

EXHIBIT 14

***Work Plan for 2014 Groundwater Monitoring
Network Augmentation***

***Elk River Landfill
Elk River, Minnesota***

***Prepared for
Elk River Landfill, Inc.***

February 2014



Work Plan for 2014 Groundwater Monitoring Network Augmentation

***Elk River Landfill
Elk River, Minnesota***

***Prepared for
Elk River Landfill, Inc.***

February 2014



4700 West 77th Street
Minneapolis, MN 55435-4803
Phone: (952) 832-2600
Fax: (952) 832-2601

Work Plan for 2014 Groundwater Monitoring Network Augmentation

February 2014

Table of Contents

1.0 Introduction.....	1
2.0 Background	2
2.1 Previous RL/TB Investigations.....	2
2.2 Routine Groundwater Monitoring Results.....	3
3.0 Technical Approach	5
3.1 Well Locations	5
3.2 Well Screen Placement	5
4.0 Methods.....	7
4.1 Well Construction, Development, and Surveying.....	7
4.2 Background Monitoring.....	7
5.0 Schedule	9
6.0 References	10

List of Tables

Table 1	Summary of Vertical Hydraulic Head Gradients – 320 Well Nest (2006 – 2013)

List of Figures

Figure 1	Site Location
Figure 2	Site Map

List of Appendices

Appendix A	Cross Sections
Appendix B	Groundwater Flow – Lower Outwash, October 16, 2012

1.0 Introduction

This Work Plan describes the planned 2014 groundwater monitoring network augmentation at the Elk River Landfill (ERL; Figure 1). The network augmentation will include installing two monitoring wells on ERL property at locations downgradient of existing monitoring wells.

The planned scope of work is based on the results of ERL's ongoing hydrogeologic investigation of Rice Lake/Tibbits Brook (RL/TB), routine groundwater monitoring results, and discussions/correspondence with the Minnesota Pollution Control Agency (MPCA), Sherburne County, and the City of Elk River.

The following sections of this Work Plan provide a summary of pertinent background information, a description of the approach used to site the planned wells and to determine well screen intervals, a description of the drilling and well installation methods, and the project schedule.

2.0 Background

A summary of pertinent groundwater investigations and routine groundwater monitoring results that were used to scope the monitoring network augmentation work is provided below.

2.1 Previous RL/TB Investigations

Previous groundwater investigations have included advancing direct-push soil borings in RL/TB and the installation of monitoring wells between the ERL and RL/TB. The locations of RL/TB soil borings and current monitoring wells are shown on Figure 2.

In 2004/2005, twelve soil borings and four piezometers were installed in RL/TB (Geomatrix, 2005). The results of these investigations confirmed the following:

- RL/TB is largely covered by floating bog vegetation and is over 30 feet deep in some locations.
- The geologic units beneath RL/TB include lake bottom muck, which is underlain by poorly graded sand (up to 14 feet thick), till (ranging from 4 to 15 feet thick), and the lower outwash (which is monitored by ERL monitoring wells)
- The till beneath RL/TB is softer/less dense and exhibits a more uniform thickness than the hard, over consolidated till that is present at the site. Based on these characteristics, the till beneath RL/TB is interpreted to be an ablation (melt-out) till (which is consistent with the Minnesota Geological Survey's interpretation that RL/TB is an ice-block lake; MGS, 2013).
- The hydraulic head in the lower outwash varied from approximately 8 to 11 feet above the RL/TB ground surface. The hydraulic head measurements equate to an approximate upward vertical gradient or 0.45 between the lower outwash and RL/TB.
- The horizontal hydraulic gradient between the three RL/TB piezometers installed in lower outwash had an easterly component (which contrasted with the westerly gradient consistently measured at the site).
- No volatile organic compounds (VOCs) were detected in groundwater samples collected from PZ3 and PZ6 in 2004. PZ3 and PZ6 were completed at the top of lower outwash unit.

After the 2005 investigation, relatively warm winter seasons prevented further drilling in RL/TB so the groundwater investigation focus shifted to the area between the ERL and RL/TB. In 2006/2007,

monitoring wells P320C, P320C2, and P320L (320 well nest) were installed for the purpose of monitoring vertical gradients and profiling groundwater quality in the lower outwash downgradient of the unlined (Pre-Subtitle D) portion of the landfill. Results from the 320 well nest included:

- Average vertical hydraulic gradients in the lower outwash based on 16 hydraulic head measurement events conducted between 2006 and 2013 (Barr, 2014) are provided in Table 1 and are summarized below:
 - Average vertical hydraulic gradients are upward between the top and middle portions and the top and bottom portions of the lower outwash (as measured by well pairs P320C/P320C2 and P320C/P320L, respectively).
 - Upward gradients were measured between the top and middle portions of the lower outwash during two-thirds of the monitoring events and between the top and bottom portions of the lower outwash during half of the monitoring events. Upward gradients were measured between the middle and bottom portions of the lower outwash during a quarter of the monitoring events.
- VOCs were detected in groundwater at the base of the lower outwash in monitoring well P320L. No VOCs were detected in groundwater at the top of the lower outwash in P320C.

Based on the water quality monitoring results at the 320 well nest, the ERL installed six additional L-series wells to monitor groundwater quality at the base of the lower outwash unit. The installation of the L-series wells provided substantial geologic and water quality data west of the landfill. Cross sections showing the lateral extent and thickness of the lower outwash along the west side of the ERL and beneath the RL/TB are included in Appendix A. Water quality monitoring results are discussed in the following section.

2.2 Routine Groundwater Monitoring Results

Routine groundwater monitoring has been performed in accordance with solid waste permit SW-74 and the permits and agreements with Sherburne County and the City of Elk River since the mid-1980s. Monitoring results are reported in triannual monitoring reports and are evaluated in annual water quality monitoring reports. The details of the current groundwater monitoring program are provided in the Sampling and Analysis Plan (SAP; Barr, 2011).

Below are summaries of 2012 and 2013 HRL exceedences from selected locations downgradient of the ERL.

- **320 Well Nest (including P-29C):** No VOCs were detected above the HRL in the 320 well nest area except for one vinyl chloride detection in the spring 2012 groundwater sample from P320L. No VOCs were detected in groundwater from P320C. Total VOC concentrations in P29C and P320L have decreased from past results (see Appendix F in Barr, 2013).
- **P-321L and P-323L:** Vinyl chloride was detected above the HRL in groundwater at P-321L in 2012 and 2013 and in groundwater at P-323L in 2013.
- **P-304C area:** Vinyl chloride was detected above the HRL in groundwater at P313C and P314C during the three 2012 routine monitoring events and in only one groundwater sample collected from P314C during 2013. Total VOC concentrations in P313C and P314C have demonstrated stable to decreasing trends over recent years (see Appendix F in Barr, 2013).
- **P-301L, P-322/P324L:** No VOCs have been detected above HRLs in groundwater at P-301L, P-322L, or P-324L. These well delineate the northern and southern extent of groundwater impacts west of the ERL.

3.0 Technical Approach

The planned monitoring wells will be used to define the extent of VOC-impacted groundwater and provide sentinel groundwater monitoring data west of the ERL. The technical approaches for well location and screen placement selection are discussed below.

3.1 Well Locations

The planned well locations are shown on Figure 2. Monitoring wells P-325L and P-326L are located downgradient of monitoring wells P-321L, P-323L, and P-314C (i.e., where VOCs have recently been detected above HRLs).

- Monitoring well P325L will provide groundwater monitoring data west of P-321L and the P-17C area. This location was selected based on the westerly groundwater flow directions inferred from hydraulic head data from the ERL monitoring well network (Barr, 2013).
- Monitoring well P326L will provide groundwater monitoring data southwest of P-321L/P-323L and west of P-313C/P314C. This location was selected based on the southwesterly groundwater flow direction inferred from hydraulic head data from the L-series monitoring wells which are completed at the base of the lower outwash (Appendix B).

The new monitoring wells will provide sentinel groundwater monitoring data that will be used to define the extent of VOC-impacted groundwater downgradient of the ERL.

3.2 Well Screen Placement

The thickness of the lower outwash and the elevation of the underlying bedrock are not fully known at the proposed well locations. The elevation of the top of bedrock (or the top of till directly overlying bedrock) at the L-series well east of the RL/TB ranges from approximately 840 to 860 feet MSL (which equates to 80 to 100 feet below the surface of RL/TB). Due to the uncertainty of the thickness of the lower outwash unit at the proposed well locations, specific well screen intervals will be determined in the field during drilling. However, the following general rationale for well screen interval selection will be employed:

- If the lower outwash is 30 or less feet thick, the bottom of the monitoring well screen will be placed at the base of the lower outwash. The well screen will be no longer than 15 feet. This scenario will result in a monitoring well that is screened in the stratigraphic interval

monitored by wells P-321L and P-323L (and similar to P313C and P314C) where vinyl chloride has been detected above the HRL.

- If the lower outwash is greater than 30 feet thick, well screens may be adjusted and set to the approximate center elevation of the L series wells (P-321L and P-323L). Nested monitoring wells may also be considered but it is noted that achieving a proper well seal given the high hydraulic head differential expected is critical. Nested wells further reduce the likelihood that a proper well seal can be achieved; so nested wells will only be considered if deemed crucial. If nested wells are installed, the lower monitoring well may be set at the base of the lower outwash and the upper nested well will be screened at the elevation of the L-series well located to the east (i.e., the upper well at P-325L will be screened at an elevation consistent with P321L and the upper well P-326L will be screened at an elevation consistent with P323L).

It is important to note that the well screen placement strategy outlined above will insure monitoring in the same screen interval of known groundwater detections at wells P321L, P323L, and P314C. If no significant discharge is occurring to RL/TB then this interval should be ideal for detection monitoring. If discharge is occurring to RL/TB then no detections or very low levels may be evident. In either case this work will result in important information concerning nature and extent VOC-impacted groundwater as well as informing potential corrective actions.

4.0 Methods

The monitoring wells will be constructed in accordance with State of Minnesota Well code by a licensed well contractor. The wells will likely be constructed using rotasonic drilling or equivalent driven casing methods. Geologic samples will be collected and logged by Barr staff. One of the key advantages of driven casing techniques is the improved odds of maintaining a well seal through the relatively thin ablation till that is present beneath RL/TB.

4.1 Well Construction, Development, and Surveying

The boreholes for monitoring wells P325L and P326L will likely be constructed using double-cased well installation methods. At each location, 6-inch inner diameter, permanent steel casing will be set into the till above the lower outwash and grouted in-place. After the grout sets, the borehole will be advanced through the permanent casing to total depth and the monitoring wells will be constructed with 2-inch diameter stainless steel well screens and low carbon steel risers. If feasible, filter pack sand will be placed from the bottom of the borehole to two feet above the top of the well screen and the remainder of the borehole annulus will be sealed with neat cement grout. Based upon previous experience with well construction in RL/TB, strong upward gradients are expected as well as heaving sands. These conditions challenge well construction and especially seal placement. If the upward gradient/flowing conditions prevent the placement of filter pack sand, a natural sand pack (i.e., lower outwash) will be used and the remainder of the borehole annulus will be sealed with neat cement grout. Each monitoring well will be water tight and completed above grade with a lockable well cover.

The wells will be developed after construction to remove fines from the screened interval and to ensure a good hydraulic connection between the screen and the surrounding geologic media.

