8-2023

Potential drinking water impacts from road salt storage facilities in Vermont’s Lake Champlain Basin

Stephanie E. Hurley

Dana Allen

Potential drinking water impacts from road salt storage facilities in Vermont's Lake Champlain Basin

August 2023

Principal Investigators:

Dr. Stephanie Hurley
Associate Professor
221 Jeffords Hall
Department of Plant & Soil Science
University of Vermont

Dana Allen
Principal
FluidState Consulting
48 Stowe Street
Waterbury, VT

Funding: This research was supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G21AP10630 to the Vermont Water Resources and Lakes Studies Center.

Summary

Use of deicing materials (road salt) in Vermont has increased in the past decades. Chemical constituents associated with deicing materials can potentially pose a risk to drinking water quality. While deicing materials applied to roads represent a distributed, ephemeral source of salts, deicing material storage facilities are a potential year-round source of materials that can impact drinking water wells. Prior to this project there was no existing spatial database of these facilities in Vermont's Lake Champlain Basin. A database of deicing material storage facilities was created for this project, with the aim to make it publicly available in order to benefit numerous stakeholders, including the VT Department of Health, VT Department of Environmental Conservation, Vermont Agency of Natural Resources and the Vermont Open Geodata Portal, and Vermont Rural Water Association. This report (1) documents the locations and storage methods for municipal, as well as Vermont Agency of Transportation (VTrans) road salt and deicing material storage facilities in the Vermont portion of the Lake Champlain Basin and (2) analyzes these locations with respect to public and private drinking water wells. We also conducted an analysis to identify drinking water wells at parcels and schools hydrologically downgradient of the facilities and explored geospatial methods to evaluate whether these facilities pose a higher risk to vulnerable communities in the Lake Champlain Basin.

Table of Contents

List of Tables

List of Figures

Introduction

Forty percent of drinking water in Vermont comes from private wells. The quality of the water in those wells is not regulated by State or Federal Agencies, and monitoring of the water is the responsibility of the private owner (Vermont Department of Health, 2021). Wells can be contaminated by a range of naturally-occurring and anthropogenic pollutants that are harmful to human health (Duggal, et al., 2015). Because there can be costs associated with well water testing, and addressing potential problems revealed, those in rural and economically-disadvantaged communities are less likely to evaluate the quality of their water – potentially exposing themselves and their families to unknown health risks (Duggal, et al., 2015). Further, even in areas where well water has historically been considered safe for drinking, emerging pollutant sources pose a concern. Road salt and other deicing materials is one such emerging pollutant; these substances and their chemical constituents can leach into drinking water supplies with potentially dangerous effects (Duggal, et al., 2015; USGS, 2021).

Road salt is a common component of transportation management in winter months in cold climate areas, including the Lake Champlain Basin (LCB), where deicing materials are used as a safety measure to minimize ice on roadways and other hard surfaces (Bolen, 2015). Use of deicing materials is effective at reducing traffic accidents (Hanbali & Kuemmel., 1993). As such, its use has tripled in the US since 1970 with more than 20 million metric tons spread on roadways each year nationwide (USGS, 2021). Despite the efficacy of these deicing materials in reducing traffic accidents, when they flow off roadways and enters ground and surface waters, they can cause aquatic ecosystem harm through salinization and toxicity to organisms (Corsi, et al., 2010; Hintz & Relyea, 2019; Ledford, et al., 2016). Road salt is also known to corrode bridges and other infrastructure, resulting in billions in repair costs each year in the US (Hinsdale, 2018).

While roadways present an ephemeral and diffuse source of salt during winter, the point-source locations of storage facilities for deicing materials can potentially generate pollutants year-round. There are hundreds of deicing material storage facilities in Vermont but no previous centralized database of their locations or storage methods. Storage methods vary widely; in general, the combination of using a pad under and cover over the salt pile, is less likely to be a risk to salt movement from the facility compared to less formal storage methods. Lacking location-specific information about where and how these deicing materials are stored, residents cannot make informed choices about their drinking water sources, and other government and nonprofit stakeholders are limited in their ability to assess potential risk.

This project identified locations of municipal and transportation agency (VTrans) deicing material storage facilities in the Vermont portion of the LCB. We created a geospatial database documenting locations and storage methods for deicing materials and analyzed these locations with respect to different types of drinking water wells (private wells and public water sources). We also evaluated whether wells topographically downgradient of deicing material storage facilities posed a higher risk to vulnerable communities in this geographic area.

The two geospatial data sets we explored to identify potential risk to vulnerable communities were the Vermont Environmental Disparity Index (VT EDI) and Vermont's Grand List Joined Parcel Data. The VT EDI (Ren, et al. 2022) is based on exposure to environmental hazards and population characteristics (including underlying health risk factors and social vulnerability). The VT Grand List, which includes the full real estate value of each parcel (as assessed by each municipality), was also considered as a component of socioeconomic status. However, use of these data may be problematic or incomplete, as real estate value of a residential parcel does not necessarily correspond with income of those who reside (and/or drink water) there. In addition, in consideration of children being vulnerable to drinking water contamination, we also identified locations of private wells and public water sources for schools within the study area and their proximity to deicing materials storage locations.

In preparation for this study, we communicated with members of water advocacy groups and officials with Vermont Agency of Natural Resources Information Technology, VTrans, and Vermont Department of Health (DOH), as well as staff at the nonprofit Vermont Rural Water Association. The database itself will be shared on the Vermont Open Geodata Portal, which is managed by VT Agency of Natural Resources and Vermont Center for Geographic Information. Study findings will be shared with these entities. The study report and associated maps will be sent to the list of town clerks originally emailed as participants in this study.

Methods

Database Creation and Mapping of Deicing Material Storage Facilities

Municipal Facilities

Mapping of deicing material storage facilities in the LCB was conducted during the late fall and winter of 2022-23. An initial selection of towns was conducted in Geographic Information Systems (GIS) software (ArcGIS Pro 2.9). This resulted in a list of 126 municipal boundaries (some divisions within the GIS towns data are unincorporated "gores"). Using this list, town clerk contact information was obtained from the Vermont Secretary of State's website, which maintains a database of contact information for each town.

Each town was contacted to request information about their deicing material storage locations and methods. Email and telephone scripts were developed to briefly introduce the project and ask questions about the address of any deicing material storage locations in the town, type of materials stored at each site, duration of time each site has been used, whether materials on site are covered, and the type of surface the materials are stored on, if any. The script used to introduce the project, and the specific questions used for developing the database, can be seen in Appendix A – Outreach Script and Survey Questions.

Town clerks were the first point of contact for each town. The email inquiry gave the recipient the option to respond directly to the email, or to use an online survey (Google Survey based). Two rounds of emails were sent and garnered roughly 15 responses (~12% of the total list). Following the emails, direct calls were made to the remaining towns, either to the town clerk, or referred to the town's road foreman or public works head, to obtain accurate, complete information.

Data were entered into a geospatial database application (Fulcrum). Information was gathered there and exported as ArcGIS file geodatabases and Comma Separated Values (CSV) files for use in Microsoft Excel. Data were collected for 118 towns out of the original 126 on the list. Forty-three (43) towns reported that they are storing multiple material types at their facilities. Four (4) towns have multiple sites where they store material (Dorset, Pawlet, Morristown, and Castleton). Of these, three (3) store multiple materials at one or both of their sites (Pawlet, Morristown, and Castleton). Where towns have multiple materials or locations, the record information from the overall town identifier is linked to the material stored using a unique 'one-to-many' identifier. Locations of deicing material facilities, as shown in the database, were based on the addresses or location descriptions provided by town staff members and were verified only using the most recent aerial imagery (typically later than 2018 for all towns). Locations have not been field verified, nor have site conditions and infrastructure or other information provided by town staff.

Vermont Agency of Transportation (VTrans) Facilities

VTrans facility geospatial data were obtained by contacting VTrans directly. All information shared by VTrans is publicly available within VTrans Geographic Information System (GIS, https://vtransmaps.vermont.gov/). The same five questions posed to towns were also posed to VTrans (see Appendix A).

Selection of Private Wells and Public Water Sources Downgradient of Facilities

Data for private wells and public water sources were obtained via the Vermont Open Geodata Portal (https://geodata.vermont.gov/) maintained by the Vermont Center for Geographic Information (VCGI). Private well data are collected by the Vermont Agency of Natural Resources (VT ANR) by the Department of Environmental Conservation's Water Supply Data Composite and the Water Well Advisory Committee from reports filed since 1966 by private well drillers in accordance with the Water Well Driller Licensing Rule; the data set includes over 110,000 reports. Well information is only as complete as the reports filed by drillers and may be inaccurate spatially or otherwise. Public water sources are drawn from the State Drinking Water Database developed by VT DEC.

To determine which water supplies (private wells and public water sources) were in proximity to—and potentially hydraulically downgradient of—deicing material storage facilities, topographic gradient was used as a substitute for sub-surface hydraulics. This method was chosen based on two similar studies performed in New York state. The first is a study from 2018 in the town of Orleans, NY that used well elevations derived from 2-meter resolution Lidar (Light Detection and Ranging) topography data to determine wells potential hydraulically downgradient of a 'salt barn' (Pieper, et al., 2018). The second is also from 2018, investigating salt concentration in drinking water wells in East Fishkill, NY; researchers used a combination of Lidar elevation with surficial geology and Hydrologic Soil Group (HSG). That study found that elevation was primarily significant when wells were within 30 meters of roads or impervious surfaces (Kelly, et. al, 2018). This method does not explicitly control for sub-surface features which could affect groundwater hydrology and hydraulics. Groundwater flows have not been field verified, nor have they been modeled. Groundwater flow and modeling is essential to understand groundwater hydrology and would be required to confirm any drinking water contamination that is identified is associated with storage of deicing materials. In this study we focus on proximity, not actuality or causality of any contamination.

