment Available to Fight Winter Storms: (Including MDOT SHA, MDTA and contract forces)	Up To 2,700

Winter Operations Expenditures and Salt Usage (5-year period)

Fiscal Year	Expenditures	Salt Used
2016	$100,176,147	138,231 tons
2017	$53,679,482	92,990 tons
2018	$86,686,146	184,877 tons
2019	$95,498,676	210,660 tons
2020	$36,356,142	39,161 tons
2021	$103,587,875	241,067 tons

STRATEGIES FOR WINTER OPERATIONS

Anti-Icing – In the days before a storm, MDOT SHA applies salt brine to the pavement, which prevents snow from initially bonding to pavement. MDOT SHA is expanding its operations to lessen salt usage throughout Maryland. Salt brine, which is 23.3% salt and 76.7% water, is produced at 15 MDOT SHA maintenance facilities. MDOT SHA will not anti-ice highways with salt brine if a storm is forecasted to start as rain as this will wash the salt brine solution off the pavement. Additionally, MDOT SHA will not apply salt brine in temperatures 20 degrees or colder because the application may freeze on contact.

Deicing – This is the traditional winter maintenance strategy of salting. Rock salt requires more material to break the bond than to prevent it. Salt is the primary material used to treat pavement in snow or ice operations. In colder areas or for a thicker snowpack on the road, crews can add magnesium chloride or "Liquid Mag" to rock salt/salt brine during extremely cold temperatures to enhance the salt's effectiveness.

Liquid Salt Brine Only or Direct Liquid Application (DLA) Snow Routes - This operation consists of a designated snow route that only uses a salt brine solution to prevent the snow and ice from bonding to the pavement. Unlike anti-icing, which only takes place prior to the event, this strategy is performed for the duration of the event. MDOT SHA now has a DLA snow route in each of its seven engineering districts. When compared to snow routes using granular rock salt as the main snow fighting compound, the DLA snow routes not only perform at or above the expected level-of-service but use far less salt. MDOT SHA has strategically placed an additional 79,000 gallons of storage around the state.

Loader Scales - MDOT SHA has purchased a total of 34 loader scales that are mounted on MDOT SHA loaders at salt facilities. The scales accurately capture the precise amount of salt being loaded for distribution onto Maryland roadways. This allows MDOT SHA to accurately control storage, handling, application, and recovery of dispensed granular salt. Precision application of salt helps MDOT SHA reduce overall salt usage.

Rubber Plow Blade w/ Ceramic Inserts - The rubber/ceramic blades are superior to steel blades from both a performance and efficiency perspective. These newer plow blades move more snow from the roadway, which results in less salt to treat the road during plowing operations. To meet the demands of our operators, MDOT SHA placed a bulk order for the hybrid blades this winter season to ensure enough resources are on hand for each facility.

Winter Operations Training - This takes place in the form of a required Snow College that 20 percent of maintenance personnel are required to attend each year. MDOT SHA's goal is to train 100 percent of our employees at least once every five years. Past data obtained with winter training was so beneficial it led to the creation of a best practices document that was distributed accordingly statewide. This statewide initiative will be a staple in our salt reduction tactics for years to come. Due to COVID-19 protocols in 2020 most of our trainings occurred in a virtual environment, however in 2021 our approach has transitioned back to pre-covid practices.

TECHNOLOGY AVAILABLE FOR 2021-2022 WINTER SEASON

In addition to its fleet of salt spreading/snow plowing dump trucks, MDOT SHA will deploy:

550 Truck-Mounted Saddle Tanks - This equipment is used to pre-wet salt with salt brine or liquid magnesium as the salt is spread on highways. Pre-wetting salt helps it adhere to the pavement (reducing waste), dilute into a brine solution quicker (making salt more effective) and work at lower temperatures. Nearly all MDOT SHA's fleet of single axle dump trucks are equipped with this technology.

Slide-In Tanks - MDOT SHA has equipped 10 Quad-Axle trucks with 2,600-gallon slide-in tanks that will be used for anti-icing operations and for DLA snow routes where no granular salt is used. These tanks are easily removed to allow the trucks to spread granular salt if needed.

310 Wing Plows - A wing plow is an additional plow mounted on the right side of a plow truck or grader. The extra plow allows crews to clear more snow from the road and shoulder in one pass, increasing efficiency while reducing the need for extra trucks and our carbon footprint.

14 Truck/Trailer-Mounted Liquid Applicator Spray Tanks - These units are used for anti-icing operations and liquid only routes (spraying salt brine on roads and bridges prior to precipitation to prevent snow and ice from bonding to the pavement).

15 Automated Salt Brine Makers - These automated salt brine makers are strategically placed around the state to fill and replenish the 77 brine tank farms throughout Maryland. This year, MDOT SHA has installed all but four of its new brine makers with automated units which can produce up to 9,000 gallons of brine per hour. This will help ease the burden of brine tank replenishment by quadrupling the output of our current units while producing a perfectly blended solution.

2 Tow Plows - A tow plow is a separate plow that is towed behind an MDOT SHA salt/plow truck and will clear an extra highway travel lane. Tow plows will be used in conjunction with snowplow trains (several trucks driving in tandem). The introduction of the tow plow into MDOT SHA's fleet will help enhance highway snow clearing operations with fewer passes and less trucks on the highway.

4 Dual-Wing Plows - MDOT SHA is employing four dual-wing plows in Allegany, Frederick, Garrett, and Montgomery counties. The extra wing plow can clear a two-lane highway in one pass.

23 Quad-Axle Trucks - MDOT SHA is employing trucks with enhanced material carrying capacity to treat longer sections of road. The enhanced capacity will allow the plow trucks to apply anti-icing material to more lane miles thus allowing better clearing results.

78 Non-Invasive Roadway Sensors - Non-invasive sensors are mounted to overhead signs or poles and can detect the thickness of water, snow, or ice within 1 mm of accuracy. It also measures surface temperature, road condition, and freeze point/salt concentration on the road surface. This type of unit eliminates the need to install a sensor in the pavement.

102 Mobile Advanced Road Weather Information Sensor (MARWIS) - These mobile road weather sensors will transform vehicles into mobile weather stations by detecting several critical road weather parameters, including temperatures, precipitation amounts and type (rain, snow, sleet, etc.), relative humidity, dew points and friction values. Together with other sensors on MDOT SHA weather stations, the technology will enable MDOT SHA maintenance forces to have real-time information and help in tactical deployment of equipment.

Contacting MDOT SHA

Citizens can also log onto **www.roads.maryland.gov** and click "Contact us." There is an online submission form to report any issues pertaining to MDOT SHA-maintained highways for non-emergencies. For real-time travel information, log onto **www.md511.org**. MDOT SHA is on Twitter **@MDSHA** and Facebook at **www.facebook.com/MDOTSHA/**.

###

MATERIALS AVAILABLE FOR 2021-2022 WINTER SEASON

ROCK SALT is the principal winter material used by MDOT SHA. It is 100% effective at pavement temperatures of 20° F and above but starts to lose its melting properties once below this threshold.

SALT BRINE is a solution that can be used as an anti-icing agent on highways prior to the onset of storms, or as a deicer on highways during a storm. Salt brine is 23.3% salt and 76.7% water. MDOT SHA makes extensive use of this material. It has a freeze point of -6° F and costs approximately 14.8 cents per gallon to produce and transport. Salt brine will be produced and used at MDOT SHA's 15 brine making facilities.

MAGNESIUM CHLORIDE is a liquid winter material used in de-icing operations. The material has a freeze point of approximately -26° F. It is used in the colder regions of the state, primarily in the northern and western counties. In Maryland, magnesium chloride is typically used in conjunction with salt brine by creating an 80/20 blend which can cut usage costs by up to 80 percent. This not only cuts down on expenditures and impacts to infrastructure but makes salt brine now usable down into negative double-digit temperatures.

ABRASIVES including sand and crushed stone are used to increase traction for motorists during storms. These are only used in Western Maryland due to the steep topography and environmental restrictions across the rest of the state.

Please use the following link for MDOT SHA's Salt Management Plan and more information on our winter resource management initiatives:

https://www.roads.maryland.gov/OOM/Statewide_Salt_Management_Plan.pdf

Almanac Data

Average Number of Winter Snowstorms per Year Since 2010
(Does not include the numerous maintenance shop activations for frost, black ice, and post-storm blowing and drifting snow)

Lower Eastern Shore	5.1
Upper Eastern Shore	10.2
Southern Maryland	5.2
Baltimore/Washington DC Metro Area	10.3
Western Maryland	28.1

Date of Earliest Metro Area Winter Storm since 2010:	10/29/2011
Date of Latest Metro Area Winter Storm since 2010:	3/30/2014

Figure 53. MDOT SHA winter operations fact sheets for the 2021-2022 snow season (MDOT SHA 2021).