A licensed land surveyor will survey the horizontal location, ground surface elevation, and top of casing elevation.

4.2 Background Monitoring

The monitoring wells will be sampled for background parameters in accordance with the Sampling and Analysis Plan (SAP; Barr, 2011) during the 2014 routine monitoring events. Background monitoring data will be submitted in quarterly monitoring reports and summarized in the 2014 Annual Water Quality Report. The ERL will provide a recommendation regarding the inclusion of

P325L and P326L in the groundwater monitoring network in the 2014 Annual Water Quality Monitoring Report.

5.0 Schedule

The monitoring well installation work is planned for as soon as ice road conditions allow safe access (anticipated to be February 2014) and is anticipated to take approximately 4 weeks.

Please note, the RL/TB is covered by floating bog vegetation and winter ice conditions have been variable in the past due to apparent water upwelling. The implementation of this work plan is contingent on the driller's verification that conditions are sufficient to safely support the drill rig, ancillary equipment, and the crew. If unforeseen circumstances that could jeopardize the safety of the crew arise, work will be stopped.

6.0 References

Barr, 2014. Fall 2014 Quarterly Report, Elk River Landfill.

Barr, 2013. 2012 Annual Water Quality Monitoring Report, Elk River Landfill.

Barr, 2011. Sampling and Analysis Plan, Elk River Landfill (SW-74).

Geomatrix, 2007. Groundwater Investigation Progress Report, P-304C and P-29C Areas, Elk River Landfill, Elk River, Minnesota.

Geomatrix, 2005. Final Report of Rice Lake/Tibbits Brook Groundwater Discharge Investigation, Elk River Landfill, Elk River, Minnesota.

MGS, 2013. Personal Communication with Barbara Lusardi, Minnesota Geological Survey.

Tables

Table 1
Summary of Vertical Hydraulic Head Gradients - 320 Well Nest (2006 - 2013)
Elk River Landfill
Elk River, Minnesota

Well Pairs	Well Pair Screen Placement in Lower Outwash	2006 - 2013				
		Number of Water Level Measurement Events	Number of Events with Upward Hydraulic Gradients	Average Upward Hydraulic Gradient ¹	Ave Downward Hydraulic Gradient ¹	Overall Average Hydraulic Gradient ¹
P320C/P320C2	Top/Middle	15	10	-0.0028	0.0023	-0.0011
P320C2/P320L	Middle/Bottom	16	4	-0.0107	0.0055	0.0014
P320C/P320L	Top/Bottom	16	8	-0.0031	0.0026	-0.0002

Notes:

Negative values indicate an upward vertical gradient.

Hydraulic head data included in the 2013 Fall Quarterly Monitoring Report (Barr, 2014).

Figures

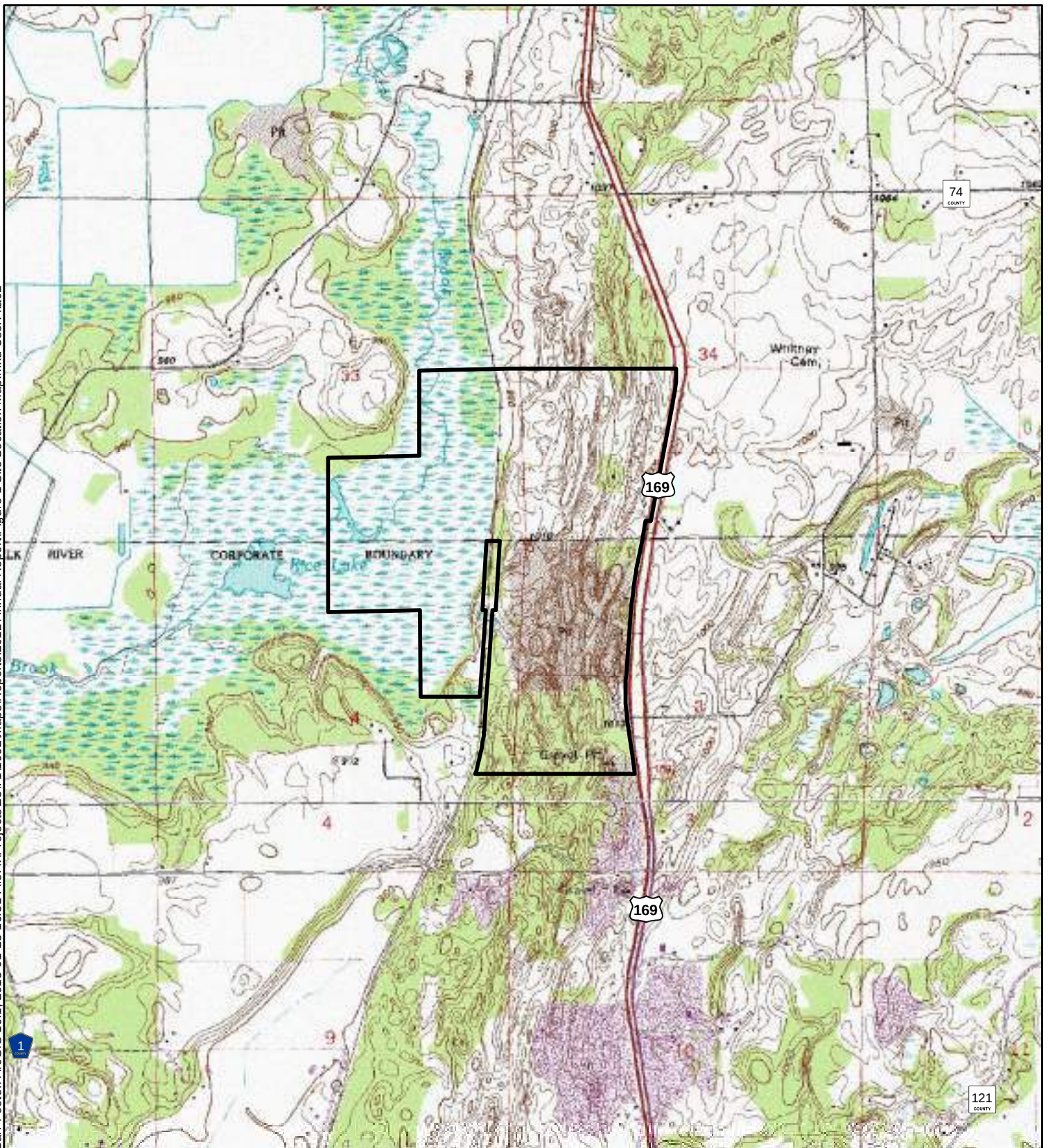


Figure 1

 Site Boundary



Feet
0 2,000 4,000

SITE LOCATION MAP
Elk River Landfill
Elk River, Minnesota

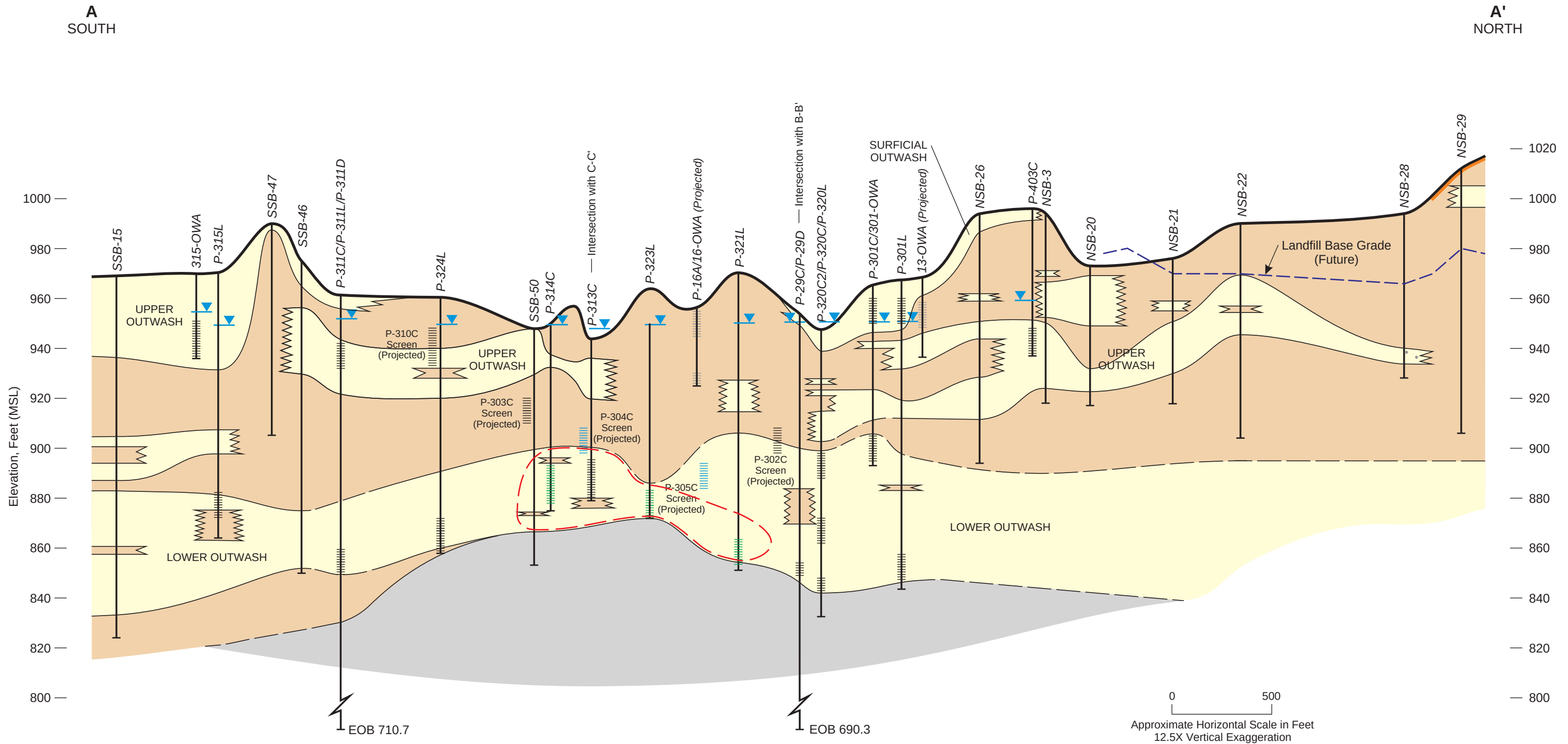


Appendices

Appendix A

Cross Sections

P:\Mpls23 MN7123711005\WorkFiles\2014 RL TB Work\Work Plan\Figures\Source File\HydrogeologicCross Section A-A'.CDR RLG 01-27-14



EXPLANATION

OUTWASH	Includes the following soil types: SP: Sand with <5% fines; thin/discontinuous gravel lenses rare to common. SM: (Where in contact with SP); Silty sand; silt content approximately 30 to 50%.
TILL/LACUSTRINE	Includes the following soil types: ML: Sandy silt - diamict with approximately 10 to 50% Sand and Gravel; firm to very hard. CL: Clay textured diamict with varying amounts of sand and gravel; firm to hard. SM: (Where bounded by ML or CL); Silty sand; silt content approximately 30 - 50% ML/CL: Silt or clay, <5% sand, massive to thinly bedded
BEDROCK	Fine-grained sandstone/siltstone with shale partings present locally.

