Construction and demolition

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Groundwater Impacts of Unlined Construction and Demolition Debris Landfilling

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Contents

Glossary and acronyms

As: Arsenic

B: Boron

CCA: Chromated Copper Arsenate. A common active ingredient in some treated lumber

CCR: Coal Combustion Residuals

C&D: Construction and demolition debris

CLP: Contract Laboratory Program at the United States Environmental Protection Agency

COCs: Contaminants of Concern. Analytes the MPCA evaluated in this report, which include Arsenic, Boron and Manganese.

CRQL: Contract Required Quantitation Limit. A limit set by the EPA CLP. For this report, the term Reporting Limit is considered an equivalent to a CRQL.

Data Validation Qualifiers: Observations flagged with a "J", "U", or "UJ" data validation qualifier.

- **U**: The substance or analyte was analyzed for, but no quantifiable concentration was found at or above the CRQL (CLP National Functional Guidelines for Data Review). (USEPA 1996, p.6)
- **J:** The analyte was positively identified-the associated numerical value is the approximate concentration of the analyte in the sample. The "J" qualifier indicates that one or more QA/QC requirements have not met contact required acceptance criteria but the instrumentation was functioning properly during the analysis. For example, a "J" qualifier may indicate that the sample was difficult to analyze or that the value may lay near the low end of the linear range of the instrument. "J" data are considered biased, but provide definitive analyte identification (CLP National Functional Guidelines for Data Review). (USEPA 1996, p.6)
- **UJ:** The analyte was not quantifiable at or above the CRQL. In addition to not being quantifiable, one or more QA/QC requirements have not met contract acceptance criteria (CLP Functional Guidelines for Data Review). (USEPA 1996, p.6)

DLGD: Demolition Landfill Guidance Document. 2005 guidance developed by the MPCA in consultation with stakeholders. Found at https://www.pca.state.mn.us/sites/default/files/w-sw5-04.pdf

Drinking Water Standard: Values determined by the MDH and the EPA. The value types used in this report include the HRL, RAA, HBV, and MCL.

- **HRL:** A Health Risk limit is the concentration of a groundwater contaminant, or a mixture of contaminants, that can be consumed with little or no risk to health and which has been promulgated under rule. (MDH HBWG)
- **RAA:** Risk Assessment Advice for water is a technical guidance concerning exposures and risks to human health. RAA may be quantitative (e.g., a concentration of a chemical that is likely to pose little of no health risk to humans) or qualitative (e.g., a written description of how toxic a chemical is in comparison to a similar chemical). Generally, RAA contains greater uncertainty than HRLs and HBVs because the information is more limited. Sometimes MDH derives guidance as RAA because new risk assessment methodology was applied to develop the value. (MDH HBV RAA)

HBV: Health Based Value is the concentration of a chemical (or a mixture of chemicals) that is likely to pose little or no risk to human health. HBVs are calculated using the methodology adopted in the Health Risk Limits Rules. HBVs meet the same data requirements as HRLs. HBVs have not been promulgated using the public process described by the Administrative Procedures Act (Minnesota Statutes Chapter 14). Instead, an HBV is technical guidance made available by MDH. These values may be used by the public, state and local risk managers, and other stakeholders to assist in evaluating potential health risks to humans from exposures to a chemical. If a chemical has been detected in water, MDH anticipates that HBVs for Minnesota's groundwater will become HRLs (i.e., be promulgated) at the time that MDH next amends the Health Risk Limits for Groundwater rule. (MDH HBV RAA)

MCL: Maximum Contaminant Levels are set by the United States Environmental Protection Agency and enforced by MDH. All public water supplies in Minnesota must meet these standards. MCLs are established through a scientific process that evaluates the health impacts of the contaminant and the technology and cost required for prevention, monitoring, and/or treatment. States are allowed to enforce lower (more strict) standards than MCLs, but are not allowed to enforce higher (less strict) standards. New MCLs or changes to existing MCLs are rarely made. (MDH GV)

EPA: United States Environmental Protection Agency

EQuIS: Environmental Quality Information System. Database developed by Earthsoft that stores environmental data submitted to and/or collected by the MPCA.

Exceedance: The concentration of a contaminant in a groundwater sample is greater than or equal to the IL or HT.

HT: Health Threshold. Broad term for the Drinking Water Standard set by the EPA or MDH.

IL: Intervention Limit. Limit for permitted Solid Waste Facilities that are required to monitor groundwater. The limit is 25% of the HT, unless alternative site specific values are developed based on elevated background concentrations.

ISWMP: Industrial Solid Waste Management Plan. Describes which industrial solid wastes will be accepted at the facility and how a facility will manage will manage them.

MDL: Method Detection Limit. The minimum measured concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results. (USEPA, 2016)

Minn. R.: Minnesota Rules

Mn: Manganese

MPCA: Minnesota Pollution Control Agency

MDH: Minnesota Department of Health

MSW Landfill: Mixed Municipal Solid Waste Landfill accepts household, business, and industrial solid waste in lined cells.

Observations:

Censored Observation: "Low level concentrations of organic or inorganic chemicals with values known to be only to be somewhere between zero and the laboratory's detection/reporting limits. The chemical signal on the measuring instrument is small in relation to the process noise. Measurements are considered too imprecise to report as a single number, so the value is commonly reported as being less than an analytical threshold, for example, "<1". (Hensel, p. 1)

Measured Observation: Single numerical values reported above the RL.

Qualified Observation: Single numerical values associated with a data validation qualifier by the laboratory that performed the analysis, where the numerical values are below the RL.

Oxidation-Reduction (Redox): A chemical reaction where the participating atoms change their valence state by gaining or losing an electron.

RL: Reporting Limit. Quantification limit where all values reported above this threshold are reliable single numerical values, and whereas values reported below this threshold are a Censored Observation, unless they are flagged with a Data Validation Qualifier.

Sampling Event: Groundwater quality samples collected at a facility during the same month for that calendar year.

SAP: Sampling and Analysis Plan. A plan proposed by a facility operator for approval by the MPCA. A SAP provides detail on sampling procedures, parameters, sampling frequency, analytical method, and groundwater performance criteria.

Self-Reported: Data supplied to the MPCA gathered by the facility operator.

Solid Waste Activity: The storage, processing, transfer, utilization, treatment, or disposal of solid waste and waste by-products.

Solid Waste Facility: A facility used to dispose of solid waste in or on the land.

TEMPO: MPCA database, used agency-wide to store data thereby standardizing business functions including compliance, enforcement and permitting.

Executive summary

This report is based upon self-reported data from unlined construction and demolition (C&D) landfills. The Minnesota Pollution Control Agency (MPCA) prepared this report to help inform policy discussions and possible C&D landfill rule amendments. The Request for Comments for those amendments was published on October 1, 2018 (MPCA, 2018, p. 417).

The groundwater-monitoring data on which this report is based is from wells installed in accordance with a 2005 guidance document drafted by the MPCA in consultation with C&D landfill operators ("Demolition Landfill Guidance Document" (DLGD) (MPCA, 2005). The 2005 DGLD did not change Minnesota rules or statutes; rather it established best practices based on what was then known about possible risks to groundwater. The DGLD was intended, in part, to provide data on possible effects of unlined C&D landfills on groundwater quality. Following the guidance, over time, most C&D landfills installed at least one upgradient and two downgradient groundwater-monitoring wells.

This report contains conclusions based on the analysis of self-reported data from 43 C&D landfills with adequate groundwater monitoring, spanning eight calendar years from 2010 through 2017. Three contaminants of concern (COCs) were closely evaluated for the study: Arsenic, (As), Boron (B) and Manganese (Mn). As of 2014 these COCs, and in some cases other contaminants, were being commonly detected above intervention limits (ILs) and health thresholds (HT). The data from each of the 43 C&D landfills used for this study is located here: https://www.pca.state.mn.us/waste/construction-and-demolition-landfills-groundwater

The overall design of unlined C&D landfills does not prevent the leachate from impacting the underlying aquifer. The migration of leachate into the groundwater not only introduces contamination from buried waste. In addition, through the process of oxidation-reduction reactions, it can create an environment in the groundwater that mobilizes previously stable contaminants.