5.4.4 Anne Arundel County, MD

Anne Arundel County provides a variety of informational webpages to its residents including a Winter Snow Removal webpage (AAC 2024) which describes efficient salt application practices with regard to human and pet health, infrastructure, and the general environment as well as salt BMPs for residents and business owners.

5.4.5 Montgomery County, MD

Similarly, Montgomery County provides its residents with many online resources to its residents (MoC 2023). For example, several informational graphics (Figure 54) and webpages detailing road salt BMPs are available to residents online.

Figure 54. Informational graphics provided by Montgomery County (MoC 2023).

5.4.6 Montgomery County and WSSC

Montgomery County in partnership with Washington Suburban Sanitary Commission (WSSC) broadcasted the Salt Wise campaign (described in Section 5.1; MoC 2020). The campaign included a tip card available in English and Spanish (Figure 55) and several other graphics which aid in understanding the necessity of appropriate salting practices and salt runoff's effect on local waterways (Figure 56).

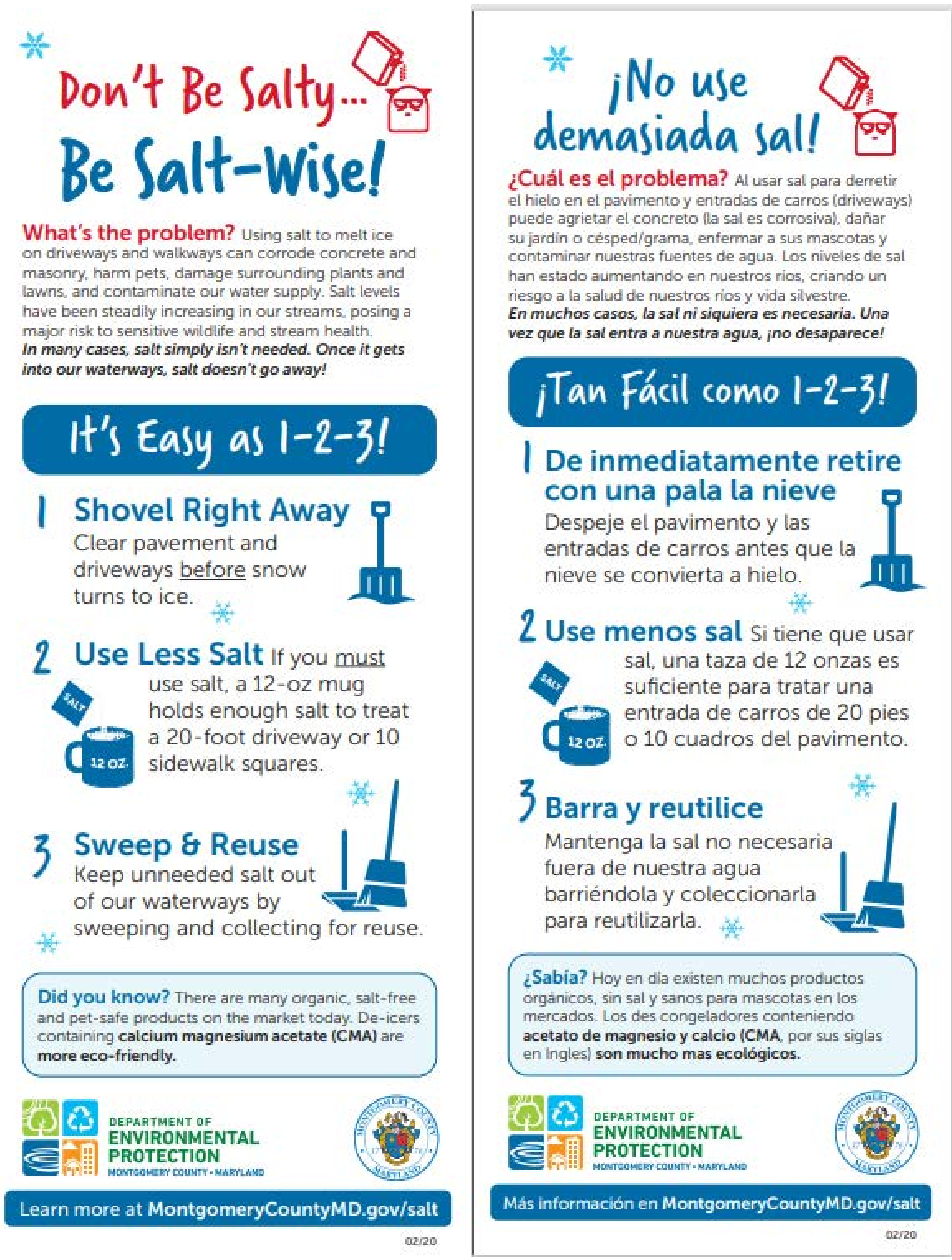


Figure 55. SaltWise tip cards in English and Spanish (MoC 2020).

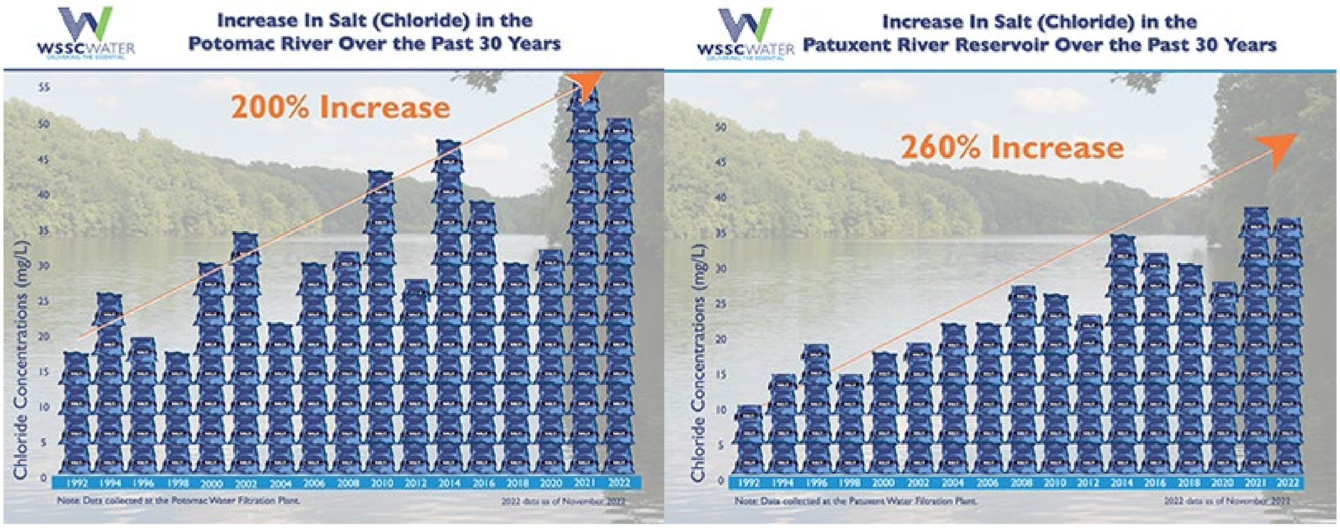


Figure 56. Graphical depiction of the increase of chloride in the Patuxent and Potomac rivers provided by WSSC Water (WSSC 2023).

5.4.7 Virginia

The following is a collection of the best available educational outreach methods employed by MS4 permit holding municipalities across Virginia. Multiple municipalities across Virginia—including the city of Fairfax, town of Vienna, and Arlington County—separately maintain online Winter Salt Smart campaigns that cover salt effect on water quality, human, pet, and wildlife health and infrastructure. Winter Salt Smart webpages contain information for residents and professionals regarding winter storm procedures and salt usage as well as tips on how to limit salt usage with alternatives and BMPs for salt and deicer usage.

The town of Vienna made outreach efforts to homeowners associations through a series of infographics with intentions of amplifying the MWCOG's #WinterSaltSmart messaging (Figure 57).