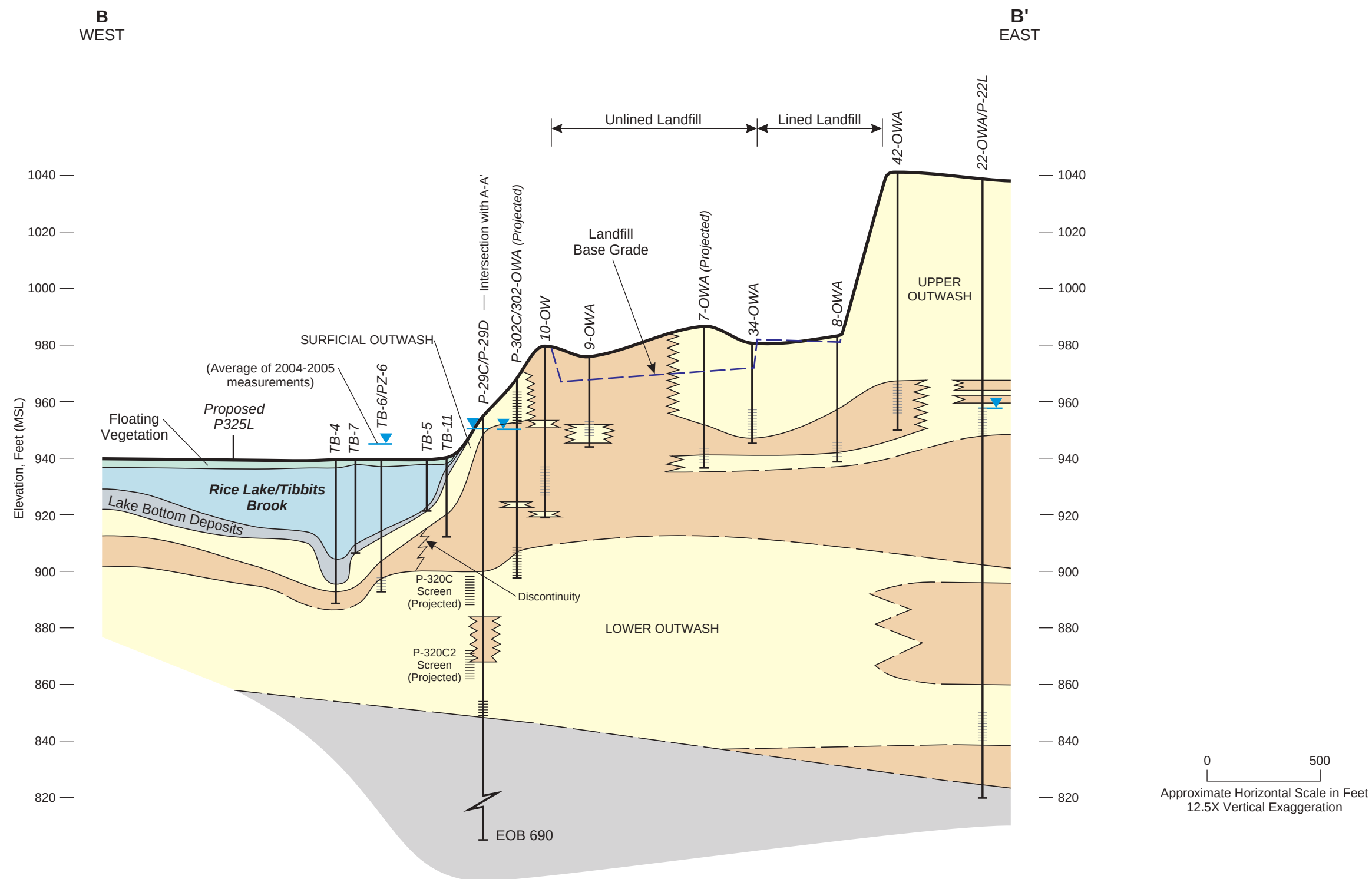
GROUNDWATER CRITERIA EXCEEDENCES - 2013

	Estimated Extent of Groundwater-Based Intervention Limit Exceedences
	HRL Exceedence
	Surface Water-Based Intervention Limit Exceedences (Excluding Chloride and Iron)

LEGEND

	Ground Surface (Approximate)
	Geologic Contact (Dashed where approximate)
	2011 Groundwater Elevations (Measured in deepest nested well)
	Future Landfill Base Grade (Approximate)
	Existing Well Screen
	Former Well Screen or Gas Probe

Figure A2
HYDROGEOLOGIC CROSS SECTION A-A'
Elk River Landfill
Elk River, Minnesota

EXPLANATION

OUTWASH	Includes the following soil types: SP: Sand with <5% fines; thin/discontinuous gravel lenses rare to common. SM: (Where in contact with SP); Silty sand; silt content approximately 30 to 50%.
TILL/LACUSTRINE	Includes the following soil types: ML: Sandy silt - diamict with approximately 10 to 50% Sand and Gravel; firm to very hard. CL: Clay textured diamict with varying amounts of sand and gravel; firm to hard. SM: (Where bounded by ML or CL); Silty sand; silt content approximately 30 - 50% ML/CL: Silt or clay, <5% sand, massive to thinly bedded
BEDROCK	Fine-grained sandstone/siltstone with shale partings present locally.

GROUNDWATER CRITERIA EXCEEDENCES - 2013

Estimated Extent of Groundwater-Based Intervention Limit Exceedences

HRL Exceedence

Surface Water-Based Intervention Limit Exceedences (Excluding Chloride and Iron)

LEGEND

 Ground Surface (Approximate)
 Geologic Contact (Dashed where approximate)
 2011 Groundwater Elevations (Measured in deepest nested well)
 Landfill Base Grade (Approximate)
 Existing Well Screen
 Former Well Screen or Gas Probe

Figure A3

HYDROGEOLOGIC CROSS SECTION B-B'

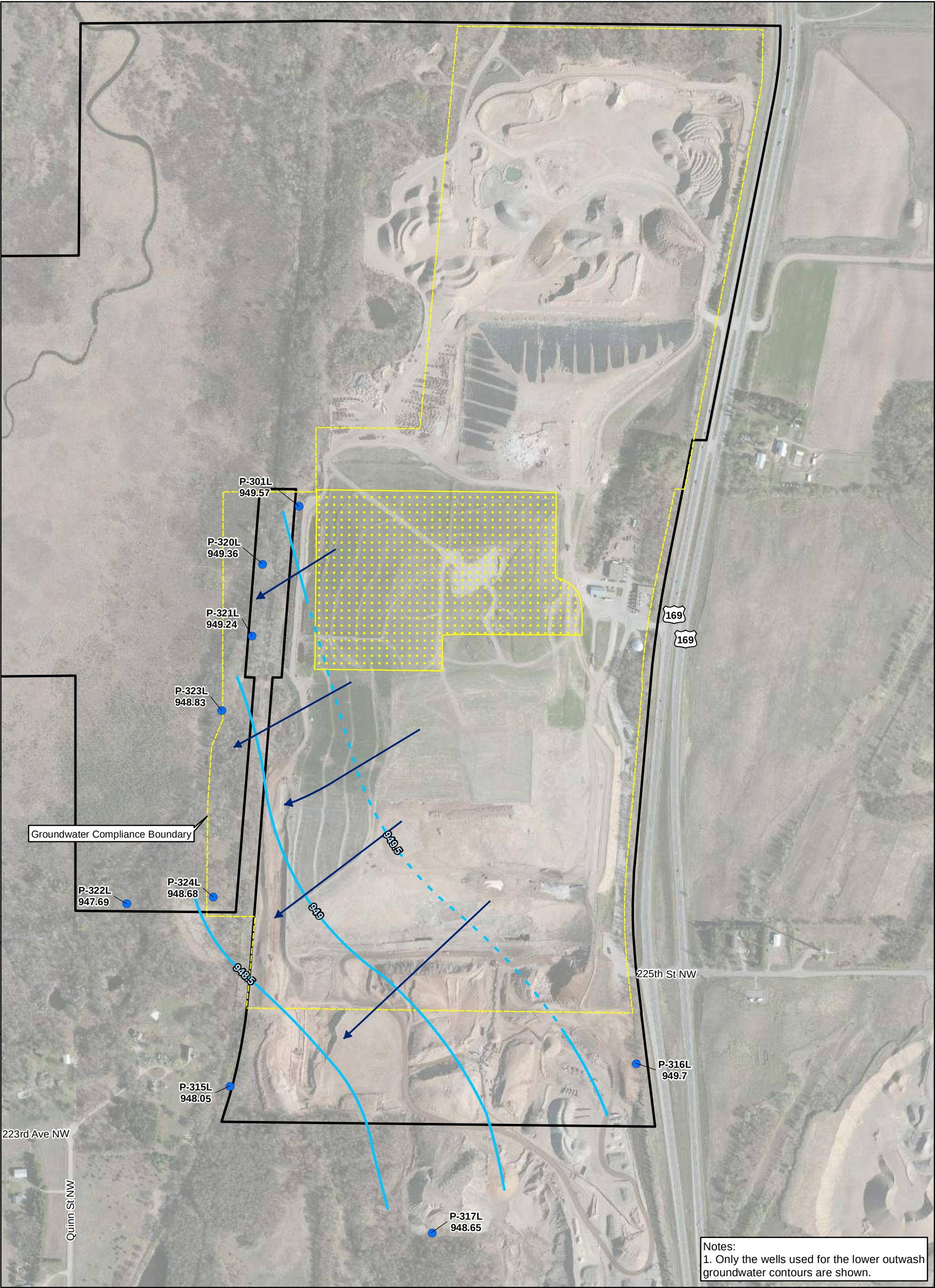
Elk River Landfill

Elk River, Minnesota

Appendix B

Groundwater Flow – Lower Outwash, October 16, 2012

Barr Footer: ArcGIS 10.2.1, 2014-01-27 13:21 File: I:\Projects\2371\1005\Maps\Reports\2014 RLTB Work Plan\Appendix\Groundwater Flow - Lower Outwash.mxd User: kac2



Notes:
1. Only the wells used for the lower outwash groundwater contours are shown.

- Lower Outwash Monitoring Well
- ~ Groundwater Contour
- ➔ Flow Line
- ▭ Site Boundary
- ⋯ Pre-Subtitle D Area



0 500 1,000
Feet

GROUNDWATER FLOW -
LOWER OUTWASH
October 16, 2012
Elk River Landfill
Elk River, Minnesota



Background Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community (March 2012)
Data Source: Barr, Wenck, MN DOT

EXHIBIT 15



Doc. ID #1002

Groundwater Corrective Action Evaluation Report

Elk River Landfill (SW-74)

Elk River, Minnesota

Prepared for
Elk River Landfill, Inc.