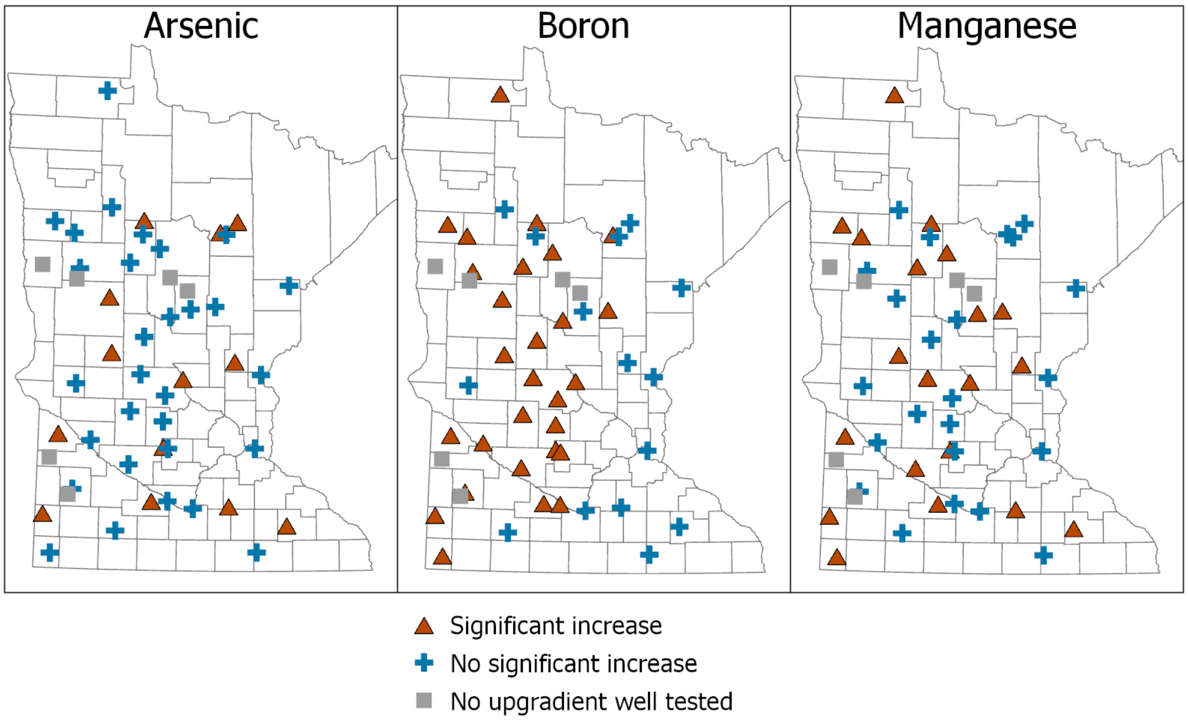
The methods and statistical basis for the results of this report are provided throughout. Overall, conclusions of the groundwater data analysis can be summarized as such:

- There is a statistically significant impact to groundwater from unlined C&D landfilling. Of the 43 landfills, 33 showed a significantly higher concentration for at least one of the three COCs (As, B, Mn) in groundwater that was downgradient of the landfill as compared to upgradient groundwater (Appendix A, Table 2). Further, occurrences of significantly higher concentrations of As, B, and Mn are not confined to particular regions of the state. Instead, they are a statewide challenge.
- **Exceedances of the contaminants of concern are above ILs and HTs.** Of the 43 C&D landfills evaluated for exceedances, 32 (74%) observed an exceedance of the IL for one or more of the COCs on at least one occasion, while 28 of them (65%) also showed an exceedance of the HT (Appendix A, Table 1).
- **Concentration trends show no evidence of improvements to groundwater.** At the 33 C&D landfills that showed a significantly higher concentration in a contaminant of concern in groundwater downgradient versus upgradient, the MPCA examined the results at individual downgradient wells for trends of the contaminants from 2010 through 2017 (Appendix A, Table 3). Eighty-four percent of the trends showed no significant statistical increase or decrease. Of those trends that did show statistical significance, there was no C&D landfill that only showed decreasing trends for the COCs.

It is important to note that while confirmed exceedances above ILs and HTs at a permitted landfill trigger a regulatory response, the issue of what to do depends on site-specific circumstances.

Additionally, another finding is that even C&D landfills attempting to accept only construction and demolition debris, as listed in the 2005 DLGD, have contaminated the groundwater to above ILs and HTs. A prime example is dissolved Boron, which measured typically low in upgradient wells and elevated in downgradient wells. Likely sources of Boron are discarded drywall and concrete, and in particular, those materials that beneficially reused coal-combustion fly ash as a replacement for Portland cement.

Figure 1. Displays the geographical distribution of C&D landfills where there was a significantly higher concentration downgradient of a contaminant. If no increase was found, they are represented in blue.



Since August 2005, there have been six construction and demolition debris disposal areas that are expansions or new areas capable of being monitored separately from other waste management or prior C&D landfills. This sub-population of landfills warranted a special assessment as they were to be operated entirely under the recommended screening procedures of the DLGD for all waste disposed at the disposal areas. Of the six C&D landfills in this sub-group, two were not included in the report. One was due to the landfill having a liner and leachate collection system installed and the other has yet to landfill any construction and demolition debris. Of the remaining four post-2005 C&D landfills, three (75%) have observed exceedances of both the IL and the HT for one or more of the COCs. This sub-population does contain the only landfill to report no exceedances of the IL for any of the COCs.

Background

Groundwater and solid waste regulation

Groundwater is subsurface water in the saturated zone. Aquifers are water-bearing units capable of providing quantities of groundwater sufficient for extraction and use. Aquifers can be unconsolidated deposits such as sand or gravel or can be bedrock units.

Groundwater is a valuable natural resource used for drinking water for large municipalities and single homeowners. In Minnesota groundwater supplies 75% of the state's drinking water and 90% of water used for agricultural irrigation. Groundwater resources are especially valuable in rural Minnesota where either the infrastructure is not available to provide drinking water to a residential location or for communities that do not have safe sources of surface water to use as sources of drinking water. Private well owners are responsible for testing their drinking water, unlike municipal drinking water systems.

In the Groundwater Protection Act of 1989 (Minnesota Session Laws 1989, Chapter 326), Minnesota set this policy: "It is the goal of the state that groundwater be maintained in its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities this degradation prevention goal cannot be practicably achieved. However, where prevention is practicable, it is intended that it be achieved. Where it is not currently practicable, the development of methods and technology that will make prevention practicable is encouraged." (Minn. Stat sec. 103H.001).

Minn. Stat. § 115.03, subd. 1 was the basis of the statutory authority to promulgate general technical requirements within the context of Minn. R. 7035.2525 to 7035.2655 for all solid waste facilities in Minnesota. Minn. R. 7035.2565 "Groundwater Quality, Surface Water Quality, and Air Quality and Soil Protection" specifically establishes performance criteria that all solid waste facilities must maintain, including C&D landfills, to ensure solid waste facilities are designed and operated to prevent releases to and protect our groundwater resources.

> Minn. R. 7035.2565 GROUNDWATER QUALITY, SURFACE WATER QUALITY
>
> Subpart 1: **Duty to protect water**: Solid waste management facilities must be located designed, constructed, and operated to contain sediment, solid waste, and leachate and to prevent pollution of groundwater and surface water. The owner or operator must take corrective action as necessary to end continuing releases and to minimize or abate any resulting groundwater or surface water pollution. As required by Minn. R. 7050.0150 and 7060.0600, the owner or operator must monitor the facility, surface water, and groundwater as directed by the agency.
>
> Subpart 2**: Designation of compliance boundaries, standards, intervention limits.** The commissioner shall designate compliance boundaries, standard, and intervention limits for mixed municipal solid waste land disposal facilities in the permit, order, or stipulation agreement, as required in Minn. R. 7035.2815, subp 4. The commissioner shall designate compliance boundaries, standards, and intervention limits for other solid waste facilities, including demolition debris land disposal facilities, and compost facilities, if a release could pollute or degrade groundwater or surface water.

As part of the duty to protect public waters, C&D landfill operators with groundwater-monitoring wells are to sample and keep records of groundwater quality inside their permit boundaries. During the duration of a permit, or at the time of renewal, the MPCA may request operators to extend testing to samples drawn from drinking-water wells outside of that perimeter, if justified by groundwater flow and contaminant concentrations. Results are sent to the Minnesota Department of Health (MDH). To date the MDH has sent well advisories to property owners with private wells near three C&D landfills:

- SW-318 (two residences)
- SW-412 (one business)
- SW-556 (three residences and one business)

At those neighboring properties, tests in recent years have shown that their wells' drinking water is not safe for consumption by bottle-fed infants due to elevated concentrations of Boron and/or Manganese. Further, one of those wells (near SW-318) is not approved for use by adults under the EPA's Lifetime Health Advisory, due to Manganese. Residences with well advisories are receiving alternative supplies either from bottled water or a treatment system. Testing will continue at least once per year.

What do permit applications need for MPCA review?

The MPCA's Solid Waste Permitting Program uses primarily Minn. R. chs. 7001 and 7035 when reviewing applications and writing permits. Minn. R. 7001 details what the permit application must contain for MPCA review. Minn. R. 7001.0010 thru 7001.0210 are general requirements that apply to all agency permits. Minn. R. 7001.3000 thru 7001.3550 are specific to solid waste facilities. These requirements detail what activities require a permit and what information must be included in an application. A complete permit application must be submitted to the MPCA for review prior to issuance or reissuance of a solid waste permit. The application must include several plans that detail every aspect of the facility design, operations and maintenance, and monitoring. MPCA staff review the application for completeness and technical adequacy.