Figure 57. An example of Salt Smart informational graphic provided to Homeowners Associations by the town of Vienna, VA. (Vienna 2023)

According to the October 2022 annual MS4 report Prince William County hosted a Snow Rodeo for over 150 County staff with responsibilities related to snow and ice removal, where the Environmental Council hosted a "Smart Salting" booth which provided information and games relating to preventing excess salt use during the winter. Finally, winter training for appropriate government employees and contractors includes salt BMPs. Similarly, the city of Manassas has standard operating procedures in place for appropriate employees and contractors regarding salt, deicer, and brine containment, application, and clean-up.

Fairfax Water briefly lists the downsides to salt use with a focus on the Potomac River and Occoquan Reservoir including impacts to streams, drinking water, plumbing and human health as well as just recently developed pamphlets on best practices for deicing aimed at property managers and homeowners with detailed information on salt type and quantity needed for varying temperatures and areas. These informational flyers were developed by the Northern Viginia Regional Commission's (NVRC).

Fairfax Water has an excellent Winter Ninjas publication emulating a comic book that explains the impacts of deicing with salt (Figure 58).

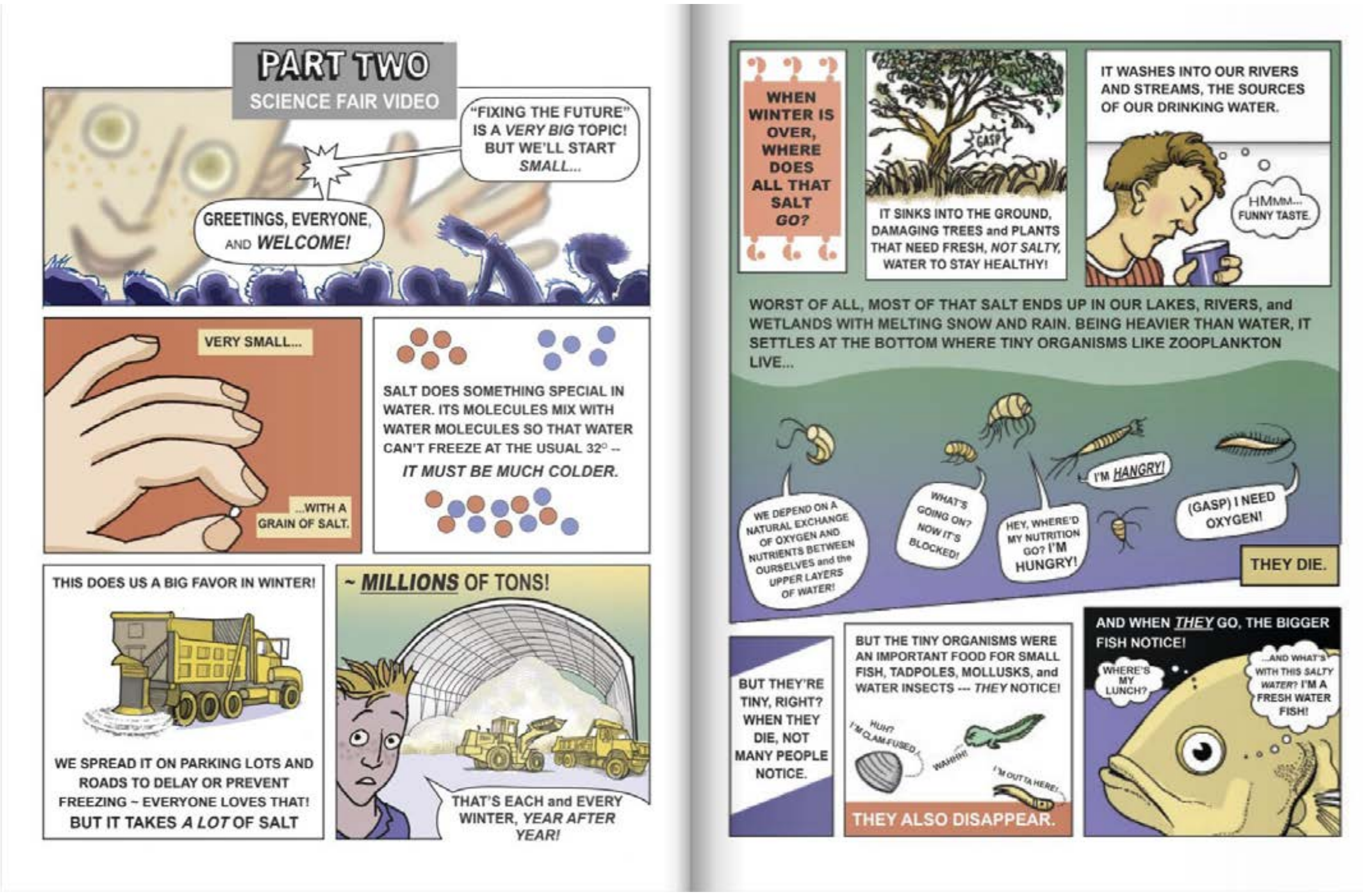


Figure 58. Excerpt from Water Ninjas comic book Winter Warriors edition (Fairfax Water 2020).

The Northern Virginia Regional Commission's webpage on salt management includes resources for residents, in the form of a 2 page pamphlet entitled "Snow and Ice Maintenance Tips for Residents Winter 2023", in English and Spanish, shown in Figure 59.

Fairfax Water and NVRC are part of the SaMS (Salt Management Strategy) Stakeholder Advisory Committee, which is a multijurisdictional effort that is facilitated by Virginia DEQ. In 2020, the Interstate Commission on the Potomac River Basin (ICPRB) developed a 417-page SaMS Toolkit document, which is a "toolkit to reduce the environmental impacts of winter maintenance practices." The document offers options for salt management including those referenced in this document.

Loudoun Water, the utility's for the county, has a webpage on salt use that offers basic tips on when and how much salt to use as well as a brief statement on the repercussion to infrastructure and stream health from deicing salts.

Snow and Ice Maintenance Tips for Residents
Winter 2023

Did You Know...

Road salts can make it safer for us to walk and drive around in the wintertime. It helps keep roads open, and allows businesses, government, and social services to stay open with little interruption.

However, it only takes one teaspoon of salt to permanently pollute 5 gallons of water.

Salt seeped into the environment can:

- Raise sodium levels in our drinking water and increase treatment costs.
- Harm fish, plants, and other wildlife.
- Corrode vehicles, roads, bridges, and parking lots.

Since there's no easy or cheap way to remove salt from our environment, we can all do our part to be #WinterSaltSmart by following the below tips for snow and ice maintenance.

How should you prepare for a storm?

Have your shovel or snow blower ready!

- Shovels may be all that you need for winter weather in Northern Virginia. To make it easier on your back, you can choose shovel products with wheels. Remember to take breaks and avoid overloading your shovel with wet snow.
- For big storms or heavy weight snow, snow blowers may also be helpful.
- Always make sure to assemble an emergency or storm preparedness kit.
- Have your salt and traction materials ready and be sure to store them away for rain and snow!

Make sure to stock up on enough food, drinks and medicine (including prescriptions) before the storm!

www.wintersaltsmart.com

nvrc
Northern Virginia Regional Commission

Smart Salt Management

Choosing the Best Salt or De-icing Product

- Always check product ingredients. Labels like "safe," "pet-safe" and "environmentally friendly" can be used inaccurately on certain salt products.
- **All nitrogen and phosphorus salts are illegal in Virginia.**
  - Nitrogen salts include urea, ammonium sulfate and potassium nitrate, etc.
  - Phosphorus salts may have "phosphate" (PO4) in the ingredients, although these are rare.

If applying a salt to your driveway or sidewalk, choose a product based on the **Lowest Practical Melting Temperature**, not the **Eutectic Temperature**. See the table below for different product options:

Product Type	Chemical (3)	Lowest Practical Melting Temperature (1)	Eutectic Temperature (2)
Salts (contain chloride)	**NaCl** (sodium chloride) - also called rock salt **MgCl2** (magnesium chloride) **CaCl2** (calcium chloride) **KCl** (potassium chloride)	15° F -10° F -20° F 25° F	-6° F -28° F -60° F 13° F
Other Salts (do not contain chloride)	**CMA** (calcium magnesium acetate) **KAc** (potassium acetate)	20° F -15° F	-18° F -76° F

For more information on these salts and some alternatives, visit **"Materials to Treat Snow and Ice"** and for more information on the temperature ranges of the different salts , see **"Temperature Ranges and Terminology for Salts."**

1 The temperature that a salt will melt ice in a reasonable amount of time. Also called "Lowest Effective Temperature."
2 The lowest temperature that a salt can melt ice. This is not a practical temperature to reference (see the warnings below).
3 Source: https://stormwater.pca.state.mn.us/index.php?title=Lowest_practical_melting_temperature

Post-Storm Maintenance

- Clear snow by shoveling early and often.
- Make sure to clear snow and apply salt only where needed.
- Never use salt to "burn off" snow. It will quickly dilute and requires excess use.
- If the sun comes out and you can wait, let the sun do some of the work before you apply salt.
- After the storm, sweep up the extra salt or traction material and use it again next time winter weather hits.