June 2020

Groundwater Corrective Action Evaluation Report

June 2020

Contents

Executive Summary.....	v
1.0 Introduction	1
2.0 Background	2
2.1 Facility Description	2
2.2 Site Hydrogeology	2
2.3 Groundwater Quality	3
2.4 Vinyl Chloride Extent and Mass in Groundwater	4
2.5 Area Water Supply	5
2.6 Prior Corrective Actions.....	6
2.7 Conceptual Release Model	7
3.0 Corrective Action Objectives.....	9
3.1 Corrective Action Goals	9
3.2 Constituents of Concern	9
3.3 Potential Exposure Pathways and Receptors.....	9
4.0 Corrective Action Technologies	11
4.1 Alternate Residential Water Supply.....	11
4.2 Monitored Natural Attenuation	11
4.3 Groundwater Extraction and Treatment	13
4.4 In-Situ Treatment.....	14
4.5 Pre-Subtitle D Landfill Excavation and Placement on Liner	15
5.0 Corrective Action Alternatives Evaluation	17
5.1 Alternative #1: Monitored Natural Attenuation and Residential Water Supply Replacement	17
5.2 Alternative #2: Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement	20
5.3 Alternative #3: Pre-subtitle D Landfill Excavation and Placement on Liner.....	23
5.4 Alternative #4: Groundwater Extraction (on and off-site) and Treatment	25
6.0 Comparison of Alternatives	27
7.0 Summary and Next Steps.....	29
8.0 References	30

List of Tables

Table 1	Corrective Action Evaluation Summary

List of Figures

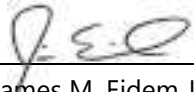
Figure 1	Site Location
Figure 2	Site Map
Figure 3	Groundwater Contours – Lower Outwash, October 22, 2019
Figure 4	Estimated Extent of Vinyl Chloride
Figure 5	Residential Water Supply Well Network
Figure 6	Hydrogeologic Cross Section Locations
Figure 7	Hydrogeologic Cross Section H''-H'''
Figure 8	Hydrogeologic Cross Section A-A'

List of Appendices

Appendix A	2018 – 2020 (April) Groundwater Monitoring Data
Appendix B	Concentration Trend Plots
Appendix C	Preliminary Attenuation Rate Calculations
Appendix D	Area Water Supply Wells
Appendix E	Cost Estimate Details
Appendix F	Monitoring Well Network Considerations

Certifications

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Geologist under the Laws of the State of Minnesota.



James M. Eidem Jr.
PG #: 44064

June 1, 2020

Date

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the Laws of the State of Minnesota.



Anthony D. Neuens
PE #: 50822

June 1, 2020

Date

Acronyms

Acronym	Description
bgs	below ground surface
CAAR	Corrective Actions Alternatives Screening Report
cDCE	cis-1,2-dichloroethylene
COC	constituent of concern
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DCE	1,2-cis-dichloroethylene
ERL	Elk River Landfill
gpm	gallons per minute
HRL	health risk limits
IL	Intervention Limit
lbs	pounds
MCY	million cubic yards
MDH	Minnesota Department of Health
MDNR	Minnesota Department of Natural Resources
µg/l	micrograms per liter
mg/l	milligrams per liter
MNA	Monitored Natural Attenuation
MPCA	Minnesota Pollution Control Agency
MSL	mean sea level
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
PCE	tetrachloroethylene
POET	point-of-entry treatment
POTW	publicly owned treatment works
PRB	Permeable Reactive Barrier
RCRA	Resource Conservation and Recovery Act
RL/TB	Rice Lake/Tibbits Brook
TCE	trichloroethylene

Executive Summary

On behalf of Elk River Landfill, Inc., Barr Engineering Co. has prepared this Corrective Action Evaluation Report to evaluate options for addressing groundwater quality downgradient of the unlined (Pre-Subtitle D) portion of the Elk River Landfill (ERL or Site). The evaluation has been prepared in accordance with Minnesota Pollution Control Agency's (MPCA) process for implementing corrective actions at solid waste facilities. The report appendices include supporting documentation and preliminary estimates of natural attenuation rates and feasibility-study level cost estimates for alternatives comparison purposes.

ERL has developed an extensive groundwater monitoring network that is based on numerous hydrogeologic investigations and groundwater quality monitoring activities that have taken place over the last 40+ years. These investigations have included the installation/placement of approximately 277 monitoring wells and borings at and around the Site (Appendix B, B-5; Barr, 2018 and 2015a). ERL placed final cover over the unlined portion of the landfill and installed an active gas extraction system in the early to mid-1990s as part of groundwater corrective actions that stemmed from the detection of a leachate (slug) release from the Pre-Subtitle D portion of the landfill. Since then, groundwater investigations have included the evaluation of hydrogeologic conditions and water quality in the areas north, south, and west of the landfill to better understand the fate and transport of organics in groundwater. ERL incorporated low level reporting methods for vinyl chloride in 2015 and for other organics in 2017. Results attained from the low level reporting methods led to ERL completing a remedial investigation in 2018 that largely defined the extent and concentration of vinyl chloride in groundwater at, and downgradient of, the Site (Barr, 2018). Vinyl chloride has been detected in groundwater samples at concentrations above Minnesota Department of Health (MDH) groundwater criteria known as Health Risk Limits (HRLs) in wells located approximately 1,100 feet from the unlined portion of the landfill and sporadically at lesser concentrations in samples collected from a distal monitoring well located approximately 4,600 feet from the unlined portion of the landfill. Based on groundwater monitoring data and delineation results, the estimated mass of vinyl chloride in the groundwater downgradient of ERL is approximately 1 pound (lb) and the estimated vinyl chloride flux from the landfill at present is 0.07 lbs/year (Appendix C).

This report builds on prior alternatives and natural attenuation screening reports (Barr, 2019 and 2020b, respectively) and evaluates the feasibility, costs, risks / benefits of the following corrective action alternatives designed to address vinyl chloride in groundwater at and downgradient of the ERL:

- Alternative #1, Monitored Natural Attenuation (MNA) and Residential Water Supply Replacement
- Alternative #2, Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement
- Alternative #3, Pre-Subtitle D Landfill Excavation and Placement on Liner
- Alternative #4, Groundwater Extraction (on and off-site) and Treatment

Each of the alternatives described below is considered protective of human health and the environment and are judged potentially capable of meeting applicable groundwater criteria¹.

Alternative #1 – Monitored Natural Attenuation and Residential Water Supply Replacement

This alternative includes the development of a monitored natural attenuation (MNA) program to evaluate and document the natural attenuation of organics. Additional monitoring wells would be established on privately-owned land (contingent on access) to provide further definition of organics and data necessary to better understand attenuation processes, rates and organics migration over time. The MNA approach has on-site and off-site components based on the refined natural attenuation analysis appended to this report. This alternative also includes replacing the lower outwash water supply wells that are located downgradient or near sidegradient of the projected migration pathway of organics with deeper wells screened in the Mt. Simon aquifer to eliminate the risk of exposure to downgradient residents. Alternatives to well replacement are also discussed should residents prefer a different option. The estimated total cost (capital plus 30 year operation and maintenance, Net Present Value [NPV]) for this alternative ranges from \$590,000 to \$1,300,000.

Alternative #2 – Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement

This alternative includes the construction and operation of a groundwater extraction system along the west side of the landfill, treating and discharging the extracted groundwater at the Site, development of a focused MNA program, and replacing residential water supply wells. Under this alternative, extracted groundwater would be treated for organics and re-infiltrated at the Site. Groundwater extraction systems present unique challenges to the attainment of groundwater criteria, result in the withdrawal of significant volumes of groundwater to remove little mass, and require the long-term management of extracted groundwater. The MNA component would focus on documenting the efficacy of MNA in areas along the west side of the landfill where applicable. Residential water supply replacement would be consistent with Alternative #1. The estimated total cost (NPV) for this alternative ranges from \$3,400,000 to \$7,000,000.

Alternative #3 – Pre-Subtitle D Landfill Excavation/Placement on Liner

This alternative evaluated at the request of MPCA and includes excavation of the unlined pre-Subtitle D landfill and placement on new liner at ERL. This alternative would include the excavation of approximately 4.9 million cubic yards (MCY) of in-place waste, including volumes in overlying lined phases and adjoining lined cells, and approximately 1 MCY of excavated (non-waste) fill as needed. This alternative would require an expansion of the ERL to accommodate the

¹ MPCA requested the alternatives consider meeting Intervention Limits (ILs) at the ERL groundwater compliance boundary. The application of ILs are unique to the solid waste program in Minnesota and are intended to trigger assessment monitoring and/or corrective actions. ERL has moved to corrective action, therefore, ILs are not applicable. The subject release is from the Pre-Subtitle D portion of the landfill which, in accordance with Minnesota Rule 7035.2815 Subpart 4 (H)(2), may necessitate the establishment of appropriate groundwater criteria.

excavated Pre-Subtitle D waste. Identification and feasibility planning for significant construction, geotechnical, interim leachate management, oxygen intrusion, odor/landfill gas management, unknown/restricted waste management, and other issues related to implementing this alternative is beyond the scope of this document. Operation of a groundwater extraction/treatment system and replacement of residential water supply wells would be required to mitigate risk to downgradient residents and control releases to the groundwater system as a result of waste excavation activities. The preliminary estimated total cost for this alternative is based on an estimated feasibility-study level cost estimate from a similar project at a non-operating facility in the Twin Cities area and ranges from \$63,000,000 to \$140,000,000.

Alternative #4 – Groundwater Extraction (on and off-site) and Treatment

This alternative was evaluated at the request of MPCA and includes constructing and operating a groundwater extraction system along the west side of the landfill and a second groundwater extraction system on private property (contingent upon access), near the downgradient end of the vinyl chloride plume. The combined flow from both systems would be treated and discharged at ERL. This alternative would require the installation and ongoing operation and maintenance of a groundwater extraction system on privately-owned land west of ERL. Challenges to this alternative include the lack of ownership of the property where the off-site system would be implemented and the long distance that groundwater forcemain piping would need to be installed for extracted groundwater conveyance. The preliminary estimated total cost for this alternative ranges from \$6,400,000 to \$14,000,000.

The corrective action alternatives were evaluated against seven criteria that are based on Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance (USEPA, 1988). Consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the selected alternative must meet two threshold criteria and achieve the best balance of trade-offs with respect to the balancing criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost) in a cost-effective manner. The NCP says, “a remedy shall be cost-effective if its costs are proportional to its overall effectiveness.”

Alternative #1, MNA and Residential Water Supply Replacement achieves the threshold criteria and is the most cost-effective alternative that achieves the best balance of the evaluation criteria, assuming further evaluation demonstrates MNA is occurring sufficiently and applicable alternative groundwater requirements are met. Based on the refined preliminary analysis presented here, MNA is anticipated to sufficiently reduce the toxicity, mobility, and volume of vinyl chloride via natural processes and protectiveness to human health would be addressed with water supply well replacements. Alternative #1 would be equally protective in the short-term and long-term, reasonably implementable, and is the lowest cost alternative evaluated in this report. Alternative #1 is consistent with the MPCA Closed Landfill Program strategy for understanding if there is risk to human health and addressing it using a risk based approaches (MPCA, 2020).

Alternative #2, Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement is equally protective to downgradient residents as Alternative #1 but is not a cost-effective

alternative due to the operation of the groundwater extraction and treatment system. Alternative #2 provides a means to make progress towards achieve groundwater criteria at the compliance boundary (above and beyond natural processes) by intercepting the migration of groundwater with vinyl chloride along the west side of the landfill, however, preliminary estimates suggest that, on an annual basis, an extraction system would remove approximately 0.2 pounds (lbs) of vinyl chloride from approximately 21,000,000 gallons of extracted groundwater on an annual basis. This alternative could be considered in the future if MNA is not demonstrated to be protective.