The following methods were used in ArcGIS to determine which wells or public water sources are downgradient of deicing material facilities:

- Each deicing material facility was assigned an elevation using the Vermont Lidar Digital Elevation Model (DEM), which is accurate to +/- 20cm. This field became the 'Pile Elevation'.
- A multiple ring buffer function was run for distance of 30m, 60m, 100m, 200m, and 300m from each facility. 30m was chosen based on previous research indicating that water resources could be influenced by road salt applied to roads within this distance (Heindel, 1982; Pieper, et al., 2018). 60m (or approximately 200 feet) was chosen as it is the minimum simple buffer distance used for private wellhead protection in Vermont (Vermont Agency of Natural Resources, 1997). 100m to 300m buffer distance increments were also evaluated in an effort to be broad in identifying at-risk wells in the maps.
- For each deicing material storage facility, its National Hydrography Dataset (NHD) High Resolution (HR) catchment was identified. In some cases, the catchment contained multiple facilities. A 60m buffer was applied to extend the area of the selected catchment to account for facilities on relatively flat areas or topographic breaks like ridges or highpoints where runoff (or groundwater) could potentially flow to either adjacent catchment, depending on micro-topographic variation. Because of the 60m buffer around each catchment, in some cases a facility has the potential to influence, or be situated in, more than one catchment.
- Private Wells and Public Water Sources geodata were downloaded from the Vermont Open GeoData Portal in January 2023; these represent the most accurate, up-to-date data available.
- Private Well and Public Water Sources were selected that fell within either or both of (A) the multiple ring buffer distances (buffers) and (B) the NHD HR catchments. Wells and sources were then labeled to indicate if they were within a buffer, a catchment, or both.
- Wells and sources were assigned Lidar DEM elevation values.
- All wells and sources lower in elevation than their respective nearby deicing material storage facility were identified. These are the wells and sources determined to be "downgradient" of facilities.

Additional attributes related to wells and water sources, such as well depth, well type (bedrock, gravel, or other) or well drilling method, were catalogued where possible, but not evaluated to determine their downgradient status. Although information about some wells or water sources is available in the GeoData Portal, for many individual wells only the location of the surface of a well has been identified in the data set, making further analysis of well depth relative to well surface elevation and/or storage facility elevation infeasible.

Comparison with Vermont Environmental Disparity Index Data

The Vermont Environmental Disparity Index or VTEDI was published in 2021 (Ren, et. al, 2021). The VTEDI summarizes Social Vulnerability, Health Risk Factors, and Environmental Risk Factors at the Census Block group level to create a Disparity Percent (based on the calculation: VT Environmental Disparity Index = Environmental Exposure * (Health Risk Factors * 0.5 + Social Vulnerability * 0.5)) as well as an Environmental Risk score. The VTEDI can be seen at the following URL, which details the data sources and their respective analysis procedures: https://www.arcgis.com/apps/webappviewer/index.html?id=68a9290bde0c42529460e1b8deee8368.

The VT EDI data are lumped by US Census Block Groups which do not always correspond with municipal boundaries. In order to compare the VT EDI values with results from this study, which are at the town level, a spatial join was performed that assigned the value from the VT EDI to the town boundary. Locations within municipalities in the LCB where deicing material storage was mapped (municipal or VTrans sites) were then selected. This then allowed for the selection of the municipalities within the study with the highest EDI values.

Additionally, a comparison of private well distance to the nearest deicing material storage facility to EDI was conducted by running a "near function" analysis in ArcGIS to assign each well a distance in meters to the nearest facility. This distance was then averaged by municipality (i.e. where there are multiple well sites near a deicing material storage site, the distance to them was averaged, and if a town had multiple storage facilities the average also included their well-distances). These average distances were then compared to EDI, using regression analysis (in Microsoft Excel) to determine if there is a linear relationship between the two variables. An initial overall regression was conducted for all municipalities and all wells. Subsequent regression analyses divided the average well distance to facilities into thirds to evaluate whether EDI might be associated with a shorter, medium, or longer distance between wells and salt piles.

Determination of School Proximity and Connection to Facilities

Given potential vulnerability of school-age children to drinking water pollution, we also analyzed schools specifically in the context of deicing materials storage facilities and drinking water sources. The private wells and public water sources data contain fields with owner, purchaser, and/or system names. For private wells, the fields 'OwnersLast' (as in Owner's Last Name) and 'PurchaserLast' was searched for the term "school" as there was no other identifying feature within the database for school-specific wells. This resulted in a schools-wells layer used for proximity analysis to deicing material storage facilities. Similarly, for the public water sources data the field 'SystemName' was searched for the term "school" as there was no other identifier for a public water source serving a school or other institution. Notably, this method may pull in systems that are also either colloquially named “school” or facilities that house schools only part time (religious schools or daycares, for example). Additionally, these data may be limited because some schools may rely on either a private well or a public water source, but the affiliated owner or system name may not contain the term “school.”

Evaluation of Property Values Near Facilities

To determine if properties reliant on wells or sources downgradient of deicing material storage facilities belong to socioeconomic groups potentially more at risk of adverse impact from deicing material pollutant contamination of drinking water, an analysis of parcel value was conducted. Notably, it is likely that vulnerable individuals may be renters rather than property owners, so the evaluation of real estate value is inherently imprecise in terms of resident well-being. However, it is still an interesting research question to consider whether deicing storage facilities could be more or less likely to be located near properties of lower or higher value. Details of the Methods and Results for the Property Values Analysis can be found in Appendix B.

Results and Discussion

Locations and Descriptions of Deicing Material Storage Facilities

Municipal Facilities Results

Initially there were 126 municipal boundaries identified as falling within the boundary of Vermont’s portion of the Lake Champlain Basin. Of these 126 municipalities, two areas are “gores,” Buel’s Gore and Mt. Tabor, which have no official public infrastructure. Another is St. George, which does not have its own highway department and uses the services of a private contractor to maintain its approximately 2 miles of roads. Additionally, the town of Waltham uses the services of nearby Panton to store its road maintenance equipment and materials and the town of North Hero uses the VTrans garage to store their deicing material. One town, Lincoln, elected not to submit information to this study per a decision by their Select Board. Two towns were missed in this survey – Benson and Lowell. Both were contacted multiple times (email and phone) and no response was obtained. There was a final total of 122 storage locations mapped over 118 towns and recorded in this study. Four of the towns have two sites each and 43 towns have multiple materials stored on their sites. This results in 170 individual material piles. We consider the 122 individual locations to be the “deicing storage facilities” in this report. Figure 1 shows each town mapped herein, including whether the deicing materials are covered at each site.

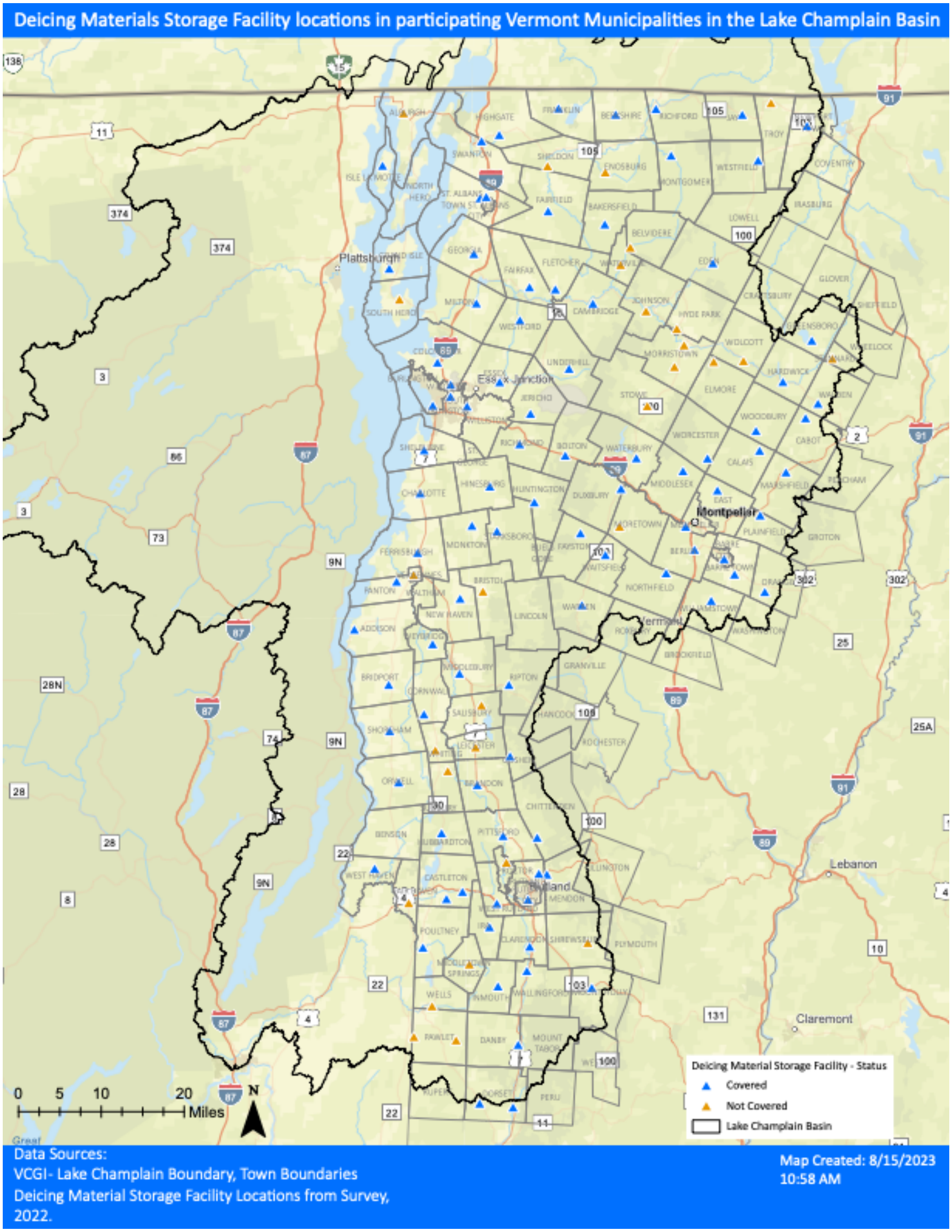

Figure 1: Deicing Materials Storage Facility locations in participating Vermont Municipalities in the Lake Champlain Basin. Locations are annotated as having deicing materials covered or uncovered based on survey responses.