Minn. R. 7035.2525 thru 7035.2655 detail technical requirements for all solid waste facilities except industrial waste disposal facilities. Minn. R. 7035.2815 thru 7035.2915 detail more specific requirements based on the specific waste management activity-taking place.

Minn. R. 7035.2825 is specific to C&D landfills, and set a performance goal of protecting health and the environment without listing detailed requirements, such as for mixed municipal solid waste (MSW) landfills.

Difficulties of original C&D landfills rule approach

From the outset, the biggest shortcoming of the original rule's approach for unlined C&D landfills was that owner or operators were required to design a monitoring system based on the need (Minn. R. 7035.2825, 8. G.) by which the performance standards could be evaluated and enforced. It was assumed that construction and demolition debris in unlined landfills was innocuous and also assumed that operators would keep the unacceptable materials out of the landfill's working face, therefore there was no need for a monitoring system. That is, the operators were to protect the environment, including the public's groundwater flowing underneath, but there was largely no monitoring to ensure operators were meeting that obligation.

In 2005, out of concern that more information was needed, a panel of MPCA, local government, and private-sector participants developed the DLGD. The intent was to promote consistency and predictability in how the MPCA and C&D landfill owners/operators would operate and monitor them in Minnesota. It did not prohibit existing or new C&D landfills from relying on an unlined design. The Demolition Landfill Guidance document contains more detail such as the complete list of parameters to be analyzed from samples.

What does the Demolition Landfill Guidance Document cover?

The DLGD provides guidance on siting of C&D landfills, developing initial site evaluation, determining classification, establishing an acceptable waste list, waste-screening, content of an Industrial Solid Waste Management Plan (ISWMP), groundwater monitoring, and when liners and leachate collection is needed. The nature of the site and types of waste planned for acceptance were drivers of what class of protection would be appropriate.

The DLGD also outlines how and when groundwater-monitoring networks would be established at demolition landfills. If unlined C&D landfills did not qualify for exemptions, the operator would need to install a groundwater-monitoring network before the next permit renewal. Incorporating groundwater-monitoring requirements into a permit allowed operators up to five years to plan for installation. This time was useful because adding monitoring networks at existing unlined C&D landfills did add costs and posed other challenges, such as finding spots suitable for piezometers and monitoring wells.

In order to evaluate the data, the owner/operator developed a sampling and analysis plan (SAP) for MPCA approval. It detailed sampling procedures, parameters, sampling frequency, analytical method, and groundwater performance criteria. The performance criteria are based on health standards. The MPCA uses ILs to determine if a landfill is impacting groundwater enough to require corrective action. Unless proposed otherwise by the operator and accepted by the MPCA, the ILs are one quarter of the health standard developed by the Minnesota Department of Health (MDH) and/or the U.S. Environmental Protection Agency (EPA). The reason for setting ILs at a quarter of the health threshold is to serve as a preventive measure, alerting the MPCA and operators that contamination of the public's groundwater appears to be occurring. Otherwise, attention would not be given to the situation until the problem was too late to remedy.

The MPCA has developed standard permit requirements based on the rules and standard industry practices. Based on rules and the 2005 DLGD, permit requirements were drafted and in some cases modified on a case-by-case basis given site-specific conditions. The permittee reviewed the MPCA's draft and the final draft was placed on public notice for a period of 30 days, for possible amendment given those comments.

In accordance with Minn. R. 7035.2585, all solid waste facilities are required to submit an annual facility report. Facilities with groundwater monitoring are also required to submit an annual groundwater report summarizing the quarterly monitoring data collected and providing groundwater contour maps of each sampling event. All analytical groundwater data are also submitted to the MPCA electronically, via EQuIS.

MPCA compliance staff visit permitted landfills at least once per calendar year to determine compliance with operational requirements. When non-compliance is reported, the facility must implement an approved contingency action plan to correct the issue.

Groundwater quality monitoring at unlined C&D landfills

After development of the 2005 DLGD, unlined C&D landfills began phasing in the installation of groundwater quality monitoring networks at the time of their subsequent solid waste permit reissuance. The evaluation process for requiring groundwater quality monitoring and the criteria for installation of a groundwater quality monitoring network is on page 7 of the DLGD.

The most effective monitoring network is one based strictly on waste placement geometry following a complete review of local hydrogeological conditions. This is much easier to arrange at new landfills compared to landfills that have been operating for years. Limitations encountered when applying the DLGD criteria for installation of a groundwater quality monitoring network to pre-existing C&D landfills include the following:

- Pre-existing waste in place prior to the installation of a groundwater quality monitoring network creates challenges in putting groundwater-monitoring wells in the proper location. While it is desirable to know the hydrogeology under the existing waste mass, it is difficult to bore through waste. In practice, investigation-soil borings usually end up on the borders of the existing waste mass. Since the conditions under the waste are unknown, this introduces a large blind spot in determining the hydrogeological conditions at the facility.

- Minn. R. 7035.2825 subp. 4 Item E requires a minimum separation distance of 50 feet between the fill boundary and the property line. In order to maximize the airspace available to the landfill, some of the C&D landfills were designed to maximize the available footprint, and therefore had only the minimum separation distance. This limited the available area outside of the waste mass for hydrogeological investigation, site characterization, and the installation of a groundwater-monitoring network.

Structures (e.g. roads, buildings, trees) and other permitted solid waste activities often prevented or restricted soil boring investigations and proper placement of permanent groundwater-monitoring wells.

MPCA hydrologists worked with each C&D landfill when permitting the groundwater quality monitoring network in attempting to get a workable design. Some landfills established only the minimal groundwater quality monitoring network as outlined in the DLGD: one well upgradient and two wells installed downgradient of the C&D landfill.

Availability of groundwater quality data from unlined C&D landfill

Permitted solid waste facilities required to monitor groundwater quality must collect water samples from monitoring wells specified in their solid waste permit. The facilities submit analytical data to the MPCA according to the schedule stated in their solid waste permit and use those data in producing their annual monitoring report. The sampling schedules vary from once annually to three times a year (spring, fall, and summer) for a given monitoring well. These are referred to as sampling events. This means multiple samples are taken each year from a given monitoring well. Not all monitoring wells at a site will be included in a sampling event according to their permitted sampling schedule. That is, there are months when samples are taken from a downgradient well, but not from the upgradient well.

The groundwater sampling procedures and methods used for lab analysis are detailed in each permitted facility's SAP, which is on file with the MPCA. Groundwater samples are compiled from multiple self-collected sources however, the sample collection methods and lab methods are similar enough for comparative analysis in this report. All labs used for analyses must be certified by the MDH.

Groundwater quality data used for this report came from self-reported sampling events at unlined C&D landfills, collected from the eight-year span of 2010 through 2017, inclusive. The reason for the start year of 2010 was that, while the groundwater-monitoring initiative for unlined C&D landfills originated with the DLGD in 2005, the installation of networks happened later. It was tied to the next permit issuance, so it was not until 2010 that enough unlined landfills had their permits reissued using the groundwater-monitoring criteria recommended in the DLGD. The reason for the end date of 2017 was those data from calendar 2018 were not complete and verified while MPCA staff were working on the report.

The facilities are required by permit to submit all groundwater quality data to the MPCA electronically (in the LAB_MN format), which is stored in EQuIS, the MPCA database. Electronic data are primarily submitted to the MPCA from the laboratory that performed the analysis on behalf of the landfill.

However, not all C&D landfills have been submitting data electronically to the EQuIS database. For those landfills, MPCA staff obtained the values from the permit-required hard copy submittals of Quarterly Groundwater and Annual Groundwater Reports. These data, numbering in the thousands for the three COCs, had to be transcribed from these submittals and compiled along with the EQuIS data to generate the data set used for the evaluation for this report. The compiled data set can be found and downloaded for further analysis at https://www.pca.state.mn.us/waste/construction-and-demolition-landfills-groundwater.

Contaminants of concern – Arsenic, Boron and Manganese

As unlined C&D landfill operators began sampling their groundwater-monitoring networks, owners and operators hired professional consultants to collect, compile, and review groundwater data for submittal to the MPCA. Annual monitoring reports submitted included a discussion of analytes detected in groundwater, a comparison of analyte concentrations in downgradient and upgradient wells, a comparison of concentrations with drinking water standards and intervention limits, and temporal trends in concentration over time. Annual reports included conclusions and recommendations for the next year of monitoring.

As MPCA, staff began reviewing these reports and looking for patterns through 2014, it became evident that concentrations of various analytes exceeded ILs, and in some cases, HTs. MPCA staff observed this pattern statewide. MPCA staff were interested in whether the "acceptable" construction and demolition debris, as listed in the DLGD, might be responsible for these exceedances. Therefore, the MPCA began looking for common denominators in the nature of contamination that was occurring above ILs at unlined C&D landfills statewide. If a vast majority of the waste type being disposed of at any C&D landfill is the same, then the nature of groundwater contamination being caused should be the same or very similar. The purpose was to identify parameters that could serve as key indicators to determine if the acceptable waste types being disposed at all unlined C&D landfills were causing groundwater impacts above ILs.