Alternative #3, Pre-Subtitle D Landfill Excavation/Placement on Liner best addresses long-term effectiveness and permanence but is not cost effective. This alternative is not feasible because lined waste is present in cells adjacent to and overlying the Pre-Subtitle D area and capacity does not exist to accommodate the excavated waste. The alternative is not judged to be effective in the short-term due to the long lead time required to plan and implement it and because excavation of the unlined waste will require removing the landfill cap, resulting increased contaminant flux to the groundwater system. Incomplete waste removal and/or residual impacts below the closed Pre-Subtitle D area would require long-term operation of a groundwater treatment system and residential water supply well replacements would be needed to protect the downgradient residents to the same extent in Alternatives #1 and #2.

Alternative #4, Groundwater Extraction (on and off-site) and Treatment is equally protective of downgradient residents as Alternatives #1 and #2 but offers less certainty than residential water supply well replacement. Implementation of this alternative is considered difficult given the need to negotiate access to construct, operate, and maintain a groundwater extraction system on privately-owned land. This alternative will also entail extracting groundwater with low vinyl chloride concentrations (e.g., at or below the reporting limit), pumping the groundwater to ERL for treatment, and discharging at the Site. The estimated range of combined flows from the two extraction systems would also be challenging to discharge at the Site. Preliminary estimates suggest that, on an annual basis, the removal of approximately 0.21 lbs of vinyl chloride from approximately 42,000,000 gallons of extracted groundwater (assuming a rate of 80 gallons per minute [gpm]).

Upon receiving concurrence with MPCA on Alternative #1, a work plan including implementation steps and schedule will be submitted under separate cover to MPCA for review and approval. Implementation would prioritize the installation of replacement water supply wells and the installation of additional MNA monitoring network points downgradient of the ERL.

1.0 Introduction

On behalf of Elk River Landfill, Inc., Barr Engineering Co. has prepared this Corrective Action Evaluation Report to evaluate options for addressing groundwater quality downgradient of the unlined (Pre-Subtitle D) portion of the Elk River Landfill (ERL or Site; Figure 1). The content of this report is based on Minnesota Solid Waste Rules; a corrective action alternatives screening report (Barr, 2019); an informational report assessing groundwater natural attenuation conditions at the Site (Barr, 2020b); feedback from MPCA, Sherburne County, and City of Elk River staff; Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance (USEPA, 1988) and MPCA Closed Landfill Program's strategy for understanding and addressing groundwater impacts (MPCA, 2020). The following sections summarize background information, describe the contemplated corrective action technologies and approaches, and evaluate corrective action alternatives to address groundwater quality at and downgradient of the ERL. The report appendices include supporting documentation and preliminary estimates of natural attenuation rates (based on comments received on prior submittals) and feasibility-study level cost estimates for alternatives comparison purposes.

2.0 Background

2.1 Facility Description

ERL is authorized for operation as a solid waste disposal facility by the MPCA under Solid Waste Permit SW-74 and licenses and permits from Sherburne County and the City of Elk River. The ERL was initially permitted for waste disposal in 1972. A portion of the landfill, including landfill cells 1 through 5, 7, 9, and the northern portion of cell 6 (6N) was constructed prior to the effective date of Resource Conservation and Recovery Act (RCRA) Subtitle D regulations. Landfill cells 1 through 5, 7, and 9 are unlined and capped (closed) with final cover (or covered with lined construction and demolition debris disposal cells DC-1 through DC-3). Cell 6N was constructed with a Pre-Subtitle D liner consisting of 80-millimeter-thick, high-density polyethylene and a leachate collection system. The other landfill cells, including construction and demolition debris disposal cells DC-4A and DC-5A, were constructed with composite liners and leachate collection systems. The leachate collected from the lined cells is disposed off-site at a publicly owned treatment facility. Figure 2 shows the Site layout and groundwater monitoring locations. MPCA Permit SW-74 provides additional details on the ERL's construction and operating history.

2.2 Site Hydrogeology

The geology at the ERL includes 100 to 200 feet of glacial deposits overlying Paleozoic bedrock. The predominant glacial deposits include two outwash units, referred to as the upper and lower outwash that are separated by sandy-silt textured till deposited from ice advances from the northeast (predominantly Cromwell and older Pre-Wisconsinan tills) (Barr, 2015a). The till is inferred to be discontinuous or leaky in the Pre-Subtitle D area based on downward migration of organics and the presence of organics in the lower outwash downgradient of the landfill (Barr, 2015b). The lower outwash, which is present from approximately 60 to 100+ feet below ground surface (bgs) west of the landfill, is laterally continuous beneath the ERL and Rice Lake/Tibbits Brook (RL/TB) (Barr, 2018) and is the focus of contemplated corrective actions based on the presence of organics in groundwater. Along the west side of the landfill, the lower outwash grades from fine/medium sand at the top of the unit to coarse sand with discontinuous gravel lenses near the base of the unit. The coarsest intervals of lower outwash have been observed near the base of the unit at wells P-325L and P-326L in RL/TB and at well P334L. The lower outwash is confined along the west side of the landfill by till of the Late-Wisconsinan, Cromwell Formation (Barr, 2015a).

The lower outwash extends to the west across the investigation area at/around elevation 860 feet MSL. The thickness of the lower outwash varies from approximately 60 feet thick west of the Pre-Subtitle D portion of the landfill to approximately 25± feet west and southwest of the landfill (Barr, 2018). Recent investigations have shown the lower outwash is continuous beneath and beyond RL/TB with the exception of one boring location south of well P-333L (Barr, 2018). RL/TB, the large wetland complex located west of the landfill, is with covered with floating bog vegetation with the exception of small areas of open water. The floating bog makes for difficult/unsafe access, especially to equipment traffic. The RL/TB is underlain with loose organic silt/clay (i.e., lake sediments). Water and mucky lake sediment depths near 30 feet have been encountered during past drilling operations in RL/TB.

The groundwater flow direction in the lower outwash unit is to the west beneath the Pre-Subtitle D portion of the Site and west-southwest beneath RL/TB (Figure 3). The groundwater velocity at the lower outwash unit (where organics mass transport is predominantly occurring west of ERL) is estimated to be between 60 and 112 feet/year, based on aquifer parameter estimates (Barr, 2020b) and the observed extent of organics downgradient of the landfill. Groundwater velocity may be higher in portions of the lower outwash unit due to heterogeneity, particularly beneath RL/TB.

The Eau Claire Formation, a regional confining unit, is the uppermost continuous bedrock unit at the Site. The Eau Claire Formation forms a local bedrock high in the southwestern portion of the Site and, in places, is capped by clayey, Pre-Wisconsinan till and/or a thin mantle of fine sandstone/siltstone from the basal Wonewoc Formation (Barr, 2015a). The Mt. Simon Sandstone is the uppermost bedrock aquifer in the area and is underlain by crystalline Pre-Cambrian bedrock. Prior groundwater investigation has shown the Mt. Simon does not contain modern (i.e., tritiated) water (Geomatrix, 1998), indicating that it does not receive recharge at or near the Site.

2.3 Groundwater Quality

ERL is committed to preventing exposure to organic compounds from the landfill in nearby water supply wells. ERL has developed an extensive groundwater monitoring network that is based on numerous hydrogeologic investigations that have been conducted over the past 20+ years (Barr, 2015a, 2018). The 2019 groundwater monitoring network included 39 monitoring wells and 11 piezometers (Figure 2). Additional monitoring network information is provided in the 2019 Annual Water Quality Monitoring Report (Barr, 2020a).

Routine monitoring includes sampling and analysis of organic and inorganic compounds including metals and general chemistry parameters. ERL began low level reporting for vinyl chloride in 2015 and for nine other organic compounds (including trichloroethylene [TCE]) in 2017.

A summary of the 2018 through 2020 (April) data is included in Appendix A and vinyl chloride concentration trend plots are included in Appendix B. No organics have been detected above their respective HRL in wells located off of ERL Property². On ERL property, no organics have been detected above their respective HRL in wells located at or beyond the groundwater compliance boundary except for vinyl chloride and TCE. Vinyl chloride was detected above the HRL (0.2 µg/L) in twelve monitoring wells (and above the Intervention Limit [IL] of 0.050 µg/L in five additional monitoring wells). TCE was detected above the HRL (0.4 µg/L) in one monitoring well (P-323L) (and above the IL in two other monitoring wells). The highest vinyl chloride concentration detected in groundwater in 2019 was at non-compliance well P-308L (1.9 µg/L) located approximately 20 feet from the western edge of the fill. The highest detected TCE concentration in 2019 was at well P-323L (1.3 µg/L). Vinyl chloride concentrations are typically not detected in leachate samples, although reporting limits usually elevated due to sample matrix effects.

² Vinyl chloride was detected in one sample collected from investigation borings B330 and B331 in 2016 (Barr, 2018). These data are considered in the vinyl chloride delineation included in this report.

Other confirmed organics detections in groundwater at concentrations below HRLs (if established) in monitoring wells located at or beyond the compliance boundary included cis-1,2-dichloroethylene (cDCE), 1,1-dichloroethane, 1,2-dichloroethane, chloroethane, dichlorodifluoromethane (Freon-12), dichlorofluoromethane (Freon-21), ethyl ether, and tetrahydrofuran (Appendix A). Of these, only 1,2-dichloroethane was detected above the IL (and was in the presence of vinyl chloride). Organic compounds (other than vinyl chloride) in groundwater at distal wells P-334L and P-694477 include 1,1-dichloroethane (unconfirmed), dichlorodifluoromethane, dichlorofluoromethane, and ethyl ether. The 2019 groundwater quality data are described in more detail in the 2019 Annual Water Quality Monitoring Report (Barr, 2020a).

Vinyl chloride and TCE are the constituents of concern (COCs) and the drivers for consideration of corrective actions at the Site.

2.4 Vinyl Chloride Extent and Mass in Groundwater

Recent groundwater investigations have focused on defining the extent of COCs in the groundwater at and downgradient of the ERL (Barr, 2016 and 2018). Because TCE was detected above the HRL in only one well (P-323L), the following discussion focuses on vinyl chloride.

The estimated width of the vinyl chloride plume above the HRL on the west side of the landfill (i.e., roughly transverse to the groundwater flow direction) is approximately 1,500 feet and is defined by wells P-301L and P-324L, respectively (Figure 4). Farther west, the plume is defined to the south by wells P-322L, P-324L, and P-335L. The southern edge of the vinyl chloride plume is located near monitoring well P-694477 based on the initial detection of vinyl chloride slightly above the IL (0.05 µg/L) but below the HRL in September and December 2019. The northern extent of vinyl chloride has been defined approximately by past sampling of well P-327L (non-detect). The maximum extent of vinyl chloride at concentrations at or above the IL shown on Figure 4 is based on an evaluation of lower outwash groundwater contours from 2014 through 2019.

The western extent of vinyl chloride is depicted on Figure 4 and is estimated to be near well P-334L based on detections at or slightly above the IL (but below the HRL). Vinyl chloride was not detected in April 2020 sample from well P-334L (Appendix A). This western (leading) edge of vinyl chloride is approximately 3,500 feet from the nearest downgradient residential well located farther west/southwest (Figure 5). Based on the estimated of groundwater flow rate (112 feet per year), the travel time from well P-334L to the nearest residential well is estimated to be between 25 to 35 years based on advective transport using recent monitoring results; however, uncertainties regarding outwash heterogeneities make it difficult to develop a prediction with a high degree of certainty.