Twenty-nine of the towns have uncovered piles of materials (in some cases in multiple locations), for a total of 36 material piles uncovered (and 134 covered). Of the uncovered material piles, the materials within them are predominantly 'salt and sand' piles (27 of 36). Eight material piles were listed as sand or sand and gravel only.

For all material piles, the following information was recorded:

Material Type:

- Road Salt (Sodium Chloride): 102
- Salt and Sand: 24
- Potassium Chloride: 1
- Magnesium Chloride: 3

"Other materials" listed include salt and sand, road salt, and calcium chloride in one structure in Highgate Center, sand only in Orwell, sodium chloride, salt and sand, and liquid chloride in the same structure (Shelburne), and calcium chloride brine in a tank in a structure in Bakersfield.

Storage Duration:

- 10+ Years: 151 towns
- 6-10 Years: 7 towns
- 2-5 Years: 7 towns
- 0 – 2 Years: 5 towns

Coverage Method (among 134 covered piles):

- Structure: 127 piles
- Impermeable Membrane Placed Over Pile: 7 piles

Use of Pad for Storage of Materials:

124 of 170 sites have materials stored on pads, 45 have materials not on pads, and 1 site used a calcium chloride brine tank (Bakersfield), for which no pad is needed as the tank is fully enclosed.

Pad Types (among 124 sites with materials stored on pads):

- Asphalt: 46
- Concrete: 69
- Compacted Earth: 4
- 2 piles are listed as both concrete and asphalt (Grand Isle), 1 pile is listed as 'pine boards' (Fair Haven), 1 pile is listed as half asphalt, half dirt (Warren), and 1 pile is unknown (Duxbury).

Vermont Agency of Transportation (VTrans) Facilities Results

Figure 2 depicts the reported locations of deicing materials by VTrans, including those outside of the LCB. Although the same questions researchers asked of municipalities were asked of VTrans, we found that the agency does not maintain specific records for these attributes for each of their 124 facilities spread across 63 towns throughout the entirety of Vermont and was not able to answer these questions. In general, VTrans representatives indicated that all materials were stored both under cover and on impermeable pads. The scope of this study did not allow this information to be field-verified.

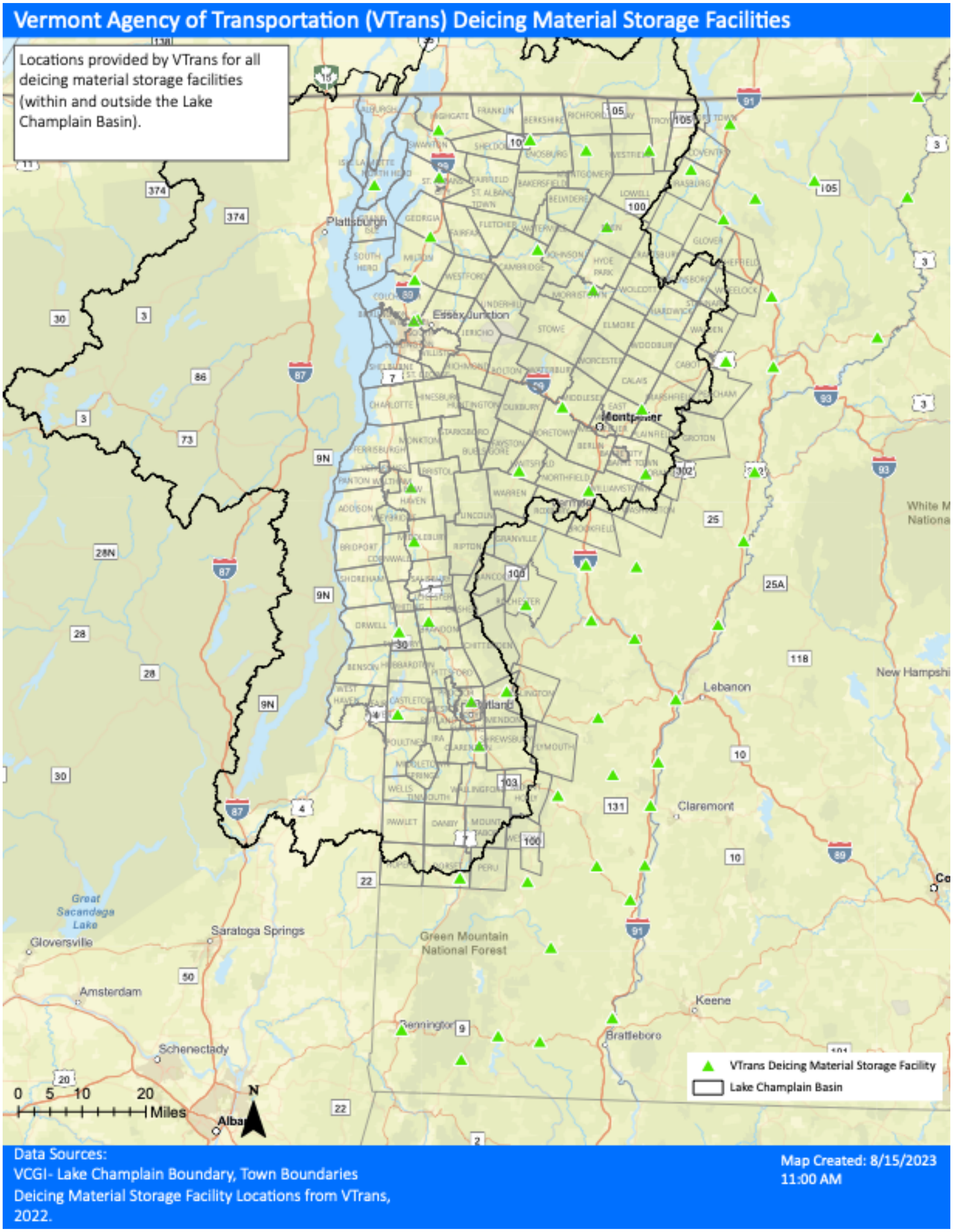

Figure 2: Vermont Agency of Transportation Deicing Materials Storage Facilities throughout Vermont, both within and outside of the Lake Champlain Basin.

Selection and Mapping of Private Wells and Public Water Sources Downgradient of Facilities

We mapped the wells and water sources identified to be located within a given distance of a deicing materials storage facility and/or within the same NHD HR catchment as a facility, considering both the distance from the facility and whether the wells are likely to be "downgradient" from that facility (see Methods for definition of downgradient). The intention was to allow map data to depict potential hydrologic connections, via surface or groundwater, and help prioritize locations for drinking water testing. Appendix C includes the resulting maps that correspond with the data below.

Results for Private Wells are as follows:

Number of wells within 300 meters of a facility or within an NHD HR catchment basin: 1665
Number of wells within 300 meters of a facility: 589
Number of wells within 300 meters of a facility AND within an NHD HR catchment basin: 464
Number of wells ONLY within an NHD HR catchment basin: 1076
Number of wells ONLY within 300 meters of a facility: 125

Approximately 44% of all mapped wells (726 wells) were noted to be downgradient of the nearest facility.

The cumulative numbers of wells in various proximities to deicing storage facilities (589 total) are reported below. Each "buffer ring" placed around a facility in the map includes the wells within the next smaller size buffer as well; for example, the 46 wells listed within 60 meters of the storage facility includes the 15 that are within 30 meters.

- 30m: 15
- 60m: 46
- 100m: 107
- 200m: 308
- 300m: 589

In total 1,076 drinking water supplies were found to be with in the same catchment as a deicing storage facility, but not within the 300m distance from deicing facilities. Of these, 673 were found to be downgradient of the nearest deicing facility. Wells within the same catchment area as a facility are potentially within the groundwater plume of that facility. These catchments are delineated at a small scale and usually consist of the drainage area for a small upland tributary or intermittent drainage path. If a well is within the catchment and downgradient of a facility, it's potentially at increased risk because of the possibility of groundwater connection, despite being further away from the deicing materials storage site.

For Public Water Sources, the results are as follows:

Number of public water sources within 300 meters of a facility or within an NHD HR catchment basin: 51
Number of wells within 300 meters of a facility: 27
Number of public water sources within 300 meters of a facility AND within an NHD HR catchment basin: 19
Number of public water sources ONLY within an NHD HR catchment basin: 24
Number of public water sources ONLY within 300 meters of a facility: 8

Approximately 63% of public water sources mapped (32 locations) are downgradient of the nearest facility.

Maps depicting these results, showing facilities in each town in the database (122 maps) can be found in Appendix C.

Additional Data on Private Wells and Public Water Sources
Although the well data are incomplete for the, to the extent practical, we have listed additional information about the types of wells and public water sources mapped.

Private Wells (1665 total) Types:
- Bedrock: 1,408
- Gravel: 138
- Blank (Unknown): 119

The mean depth (feet) for all selected wells, for which data were available from the VT ANR and Well Water Advisory Committee Reports, is 285 feet.