Salt Application Tips

Sodium chloride: One 12-oz coffee mug holds enough salt to treat a 20-foot driveway or ten sidewalk squares. Aim for about 3 inches between pieces of rock salt.

Calcium chloride: Apply at a rate that is one third of the rate used for sodium chloride.

- If it is too cold for salt to work, or you'd rather not use salt, consider using other traction materials. These include sand, bird seed (make sure to use a native blend), wood ash, and zeolite crystals (like EcoTractionTM).
- Be patient and give the salt time to work. The colder it is, the longer it will take for the salt to melt what snow or ice remains after shoveling.

Figure 59. Snow and Ice Maintenance Tips for Residents Winter 2023 (NVRC 2023).

They have links to infographics (such as shown in Figure 60) and a pamphlet on why the public should care about salt management. They also have a link to the Virginia SaMS as well as a link to the Winter Ninjas comic.

Lastly NVRC targets property managers with a 3-page pamphlet entitled, "Snow and Ice Management Tips for Property Managers Winter 2023" similar to the pamphlet shown in Figure 59 but with additional information on salt application rates for large areas.

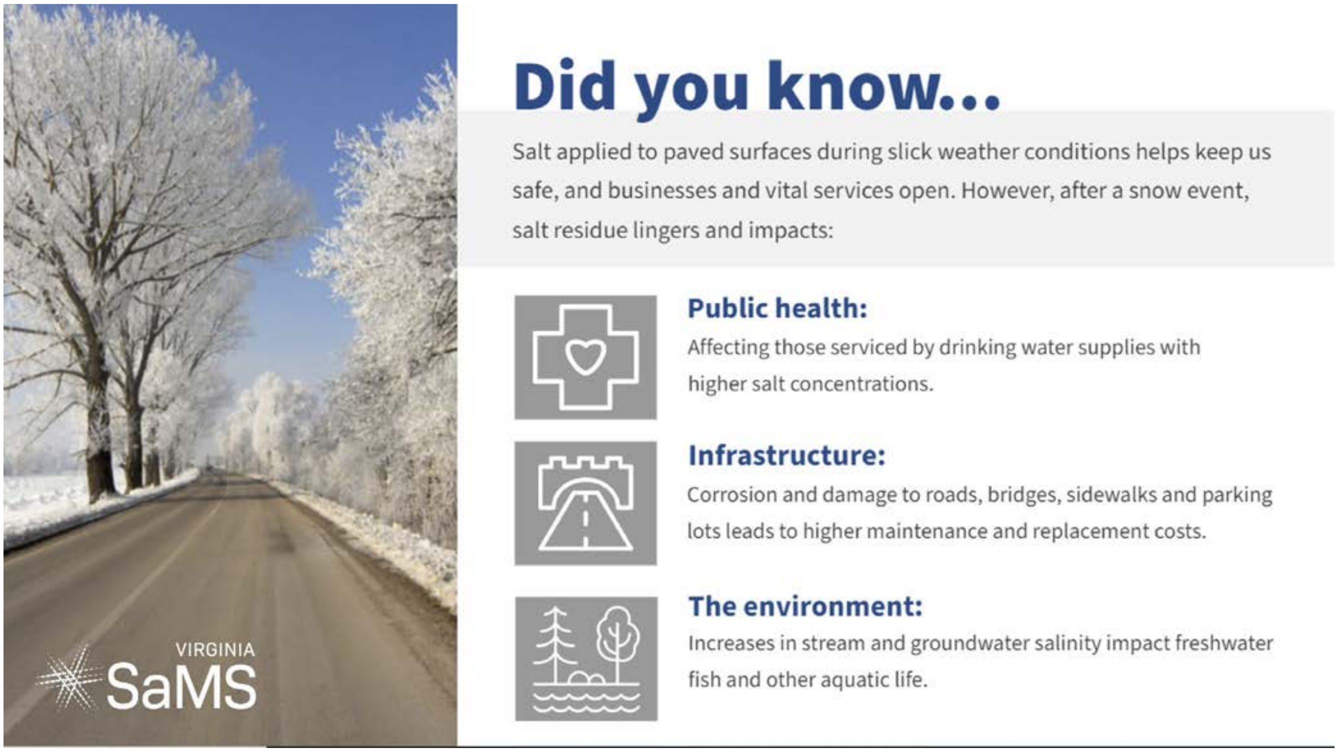


Figure 60. Infographic from NVRC on Salt Awareness (NVRC 2024).

VDOT has a pamphlet entitled "HOW VDOT KEEPS ROADS CLEAR IN WINTER; Pre-treatment, Anti-icing, Deicing" that covers the methods of pre-treatment, anti-icing and deicing and the types of products it uses (Figure 61).

VDOT

HOW VDOT KEEPS ROADS CLEAR IN WINTER

Pre-treatment, anti-icing, de-icing

A HOW ROAD TREATMENTS DIFFER

- **Pre-treatment:** A form of anti-icing where chemicals are applied to dry pavement up to 48 hours before a winter storm. This prevents a bond from forming between the pavement and the snow and ice after the storm starts.
- **Anti-icing:** Application of chemicals to roads before a snow-pavement bond occurs when the temperature drops. Anti-icing emphasizes prevention.
- **De-icing:** The practice of removing snow or ice once it has bonded to the pavement. This involves plowing and continual application of chemicals and abrasives. Plowing generally begins when an inch or more of snow has accumulated on the road.

CHEMICALS AND METHODS USED TO TREAT ROADS IN WINTER

Sodium chloride (salt), magnesium chloride, calcium chloride, calcium magnesium acetate and potassium acetate are chemicals used to prevent and remove snow and ice accumulation from roadways.

The Virginia Department of Transportation (VDOT) uses liquid magnesium chloride, calcium chloride and sodium chloride for anti-icing and pre-treatment.

Sodium chloride and calcium chloride in dry form are used for de-icing but can be used in some cases for anti-icing.

Sodium Chloride (salt):
Dry sodium chloride is VDOT's primary snow-removal and ice-control chemical. It is applied directly to the pavement once a storm starts. Salt is sometimes mixed with sand before it is applied to the road.

Dry salt is most effective after snow has accumulated about an inch and the temperature is 27 degrees or higher. If the temperature is below 27 degrees, salt may not melt enough snow and ice to form a barrier between the pavement and the snow, and it could even produce more ice as melted snow refreezes. At these temperatures, abrasives such as sand are put down to break up ice and increase traction. Liquid sodium chloride (brine) is an economical anti-icing and pre-treatment chemical.

Magnesium Chloride and Calcium Chloride:
These products can melt ice at lower temperatures than salt. Both chemicals in liquid form can be used for anti-icing. In its dry form, calcium chloride is used only as a de-icer.

Abrasives:
Small gravel or sand cannot melt ice or snow, but are often mixed with salt to provide additional traction and reduce the cost of applying chemicals.

Abrasives can be used on roads generally not treated with chemicals. De-icing chemicals, such as salt and calcium chloride, are detrimental to gravel-surfaced and surface-treated roads (those pavements with a salt-and-pepper appearance). Chemicals are used sparingly on these types of roads and only when absolutely necessary.

ANTI-ICING

VDOT may use anti-icing in dry conditions when snow or an ice storm is predicted and when pavement temperatures are above 20 degrees. Anticipated temperature and type of precipitation at the start of a storm will determine its use.

VDOT's anti-icing program covers at least 200 miles of roads in each of its nine districts. VDOT also deploys anti-icing crews to major bridges, overpasses and areas prone to freezing to keep ice from forming.

If you see an anti-icing crew spraying chemicals on the road, slow down. For proper application, crews will be driving slower than highway speeds. Do not follow the trucks too closely, as the chemicals are slightly slippery for the first 30 to 45 seconds they are on the pavement. If you must pass an anti-icing truck, do so carefully.

It is a good idea to wash your vehicle if it comes into contact with these chemicals to protect its finish.