In taking this approach while examining the groundwater data being reported by unlined landfills, the MPCA identified three contaminants of concern commonly detected above ILs, and in some cases above HTs. These three contaminants of concern were Arsenic, Boron and Manganese.

Arsenic has a drinking water standard of 10 µg/L, a maximum contaminant level (MCL) set by the EPA (USEPA, 2001) While Boron has a guidance value of 500 µg/L (MDH, 2017), it is a risk assessment advice (RAA) guidance value designed to be protective of formula-fed infants. (MDH, 2017a) Manganese has been updated to a health based value (HBV) by the MDH based on safe levels for formula-fed infants. (MDH, 2018a) Table 1 provides the ILs and HT for the contaminants of concern.

As previously discussed, the Solid Waste intervention limit is one quarter of the drinking water standards developed by the MDH and the EPA, and serves as an alert that closer attention to groundwater contamination trends are warranted. Collectively, those standards are referred to as Health Thresholds throughout this report.

Table 1. The 2019 Intervention limits (IL) and health thresholds (HT) for the contaminants of concern associated with construction and demolition debris

Contaminate	IL (µg/L)	HT (µg/L)
Arsenic	2.5	10
Boron	125	500
Manganese	25	100

Methods

Groundwater-monitoring well identification

To maintain consistency in facility selection for this report, solid waste hydrologists and engineers conducted a desktop of review of the available self-submitted hydrogeological information. Static water table elevations are required to be collected from each well for each sampling event, and each facility is required annually to submit groundwater contour maps to the MPCA for each sampling event. These groundwater contour maps were used when available; otherwise MPCA relied on the static water table elevation measurements. The MPCA's primary focus was on relative monitoring well locations to solid waste activities on the property. Groundwater-monitoring wells were classified as either upgradient, downgradient, or sidegradient for the purposes of this report. Monitoring wells classified as upgradient measure groundwater quality with no impacts directly attributed to the unlined disposal of construction and demolition debris area being evaluated. Upgradient wells are also known as background wells, and are hydraulically upgradient from the facility.

Monitoring wells classified as downgradient have been considered to be measuring groundwater quality data that has a high potential of being impacted only by the disposal of construction and demolition debris. Monitoring wells classified as sidegradient for this report do not fit the definitions of either an upgradient well or a downgradient well. However, some sidegradient wells may be downgradient intermittently due to fluctuations in groundwater flow direction. The MPCA included these sidegradient wells to provide a complete groundwater quality profile for the C&D landfill. When determining whether a landfill has measured exceedances, sidegradient monitoring wells were not included in that assessment.

While the DLGD states that the minimum monitoring network for a C&D landfill is composed of three wells, as long as there were wells installed to determine upgradient and downgradient groundwater quality directly from the unlined disposal of construction and demolition debris, the MPCA included the landfill.

Identifying relevant facilities for this report

The focus of this report is groundwater impacts associated with unlined landfilling of construction and demolition debris. This primarily includes solid waste facilities that only landfill construction and demolition debris and that have groundwater monitoring. It also includes unlined areas that have been used for the disposal of construction and demolition debris as part of a larger solid waste complex where groundwater monitoring is for the entire facility, rather than for a single solid waste activity.

The below criteria describes how solid waste facilities were selected for evaluation. The 49 unlined C&D landfills that remain after applying all six criteria are considered to be unlined construction and demolition disposal areas that have groundwater-monitoring wells installed and that, if sampled, are capable of detecting potential impacts from the disposal of construction and demolition debris.

In particular, five C&D landfills that have multiple solid waste activities provided this challenge: while the groundwater-monitoring networks were sufficient for determining permit compliance for the overall solid waste facility, the groundwater quality data measured in the wells could not be attributed directly to unlined landfilling of construction and demolition debris. Therefore, the MPCA omitted those from this report before arriving at the list of relevant unlined C&D landfills.

The list of solid waste facilities that were considered and an explanation of why they did not meet all the criteria for suitability can be found at https://www.pca.state.mn.us/waste/construction-and-demolition-landfills-groundwater. The following criteria defines solid waste facility relevance for this report:

1. **MPCA permitted land disposal (419 solid waste facilities meet criteria)**

   There are 419 facilities that the MPCA tracks in TEMPO. This consists of 172 permitted solid waste facilities, 199 permit-by-rule C&D landfills, and 48 general concrete burial sites.

2. **Permit defines construction and demolition debris area (378 solid waste facilities meet criteria)**

   The 41 facilities omitted due to this criteria do not have separate areas designated specifically for construction and demolition debris land disposal. At these, construction and demolition debris is landfilled along with industrial or mixed-municipal solid waste, or the facility does not accept any construction and demolition debris for disposal.

3. **Permitted area only received construction and demolition debris (336 solid waste facilities meet criteria)**

   The 42 facilities omitted due to this criteria have dedicated unlined construction and demolition debris disposal areas that contain wastes other than construction and demolition debris or MPCA staff cannot confirm that only construction and demolition debris was landfilled. These facilities were identified either by the approved waste types accepted in their ISWMP or they have a compliance history of landfilling unacceptable waste.

4. **Permitted area lacks a liner and leachate collection system (335 solid waste facilities meet criteria)**

   At the time of this report, SW-629 is the only lined C&D landfill that has a liner and leachate collection.

5. **Permitted area has groundwater-monitoring wells installed (67 solid waste facilities meet criteria)**

   The 268 facilities that are omitted due to this criteria do not have a groundwater-monitoring network installed. All 48 general concrete burial sites, all 199 permit-by-rule C&D landfills, and 21 C&D landfills did not have a groundwater-monitoring network installed.

6. **Groundwater-monitoring network is adequate to determine impacts from the permitted unlined construction and demolition debris area (49 solid waste facilities meet this criteria)**

   Eighteen facilities were omitted due to this criteria, leaving 49 as suitable for this report. There were four general reasons for omission:

   - The groundwater-monitoring network was determined to be inadequate for determining impacts from the unlined demo debris disposal area (11 facilities)
   - A groundwater-monitoring network has been installed, but the facility collected no groundwater quality data (1 facility)
   - There is ongoing groundwater investigation to determine the source of contamination at the facility (1 facility)
   - Unable to distinguish impacts measured in the wells from other solid waste activities (5 facilities)

Censored and non-censored results

Contaminant concentrations that are less than the Reporting Limit (RL) and greater than the Method Detection Limit (MDL) indicate that the contaminant is present in the sample. The result was reported to the MPCA as either a censored observation or a qualified observation. Where the MPCA has censored observations, the result is flagged to indicate that it is censored and the reporting limit is recorded.

For qualified observations (results flagged with a "J", "U", or "UJ" data validation qualifier) the numerical value reported was used as the result, rather than the associated RL. If the contaminant concentration is greater than or equal to the RL, the sample result is considered to be a measured observation and the reported numerical result was used. Table 2 indicates the level of censoring for each contaminant across both up and downgradient wells. If an observation is classified as non-censored, then it is either a measured value or a qualified value.

Table 2. Censored observations by contaminant for sampling events collected between 2010 and through 2017 for upgradient and downgradient wells

Contaminant	Censored observations	Non-censored observations	Percent censored
Arsenic	1176	731	62%
Boron	947	1294	42%
Manganese	576	1457	28%

As shown in Table 2, Arsenic is a highly censored contaminant at a rate of 62% of the sampled values meaning that less than 40% of the values provided were measured/qualified. When data are highly censored it often invalidates the use of standard statistical methods (i.e. parametric approaches like the two-sample t-test) or if not handled appropriately or disregarded they can heavily bias results.

If the reporting limit that a laboratory uses is higher than the IL or HT, then it is not possible to determine if the result has exceeded, but the value can still be used to evaluate whether a facility has a statistically higher concentration downgradient as compared to the upgradient levels. Table 3 below provides the percent of censored results by contaminant that cannot indicate an exceedance of the IL.

Table 3. Ability of censored observations to be able to detect an exceedance of the IL

Contaminant	Number of observations unable to detect exceedance of IL	Number of observations able to detect exceedance of IL	Percent of censored data unable to detect exceedance of IL
Arsenic	228	948	19%
Boron	252	695	27%
Manganese	6	570	1%

Determination of exceedance

As identified previously, permitted solid waste facilities are required to submit analytical results of their groundwater monitoring based on the frequency described in their permit. For C&D landfills selected to be included in this report, MPCA used these self-reported data to assess whether or not there is an effect of the landfill on the groundwater. When determining the correct method to evaluate the effect, the following were considered:

- **Censoring:** If concentrations of a given contaminant are below the RL, then it will result in a left-censored result (i.e. all that is known is that the concentration is lower than the RL).
- **Multiple RLs:** Since this report looks at data from 2010 through 2017, it is very likely that a single C&D landfill may have taken samples to multiple labs or test methods improve at a single lab resulting in more than one RL for a given contaminant.
- **Small and/or unbalanced sample sizes:** If a C&D landfill follows the DLGD for the minimum number of wells(one upgradient well and two downgradient wells), then there will be twice as many downgradient samples as upgradient samples and possibly as few as eight samples taken upgradient (assuming one sampling event per year from 2010 through 2017).