For Public Water Sources (51 total) the following Types* are listed:
- Drilled: 39
- Gravel: 5
- Spring: 1
- Mapped "Well Points" (typically associated with a water system – most of these points appear to be drilled wells): 6

The average depth for these wells is 286 feet.

*Note that the Well Type category within the Public Water Sources database differs from that in the Private Wells database.

Comparison of Database and Well Locations with the Vermont Environmental Disparity Index Data

Figure 3 shows the deicing material storage facilities mapped in this project overlain on the Vermont-wide map of EDI percentage; the higher percentage values indicate the greater likelihood of Vermonters living in that Census Block to experience environmental injustice based on "environmental exposure" and "social vulnerability" (Ren, et. al, 2021). For the LCB portion of Vermont, the EDI score was sorted largest to smallest and graphed against average private well distance to deicing material storage facility to determine if communities with higher EDI scores are characterized by wells closer to facilities (Figure 4). Additionally, the EDI values for municipalities mapped in this study were compared against EDI values for all communities within Vermont with respect to average, median, and standard deviation of EDI values. The two cohorts did not differ significantly (Table 1).

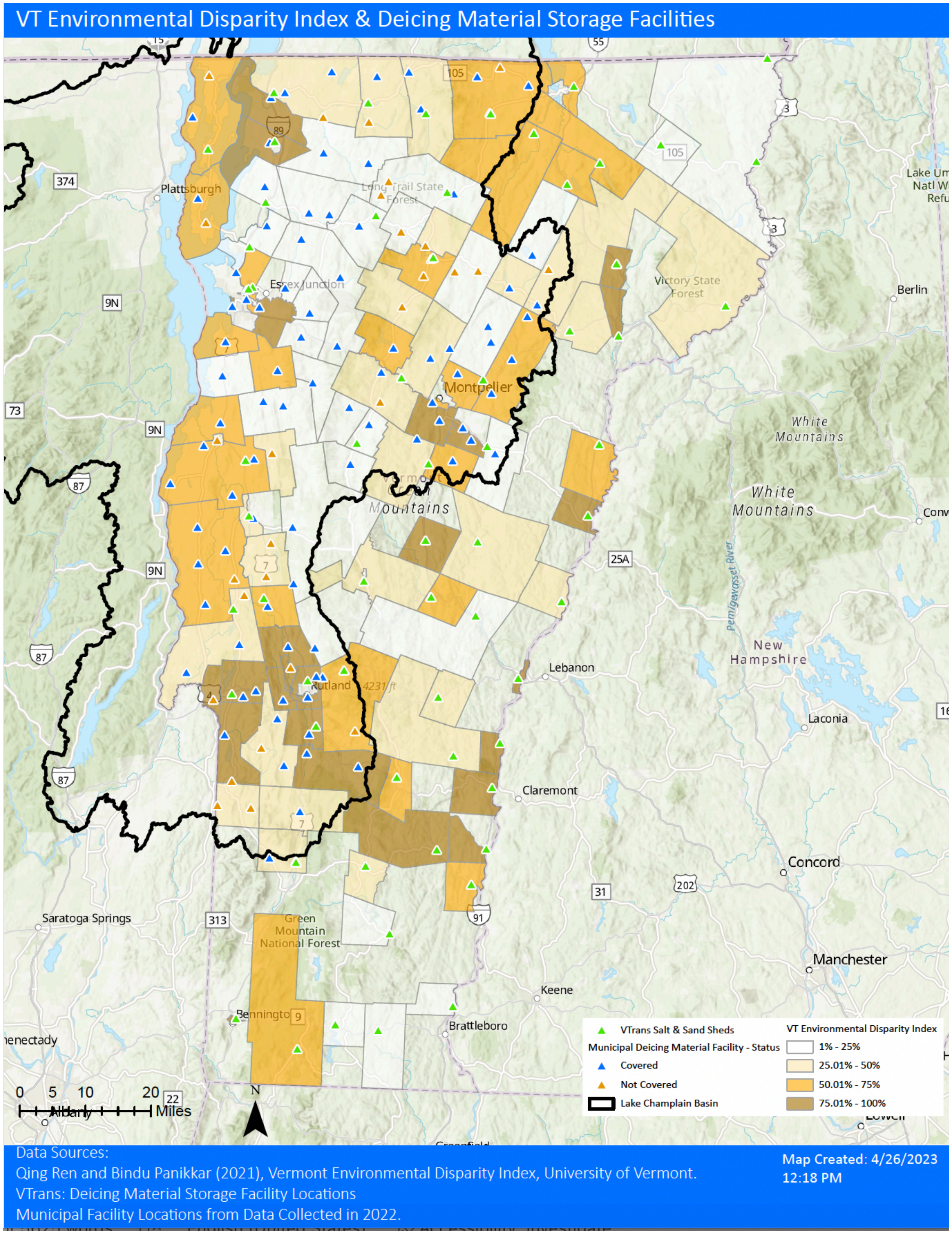

Figure 3: Vermont Environmental Disparity Index (EDI)map, showing both VTrans and Municipal (covered piles and uncovered piles) Deicing Materials Storage Facilities. Census Blocks with higher percent EDI indicate higher relative likelihood of combined environmental, social and health burdens for those communities. Vermont Environmental Disparity Index scores derived from: https://www.arcgis.com/apps/webappviewer/index.html?id=68a9290bde0c42529460e1b8deee8368

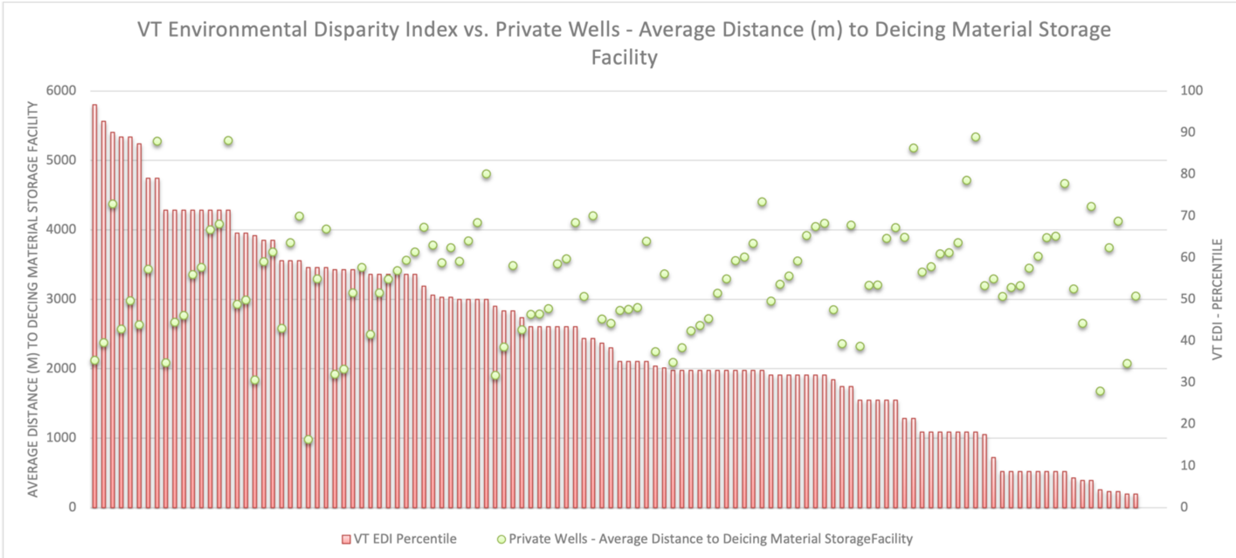

Figure 4: Vermont Environmental Disparity Index – Disparity Percentile for all municipalities mapped in this study, within the Lake Champlain Basin, arranged from highest to lowest EDI score, compared with town-wide average distance (m) from deicing material storage facilities to private wells. Vermont Environmental Disparity Index scores derived from: https://www.arcgis.com/apps/webappviewer/index.html?id=68a9290bde0c42529460e1b8deee8368

Table 1: Comparison of EDI values for mapped municipalities in the Lake Champlain Basin (LCB) versus Statewide EDI.

Statistic	EDI – Mapped Municipalities in the LCB for this research	EDI – Statewide
Average	41.06	40.56
Median	36.75	36.2
Standard Deviation	22.85	22.81

A linear regression analysis was performed to see if there was any statistical relationship between VTEDI percentage and proximity of drinking water sources to deicing storage facilities. The R-squared value returned was 0.01 with a p-value of 0.19, indicating that there is no strong relationship between the two variables.

To consider the potential impact of different ranges of distance (short, mid, and long) between deicing facilities and private wells, well distance to deicing facilities was divided into three ranges (equal thirds based on the range of values present). Regression analysis was then performed on each of these ranges against each range's EDI values (Table 2). However, no strong relationships were present.

Table 2: Regression analysis comparing EDI values to private well distance to deicing material storage facility (average in meters) for all municipalities, distance divided by thirds.

Range	Distance (m)	R-squared	p-value
Short Distance	0 – 2990	0.0008	0.95
Mid Distance	2991 – 3660	0.028	0.29
Long Distance	3660 - 5337	0.008	0.57

Despite the lack of relationship, the use of the EDI as a potential indicator for municipalities of interest is useful, and may aid in prioritizing locations for water testing. The municipalities with top 25 highest EDI scores were selected from the overall list and compared to the average distance to private wells from deicing material storage facilities (Figure 5). Regression analysis was also conducted for these municipalities. This analysis shows no strong relationship between EDI value and distance to facility (R-square of 0.004, p-value of 0.92).