Vinyl chloride can be produced as a daughter product via reductive dechlorination from cDCE. Since the 1990s, the reductive dechlorination pathway of chlorinated compounds has been well studied. The sequential dechlorination pathway (stepwise removal of a chlorine atom and replacement with hydrogen atom), that includes cDCE and vinyl chloride, is commonly from more highly chlorinated compounds tetrachloroethylene (PCE) and TCE:



Because vinyl chloride is a daughter product of cDCE dechlorination, the extent of vinyl chloride in groundwater is directly related to where cDCE degrades to vinyl chloride along the flowpath. For example, 1 µg/L of cDCE degrades to an equivalent micromolar mass of vinyl chloride with a concentration 0.6 µg/L (lower concentration because molecular weight of vinyl chloride is lower than cDCE); therefore, the low concentrations of cDCE that are observed in groundwater can degrade to vinyl chloride concentrations well above the reporting limit (0.05 µg/L). This process masks the overall magnitude of vinyl chloride degradation along the flowpath and gives the false appearance of more tempered vinyl chloride degradation because the cDCE plume overlaps the vinyl chloride plume.

As shown on Figure 4, cDCE is present in groundwater at wells P-325L and P-326L and not present in groundwater at P-334L. The limited extent of cDCE, coupled with decreasing vinyl chloride concentrations with distance, provides evidence that degradation is occurring and that the extent of vinyl chloride may be extended downgradient due to sequential dechlorination reactions and not from limited degradation of vinyl chloride. TCE in groundwater at wells located along the compliance boundary and upgradient of P-325L and P-326L and not in downgradient wells also supports evidence of degradation and may further add to the downgradient extent of cDCE and vinyl chloride.

Routine monitoring and prior groundwater investigation that included vertical water quality profiling showed that the vertical extent of vinyl chloride is limited to the lower outwash (Barr, 2020a and 2018; Figures 6, 7, and 8). Vinyl chloride is present in groundwater in the lower outwash downgradient of the Site and not detected in groundwater samples from in the upper outwash or the Mt. Simon sandstone (beneath the Eau Claire Formation). West of the landfill, near vertical aquifer profile borings B-330 and B-331, vinyl chloride was detected in the lower outwash and not detected in the outwash deposits that were encountered above (i.e., shallower than) or below (i.e., deeper than) the lower outwash or in the underlying Eau Claire Formation (uppermost bedrock) (Figure 8; Barr, 2018).

Based on groundwater monitoring data and estimated flow rates, the total mass of vinyl chloride present in the lower outwash unit west of the landfill is calculated to be approximately 1 lb. The estimated current mass flux of vinyl chloride from ERL through the cross sectional plane represented in Figure 8 is 0.07 lbs/year, which is approximately 42% lower than the estimates vinyl chloride mass flux from April 2010 (Appendix C). These low total mass and mass flux estimates reflect the relatively low vinyl chloride concentrations in groundwater downgradient of ERL. The vinyl chloride mass estimates/calculation details are included in Appendix C.

2.5 Area Water Supply

The ERL and surrounding area are not serviced by public utilities (i.e., no City water or sewer). Water at the ERL office is provided by a 360-foot well (unique ID #420558) referred to as the ERL Shop Well (Barr, 2020a). Downgradient of the Site, with the exception of the Ridges of Rice Lake Development community supply well (unique well ID #626766) and the water supply well at 22447 Tipton Street (unique ID #813437), residences have individual domestic water supply wells that are known or assumed to be

completed in the lower outwash unit. The Ridges of Rice Lake well is completed in an outwash near the base of buried bedrock valley between 294 and 325 feet bgs (approximate elevations 699-668 feet relative to mean sea level [MSL]) and the 22447 Tipton Street well is completed in the Mt. Simon Aquifer between depths of 254 and 300 (elevations 732 and 686 feet MSL). The nearby residential wells are routinely monitored per ERL permits and licenses and no organics have been detected in the existing residential wells. Appendix D includes a summary of the water supply wells located west of the Site and past residential water well monitoring data.

The ERL routinely samples 11 nearby water supply wells, including nine domestic wells, one community water supply well (Ridges of Rice Lake development), and the ERL Shop well per Permit SW-74. Nine additional residential wells have been sampled as part of recent hydrogeologic investigations (Barr, 2018). The locations of the monitored residential wells are shown on Figure 5.

2.6 Prior Corrective Actions

In response to increased concentrations of organics in groundwater, ERL completed a Corrective Action Investigation (Camp, Dresser, & McKee, 1994) and a series of groundwater investigations to investigate the organics source and extent (Geomatrix, 1998, 1999, and 2000). A spike in organics loading to groundwater at the top of the lower outwash unit was demonstrated near the southwest corner of the Pre-subtitle D portion of the landfill in 1991. Total organics concentrations at monitoring well P-17C increased from less than 1 to more than 24 milligrams per liter (mg/L) between 1992 and 1994, subsequently concentrations rapidly decreased to less than 1 mg/L by 1997 (Barr, 2015a). In this same timeframe, other wells located southeast of P-17C (i.e., beneath the future landfill footprint), such as P-43B, also had relatively high concentrations of organics in groundwater (Appendix B, Chart and Figure B-5) (e.g., vinyl chloride at 12 µg/L; Camp, Dresser, & McKee, 1994; Barr, 2015b). A

These organic detections and trends prompted the enactment of facility improvements designed to mitigate organics in groundwater and consisted of final cover installation and active gas extraction. ERL placed final cover over much of the unlined portion of the landfill, starting with cell 2 (which is adjacent to well P17C); by 1997 over cells 1, 3, 4, 5, and 7 were also covered. The active landfill gas extraction system was installed and became operational in March 1996 and was augmented in 1997 and 2001 specifically to address organics in groundwater at the landfill. Vinyl chloride concentrations in landfill gas samples collected from 2008 to 2010 ranged from 220 to 670 part per billion by volume which equates to approximately 30 to 90 lbs of vinyl chloride removal annually via landfill gas extraction applying the average LFG extraction volume between 2015 and 2019.

Groundwater investigations and isotopic sample analysis concluded that the organics spike in the P-17C Area was the result of leachate from the Pre-subtitle D portion of the landfill (Geomatrix, 1998). Due to the elevated reporting limits and sample matrix interference issues, the concentrations of chlorinated ethylene compounds (such as vinyl chloride and trichloroethylene) were largely reported as non-detect in leachate samples and from well P-17C. Despite the elevated reporting limits, based on total organics concentrations of up to 24 mg/L, it is reasonable to assume that the chlorinated ethylene inputs to groundwater from the unlined portion of the landfill were higher at that time. As discussed in this report,

vinyl chloride and TCE are the only organics detected in groundwater above their respective HRLs at ERL, concentrations of both these parameters have been low (i.e., non-detect to approximately 2 micrograms per liter [µg/L]) or decreasing since the implementation of prior corrective actions, and the extent of TCE is limited compared to vinyl chloride. In response to the slug of leachate affected groundwater observed at P-17C, an oxygen diffusive system was installed in the P-17C area to deliver oxygen to groundwater at the top of the lower outwash to spur the rapid degradation of the targeted compounds (e.g., methyl ethyl ketone, acetone, etc.) via a cometabolic degradation. The system was operated from 2003 to 2008 and, during monitoring data collected demonstrated that the operation of the system increased dissolved oxygen and decreased organics concentrations in groundwater in the P-17C area. System operation was discontinued to allow groundwater to return to reducing conditions and the target compound concentrations remained low.

2.7 Conceptual Release Model

The evidence points to both leachate and landfill gas from the pre subtitle D fill area as the source area for organic impacts to groundwater at the ERL (Barr, 2015a; Geomatrix, 1998). The pre subtitle D unlined area consists of 28.1 acres and approximately 5 million cubic yards of waste that was placed from 1972 to approximately 1990. Waste Management acquired the site in late 1995 after unlined filling had ceased. Evidence for the release of leachate to groundwater is described in the above Section 2.6. Gas migration is also attributed to be a source of impacts to groundwater (Barr, 2015; Geomatrix, 1998; Camp, Dresser & McKee, 1994) based on the fact that vinyl chloride is a relatively more common constituent of landfill gas than leachate. Since Minnesota Rules require the separation between waste and groundwater of at least 5 feet and sand exists under the liner, a potential unsaturated conduit exists between the composite liner system and groundwater. These conditions may trap landfill gas that potentially migrates from the Pre-subtitle D area allowing it to partition into groundwater.

Releases of leachate and landfill gas from the unlined waste have resulted in organics concentrations beneath, upgradient, and south of the Pre-Subtitle D area at ERL (Barr, 2015a and 2015b). A leachate (slug) release was well documented in the P-17C Area and was characterized by high concentrations of non-chlorinated organics that masked the concentrations of chlorinated organics. Elevated chlorinated organics concentrations were quantified southeast of P-17C Area prior to the construction of landfill cells 13 and 14 at monitoring well P-43B (e.g., vinyl chloride concentrations of 12 µg/L in 1996; See Appendix B, Figure B-5 for historical trend charts for wells P-17C, P-43B, P-304C, P-313C, and P-326L) (Camp, Dresser & McKee, 1994; Barr, 2015b). These chlorinated (and other) organics have migrated west (downgradient) with groundwater and have decreased in concentrations due to natural attenuation processes; however, the attenuation processes have not occurred at a rate sufficient to meet applicable regulatory criteria in areas along the compliance boundary.

Past corrective actions including final cover placement and the installation of an active gas extraction system appear to have significantly reduced the magnitude of the release from the Pre-Subtitle D, and the high concentrations at documented at P-17C and P-43B in the early to mid-1990s are no longer present in groundwater along the western side of the landfill (Barr, 2020a). Currently, organic concentration trends along the west side of the landfill include predominantly decreasing trends south of the P-17C Area and a

mix of stable, increasing, and decreasing trends to the north. Concentrations of chlorinated ethenes along the centerline of the plume evidence attenuation by reductive dechlorination with distance from the Pre-Subtitle D area (Appendix B). The current vinyl chloride concentration trends and related projections may underestimate the degree and rate of attenuation with distance (or time) due to the reductive dechlorination reactions that transform parent compounds TCE and, more prominently, cDCE to vinyl chloride.

Water quality data from 2019 and early 2020 indicate the fringe of the vinyl chloride plume is present near monitoring wells P-334L and P-694477. The first time detections of vinyl chloride in samples from these wells in 2019, coupled with some non-detect results, suggest more data is needed to determine whether the vinyl chloride plume is migrating or stable. Based on Site history the leading edge of the plume is anticipated to result from higher vinyl chloride concentration flux from the 1990s (or prior) and current vinyl chloride flux appear to be substantially lower, likely as a result of past groundwater corrective actions (i.e., final cover and active gas extraction). Based on the estimated vinyl chloride mass flux, the plume is anticipated to be stable or shrink in the future as a result of natural attenuation processes; however, additional wells and data collect are needed to substantiate this model and document the mass/concentration decreases.

3.0 Corrective Action Objectives

This section presents groundwater corrective action objectives for ERL.

3.1 Corrective Action Goals

The primary and near-term goal for implementing corrective action at the ERL is to protect human health by preventing exposure to organic compounds in water supply wells³. Recent residential water supply well monitoring data indicate that this goal is being achieved under current/natural conditions; however, ERL is committed to proactively protect residential water wells by taking appropriate actions to improve future protectiveness.