AREAS PRONE TO ICE

Ice can form on the decks of bridges and overpasses before a roadway freezes because air circulates both above and below the surface, causing the deck's temperature to drop more rapidly. Ice also can form in shaded areas. Motorists should always use caution and expect slippery conditions when driving during winter weather.

BLACK ICE

Black ice, also known as "glare ice" or "clear ice," refers to a thin coating of glazed ice on road. While not truly black, it is transparent, allowing you to see the asphalt pavement through it. Black ice often occurs along with wet roads, making it hard to see and especially hazardous for driving or walking.

Figure 61. VDOT pamphlet on how it keeps roads clear in the winter (VDOT 2024).

5.4.8 District of Columbia

The Department of Energy and the Environment has two webpages related to better deicing. The first has tips for homeowner's on how to deice more efficiently including a downloadable "Salt Application Calculator" in Microsoft Excel (Figure 62). The webpage suggests the use of alternate surfaces which are ice-free such as porous asphalt.

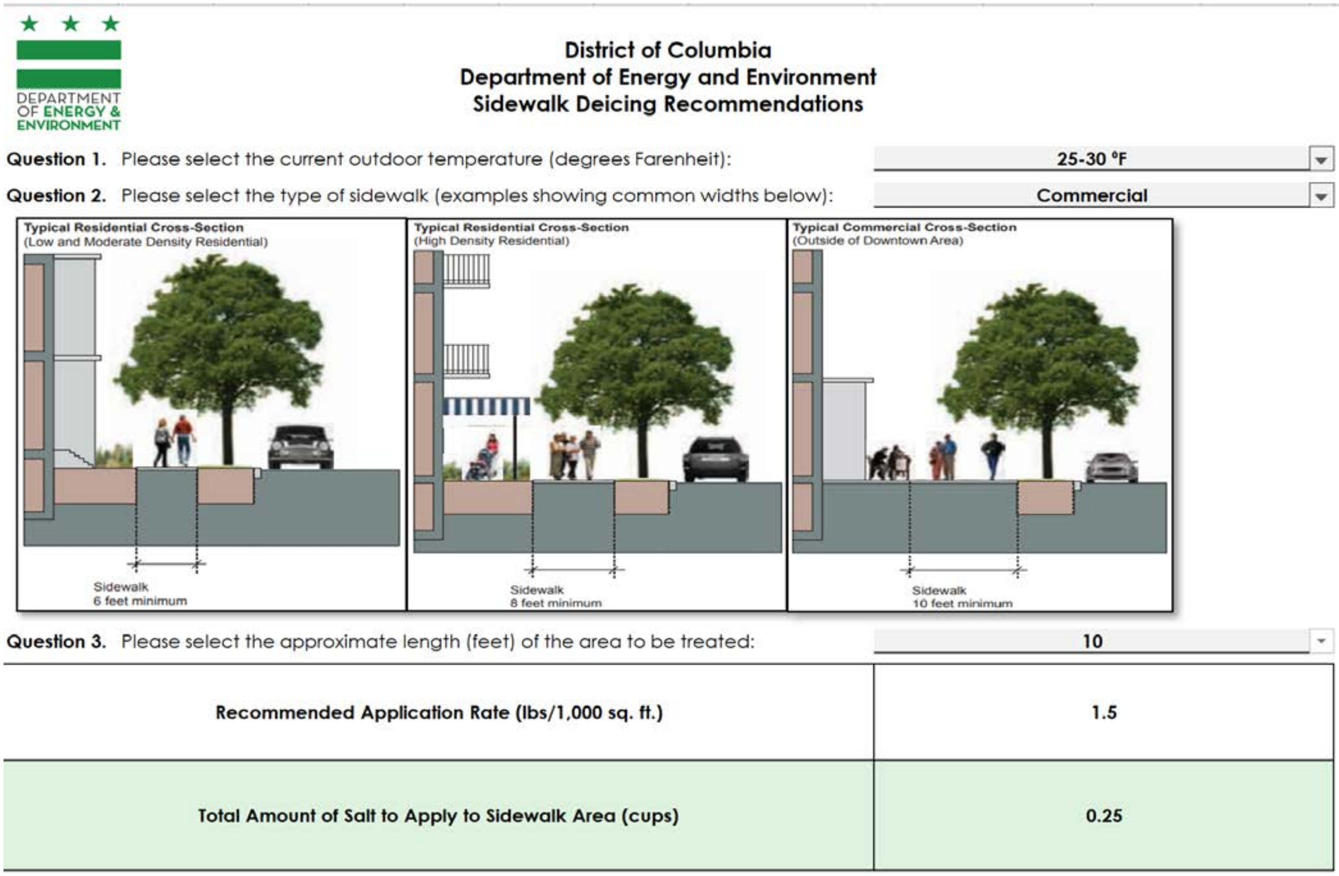


Figure 62. Screenshot of DC DOEE Salt Application Calculator (DC DOEE 2024a)

DOEE's "Protecting the Environment in Winter Weather" webpage includes a link to the "What You Can Do" webpage covers what the DOEE is doing to reduce wintertime pollutants, including advice on woodburning stoves and gas-powered snow blowers. Most relevant is research on safe alternatives to salt in conjunction with the District's Snow Team started in 2021 including a downloadable PowerPoint on for snow plow operators (Figure 63). They also have a downloadable PowerPoint for manual bridge, street and sidewalk deicing that includes commercial and residential as well snow plows (Figure 64).

Figure 63. PowerPoint for Snowplow Operators (DC DOEE 2024b).

Figure 64. PowerPoint on pollution prevention during snow operations. (DC DOEE 2024c)

5.4.9 Regional Organizations

The ICPRB's webpage on deicing and anti-icing chemicals refers to efforts with MDE on a training manual and on the Virginia Department of Environmental Quality Salt Management Strategy for Northern Virginia, particularly for the Accotink Creek chloride TMDL. They also provide a link to ICPRB's 2018 document "Salt

Management Strategy: Environmental Impacts and Potential Economic Costs and Benefits of Improved Management Practices in Northern Virginia."

The ICPRB hosts the Potomac River Basin Drinking Water Source Protection Partnership (DWSPP), with a dedicated webpage on deicing materials with additional information on:

- roadway Deicing and Impacts to Drinking Water Sources and the Environment,
- Wisconsin Be Salt Wise!,
- impact of deicers and stormwater runoff,
- airport deicing,
- common roadway deicers and alternatives; and
- winter operations training resources, covered already in this document with the exception of the New Hampshire Green SnowPro Certification Program and Resources. This program is unique in that it offers limited liability protections against damages arising from snow and ice conditions for those commercial applicators or property managers and owners that are certified under this program.

The MWCOG Salt Smart webpage summarizes the negative impacts of salting to stream, pets, and human health, offers tips on how to deice surfaces properly at home. Unlike other outreach pages, and because MWCOG is a regional organization, it includes information on how Maryland, Virginia and the District are monitoring and reducing deicing salts. Lastly it highlights MWCOGs partnerships with USGS, University of Maryland, and Virginia Tech to monitor the salinity in regional water bodies. They include a one-minute video on YouTube by the Northern Virginia Regional Commission uploaded in December 2022 entitled *Winter Snow and Ice Management Tips from NVRC* which outlines the impacts of salt and tips for better salt use for residential properties. Lastly it includes links to other sources of information in the metro area.

5.4.10 Across the United States

Many MS4 permit holding municipalities across the United States use effective outreach and public education methods which can be employed by municipalities local to the metro area with little to no adjustments. Examples of such methods can be pulled from Wisconsin, specifically the cities of Appleton, Cudahy, and De Pere which have partnered with Wisconsin SaltWise with the goal of reducing salt pollution in the state's waterways.

This partnership provides residents with an abundance of information regarding road salt safety and management including classes for maintenance professionals, lesson plans for teachers kindergarten through 12th grade, weekly informational webinars, and salt application guidelines complete with a road salt calculator (Figure 65). Classes offered to maintenance professionals include a free "Smart Salting" workshop targeting parking lots and sidewalks during which winter maintenance professionals learn the state-of-the-art winter maintenance practices, including how to use liquid deicers and reduce overall salt application. Additionally, Wisconsin SaltWise provides a 10 minute training video targeting maintenance crews in charge of clearing walkways and includes information on environmental impacts of chloride as well as tips for proper salt application and snow removal.

Another example of useful outreach strategies comes from the City of Edina, Minnesota. The city released a PSA—More isn't Always Better—detailing the proper application method of salt to sidewalks and pathways.