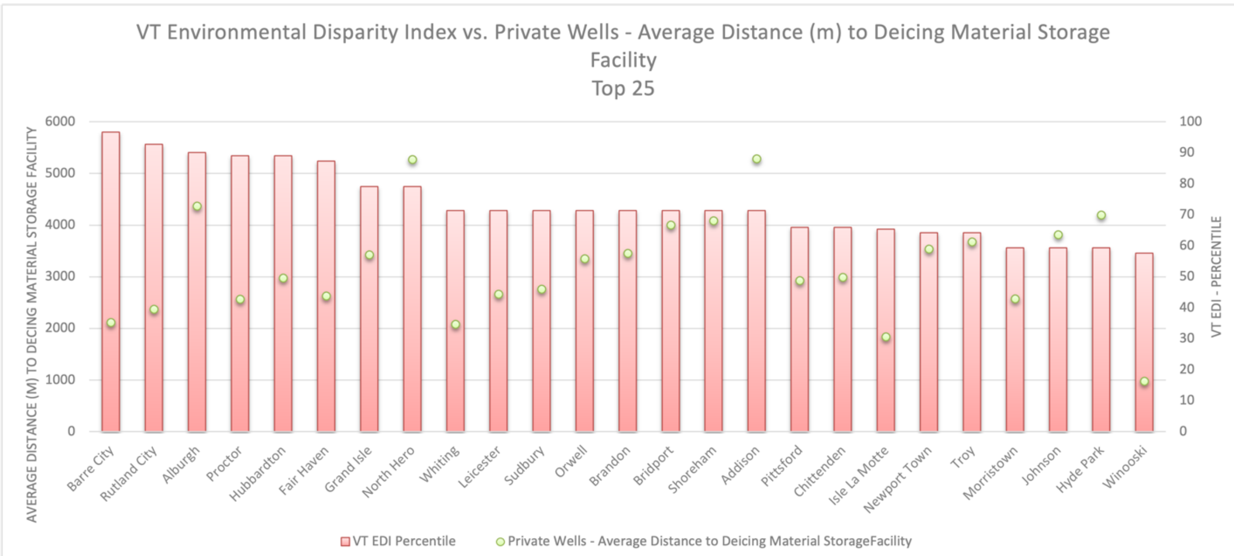

Figure 5: Top 25 highest VT EDI values for municipalities in which deicing material storage facilities were mapped compared with average distance of private wells to facility. Vermont Environmental Disparity Index scores derived from: https://www.arcgis.com/apps/webappviewer/index.html?id=68a9290bde0c42529460e1b8deee8368

It is important to note that the VTEDI is mapped at the Census Block Group level which roughly corresponds with town boundaries (though not always). Accordingly, the data, while extremely valuable at the block group level, lacks the granularity necessary to allow for intra-municipality comparisons. For example, we are unable to compare whether parcels (or residents who live within them) that have wells potentially impacted by a deicing material storage facility are higher or lower risk for environmental disparity than parcels within the same town that are not in proximity to a deicing materials storage facility. However, the index does offer a framework for the prioritization of communities within which to conduct further analysis by selecting the block group communities with the highest VTEDI Overall Score. These are the communities with the highest potential for at-risk populations and may warrant more analysis with respect to potential impact from deicing material storage than other communities with lower VTEDI Overall Scores.

Determination of School Proximity and Connection to Deicing Material Storage Facilities

There are 54 private wells within the Lake Champlain Basin with Well Use Codes listed as 'School'. Proximity analysis of these wells shows that the closest any well serving a school is to a deicing storage facility is 55 meters (Yestermorrow School in Waitsfield, which is a private elective adult education institution). The average distance is 2,934 meters with (minimum value of 55 meters and maximum value of 9,735 meters with a standard deviation of 1,895 meters).

There are two wells within the delineated buffers or catchments that have Well Use Codes listed as 'School'. They are:

- Yestermorrow School – well is located in the 60m buffer of the Waitsfield VTrans deicing material storage facility (covered). This well is below the deicing material storage facility. Given the proximity and its relative elevation, this well should be considered for future water quality analysis.
- Twinfield School District – well is located in the catchment of the Plainfield deicing material storage facility (covered). However, this well is above the deicing material storage facility (nearly 100m) and at a distance of nearly 1,500m.

There are twelve (12) public water source records where the System Name contains the word 'School,' though only ten unique locations (two are duplicates). System names and locations, as well as proximity to deicing storage facility, are listed in Table 3, and mapped in Figure 6. Of these schools, five appear to be below the nearest deicing facility, four of which have covered piles. One school's water source, at the Wolcott School Street Center, is 238 m from an uncovered salt and sand pile. Also, one facility, Mount Holly, is nearly within the 60m (200') Vermont wellhead protection zone of a school (Mount Holly School). These five schools, in particular in Wolcott and Mount Holly, should be considered higher priority for potential future analysis of well water quality. Leicester and Shrewsbury, with their uncovered salt and sand piles, may be of particular interest.

Table 3: Public Water Sources inside deicing material storage facility buffers or catchments.

System Name	Below Deicing Facility	Location	Distance to Nearest Facility (m)	Facility Type	Facility Covered?
WEYBRIDGE ELEMENTARY SCHOOL	Yes	Inside Catchment	462	Municipal	Yes
RUMNEY SCHOOL	Yes	Inside Buffer Only	228	Municipal	Yes
ISLE LA MOTTE ELEMENTARY SCHOOL	Yes	Inside Buffer Only	185	Municipal	Yes
WOLCOTT SCHOOL STREET CENTER	Yes	Inside Buffer Only	238	Municipal	No (Salt and Sand)
MOUNT HOLLY SCHOOL	Yes	Inside Buffer Only	68	Municipal	Yes
BREWSTER PIERCE SCHOOL	No	Inside Catchment	370	Municipal	Yes
LEICESTER CENTRAL SCHOOL	No	Inside Buffer (Municipal Facility)	298	Municipal	No (Salt and Sand)
SHREWSBURY MOUNTAIN SCHOOL	No	Inside Buffer (Municipal Facility)	208	Municipal	No (Salt and Sand)
TINMOUTH CENTER SCHOOL	No	Inside Buffer Only	172	Municipal	Yes
WARREN ELEMENTARY SCHOOL	No	Inside Buffer Only	257	Municipal	Yes

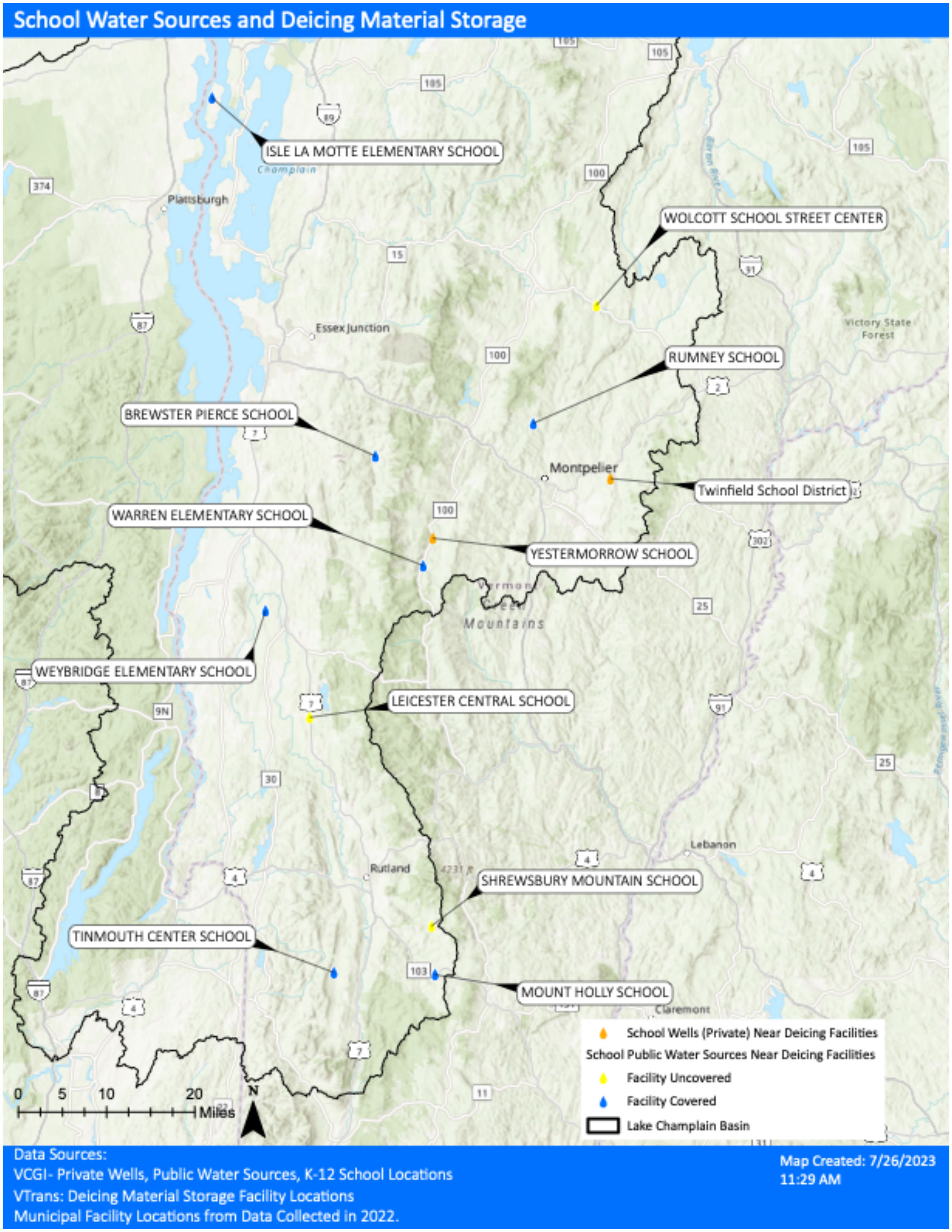

Figure 6: School Water Sources with private wells or public water sources in proximity to deicing materials storage facilities. Facilities are labeled as uncovered or covered to indicate whether de-icing materials are covered at each site.