The secondary, longer-term corrective action goal is to increase the certainty of protectiveness to nearby water supply wells by meeting appropriate groundwater criteria. ERL is addressing impacts related to the closed, Pre-Subtitle D portion of the landfill, so the establishment of alternative limits under Minnesota Rule 7035.2815, Subpart (H)(2) may be appropriate (see Section 5.1).

It should be noted, that achieving corrective action objective #1 satisfies a risk-based remedial approach and additional effort beyond verifying that corrective action objective #1 is achieved and risk to human health is mitigated is unwarranted from a technical standpoint.

3.2 Constituents of Concern

As described in Section 2.4 of this report, vinyl chloride and TCE are the COCs at the Site.

3.3 Potential Exposure Pathways and Receptors

The potential exposure pathway for COCs in groundwater at ERL is ingestion by a water well user. Municipal water is not available near ERL so nearby residents use groundwater as their water supply. Based on a search of the Minnesota Well Index, approximately 23 residential water supply wells are located within 8,500 feet of the ERL in the southwest/west direction. With a few exceptions, these wells are known or assumed to be completed in unconsolidated outwash that correlates to the lower outwash unit at the Site (Figure 5; Appendix D).

ERL has routinely collected and analyzed water samples from the residential water supply wells nearest to the landfill (Appendix D). Water samples from an extended residential well network were collected and analyzed between 2015 and 2017 as part of past groundwater investigations (Barr, 2018). Organics attributed to the landfill have not been detected in samples from water supply wells near the ERL with one

³ This corrective action objective includes the COCs and other organic compounds in groundwater attributable to the ERL.

exception that was addressed by ERL in 2014⁴. ERL has also developed a monitoring well network to provide early warning detection upgradient of nearby water well users.

Groundwater discharge to RL/TB is possible given the upward hydraulic gradients between the lower outwash and the surface water elevation. However, organics concentrations are generally below surface-water criteria established by the MPCA (see Permit SW-74) and, based on the lateral extent of vinyl chloride and the vertical extent of vinyl chloride (Barr, 2018), groundwater discharge to RL/TB from the lower outwash does not appear to be significant.

⁴ ERL arranged for the installation of a point-of-entry water treatment system at a Tipton Street residence in late 2014 as a result of a confirmed organic compound detection (at a concentration below the HRL) and arranged for the installation of a deeper replacement water supply well in 2015.

4.0 Corrective Action Technologies

The following sections describe corrective action technologies identified as potentially viable in the Groundwater Corrective Actions Alternatives Screening Report (CAAR; Barr, 2019):

- 1) Alternate Residential Water Supply
- 2) Monitored Natural Attenuation
- 3) Groundwater Extraction and Treatment
- 4) In-Situ Groundwater Treatment

At the request of MPCA, evaluation of the excavation and relining of Pre-Subtitle D portion of the landfill and off-site groundwater extraction are also included in this report. No additional action and air sparging technologies were previously screened out in the CAAR (Barr, 2019) and are not considered in this evaluation. Specific correction action alternatives for the ERL are described in Section 5 of this report.

4.1 Alternate Residential Water Supply

Eliminating the groundwater pathway between the landfill and residential water supply wells will eliminate the risk of vinyl chloride (and other organics) exposure to residents (i.e., groundwater users) and will achieve the primary and near-term goal of protecting human health by preventing the migration of organic compounds to water supply wells.

Alternative water supply options include the installation of point-of-entry treatment (POET) systems that treat groundwater at individual residences upstream of use or replacing existing individual water supply wells completed in the lower outwash and located downgradient of the plume with individual water supply wells screened in deeper geologic units. POET systems are commonly deployed in private residences and the treatment media / technology is selected based on specific treatment needs. POETs require ongoing maintenance for effective long-term treatment and the installation/maintenance requires work inside individual residences. The installation of replacement water supply wells for use at residences downgradient of the existing organics detections is an option given that organics are limited to the lower outwash and the Mt. Simon is accessible. The use of deeper wells is preferred by ERL (compared to POETs) provided water quality standards are met in the deeper units.

The installation of deeper replacement wells (or POETs) require owner permission to access, install, connect, and test the installations. ERL has a successful track record for open communication and developing mutually acceptable access agreements with individuals (without complaint to State, County, or City).

4.2 Monitored Natural Attenuation

Natural attenuation includes destructive processes (biodegradation and abiotic degradation) and nondestructive processes (e.g., dispersion, diffusion, and sorption) that affect the fate and transport of organic compounds in groundwater systems (USEPA, 1998). The application of a monitored natural

attenuation (MNA) remedy to address organics in groundwater, in whole or as part of a combined remedy, is common at groundwater sites in Minnesota and throughout the United States.

The Groundwater Natural Attenuation Report (Barr, 2020b) provided an updated screening evaluation of geochemical conditions in the lower outwash at the ERL to inform the potential application of natural attenuation as a corrective action strategy and an evaluation of geochemical conditions, terminal electron acceptors, distance-concentration plots, and estimates of degradation rates downgradient of the landfill. These evaluations showed that conditions in the P-17C area provide evidence that reductive dechlorination of chlorinated compounds is occurring. Farther downgradient (near and beyond the ERL property boundary) prevailing geochemical conditions are iron-reducing (which is suitable for the natural attenuation of vinyl chloride through other destructive and nondestructive processes).

Recent data have shown sporadic detections of low concentrations of vinyl chloride at monitoring wells P-334L and P-694477. Vinyl chloride concentrations in µg/L at well P-334L between the 2019 and 2020 spring sampling events have been 0.050, <0.050, 0.050, 0.10, and <0.050. Over this same period, vinyl chloride concentrations (in µg/L) at well P-694477 have been <0.050, <0.050, 0.10, 0.075, and <0.23. These data demonstrate that both wells are located near the fringe of the vinyl chloride plume. Further monitoring and new MNA monitoring locations upgradient and downgradient of P-334L would provide insight on vinyl chloride plume stability and attenuation rates downgradient of the landfill.

In effort to provide additional context and address feedback from the MPCA and others, additional/refined evaluation of vinyl chloride natural attenuation is provided in Appendix C. The evaluation is based on existing data through 2019 and is based on the assumption that the plume is stable. Specifically, Appendix C presents:

- Refined velocities for groundwater flow and vinyl chloride migration.
- Vinyl chloride attenuation rates based on data from individual wells and the resulting estimated timeframes to achieve the ILs at those wells - well specific attenuation rates ranged from 0.081 (at P-326L) to 0.269 (at P-314C) and projected timeframes to achieve groundwater criteria ranged from approximately 4 years (at P-314C) to 28 years (at P-326L).
- Bulk vinyl chloride attenuation rates based on vinyl chloride data and total molar concentrations (which incorporate vinyl chloride parent products) - bulk vinyl chloride attenuation rates varied from 0.045 to 0.145/yr.
- Estimated vinyl chloride concentrations that are projected to attenuate between the compliance boundary and the nearest residential well downgradient of monitoring well P-334L - 7 µg/L (average) with a range of 1 to 90 µg/L.
- Estimated ranges of vinyl chloride concentrations that are projected to attenuate between monitoring well P-334L and the nearest downgradient residential well - 0.54 µg/L (average) with a range of 0.21 to 1.8 µg/L.

- Estimated distance vinyl chloride is projected to travel downgradient from the compliance boundary - 5,400 feet (average) with a range of 3,500 to 9,000 feet.
- Estimated vinyl chloride mass and mass flux downgradient of ERL – estimated vinyl chloride mass is approximately 1 lb and the estimated vinyl chloride mass flux is 0.07 lbs/yr.

The 2019 and April 2020 vinyl chloride concentrations in groundwater along the compliance boundary and at monitoring wells P-334L and P-694477 are less than the estimated range of concentrations expected to attenuate before reaching the nearest down gradient residential well, suggesting vinyl chloride at these wells will attenuate before reaching downgradient receptors. It should be noted, however, that peak vinyl chloride concentrations are projected to reach well P-334L between 2026 and 2034 due to the leachate slug that was released in the P-17C area in the early to mid-1990s.

Based on this refined analysis, natural attenuation in the lower outwash at and downgradient of the landfill appears to be sufficient to eliminate the risk to nearby residents and can achieve the primary and near-term goal of protecting human health by preventing the migration of vinyl chloride to water supply wells; however, the given the uncertainty of plume stability, the presence of other organics at P-334L and P694477 (prior to vinyl chloride), and the lack of additional monitoring wells downgradient of P-334L, ERL does not intend to propose MNA as a standalone remedy.

In regard to natural attenuation being capable of meeting the longer-term goal of increasing protectiveness to nearby water supply wells by meeting appropriate groundwater criteria, data are mixed. The three southernmost wells located along the compliance boundary within the organics plume (P-314C, P-313C, and P-323L) have shown decreasing vinyl chloride concentration trends since 2011 (Appendix B; Barr, 2020b) and the refined analysis indicates that criteria may be achieved in these wells within 11 years; however, the presence of parent compound cDCE at these wells (and TCE at P-323L) adds a degree of uncertainty to these projections. In areas in the northern portion of the delineated organics area, projections for natural attenuation to achieve groundwater criteria were not made due to mixed vinyl chloride concentration trends (including decreasing trends at wells P-320L/P320C2, stable/no-trends in the other wells located closest to the groundwater compliance boundary, and closer to the landfill at the top of the lower outwash increasing trend is present at wells P-301C and P-302C) (Appendix B).

4.3 Groundwater Extraction and Treatment

Groundwater extraction and treatment is a corrective approach that has been applied to intercept the migration of groundwater constituents and provide treatment with physical, chemical, or biological processes. Applications include the installation and operation of a groundwater extraction well(s) to remove impacted groundwater from the subsurface for discharge with or without treatment depending on a number of site-specific factors. The application details and ultimate effectiveness of a groundwater extraction approach is a function of site hydrogeologic conditions (e.g., unconfined vs. confined groundwater conditions, etc.), placement and construction of extraction wells relative to the source, operation of the system (e.g., steady pumping vs. pulsing), and the requirements for treating and discharging the extracted groundwater. Groundwater extraction physically removes groundwater around and upgradient of the extraction well(s) and lowers the hydraulic head/potentiometric surface in the

vicinity of pumping which in turn reduces the gradient and groundwater velocity and/or can result in localized flow stagnation on the downgradient side of the extraction system. The performance of a groundwater system is primarily a function of the hydrogeologic properties of the targeted and overlying/underlying geologic units, subsurface/geologic unit heterogeneities, and physical and chemical processes in the geologic unit and extraction wells (e.g., COC back diffusion from the aquifer matrix, well fouling, etc.). For these reasons, reliable estimates of achieving groundwater criteria are difficult (or not feasible) to make and are typically made either by reviewing multiple years of water chemistry monitoring data after groundwater extraction has been occurring or grossly with the assistance of a calibrated groundwater flow model and simplifying assumptions.