Finally, the Mississippi Watershed Management Organization, while not an MS4 permit holding municipality itself, partners with many permit holding municipalities and released a 20-minute video—Winter Maintenance for Small Sites. This video contains important information on reducing salt use for snow and ice management on steps, ramps, entryways, and curb cuts and with the purpose of training seasonal and full-time property employees as well as business owners.

De-icing Application Rate Guidelines
for Parking Lots, Sidewalks and Trails
For best results remove as much snow and ice as possible before applying deicers

Pavement Temp. (ºF)	Application Rate in lbs./per 1000 square foot area Apply with calibrated equipment					
	Rock Salt*	Bagged Blend Mostly Sodium Chloride	Bagged $MgCl_2$ or $CaCl_2$	Wet at 6-12 gal/ton: Rock Salt wet with Salt Brine	Wet at 6-12 gal/ton: Rock Salt wet with other liquids	Winter Sand**
28 º to 32 º	2.3	2.3		1.6		
23 º to 28 º	2.3-4.5	2.3-4.5		1.6-3.2		
15 º to 23 º	2.3-6.8	2.3-6.8		1.6-4.8	1.6-4.8	
0 º to 15 º			2.3-6.8	3.2-4.8	3.2-4.8	Spot treat as needed
-5º to 0º			6.8		4.8	
< -5º	Plow Only					
SPEED of melting	AVERAGE The colder it is the slower it works	Faster than rock salt if gradation is finer	ABOVE AVERAGE	FAST	FAST	NONE

Figure 65. Guidelines for applying various deicing materials provided by Wisconsin SaltWise (City of Madison WI 2019).

The Lake George Association (in New York State) has a series of simple tips for residents and small businesses om its webpage which include:

- shoveling early and often,
- using an ice chipper,
- applying salt between 32 ºF and 10ºF only, when its most effective,
- keeping salt away from storm drains,
- repositioning downspouts away from hardscapes to prevent icing, and
- piling snow away from hardscapes to prevent refreezing.

5.4.11 Winter Deicer Outreach Conclusion

This section provides resources developed around the region and beyond to educate the public about the negative impacts of salt on the environment and provide strategies the public could adopt to reduce use using the plethora of publicly available information readily available. It has suggestions for using existing outreach materials, partner channels, and distribution methods for sharing information and educating the public. These suggestions include the creation of an animated movie (like Prince George's County's pet waste video) that shows the harms of salt use, the benefits of reducing use, and alternatives for combatting snow and ice. Plenty of high-quality materials already exist, from videos to comic books to pamphlets. Many are already shared across DC region municipalities. ICPRB has worked across states and with MDE on training and could be a good source of additional information. Developing an outreach program using these suggestions would strike a balance between ensuring the public's safety and lessening the deicing salt's effects on the environment.

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APPENDIX A: LITERATURE REVIEW: SALT TOLERANCE OF FRESHWATER BENTHIC MACROINVERTEBRATES IN THE MID-ATLANTIC REGION OF THE UNITED STATES

INTRODUCTION

Freshwater stream health relies on several conditions, including the presence of dissolved ionic salts at certain concentrations. Elevated ion concentrations can disrupt osmotic regulation of benthic macroinvertebrates (BMI); these ionic conditions have been identified as major ecological stressors in urbanized landscapes (Roy et al. 2003). Salinization is the term that broadly characterizes the condition of dissolved ionic salts but also can suggest that these levels are at or approaching a threshold that degrades water quality for BMI. Freshwater salinization is a growing concern in temperate and northern stream ecosystems where urban and suburban development result in an increase in ion concentrations (Kaushal et al. 2018).

Specific conductance (SC) levels help researchers and policymakers assess ionic salt concentrations in streams. Deicing salt, applied seasonally for wintertime road safety, is the predominant driver of elevated SC and chloride concentration in urban watersheds from the Mid-Atlantic northward (Moore et al. 2020, summarized below). Chloride concentration appears to be one of the many factors that impact invertebrate density and diversity measurements, with decreases in invertebrate diversity corresponding with water quality criteria for chloride concentration set for the US by the Environmental Protection Agency. It is important to note that other ionic salt species also impact water quality, but most research concerns chlorides.

In 1988, EPA set the aquatic life criteria for chloride (one of several pollutant criteria for water quality) concentration at 230 mg/L for chronic exposure (based on a 4-day average), and at 860 mg/L for acute exposure (based on a 1-hour average) with each criterion not to be exceeded more than once in a 3-year period (USEPA 1988). As of 2011 in Canada, those exposure limits are substantially lower, 120 and 640 mg/L, respectively, over indefinite periods and 24–96 h (CCME), respectively.

Reference specific conductance (SC) levels of Piedmont streams do not typically exceed 100 µS/cm (Olson and Cormier 2019). Morgan et al. (2012) found background SC across Maryland (MD) ranging from 46 to 160 µS/cm and chloride levels ranging from 4.0 to 18.2 mg/L. Moore et al. (2020) found that Mid-Atlantic sites with impervious cover of >10% have median SC >300 µS/cm.

Not many studies have been done specifically on salt tolerance abilities of freshwater BMIs for Maryland, its ecoregions, or physiographic provinces. However, the related, relevant literature on freshwater BMIs more generally is rich and extensive, with knowledge that supports inquiry into salt tolerance for Maryland and the County. Below is a summary of some relevant literature on this important topic. Note: some papers here are formal, field specific literature reviews, hence the large number of citations contained in those papers. The citations to these primary sources demonstrate trends in research, offer pathways for further discussion, and attribute sources of information, thereby improving confidence in this overall technical analysis.

HIGHLIGHTS

Below are highlights from the literature review. In the subsections below, verbatim excerpts are included in quotes. Very rarely, to maintain stylistic, units, acronym, or grammatical consistency with the rest of this report, verbatim excerpts were very slightly modified.

Macroinvertebrates

- Mayflies, stoneflies, and caddisflies are the most salt-sensitive stream insects (Hartman et al. 2005; Pond et al. 2008; Pond 2010).
- MD DNR (2013) believe that long-term salinity exposure is more harmful than acute exposure in Maryland.
- In Maryland, MD DNR (2013) found no streams with benthic index of biotic integrity (BIBI) scores higher than 4.0 (the threshold for the highest quality streams) nor with chloride concentrations above 190 mg/L.
- For Maryland, Cormier et al. (2018) estimated a SC of 227 µS/cm threshold at which 5% of the BMI genera is eliminated for the northern Piedmont (Ecoregion 64) and 243 µS/cm for the southeastern plains (Ecoregion 65-N).
- Wallace and Biastoch (2016) in a study in Toronto, Canada, identified about 50 to 90 mg/L of chloride as the level at which the BMI community demonstrated the most taxa changes, indicating that chloride may be having a non-lethal effect on these indicator BMI communities such as on hatching rates, growth, pupation, emergence rates, and fecundity.
- In St. Louis, Missouri, the total number of invertebrates collected at a site dropped by roughly half when maximum chloride concentration measurements reach the 3,000-5,000 mg/L range and when median chloride concentrations reach 700-900 mg/L. In addition, sites appear unlikely to attain a good water quality rating when the median chloride concentration is above 250mg/L (Haake et al. 2022).
- In Toronto, Canada, Wallace and Biastoch (2016) found changes to BMI communities from increased chloride showed changes at the genus/species level.
- BMI community response is not necessarily linear with respect to chloride concentrations in Toronto, Canada (Wallace and Biastoch 2016).

Chloride Measurement and Specific Conductance

- Many studies use the high correlation between SC and chloride concentrations to justify using commonly measured SC as a surrogate for chloride concentrations.
- Morgan et al. (2012) found a strong linear correlation (R^2 = 0.94) of chloride concentration in mg/L to specific conductance (SC) based on the Maryland Biological Stream Survey (MBSS) data, and converted to chloride concentration when required using

$$[Cl^-] = 0.2432 \times SC - 22.6$$

- Moore et al. (2020) found that discrete chloride concentrations and discrete SC are highly correlated with median R^2 values of 0.97 for watershed-specific regression models in the Mid-Atlantic.
- It may be difficult to differentiate the effects of chloride from the effects of other urban stressors such as temperature, contaminants, sedimentation, and habitat loss given how ubiquitous high chloride levels are in urban environments.

Where and When to Measure Chloride

- Morgan et al. (2012) is a good source of information for Maryland as they examine relationships of SC and chloride levels to key landscape attributes that may be potential drivers for water quality characteristics in six MD ecoregions (Blue Ridge, Central Appalachians, Middle Atlantic Coastal Plain, Northern Piedmont, Ridge and Valley, and Southeastern Plains).
  - Morgan et al. (2012) found strong relationships between SC and chloride levels and watershed impervious surface or road density in Maryland, roughly an R^2 of 0.60 for all four relationships.
  - They did not consider impacts to BMIs.