Conclusions & Next Steps for Further Research

The objectives of this research were to create a previously non-existent public database of municipal deicing materials facilities in the Vermont portion of the Lake Champlain Basin and to identify drinking water wells (private as well as public water sources) potentially at risk for water pollution due to salt and related deicing materials. Based on mapping methods that considered two forms of proximity—wells being located within 300m or fewer of a deicing material storage facility and/or within the same hydrologic catchment as a facility—we created maps of target locations (to be considered for drinking water testing) for each municipality participating in the study. There was 97% participation by VT towns in the LCB, (118 of 121 municipalities who were eligible to participate based on having, or sharing, deicing material storage infrastructure, and excluding the two gores). In addition, by specifically looking at the Vermont Environmental Disparity Index and School locations, we further investigated potential risk to vulnerable communities.

This report and its enclosed Appendices, including the 122 maps, lay the groundwork for several additional areas of research, including: (1) improved means of calculating and analyzing what constitutes "hydrologically downgradient" in systems where there are connections between surface (storage piles) and groundwater flows (wells), (2) alternate approaches to selection and sampling of residential and school drinking water, (3) refining the definition of, and granularity of information regarding, vulnerable populations, and (4) further use and expansion of the project's deicing materials storage database.

By including both a distance measurement and catchment-sharing approach to identifying wells in the vicinity of deicing material storage piles, we took a conservative approach allowing more wells to be labeled in our maps than would have been identified as "downgradient" of facilities using only a single-factor approach. As described in the methods, and following two previous studies, our research team opted to use surface water flow (topography) as a surrogate for groundwater flow, which is an imperfect method. The scope of this study did not allow a more nuanced evaluation of actual surface or groundwater flows in relation to surface storage of deicing materials, nor an exploration of localized influences of wells on groundwater and vice versa. Advances in groundwater science, and deeper consideration of factors such as localized topography, artificial drainage systems, soil type, soil chemistry, and bedrock conditions would allow future research to be more precise about identifying wells hydrologically connected to salt storage facilities.

Drinking water sampling to determine any impacts from salt is recommended to be conducted within buildings (e.g. at the kitchen sink), as well as within the wells themselves. One reason to test drinking water from the tap is because chlorides can liberate metals like copper and lead from pipes within a residence. Investigations in New York and Virginia identified that the presence of high concentrations of Cl in domestic well water promotes galvanic corrosion in pipes leading to the liberation of copper (Cu) and lead (Pb) (Pieper, et. al , 2015; Pieper, et. al, 2018). Sodium is also a concern for human health. Research in New York (including within the LCB) identified sodium (Na) in concentrations harmful to human health in private residential drinking water wells adjacent to salted roadways and salt storage sites (Denner, et. al, 2009; Kelly, et. al, 2018). Age of housing stock may also be a factor to consider in gaging likelihood of pipes in buildings containing lead (https://www.healthvermont.gov/environment/drinking-water/lead-drinking-water). It is recommended that individuals interested in water testing partner with the Vermont Department of Health to conduct testing.

Water testing at schools is also important, and Vermont law already requires all schools and child care facilities to have water tested for Pb (https://www.healthvermont.gov/environment/school/testing-lead-drinking-water-schools). With regard to sodium and other pollutants and proximity to salt storage piles to schools, the research methods above were an effective mapping approach. However, we also considered another method using VCGI's Schools database. All schools in Vermont are mapped with respect to their E911 address. The analysis under consideration would have considered whether or not private wells or public water sources within a certain distance of the school's mapped E911 point location could be considered the drinking water source for the school. However, this method was not used as a way to connect specific schools with their likely water sources; determination of a specific distance within which to select the water source was decided to be less accurate than using the ownership information from the respective databases as described above. Future research could expand upon the best methods to prioritize locations for well water and tap water testing, and also further explore connections between drinking water and deicing material storage in the context of other vulnerable populations, such as individuals in elderly care facilities and health care centers.

Municipalities interested in this research may want to pursue several next steps, including verification of well locations in proximity to deicing materials storage facilities (well locations are as-reported by well drillers and may not be spatially accurate and/or underreported), verification of localized groundwater flow patterns to account for geology, in particular constricting layers which could direct groundwater flows in directions other than those indicated by surface topography. Additionally, VTrans has a Municipal Assistance Program which administers a Transportation Alternatives fund which has been used by municipalities in the past to retrofit deicing materials storage facilities. This could be of interest in locations where materials are uncovered.

Although we did not identify a statistically significant connection between VT EDI percentage and distances between drinking water sources and deicing storage facilities, the Vermont Environmental Disparity Index data provide a lens through which vulnerability might be quantified and qualified across the state. As mentioned previously, the EDI's relative scale of the Census Block Group limits the ability to identify the highest priority sites for water testing at a fine scale. However, future research should investigate a more granular scale, perhaps using "neighborhood" or sub-watershed boundaries, at which to prioritize water testing for the most vulnerable and underserved individuals. In the meantime, this index, which confirms that proportionately more individuals are likely to experience environmental justice issues in some Census Blocks than others, provides a starting point for prioritizing where drinking water testing should occur.

Finally, this project created a new database that has potential to be used beyond the drinking water context to evaluate ecosystem-level risks, particularly to freshwater organisms and aquatic ecosystems associated with deicing storage facility locations and storage methods. Efforts to field-verify the data provided through the Survey (Appendix A) should be made in the future to confirm both location and methods of salt storage. Future efforts should expand the extent of this database's contents to the rest of Vermont beyond the Lake Champlain Basin, as well as other parts of the basin outside of Vermont (i.e. New York and potentially Quebec). Along these lines, there is much room to grow in establishing policies and systems for reduced-salt management practices, best practices for deicing material storage, and reducing effects of salt use on human and natural communities.

Acknowledgements

The material in this report is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G21AP10630 to the Vermont Water Resources and Lakes Studies Center.

We would like to acknowledge the hard work of our research assistant, University of Vermont student Oscar Ewald. Over the course of several months, Oscar's diligence and persistence with respect to contacting the various town officials associated with this study was crucial in obtaining the results. Without him, results would not have been obtained as quickly or as well as they were.

We would also like to acknowledge the work of Drs. Kris Stepenuck, Cheryl Morse, and Rebecca Tharp with whom we discussed this study, its methods, and its goals over the course of many months and who's input gave it shape and direction. Their input was invaluable and though they were not directly involved in this investigation, their expertise was greatly appreciated.

Sille Larsen, formerly with the Vermont Department of Health and currently serving as the Engineering and Water Resources Program Manager with VT DEC, provided valuable advice and guidance in developing this proposal, and feedback on the draft report. Her commitment to drinking water quality is truly commendable.

Diana Butler, formerly with Vermont Rural Water Association, also gave valuable input and advice on developing this proposal, and her successor, Brad Roy, was an interested and valuable audience for the presentation of this material.

Craig 'DiGi' Digiammarino, Program Manager of the Vermont Agency of Transportation's Pollution Prevention and Compliance Section, also facilitated the sharing of VTrans deicing materials facility data and provided valuable input on reporting and guidance for municipalities.

The Vermont Environmental Disparity Index is a novel and valuable tool for environmentalists within the state and arguably those outside it who are seeking to better understand how they can better interface with and work to repair the damage of environmental injustice. The research by Qing Ren, Bindu Panikkar, and Gillian Galford at the University of Vermont in 2021 to create the Index is important, groundbreaking, and should serve to inform all studies of the potential impact on communities within Vermont.

References

Bolen, W. P. (2015). US Geological Survey Minerals Yearbook 2015: Salt. Retrieved January 8, 2020, from https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/salt/myb1-2015-salt.pdf

Corsi, S. R., Graczyk, D. J., Geis, S. W., Booth, N. L., & Richards, K. D. (2010). A fresh look at road salt: Aquatic toxicity and water-quality impacts on local, regional, and national scales. *Environmental Science and Technology*. https://doi.org/10.1021/es101333u

Denner, J. C., Stewart F. Clark, J., Smith, T. E., & Medalie, L. (2009). *Effects of Highway Road Salting on the Water Quality of Selected Streams in Chittenden County , Vermont, November 2005-2007*.

Duggal, A., Frede, S., & Kasky, T. (2015). *A Public Health Legal Guide to Safe Drinking Water*. Retrieved from http://www.astho.org/Public-Policy/Public-Health-Law/Public-Health-Authority-Over-Drinking-Water-Quality-Overview/

Hanbali and D.A. Kuemmel., R. M. (1993). Traffic volume reductions due to winter storm conditions. *Transportation Research Record No. 1387, Snow Removal and Ice Control Technology: Papers Presented at the 3rd International Symposium on Snow Removal and Ice Control Technology, Minneapolis, MN*.

Heindel, C. (1982). *Road Salt Effects on Ground Water in the Williston and St. George Area, Vermont*.

Hinsdale, J. (2018). How Road Salt Harms the Environment. Retrieved from https://news.climate.columbia.edu/2018/12/11/road-salt-harms-environment/

Hintz, W. D., & Relyea, R. A. (2019, June 25). A review of the species, community, and ecosystem impacts of road salt salinisation in fresh waters. *Freshwater Biology*. https://doi.org/10.1111/fwb.13286

Kelly, V. R., Cunningham, M. A., Curri, N., Findlay, S. E., & Carroll, S. M. (2018b). The Distribution of Road Salt in Private Drinking Water Wells in a Southeastern New York Suburban Township. *Journal of Environmental Quality*, *47*(3), 445–451. https://doi.org/10.2134/jeq2017.03.0124

Lead in Drinking Water (https://www.healthvermont.gov/environment/drinking-water/lead-drinking-water), Vermont Department of Health, Accessed July, 2023.