Environmental data of this type lends itself well to utilizing nonparametric methods or distribution-free methods for determining if there is a statistical difference. Nonparametric methods use the relative positions or quantiles of the data to determine differences versus the measured values or assumptions regarding the underlying distribution of the population.

The analysis for a C&D landfill can be broken down into the following parts:

1. Is there a significantly higher concentration downgradient in a given contaminant as compared to upgradient?
2. If there is a significantly higher concentration downgradient, are any of the downgradient results higher than the IL/HT?
3. If there is a significantly higher concentration for a contaminant downgradient, what is the trend of concentration over time for individually sampled wells? Is the trend decreasing, increasing, or flat?

Statistical significance

The MPCA grouped all groundwater quality data from wells classified as downgradient and compared them against all groundwater quality data from wells classified as upgradient for each C&D landfill and contaminant individually using the Peto-Prentice Generalized Wilcoxon. (Helsel, 2012) The MPCA is assuming that downgradient samples are independent of upgradient samples and while there may be well-to-well differences, it will likely be overshadowed by any true impact to the groundwater from the C&D landfill. Below is a description of the directional hypothesis test performed for each landfill and contaminant:

H_0: Downgradient concentration is less than or equal to upgradient concentration

H_A: Downgradient concentration is greater than upgradient concentration

The Peto-Prentice Generalized Wilcoxon is a special case of the general class of weighted log-rank tests which are nonparametric score tests used to determine whether the distribution functions differ between groups. The Peto-Prentice test is more appropriate than other members of this class if there are deviations from assumption of proportional hazards and the Peto-Prentice test statistic has a chi-squared distribution with one degree of freedom when the null hypothesis is true. (Collett, 2003)

A test result will be considered statistically significant if the p-value for the one-sided test is less than 0.05. The NADA package in the statistical software R was used to perform this analysis, which defaults to a two-sided test so all reported p-values are the two-sided values divided by 2 and only considered significant if the Upgradient Observed is greater than Upgradient Expected (i.e. there are fewer actual instances where upgradient is higher than downgradient than expected if all other things were equal).

Downgradient comparison to thresholds (IL/HT)

Downgradient samples were evaluated against the IL/HT for C&D landfills where there was a significantly higher concentration downgradient for one or more of the contaminants of concern. For each contaminant identified, the MPCA compared each sampled value to the IL and HT for the downgradient wells and tallied the number of exceedances (if any).

Trend analysis

In order to assess trends over time for those contaminants that showed significantly higher concentrations downgradient, the Kendall tau test for correlation and the Akritas-Theil-Sein slope estimator were used. (Helsel, 2012) Trends could only be assessed at individual wells in order to control for variation in groundwater flow at the C&D landfill. So for a given contaminant, each individual downgradient well at the landfill was evaluated. If most of the data for a well were censored or if there were extremely small sample sizes, a trend at that well could not be assessed.

Results

Summary of findings

The statistical basis for the three primary conclusions below are provided in the sections following.

- **Groundwater changes from upgradient to downgradient wells**: Of the 49 C&D landfills that were included in this report, 43 had upgradient groundwater quality data for comparison from 2010 through 2017 and are evaluated for exceedances.
    - Of the 43 landfills, 33 showed a significantly higher concentration for at least one of the three COCs in groundwater that was downgradient of the landfill as compared to upgradient groundwater (Appendix A, Table 2).
    - The results from the rigorous statistical analysis gives confidence that these higher concentrations are not due to random variations in the groundwater and are the product of leachate from the unlined facilities.
- **Exceedances of ILs and HTs:** Of the 43 C&D landfills evaluated for exceedances, 32 (74%) observed an exceedance of the IL for one or more of the contaminants of concern on at least one occasion, while 28 of the landfills (65%) also showed an exceedance of the HT (Appendix A, Table 1).
    - Of those C&D landfills that showed a significantly higher concentration in groundwater downgradient as compared to upgradient, only one C&D landfill, SW-17, showed no exceedances of the IL for any of the contaminants of concern.
- **Concentration trends for contaminants showing higher concentrations downgradient**: At the 33 C&D landfills that showed a significantly higher concentration in groundwater downgradient versus upgradient for at least one contaminant of concern, the MPCA examined the results at individual downgradient wells for trends in the concentrations of the contaminants from 2010 through 2017 (Appendix A, Table 3).
    - Thirty-seven well-contaminant combinations could not be evaluated for statistical significance with respect to trend analysis.
        - Seventeen well-contaminant combinations had groundwater quality results comprised completely of censored data and thus could not be evaluated.
        - Twenty well-contaminant combinations could not be evaluated due to a combination of lack of distinct values, small sample sizes, and higher percentage of censored data compared to measured data in the results.
    - Of the 188 trends that could be evaluated at individual wells, 157 (84%) of the trends showed no significant statistical increase or decrease. Of those trends that did show statistical significance, 14 trends (7%) were decreasing and 17 trends (9%) were increasing.
- **Statewide scope:** Overall, occurrences of significantly higher concentrations of As, B, and Mn are not confined to particular regions of Minnesota but are a statewide challenge.

C&D landfill impacts on groundwater

Of the 49 C&D landfills selected for this report, six (12%) landfills did not test upgradient wells during the 2010-2017 period. These six landfills were omitted from the MPCA's effort to determine exceedances due to the inability to compare background groundwater quality to water quality downgradient of the landfill. The remaining 43 C&D landfills have sampling events for both upgradient and downgradient wells.

Of the 43 C&D landfills that could be evaluated, 33 demonstrated a significantly higher concentration downgradient of the landfill as compared to the background levels for at least one of the contaminants of concern (Appendix A, Table 2).

Table 4. Count of C&D landfills showing significantly higher concentrations downgradient vs upgradient for each contaminant. Results are based off the Peto-Prentice Generalized Wilcoxon test.

Outcome of the Peto-Prentice generalized Wilcoxon	Contaminant		
	Arsenic	Boron	Manganese
Number of facilities showing significantly higher concentrations downgradient	13	28	20
Number of facilities showing no significantly higher concentrations downgradient	40	15	23

Exceedance of thresholds (IL/HT)

As shown in Table 5, of the 43 C&D landfills evaluated for exceedances, 32 (74%) observed an exceedance of the IL for one or more of the contaminants of concern on at least one occasion while 28 (65%) also showed an exceedance of the HT (Appendix A, Table 1).

Table 5. Summary of C&D landfills results by whether there was a significantly higher concentration downgradient for a least one contaminant of concern and whether there also followed an exceedance of either the IL or HT.

Exceedance level	Outcome of the Peto-Prentice generalized Wilcoxon		
	Number of facilities showing significantly higher concentrations downgradient	Number of facilities showing no significantly higher concentrations downgradient	Total facilities
HT	28	N/A	28
IL	32	N/A	32
No exceedance	1	10	11
Total	33	10	43

Out of the 33 C&D landfills that show a significantly higher concentration downgradient vs upgradient for one or more of the contaminants, only SW-17 showed no exceedances of IL for any of the contaminants of concern. While there is a significantly higher concentration downgradient for both Arsenic and Manganese, further analysis does not detect any significant trends at individual wells, which can be seen on the profile sheet for this landfill in Appendix B.

Table 6 shows the results of samples collected at C&D landfills that showed strong evidence they were causing impacts to the groundwater. Sixty-eight percent of samples tested for Boron showed exceedances of either the IL or HT while 83% showed exceedances for Manganese. Overall, over half of the sample results (63%) showed exceedances at either the IL or HT level.

Table 6. Sample result exceedances by contaminants. Samples are only included if the contaminant showed significantly higher concentrations downgradient based on Peto-Prentice generalized Wilcoxon test.

Contaminant	Number of exceedance of HT	Number of exceedance of IL only	No exceedance determined	Total
Arsenic	61	38	352	451
Boron	449	267	336	1052
Manganese	462	74	107	643
All	972	379	795	2146

Concentration trends for significant contaminants

For each of the 33 facilities that showed strong evidence of groundwater impacts due to the facility, the MPCA examined all downgradient wells for trends in the contaminants showing significantly higher concentrations. A trend could only be evaluated for a single well-contaminant combination (i.e. MW-5 sample results for Boron) and only between the selected time period of 2010 through 2017.

There were 37 well-contaminant combinations that could not be evaluated for statistical significance with respect to trend analysis. Of these, there were 17 well-contaminant combinations whose sample results were comprised completely of censored data and thus could not be evaluated. The additional 20 well-contaminant combinations could not be evaluated due a variety of issues: lack of distinct values, small sample sizes, and higher percentage of censored data compared measured data in the results. Of the 188 trends that could be evaluated at individual wells, 157 (84%) of the trends showed no significant statistical increase or decrease. Of those trends that did show statistical significance, 14 trends (7%) were decreasing and 17 trends (9%) were increasing (Appendix A, Table 3).