- The level of urbanization or percentage of paved road in watersheds was not a good predictor of chloride concentrations in St. Louis County Missouri, making choosing locations for water quality monitoring of chlorides more difficult, as per Haake et al. (2022).
- On the other hand, Moore et al. (2020) commonly found chloride exceedances in watersheds with greater than 9-10% impervious cover and with median chloride concentrations greater than 30-80 mg/L at 93 sites on an East Coast study. They found that SC and chloride are significantly correlated with impervious cover for the Mid- Atlantic and New England.
- Moore et al. (2020) found that in the Mid-Atlantic, chronic chloride exceedances occur primarily between December and March.

Ionic Salts of Concern in Addition to Chloride

- The chloride ion may not be the only ion of concern. Other major ions also present: Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-} and HCO_3^{-}; all of these need to be considered along with the heavy metals liberated under high salinity conditions.
- Salt generally and chloride itself may not be the direct cause of impacts on BMI communities because for chloride, its presence increases the mobilization of some heavy metals, potentially increasing their toxicological effect and leading to consequences throughout the food web [Moore et al. (2022), summarized below, citing Schuler and Relyea (2017)].
- Laboratory experiments have shown that the toxic effects of chloride are reduced in the presence of a mix of ions, especially Ca^{2+}. However, little research has been done to characterize the behavior of all the major ions on varied timescales, during high-chloride events (Moore et al. 2020).

HIGHLIGHTED STUDIES FROM SELECT STATES/REGIONS

To get a holistic perspective on the salinization of streams, studies from multiple regions were considered in this literature review. The regions considered included:

- Maryland (2)
- Missouri
- Eastern US
- Multi State (includes Maryland)
- Toronto, Canada
- Study outside North America

Maryland

MD DNR (Maryland Department of Natural Resources). 2013. Do Road Salts Cause Environmental Impacts?

"According to results from field and laboratory studies, stream BMIs, as a group, appear to be less sensitive to elevated concentrations of salt/chloride compared to some other freshwater animals. Yet, there is a great deal of disparity among BMI species in terms of their salinity tolerances (Blasius and Merritt 2002). Toxicity also depends on length of exposure. Long-term exposure is more harmful than acute exposure. Mayflies, stoneflies, and caddisflies are the most salt-sensitive stream insects (Hartman et al. 2005; Pond et al. 2008; Pond 2010). Certain dragonflies, crustaceans, beetles, and true flies tolerate the highest salt concentrations (Cañedo-Argüelles et al. 2013). Due to the variability in salinity tolerance across taxa, the highest insect richness in streams can occur at slightly elevated salinity levels (Kefford et al. 2011). In a literature review by Blasius and Merritt 2002, the most sensitive stream insects were affected by sodium chloride (NaCl) concentrations of approximately 800 mg/L (240 mg/L chloride) and many were not affected until concentrations exceeded 2,000 mg/L (800 mg/L chloride)" (MD DNR 2013).

Maryland Biological Stream Survey (MBSS) results largely support findings from the literature. However, BMIs may be more sensitive in Maryland, or other factors may be coupled with chloride here. BMI index of biotic integrity (BIBI) scores appear to decline as chloride concentrations increase. *No streams with BIBI scores higher than 4.0 (the threshold for the highest quality streams) had chloride concentrations above 190 mg/L*. Only one stream with a chloride concentration above 500 mg/L had a BIBI score higher than 3.0. The 3.0 BIBI score is relevant here because watersheds with scores averaging less than 3.0 are included on Maryland's List of impaired waters by the Maryland Department of the Environment (MDE). Thus, chloride from road salt could be (at least partially) responsible for the listing of certain impaired streams in Maryland" (MD DNR 2013).

The group of BMIs in Maryland streams that tends to be most sensitive to pollution and watershed disturbance is the mayflies. The richness (number of genera) in this insect order declined with increasing chloride concentration at MBSS sites. Almost no mayflies were found in streams with chloride concentrations greater than 500 mg/L" (MD DNR 2013).

Hopkins et al. 2022. Lessons learned from 20 years of monitoring suburban development with distributed stormwater management in Clarksburg, Maryland, USA.

Hopkins et al. (2022) synthesized all literature published regarding a >1 km^2 watershed in Clarksburg, Maryland, with watershed-scale implementation of distributed stormwater facilities under three different stormwater management treatment scenarios. This study used an urban control watershed and a control forested area; this extensive literature review provides a unique opportunity to assess how ecological function changes during construction and after, amongst these different treatment scenarios, and in headwater streams. The synthesis "assessed trends in SC, BIBI scores, and the relative abundance of the Chironomidae family (midges) using Mann-Kendall tests and Sen's slope tests with the trend package in R" (Hopkins et al. 2022).

Among other factors, the Hopkins study addressed how the use of distributed stormwater facilities on a watershed scale in Clarksburg affected benthic assemblages in these conditions generally, with additional opportunities to observe how these assemblages in the stormwater treatment streams (or treatment trains) responded to both development and stormwater management.

More generally, "reference SC levels of Piedmont streams does not typically exceed 100 µS/cm (Olson and Cormier 2019), but median SC levels were higher than reference levels in all studied watersheds. Median SC for the forested control was slightly higher than regional reference SC (137 µS/cm), whereas median SC in the urban control was >7 time higher than Piedmont reference conditions (722 µS/cm)" (Hopkins et al. 2022).

The Hopkins study did not, however, isolate changes in BIBI to changes in SC but did find that higher impervious cover likely plays a critical role in stream function as opposed to the varied level of stormwater treatment density in the three treatment scenarios.

Missouri

Haake et al. 2022. Impacts of urbanization on chloride and stream invertebrates: a 10-year citizen science field study of road salt in stormwater runoff.

In this study, long-term data collected by citizen scientists with the Missouri Stream Team in St. Louis County, Missouri was used to test the relationship between watershed urbanization metrics and chloride metrics. Further, this data helped researchers "explore the effects of elevated chloride concentrations on stream invertebrate communities using a quantile regression" (Haake et al. 2022). "A total of 215 BMI sample sets were collected between 2010 and 2019" (Haake et al. 2022).

"There is some indication that background levels of chloride may be increasing in streams in the northern United States and Canada because of incomplete flushing of road salt after winter storm events due to retention in soil and groundwater, resulting in the gradual release of chloride into streams (Findlay and Kelly 2011; Robinson et al. 2017; Wallace and Biastoch 2016)" [Haake et al. 2022].

"Many studies have noted that freshwater streams can exceed the acute standard, particularly in the winter months when deicing of roads occurs, and thus have tried to determine the lethal effects of various chloride levels on a variety of aquatic invertebrate taxa (Benbow and Merritt 2004; Blasius and Merritt 2002; Gardner and Royer 2010; Mangahas et al. 2019). Most of these studies have examined these effects under short-term (24-96 hours) exposures in laboratory conditions and found wide variation in taxa responses" (Haake et al. 2022).

"The relationships between measures of the invertebrate density and metrics for both chloride and watershed urbanization were heteroscedastic (unequal variability or scatter), with greater variability in the data at low chloride concentrations. In all cases, chloride concentrations were negatively related to aquatic macroinvertebrates, both in terms of their density and diversity. This negative relationship is consistent with prior studies (Cañedo-Argüelles 2020; Hintz and Relyea 2019; and Wallace and Biastoch 2016, summarized below)" [Haake et al. 2022].

"The total number of invertebrates collected at a site drop by roughly half when maximum chloride measurements reach the 3,000-5,000 mg/L range and when median chloride concentrations reach 700‑900 mg/L." The water quality ratings in streams in the St. Louis region can be expected to drop from the excellent category (>23) to the good category (18‑23) once sites exceed a chloride Max of 900mg/L and a median chloride concentration of 100mg/L. In addition, sites appear unlikely to attain a good water quality rating when the median chloride is above 250mg/L" (Haake et al. 2022).

Eastern U.S.

Moore et al. 2020. High-frequency data reveal deicing salts drive elevated specific conductance and chloride along with pervasive and frequent exceedances of the U.S. Environmental Protection Agency aquatic life criteria for chloride in urban environmental streams.