Ledford, S. H., Lautz, L. K., & Stella, J. C. (2016). Hydrogeologic Processes Impacting Storage, Fate, and Transport of Chloride from Road Salt in Urban Riparian Aquifers. *Environmental Science and Technology*, *50*(10), 4979–4988. https://doi.org/10.1021/acs.est.6b00402

Pieper, K. J., Krometis, L. H., Gallagher, D. L., Benham, B. L., & Edwards, M. (2015). Incidence of waterborne lead in private drinking water systems in Virginia, 897–909. https://doi.org/10.2166/wh.2015.275

Pieper, K. J., Tang, M., Jones, C. N., Weiss, S., Greene, A., Mohsin, H., & Edwards, M. A. (2018). Impact of Road Salt on Drinking Water Quality and Infrastructure Corrosion in Private Wells. https://doi.org/10.1021/acs.est.8b04709

Ren, Qing, Bindu Panikkar, and Gillian Galford. Vermont Environmental Disparity Index and Risks. Environmental Justice. 2022. http://doi.org/10.1089/env.2021.0063

Testing for Lead in Drinking Water at Schools, (https://www.healthvermont.gov/environment/school/testing-lead-drinking-water-schools), Vermont Department of Health, Accessed 2023

USGS. (2021). *Mineral Commodity Summary - Salt*. Retrieved from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-salt.pdf

Vermont Agency of Natural Resources. (1997). *Protecting Public Water Sources in Vermont*.

Vermont Department of Health. (2021). *Mandatory Water Testing of Drinking Water Wells for Single-Family Residences : What Well Owners Need to Know October 2021 Why am I required to test my drinking water ?* (Vol. 1113).

Appendix A – Outreach Script and Survey Questions:

Phone Call:
Hi,

I'm a student at the University of Vermont working on a project funded by the United States Geological Survey developing a public infrastructure database. I'm hoping to find some information on salt storage in the town of ________________. Is that something you can help me with?

If Yes – ask questions.
If No – ask who the appropriate contact is.

Ok, Thanks. I have about 5 questions for you. It shouldn't take too long.

1. First, what is the address (or addresses if your town has multiple storage locations) of the site(s)? *Cross streets/intersections may substitute for street addresses.*
2. What type of material(s) are located at this site?
   a. *Options can include: Road salt / rock salt (sodium chloride),*
   b. *Mixed salt and sand piles,*
   c. *Other deicers like magnesium chloride, or potassium chloride (usually a liquid).*
3. How long has the site been used to store this material?
4. Is the material /Are the materials covered with anything?
   a. If covered, how is it covered?
   b. *If multiple material types on site – get information for covering and pad for each type of material.*
5. Is the material /Are the materials on a concrete (or similar type of) pad?

Thank you – I really appreciate your time.

E-Mail:

I'm working on a project funded by the USGS Water Center to develop a database of public infrastructure sites in the Lake Champlain Basin in Vermont.

Specifically I'm looking for the location of road salt storage sites – both road salt and salt and sand pile are. I'm also hoping to get some additional information about these sites, like how long the site has been used to store these materials and how it's stored, like whether or not there is a shed or some other cover present.

I've put together a brief online survey with 6 questions for you. It should only take about 5 minutes to fill out if you have the information readily available. The questions will ask what the address of the salt storage site is, the type of material at the site, how long it's been there, if it's covered, and if it's on a storage pad of some sort.

Here's the link to the survey
(https://docs.google.com/forms/d/e/1FAIpQLSeOC2PiL2uMKYAlIML2R82_rtwsn6pAkNPhREuaLNLtoHySYg/viewform?usp=sharing).

Also, you'll need to fill out what town you're responding from as the first question. If you aren't the right person to answer these questions, can you please pass this email and survey link along to the right person? I'd really appreciate it.

If you have any questions on this, please feel to reach out to the professor I work with at UVM, Stephanie Hurley in the Department of Plant and Soil Science: stephanie.hurley@uvm.edu. You can also reach out to Dana Allen who is a consultant on this project. His email is dana@fluidstateconsulting.com.

Appendix B – Analysis of Full Real Estate Value for Parcels Containing Private Wells or Public Water Sources in Proximity to Deicing Material Storage Facilities:

Methods

The following methods were used to determine and compare parcel value:

- Parcel data for Vermont was downloaded from the Vermont Open GeoData Portal.
- The standardized parcel database contains numerous attributes. For this analysis, the attributes of interest, drawn from each town's tax Grand List, were Property Type, Category, and Full Real Estate Value. Property Type allows for the selection of parcels versus rights-of-way associated with roads, highways, and railroads. Category contains values indicative of parcel use including:
    - Commercial and Commercial Apt
    - Farm
    - Industrial
    - Miscellaneous
    - Mobile Home
    - Other
    - Residential-1
    - Residential-2
    - Seasonal-1
    - Seasonal-2
    - Utilities-Elec and Utilities Other
    - Woodland
- The following uses were then used to select only parcels with a 'residential' use:
    - Commercial Apt
    - Miscellaneous
    - Mobile Home
    - Residential 1 and 2
    - Seasonal 1 and 2
- A town-wide average full real estate value by parcel was determined for all parcels as well as the 'residential' use parcels.
- Parcels were selected that contained either a private well or a public water source. The average full real estate value for these parcels was then determined for comparison to the town-wide average.

Results and Discussion

Results compare the town-wide average real estate value to the values of parcels selected as being in proximity to deicing materials storage facilities. For parcels containing private wells or public water sources, results can be seen in the maps which follow.

Note for public water sources – there were 51 public water sources in the Lake Champlain Basin within the buffers or catchments associated with deicing material storage facilities spread over 9 towns within the Basin. One town, Enosburgh, only had one selected residential use parcel and was left out of the analysis. That left only 8 towns with public water sources on residential use parcels for analysis. Those towns are Fairfax, Franklin, Leicester, Marshfield, Mendon, Middletown Springs, Morristown, and Warren.

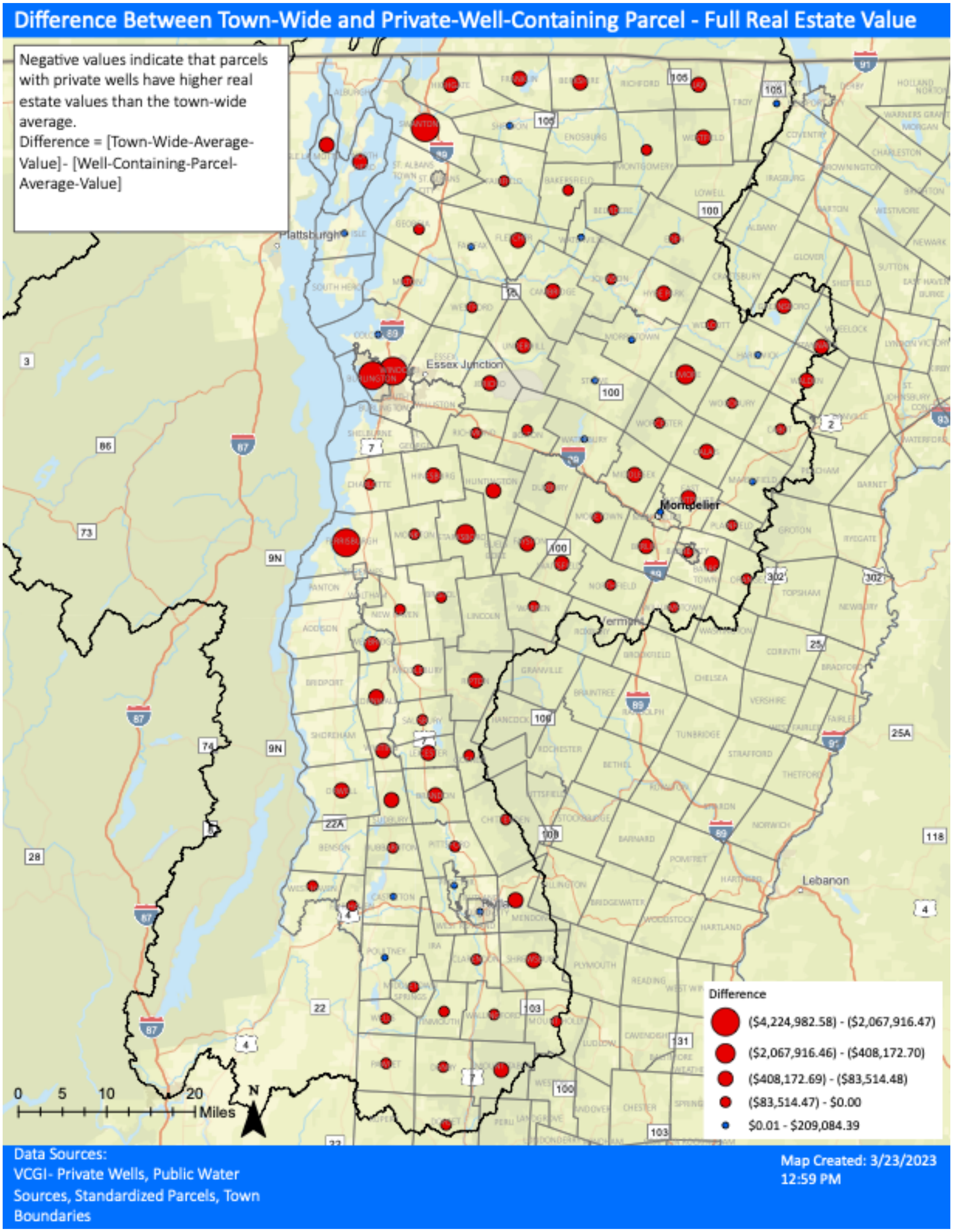

Figure 7: Difference Between Town-Wide and Private-Well-Containing Parcel - Full Real Estate Value. Negative values indicate that parcels with private wells have higher values than the town wide average.