Lack of a statistical trend can be attributed to small sample size as compared to the strength of the trend, high amounts of censored data, large outliers, or simply that the groundwater concentration is maintaining over time. This does not mean to suggest that the results are acceptable as many of these wells are still showing exceedances of both the IL and HT. In Table 7, trends without statistical significance are referred to as “N/A.”

Overall, regardless of trend type, there was a high percentage (69%) of exceedances of a threshold (IL/HT) for the well-contaminant combinations that could be assessed for trends.

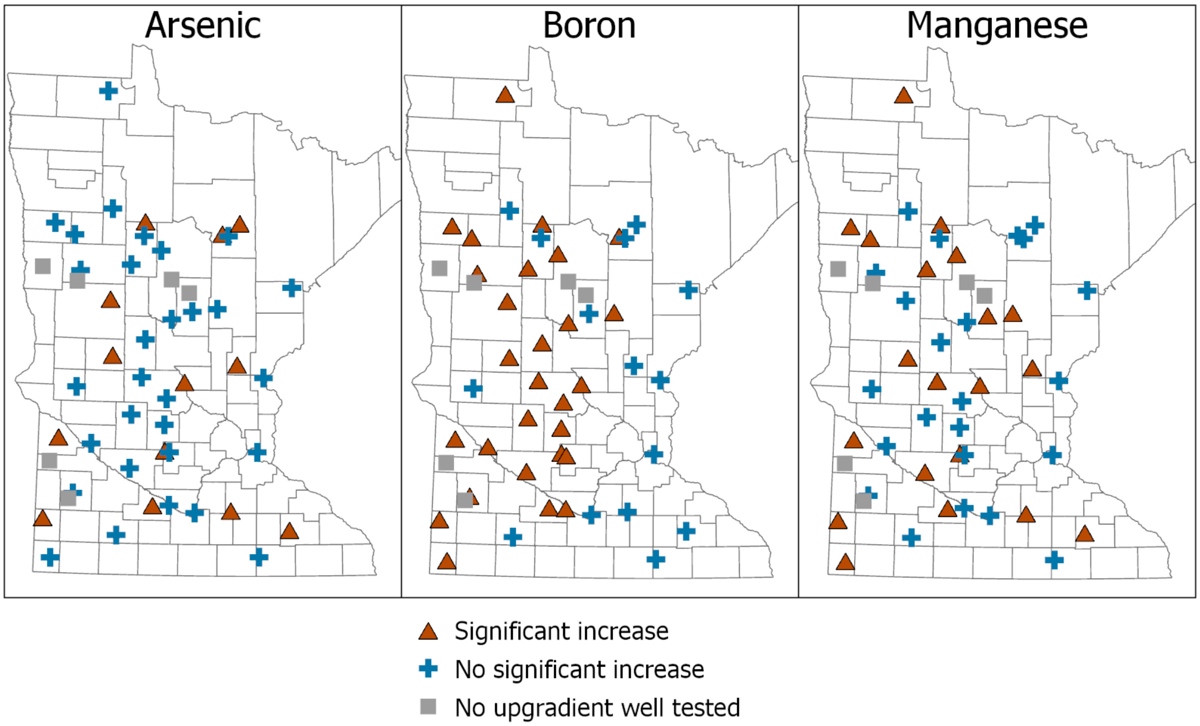
Table 7. Count of sample exceedances for well/contaminant combinations that were evaluated for trends using the Kendall-tau correlation coefficient and the Akritas-Theil-Sen slope estimator.

Trend Type	HT	IL	No exceedance determined	Percent exceeding threshold
Decreasing	96	50	41	78%
Increasing	144	78	34	87%
N/A	714	249	537	64%
All	954	377	612	69%

Geographical distribution of IL and HT exceedances

Figure 2 provides a spatial distribution of facilities showing significantly higher concentrations downgradient by contaminants of concern. Of the 49 C&D landfills evaluated for this report, six C&D landfills did not test upgradient wells during the 2010-2017 time period and are represented with a gray square on the maps below. If the concentration downgradient of a COCs was not significantly higher than upgradient, the facility is represented in blue.

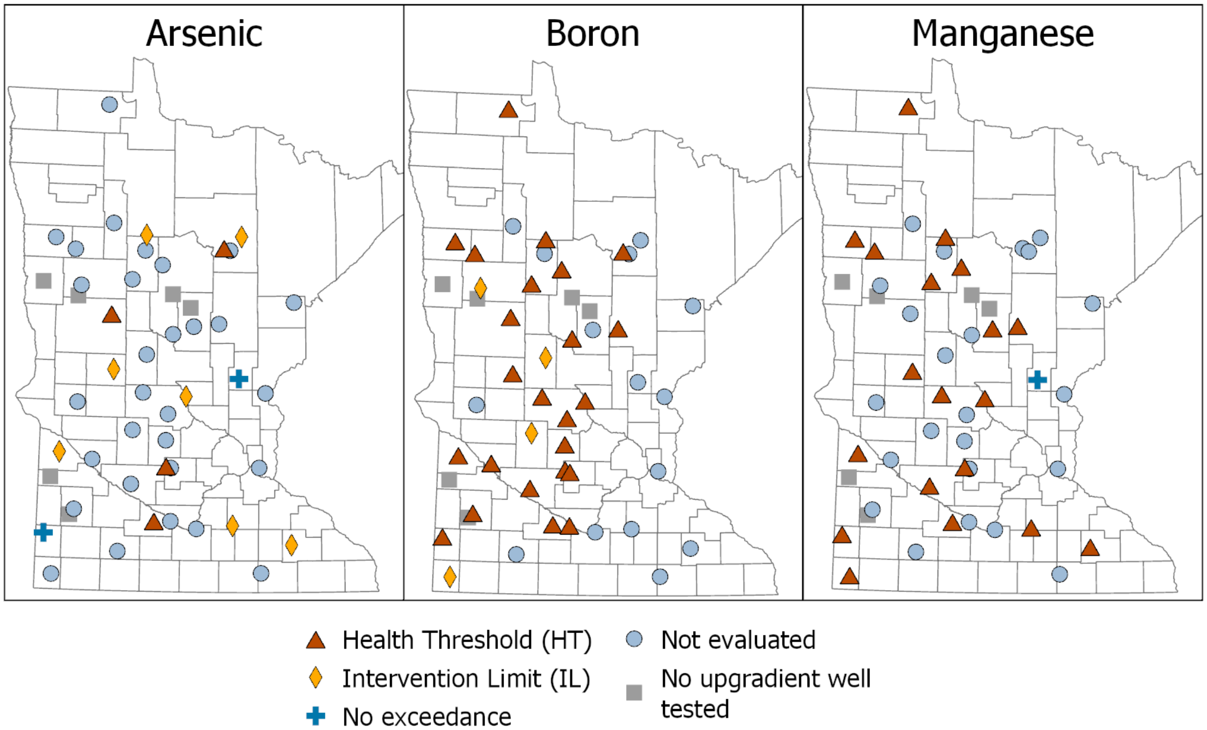
Figure 2. Geographical distribution of significantly higher concentration downgradient for Arsenic, Boron and Manganese.



In general, the pattern of facilities where Arsenic and Manganese are significant appear to be scattered across the state, while almost all facilities other than those on the east side of the state see significantly higher concentrations of Boron (28 of the 43 C&D landfills).

Overall, occurrences of significantly higher concentrations of As, B, and Mn are not confined to particular regions of Minnesota but are a statewide challenge.

Figure 3. Geographical distribution of IL and HT exceedances for Arsenic, Boron and Manganese.



Unlined construction and demolition debris disposal areas constructed after the 2005 guidance document

Since August 2005, there have been six construction and demolition debris disposal areas that are expansions or new areas capable of being monitored separately from other waste management areas or prior C&D landfills. This sub-population of C&D landfills has warranted a special assessment as they were to be entirely operated under the recommended screening and operating procedures of the DLGD, throughout the life of the in-place waste mass.

Of the six C&D landfills in this sub-population, two were not included in the report. Both had liner and leachate collection systems installed and one of these has yet to landfill any construction and demolition debris. Of the remaining four post-2005 C&D landfills, two (50%) have observed exceedances of both the IL and the HT for one or more of the contaminants of concern. One of the C&D landfills does not show a significantly higher concentrations downgradient for any of the contaminants and the other does not show any exceedances but both Arsenic and Manganese have increased concentrations downgradient of the landfill.

Of the six C&D landfills all have, or will have, a groundwater-monitoring network installed and two of the six have installed a liner and leachate collection system. While the groundwater data assessment suggests that the DLGD had not prevented groundwater impacts from post-2005 DLGD unlined C&D landfills, it has however successfully promoted the installation of groundwater-monitoring networks at both pre-existing and new C&D landfills. The construction of the only landfills with liners and leachate collection have occurred after the 2005 DLGD.