This paper looks at three regions, including the Mid-Atlantic and Maryland. While not specifically evaluating the impact of SC and chloride levels on macroinvertebrates, these Maryland researchers characterized spatial variability in SC and chloride and exceedances of Environmental Protection Agency chloride criteria; the data set used nearly 30 million high-frequency observations (2-15 min intervals) for SC, and modeled chloride, from 93 sites in three Eastern US study regions: Southeast, Mid-Atlantic (including Maryland), and New England.

Moore et al. (2020) found that discrete chloride concentrations and discrete SC are highly correlated with median R^2 values of 0.97 for watershed-specific regression models in the Mid-Atlantic; also is that a higher fraction of SC is contributed by chloride specifically in the Mid-Atlantic and New England regions. "Mid-Atlantic chronic chloride exceedances occur primarily in December-March" (Moore et al. 2020).

They found that chloride exceedances are strongly correlated with impervious cover (Moore et al. 2020). Sites with impervious cover >10% in the Mid-Atlantic have median SC >300 µS/cm. Only five Mid-Atlantic watersheds with impervious cover <8.5% had median SC values lower than 227 µS/cm – the threshold proposed by Cormier et al. (2018) to protect BMIs (see Cormier et al. 2018).

Multiple States

Cormier et al. 2018. A field-based model of the relationship between extirpation of salt-intolerant benthic invertebrates and background conductivity.

Cormier et al. (2018) tested the relationship between background SC and the SC level that extirpates 5% of BMI genera using 24 distinct data sets obtained from different state agencies in the USA. The model is based on three assumptions: a genus will rarely occur where the background exceeds its upper physiological limit, the lowest possible tolerance limit of a genus in a region is defined by the natural background, and as a result, there will be a regular association between natural background SC and the SC at which salt-intolerant genera are present.

For Maryland, these researchers estimated a 227 µS/cm threshold at which 5% of the BMI genera are eliminated for the northern Piedmont (Ecoregion 64) and 243 µS/cm for the southeastern plains (Ecoregion 65-N).

Toronto, Canada

Wallace and Biastoch, 2016. Detecting changes in the benthic invertebrate community in response to increasing chloride in streams in Toronto, Canada.

Wallace and Biastoch (2016) investigated changes in stream chloride concentrations at 51 sites between 2002 and 2012. They used the strong correlation, R^2 of 0.93, between SC field measurements and laboratory measurements of chloride levels to model summer chloride concentrations. They related chloride concentrations to corresponding changes in BMIs over the same period.

"The sensitivity of BMIs to chloride and salinity varies among taxa (CCME 2011). Thus, the ability of community-level metrics to detect responses of BMIs to increased conductivity vary. In some cases, richness and density respond to changes in conductivity (e.g., Roy et al., 2003, Cuffney et al., 2010). However, if biotic responses are synoptic (e.g., if sensitive species are equally replaced by tolerant species), aggregate metrics (e.g., species richness) *will not chang*e. Threshold Indicator Taxa ANalysis (TITAN) is a relatively new tool for identifying shifts in the structure of biological communities across a stressor gradient (Baker and King 2010) that addresses this problem. Change in the distribution of each taxon along a stressor gradient is identified and synchrony of change points of multiple taxa can be used as one indication of a potential community threshold (Baker and King 2010, 2013)" (Wallace and Biastoch 2016).

They identified most taxa changes occurring at low chloride levels, indicating that chloride may be having a non-lethal effect on BMI communities. Their results also suggest that changes to BMI communities are "at the genus/species level rather than at the order/family level," the BMI community response is not linear with respect to chloride concentrations; and, the responses to chloride could be related to multiple stressors related to urbanization.

Study Outside North America

Cañedo-Argüelles et al. 2013. Salinisation of rivers: an urgent ecological issue.

Cañedo-Argüelles et al. (2013) is an excellent introduction to the issue of secondary salinization or anthropogenic salinization of freshwaters *globally*. This extensive literature review by these authors describes the major causes of secondary salinization and salinization impacts on the stream biota generally, as well as identifies future research needs.

In the context of the US, they reference the Watershed Assessment, Tracking & Environmental Results System (WATERS) [USEPA 2012], which listed salinization as among the top 15 causes of impairment of streams.

With respect to the relationship between increased salinity and reduced diversity, a review of the global literature revealed that:

- "Some studies did not detect a strong response between diversity and salinity gradients below an electrical conductivity of 10,000 µS/cm (approximately 5,600 mg/L at 25 °C)," citing Horrigan et al. (2005). Other studies found reduced species richness or diversity (Piscart et al. 2005; Kefford et al. 2006, Kefford et al. 2011) or changes in community (Kefford et al. 2010; Cañedo-Argüelles et al. 2012; Schäfer et al. 2012) well below this level" (Cañedo-Argüelles et al. 2013).
- "Piscart et al. (2005a) found higher diversities at intermediate conductivities (420-1,240 µS/cm) rather than at low (240-340 µS/cm) or high (2,240-4,360 µS/cm) conductivities when analyzing net-spinning caddisfly assemblages along a secondary salinization gradient. They suggested that this could be related to the intermediate disturbance hypothesis (Townsend et al. 1997), i.e., diversity would be highest at an intermediate level of salinity due to the co-occurrence of freshwater and halotolerant species" (Cañedo-Argüelles et al. 2013).
- Similarly, "Kefford et al. (2011) observed that total BMI species richness peaked at slightly elevated salinities (300-490 µS/cm) in south-east Australia, while it was reduced at both lower and higher salinity" (Cañedo-Argüelles et al. 2013).

"Three hypotheses are given as to why such patterns in richness and salinity would be observed, including: some species having a physiological optimum at a slightly elevated salinity, slightly elevated salinity might support both salt sensitive and tolerant species, and the possibility of confounding variables with salinity." (Cañedo-Argüelles et al. 2013).

The literature revealed that Ephemeroptera (mayflies), Plecoptera (stoneflies) and Pulmonate (EPT) snails are the most sensitive taxa with 48-h and 72-h LC_{50} around 5,000-20,000 µS/cm [Williams et al. 2003 (South Africa); Hassell et al. 2006; Echols et al. 2010; Kefford et al. 2012] "and that these sensitive taxa have been rarely registered in salinities higher than 3,000 µS/cm" (Cañedo-Argüelles et al. 2013).

Others found that EPT species richness decreases over the entire salinity range (García-Criado et al. 1999; Kennedy et al. 2003; Hartman et al. 2005; Pond et al. 2008; Pond, 2010; Kefford et al. 2011).

"On the other hand, Crustacea, Coleoptera (Beetles), certain Diptera [e.g., Ceratopogonidae (Midges)] and Odonata [e.g., *Coena grionidae* (damselflies)] are among the most salt tolerant (Berenzin, 2002; Kefford et al. 2004a, 2006; Dunlop et al. 2008)" (Cañedo-Argüelles et al. 2013).

Cañedo-Argüelles et al. (2013) also discuss the interaction of salinity with other factors. Low temperatures have been reported to increase the salinity tolerance of the mayfly *Isonychia bicolor* (Kennedy et al. 2004) in Ohio. "The most common detected response has been a decrease in toxicity of chemicals with increasing but still non-stressful salinity (Hall and Anderson 1995), although the toxicity of some organic compounds (e.g., pyrethroid insecticides) has been reported to increase with increasing salinity (Dyer et al. 1989; Hall and Anderson 1995)" (Cañedo-Argüelles et al. 2013).

Further, Cañedo-Argüelles et al. (2013) found multiple studies which "demonstrated that different saline water types have different toxicity on aquatic invertebrates (Mount et al. 1997; Kefford et al. 2004b; Zalizniak et al. 2006, 2009; Ziemann and Schulz 2011)" [Cañedo-Argüelles et al. 2013].

"There is also a need to better understand how effects of salinity on individual organisms are affected by the ionic composition of the salinity and by other abiotic stressors. Ionic composition is particularly problematic as there are eight major ions: Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-} and HCO_3^{-}. Here," Cañedo-Argüelles et al. (2013) "hypothesize based on previous findings (Mount et al. 1997; Kefford et al. 2004b; Zalizniak et al. 2006, 2009; Ziemann and Schulz 2011) that the relative proportion of the ions is more predictive of effects than the total concentration in terms of salinity. For example, Sylvestre et al. (2001) reported for Bolivian lakes that the abundance of several diatom species was likely related to the concentration of minor ions." (Cañedo-Argüelles et al. 2013).

OTHER LITERATURE FOR CONSIDERATION

The following is a list of literature that has not been reviewed in this study, but which may provide additional information:

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