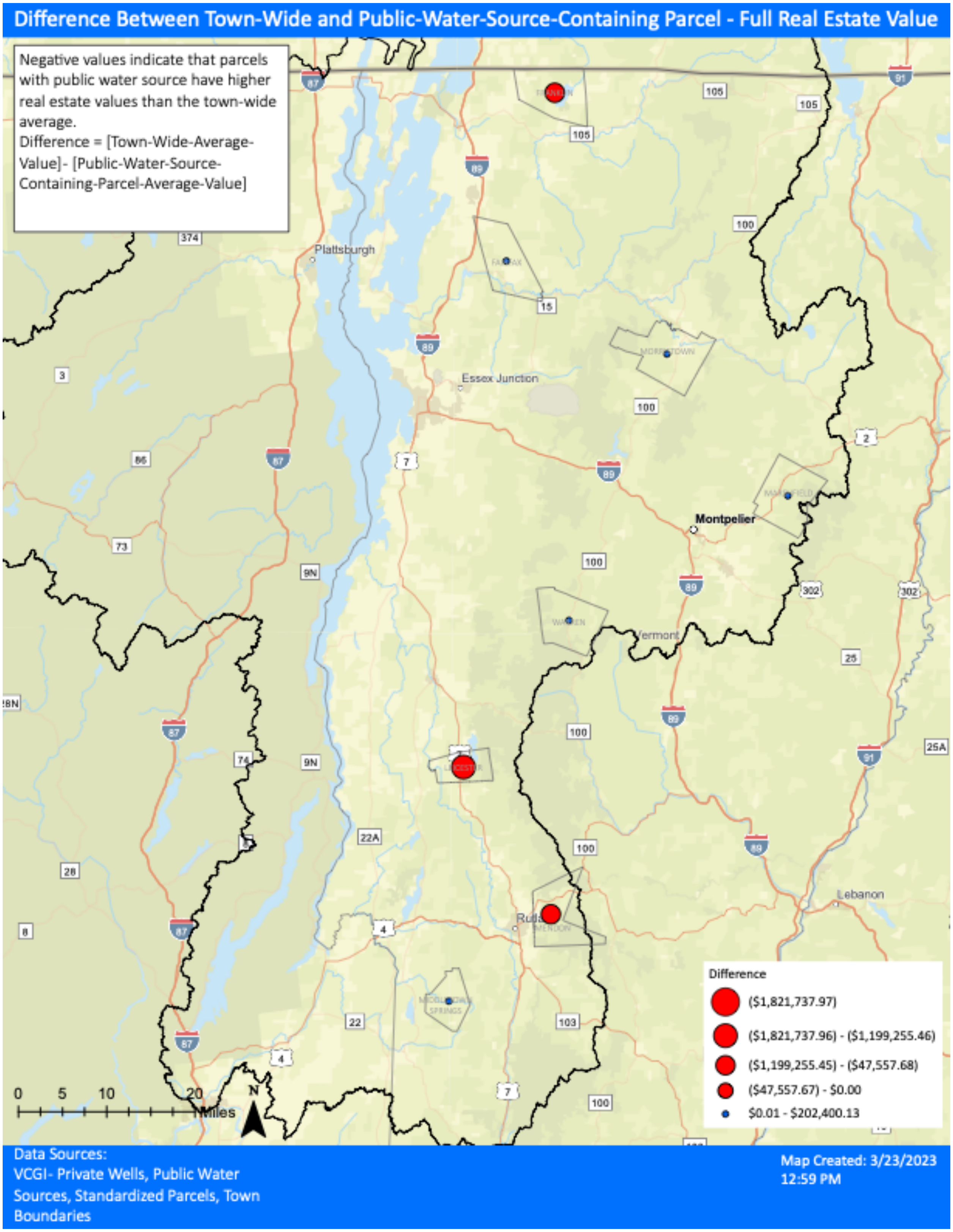

Figure 8: Difference Between Town-Wide and Public-Water-Source-Containing Parcel - Full Real Estate Value. Negative values indicate that parcels served by a public water source (n=8) have higher real estate values than the town-wide average.

Table 4: Average, Median, and Standard Deviation of Full Real Estate Value of the Difference between Town-Wide and Private Well or Public Water Source Containing Parcels for All Parcels and Residential Use Only Parcels.

		Private Wells Parcels Difference in Property Value Compared to Town Average	Public Sources Parcels Difference in Property Value Compared to Town Average
All Parcels	Average	($246,456.48)	($898,621.47)
	Median	($52,627.75)	($361,496.00)
	StDev	$872,179.32	$1,774,832.83
Residential Parcels	Average	($185,140.58)	($263,584.22)
	Median	($57,914.27)	$11,137.54
	StDev	$608,637.37	$682,417.66

A comparison was made between the average full real estate value of All Parcels (inclusive of non-residential uses like Commercial or Industrial uses) and Residential Parcels. The average full real estate value difference between parcels containing private wells or public water sources was smaller between Residential Parcels and the town-wide average full real estate value than for All Parcels and the town-wide average full real estate value. The negative values shown across the board indicate that the average full real estate value is higher in parcels containing either private wells or public water sources compared to town-wide averages. See Figures 9 and 10.

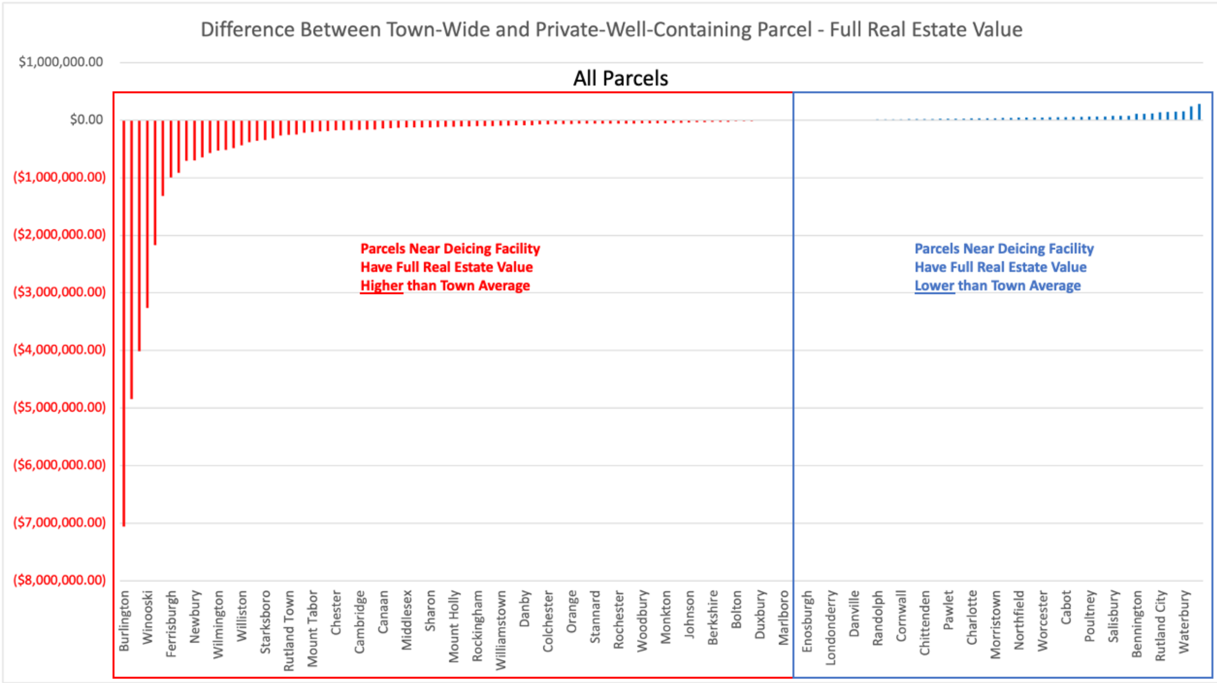

Figure 9: Town-Wide Full Real Estate Value Difference Between All Parcels (inclusive of non-residential uses) and Private-Well-Containing Parcels in proximity to Deicing Material Storage Facilities.

Figure 10: Town-Wide Full Real Estate Value Difference Between Residential Only parcels and Private-Well-Containing Parcels in proximity to Deicing Material Storage Facilities.

These results indicate, at least based on the full real estate value by parcel as recorded by town Grand List information, the properties with private wells or public water sources downgradient of deicing material storage facilities are not generally lower-value than the town-wide average. There are some towns in which the parcels in downgradient locations are of lower value than the town-wide average. Further investigation could be conducted into those specific instances.

Importantly, using property values at the parcel level as a proxy for socioeconomic risk status could be problematic for several reasons. First, this factor only accounts for property value and not income level. Second, parcels may contain multiple residential units with multiple households of differing socioeconomic status (e.g., an apartment building). Finally, residents of these parcels (or occupants/users in the case of non-residential sites) may not be the owners of the real estate itself, so the value of the parcel would not reflect the socioeconomic status of those drinking water there.

Appendix C – Municipal Facilities Maps

Municipal maps (122) of well locations with respect to deicing material facilities locations are included in a separate downloadable PDF, available here: https://www.uvm.edu/rsenr/vtwatercenter/publications