Literature Review

Sources of contaminants of concern associated with an unlined C&D landfills

The literature review identified two potential sources for the contaminants of concern that were observed in the groundwater at unlined C&D landfills:

- Contaminants in leachate generated from acceptable construction and demolition debris, where "leachate means liquid that has percolated through solid waste and has extracted, dissolved, or suspended materials from it." (Minn. R. 7035.0300) At lined facilities leachate is collected and processed for treatment of contaminants, but at unlined facilities leachate infiltrates to underlying aquifers.
- Oxidation-Reduction reactions occurring due to the leachate that infiltrates the underlying aquifers which mobilizes the naturally occurring metals in the aquifer sediment.

Concentration of the contaminants of concern in demolition debris leachate

Boron

Boric acid is used in the manufacturing process of all wallboard (sheetrock, gypsum board) disposed of at unlined C&D landfills. The amount of boric acid used in the manufacturing process on average is between 0.03 and 0.15% by weight (US Borax).

Boron is also present in coal combustion residuals (CCR) which has been approved for beneficial use by the EPA and MPCA, specifically fly ash, to be used in place of Portland cement in the concrete manufacturing process. The EPA estimates the amount of CCR in concrete is between 4.2 and 9% by weight. (USEPA, 2014) It should be noted that not all concrete manufacturing uses CCR as a substitute for Portland cement. Both wallboard and concrete are listed in the "Acceptable C&D Waste List" in the DLGD.

Manganese

Manganese is a major component in the production of iron, steel, and certain aluminum alloys. In addition to its primary use in the metallurgic industry it is also used in the pigments of paint and in the colorants for brick (*Manganese Statistics,* USGS). Metal, masonry (brick), and untreated wood (painted) are listed on the "Acceptable C&D Waste List" in the DLGD.

Arsenic

Most of the uses of Arsenic in commerce are associated with agriculture and the production of pressure treated lumber using chromated copper arsenate (CCA). In December 2003 CCA manufacturers voluntarily discontinued the production of products for homeowner use, however prior to 2004 CCA treated wood was available for residential use and was used in the manufacturing process of wood shake, shingles, permanent foundation support beams for decks and playsets (*Chromated Arsenicals*, USEPA). CCA-treated lumber is not allowed to be disposed at an unlined C&D landfills, however, due to its potential to be used in place of acceptable waste types found on the DLGD it has the potential to be inadvertently landfilled.

At the time of writing this report SW-629 is the only C&D landfill that had leachate data available to assess the contamination potential of construction and demolition debris. The landfill was permitted in 2009 and constructed in 2010 to be operated as a lined landfill that accepted only construction and demolition waste on the DLGD's "Acceptable C&D Waste List."

In 2011, the ISWMP was modified to accept the following additional materials:

- Asbestos-containing materials.
- Previously affixed carpet and carpet padding from construction, remodeling, repair, and demolition of buildings.
- Demo-like industrial wastes comprised of wood, concrete, porcelain fixtures, shingles, or window glass.
- Plastic sheeting used from construction or remodeling projects.
- Non-recyclable cardboard packaging mixed with other construction and demolition waste in a dumpster.
- Items constructed of fiberglass such as washtubs, hot tubs, washbasins or other structures such as fiberglass boats, or essentially any fiberglass structure.

Even with the additional waste types accepted, SW-629 remains a good source of leachate data indicating what can be expected from a typical unlined C&D landfills relative to As, B, and Mn contamination. This is because none of the added waste types differ from a compositional standpoint as the waste types found on the "Acceptable C&D Waste List" in the DLGD. The only difference is the source of waste generator for the additional accepted materials, in this case an industrial source as opposed to residential source. The range of concentrations measured in the leachate from SW-629 are in Table 8.

Table 8. 2011-2018 concentration ranges for the contaminants of concerned measured in SW-629 leachate

Contaminant	Minimum reported (µg/L)	Maximum reported (µg/L)
Arsenic	29.2	851
Boron	1930	24300
Manganese	1490	5850

The leachate data associated with SW-629 does indicate that the COCs are present in the waste disposed of in demolition landfills. Without individual testing of the waste types accepted at the landfill the MCPA cannot verify that the above mentioned waste types are the only sources of As, B, and Mn found in waste that was accepted at SW-629.

Oxidation – Reduction Reactions

An oxidation-reduction (Redox) reaction is a chemical reaction where the participating atoms change their valence state by gaining or losing an electron. Oxidation is the loss of an electron from an atom, and that atom is considered an electron donor, while Reduction is that the atom gains an electron and is considered the electron acceptor in the reaction. In order for a redox reaction to occur there must both be an electron donor and an electron acceptor.

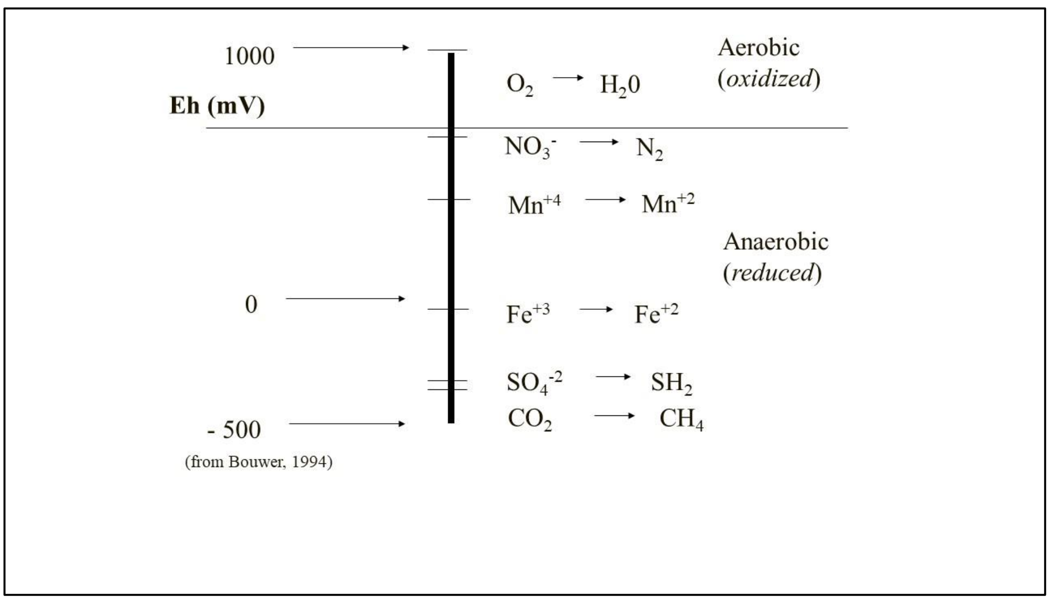
In environmental systems, such as an aquifer, microorganisms act as a catalysts speeding up these reactions. These microorganisms are commonly immobile bound to the aquifer solids, however mobile varieties can be found in aquifers as well. In order to live, these microorganisms metabolize dissolved organic carbon that is present naturally or that is due to contamination (Schwartz and Zhang, 2003).

Acceptable construction and demolition wastes listed in the DLGD that contain organic carbon are primarily untreated wood, insulation (newspaper based), and wallboard (paper facing/backing). The leachate that migrates through the aquifer transports carbon, which provides the electron donor component for the redox reaction.

Under aerobic conditions oxygen is the electron acceptor, whereas under anaerobic conditions nitrate, Manganese, Iron, sulfate, and carbon dioxide are the electron acceptors (Fetter, 1993). As the microorganisms metabolize the carbon in the leachate they are depleting the available oxygen in the groundwater causing a shift in the source of an electron acceptor. Abundant elements found in aquifer sediments of Minnesota then provide the electron acceptor portion of the redox reaction in these environments.

The redox potential (Eh), which is dependent on pH and temperature, is a measurement in volts that indicates which electron acceptor is available for the redox reaction, or which phase of redox the groundwater is at. Figure 3 shows the phased order of electron acceptors at a given Eh of the groundwater. After oxygen is depleted, nitrate in the aquifer sediments is the next preferred source followed by Manganese, Iron, sulfate, and then carbon dioxide.

Figure 4. Oxidation – Reduction source of electron acceptor in groundwater



These redox reactions create an environment for the reductive dissolution of elements typically in solid stable forms in oxygen rich groundwater to dissolve in oxygen starved groundwater. Minnesota soils contain an abundance of Mn, a commonly found form is in insoluble MnO_2, which after completion of the redox reaction creates a species of Mn, in the form of Mn^{2+}, which readily dissolves in the groundwater (MGWA, 2015).

$$C + MnO_2 \Rightarrow Mn^{2+} + CO_2 + 2e-$$

Under the above conditions, Arsenic bound to Manganese bearing aquifer sediment is released. Similarly, under Iron-reducing conditions, Arsenic associated with iron-bearing aquifer sediment will be released. Observations from glacial aquifer systems suggest that the main source of Arsenic is iron oxides and the predominant mechanism for releasing Arsenic to the groundwater is reductive dissolution (Thomas, 2007) (Erickson, 2005).

Figure 5 and 6 illustrate the statewide distribution of Arsenic and Manganese found in Minnesota soils. While soil generally is reserved to describe the material to an approximate depth of one meter below the ground surface, soil is a component of the aquifer sediment material. The data provided by the Minnesota Geological Survey indicates that the COCs are available in Minnesota soils to be potentially mobilized by redox reactions in the aquifer sediment.

Figure 5. Arsenic concentrations measured in Minnesota soils (Lively, 2009)

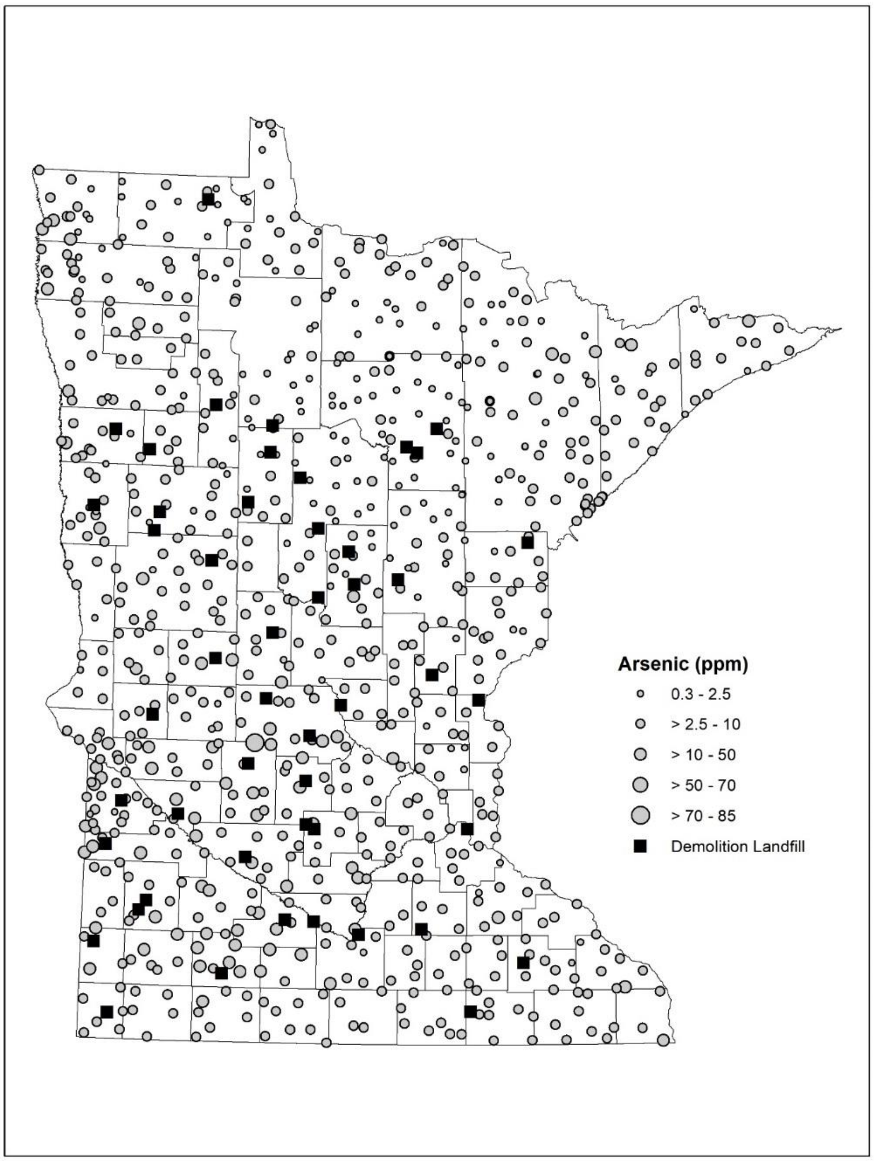
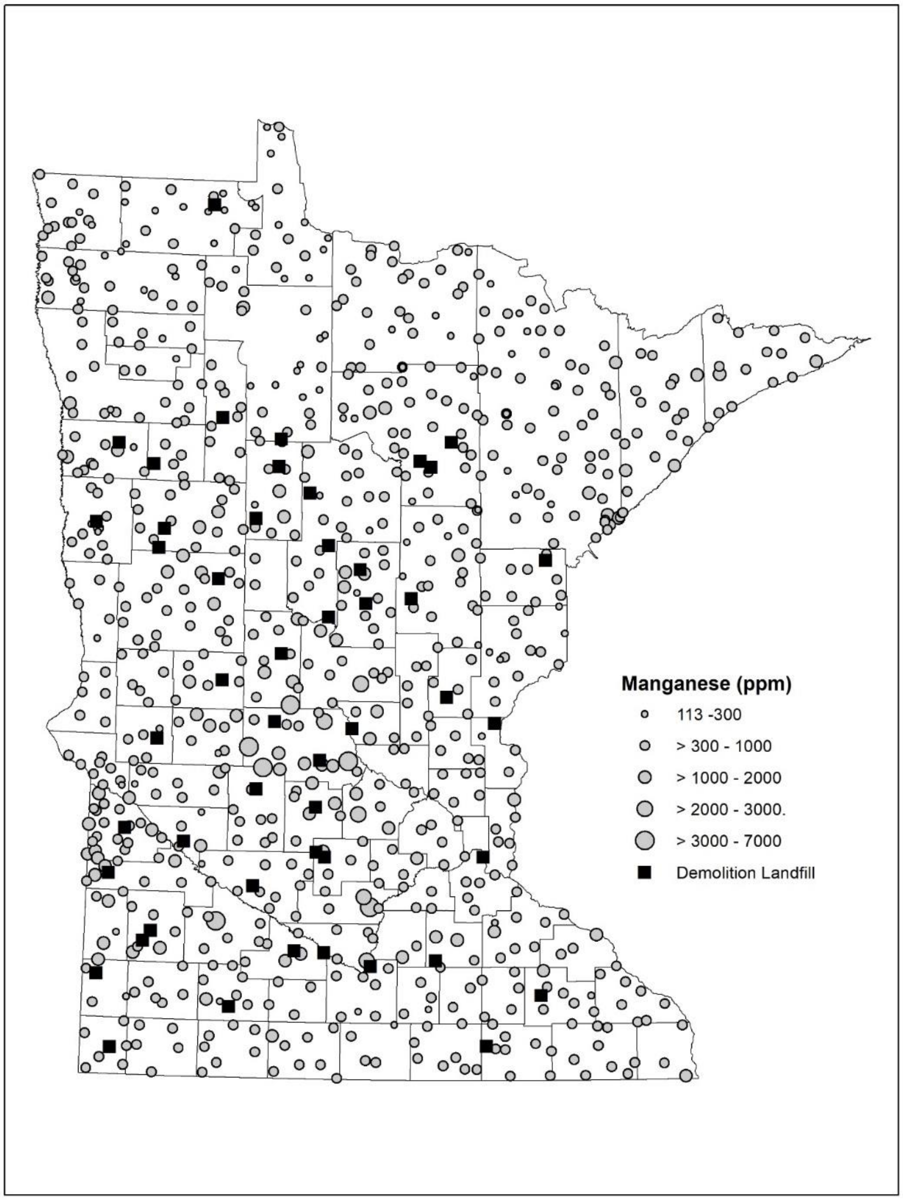


Figure 6. Manganese concentrations measured in Minnesota soils (Lively, 2009)



Conclusions

Self-reported groundwater-monitoring data from unlined C&D landfills in Minnesota shows that a majority have impacted the groundwater at concentrations that have exceeded both human and environmental standards, for Boron, Arsenic, and Manganese. The evidence is strongest for Boron and Manganese, with more information needed concerning Arsenic, given gaps in available data.

The problem does not appear to be confined to particular regions of Minnesota and is not being resolved by changes in landfilling practices following the DLGD of 2005. This is because the three contaminants are leaching from what had been previous considered “acceptable,” innocuous materials such as concrete, reinforcing steel, and drywall. It is also possible that Manganese and Arsenic native to some Minnesota aquifer sediments are being released through an oxidation-reduction reactions. The “acceptable” materials can also be found in the waste streams going to permit-by-rule demolition landfills and general concrete landfills. These were not evaluated in this report, since they lack groundwater-monitoring systems, but they contain some of the same materials, concrete in particular.

The 2005 DLGD was a step forward in laying the foundation for fact-based policy about unlined C&D landfills, because most of them lacked groundwater monitoring and therefore it was not possible for the MPCA to determine whether they were meeting their performance goals of preserving groundwater quality.

However, more can be done at existing C&D landfills to monitor performance. Even after 15 years’ implementation of the DLGD, this report shows that not all landfills are providing a sufficient assessment of environmental impacts. Some C&D landfills have no monitoring networks, others lack monitoring networks specific to the unlined construction and demolition management areas, and some others have large sampling gaps or use insufficient analytical methods. All groundwater sampling analysis should use a reporting limit that is below the intervention limit.

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