Although the concept of extracting groundwater to remove COCs is straightforward, groundwater extraction systems present unique challenges in the attainment of groundwater performance standards due to asymptotic COC response as a result of physical and chemical processes in the subsurface and result in a significant withdrawal of groundwater volume that may affect surrounding groundwater users or surface water habitats while producing a steady stream of effluent that requires management (typically under a discharge permit). Furthermore, the efficiency of COC removal on a mass per volume of water basis is often low and can decrease with continued pumping. At ERL, assuming a groundwater extraction system is implemented west of the Pre-Subtitle D area, it is estimated that the current annual flux of vinyl chloride (0.2 lbs) will be removed via treatment of 21,000,000 gallons (at an average withdrawal rate of 40 gpm) of groundwater in one year.

Given the hydrogeologic conditions and nature of the Pre-Subtitle D source, groundwater extraction is an option that could be employed to help achieve the secondary corrective action objective (meeting applicable groundwater criteria) by using a groundwater extraction well(s) located along the western edge of the landfill for the targeted removal of groundwater from the lower outwash unit. The lower outwash unit is confined unit which may be favorable for gradient control purposes but can present unique geochemical challenges. Existing wells P-308L (6-inch dia.), P-321L or P-324L (4-inch dia.) may be viable options. The preliminary estimated total pumping rate along the western side of the landfill ranges from 20 to 60 gallons per minute (gpm). Groundwater extraction in this range will require groundwater appropriations permitting with the Minnesota Department of Natural Resources (MDNR).

Options for managing the extracted groundwater include treatment via an on-site water treatment system with discharge to and infiltration system or into RL/TB. Both options require permitting, design, pilot testing, construction, start-up, and long-term system operation and maintenance. Discharge to a publicly owned treatment works (POTW) is not considered in this report due to the high disposal costs and concerns regarding long-term viability of discharge of impacted groundwater.

At MPCA's request, a corrective action alternative involving the construction of an off-site groundwater extraction is also evaluated in Section 5 of this report.

4.4 In-Situ Treatment

In-situ treatments involve the introduction of amendments that are intended to foster or enhance the attenuation, fixation, or destruction of COCs in the subsurface. In-situ treatment agents are applied to the

subsurface to contact/interact with COCs and have the benefit of not generating waste streams that require ongoing management.

The hydrogeologic conditions (heaving sands), vinyl chloride plume size and depth, and the size and nature of the source limits the practicality of in-situ treatment at ERL to targeted applications of injections via appropriately spaced permanent wells, injection via soil borings, or diffusive technologies. Implementation of in-situ remedies downgradient of the ERL (off-site) to address low COC concentrations is inefficient and presents several challenges including access to privately-owned land and safety concerns with working in RL/TB. For these reasons, in-situ treatment is not evaluated as a plume-wide treatment in this report; however, two in-situ treatment approaches, enhanced natural attenuation and permeable reactive barrier, could be considered in the future to help achieve the second corrective action objective in targeted areas under an Adaptive Site Management strategy. Overviews of conceptual approaches for each option are described below:

Enhanced natural attenuation can promote the increased biodegradation of vinyl chloride via the addition of electron donors, nutrients, and microbes to the aquifer. Vinyl chloride can attenuate under aerobic and anaerobic conditions and the rate and efficiency of the attenuation processes can be enhanced by carefully altering geochemical conditions in the aquifer through in-situ delivery of treatment agents or dissolved gases. General and proprietary treatment agents can be used to stimulate the microbial community in the aquifer and promote conditions to support aerobic or anaerobic biodegradation. These or other commonly available products may be used individually, or in combination, to enhance biodegradation rates at some sites provided field and aquifer conditions are suitable.

Permeable Reactive Barriers (PRBs) are installations of reactive materials that can attenuate dissolved phase contaminants in groundwater by sorption or transformation as they flow through the reactive zone under a natural or induced gradient. Various materials (e.g., zero-valent iron or carbon-based products) can be used. The effectiveness of the injection media in addressing vinyl chloride is highly dependent on direct contact, geochemical conditions, small scale hydraulic properties (e.g., hydraulic conductivities), and uniform placement of the media.

Permitting through the Minnesota Department of Health and U.S. Environmental Protection Agency may be required for the use of inject treatment agents.

4.5 Pre-Subtitle D Landfill Excavation and Placement on Liner

This technology is included in this report at the request of MPCA. The legacy waste in the unlined, Pre-Subtitle D closed portion of the landfill is the source of organics in leachate-impacted groundwater at the ERL. Waste removal from the unlined portion of the landfill and placement in a lined cell would eliminate the original source of organics in groundwater; however, the flux of remaining impacted groundwater, leaching from residual source material, back diffusion of organics sorbed onto geologic units, or leaching from unlined wastes that may not feasibly be excavated is expected to continue after excavation and relining is completed. The flux of impacted groundwater from the residual/remaining source materials would end significantly sooner if the area was excavated but would likely require groundwater corrective action downgradient of the landfill during and after implementation as leachate leakage rates to the

groundwater system would likely increase as a result of increased infiltration and disturbance of the unlined waste.

The ERL has approximately 4 million cubic yards (MCY) of remaining permitted airspace. The Pre-Subtitle D waste (approx. 4.9 MCY of waste) would be excavated to the extent feasible and would require transport to another lined cell for which there is not sufficient capacity. Safe excavation would require removal of significant volumes of wastes that are currently on lined areas to provide adequate factor of safety for slope stability. This approach would also require existing, overlying, or abutting lined cells (DC-1, DC-2, 6S, 10, and 11) to be partially excavated for access to the unlined legacy waste plus the excavation of an estimate 1 MCY of non-waste soils. Identification and planning for significant construction, geotechnical, interim leachate management, oxygen intrusion, odor/landfill gas management, unknown/restricted waste management, and other issues associated with implementation of this option is beyond the scope of this document.

5.0 Corrective Action Alternatives Evaluation

The following corrective action alternatives for organics in groundwater at and downgradient of the ERL are evaluated below:

- Alternative #1: Monitoring Natural Attenuation and Residential Water Supply Replacement
- Alternative #2: Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement
- Alternative #3: Pre-subtitle D Landfill Excavation and Placement on Liner
- Alternative #4: Groundwater Extraction (on and off-site) and Treatment

Each corrective action alternative is evaluated individually against the corrective action objectives and additional criteria based on CERCLA guidance (USEPA, 1988) below and a summary is provided in Table 1.

5.1 Alternative #1: Monitored Natural Attenuation and Residential Water Supply Replacement

Alternative #1 would involve preventing exposure to downgradient residents by replacing residential water supply wells and the development of a groundwater monitoring network and program to evaluate and document the effects of natural attenuation. Under this alternative, ERL would replace lower outwash water supply wells that are located downgradient or near sidegradient of the projected migration pathway of organics with deeper wells completed in a hydraulically separated unit (assuming Mt. Simon aquifer for the purposes of this report). Subject to the owner's acceptance, at no cost to the resident, ERL would arrange for the permitting, drilling, installation, and well development. In addition, ERL would sample the well to evaluate groundwater quality. If the water is free of organics and analyte concentrations meet HRLs and USEPA Maximum Contaminant Levels, a new submersible pump would be installed and the well would be connected to the house and put into service. The former residential well would be sealed. The work would be conducted under an access agreement with the owner and performed by a licensed well contractor with knowledge of the area.

This alternative assumes that ten replacement wells will be installed. If a resident does not accept the well replacement offer, the installation POET system or, if feasible, installation and monitoring of a sentinel well on their property will be offered. If a resident insists on a "no action until organics detected approach," a response that includes follow-up actions (e.g., providing bottled drinking water, expedited verification resampling, communications, and an anticipated timeframe for establishing an alternate water supply) will be prepared and implemented.

The MNA component would include installing additional monitoring wells, determining the status of the organics plume (in terms of stability), estimating the organics mass reductions that are occurring as a result of natural attenuation processes, refining the estimates of point-specific and bulk attenuation rates (and related projections) with additional data, and documenting changes in organics concentrations

versus time at locations in the plume. A monitoring plan would be developed and monitoring wells would routinely be analyzed for MNA parameters.

MNA would have on-site and off-site components that build on the details described in Appendix C. The on-site component involves tracking vinyl chloride concentration trends and monitoring geochemical conditions for changes in wells near the compliance boundary. The off-site (distal) component includes the installation and monitoring of monitoring wells up and downgradient of well P-334L to allow better understanding of attenuation and plume stability over time, evaluation of geochemical conditions, and evaluating vinyl chloride and parent compound ratios and concentration trends versus time and distance.

Overall Protection of Human Health and the Environment

Alternative #1 provides the highest degree of protectiveness to the health of nearby residents (i.e., groundwater users) by replacing lower outwash supply wells with deeper water supply wells. Eliminating the groundwater pathway between the landfill and the water supply wells will eliminate the risk of exposure to vinyl chloride (and other organics). Based on prior vertical delineation efforts, completing wells in the Mt. Simon provides a high degree of confidence that the pathway will be incomplete. Using a licensed well contractor, requiring well construction materials and methods that comply with the State well code, sealing the former wells, and conducting periodic monitoring will also support the protectiveness of this alternative.

In regards to MNA, the refined analyses presented in this report adds to the weight of evidence that natural attenuation processes are occurring to a degree that supports further evaluation of this alternative to demonstrate its future protectiveness. Recent evaluations have utilized existing wells to update screening evaluations and generate the preliminary estimates of attenuation rates and vinyl chloride travel distances. Additional monitoring points along the plume centerline and additional data to better evaluate trends and parent compound concentrations will help to better evaluate, demonstrate, and document the effectiveness of natural attenuation downgradient of the landfill.

Meeting Applicable Requirements

The primary goal of the corrective action objectives evaluated in this report is to protect human health and the environment and the secondary goal is to meet applicable groundwater criteria to improve the protectiveness of the implemented corrective action. ERL will request the MPCA establish alternative limits for the Pre-Subtitle D portion of the landfill per Minnesota Rule 7035.2815 Subp. 4 (H)(2). The request will be submitted under separate cover and will provide the proposed approach and technical basis for development of the alternative limits. The envisioned approach includes completing the MNA evaluation and, if appropriate, applying technically sound natural attenuation rates to back calculate protective alternative limits to apply at the Site. This approach is consistent with MPCA Closed Landfill Program's consideration of risk to human health, evaluation of plume stability, and strategy to collect necessary data to if environmental response actions are needed to further reduce risk (MPCA, 2020).

Alternative #1 relies on the natural processes that affect water quality at and downgradient of ERL. Given the weight of evidence that natural attenuation processes are occurring, the projections in this report

suggest natural attenuation may be a feasible approach to develop and meet alternate limits that are established under Minnesota solid waste rules.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative #1 relies on the natural processes that are occurring at and downgradient of the ERL for the reduction of toxicity, mobility, or volume of vinyl chloride. The reduction in toxicity of vinyl chloride occurs as a result of sequential dechlorination or via other destructive attenuation reactions (Barr, 2019) which, when completed, results in non-toxic daughter products. Other organics detected in groundwater downgradient of the landfill are below HRLs, indicating the concentrations are considered non-toxic. The mobility and volume of vinyl chloride and other organics would be the subject of the MNA evaluation effort; however, recent water quality data demonstrate that distal wells P-334L and P-694477 are located near the fringe of the vinyl chloride plume and increasing concentration trends are not confirmed⁵. Additional data would be required to further refine the calculation of the mobility and volume of vinyl chloride in groundwater downgradient of ERL.

Under this alternative, organics would remain in groundwater in the lower outwash until attenuating via destructive or non-destructive processes. The migration of these organics are not anticipated to pose a threat to human health or the environment.

Short-Term and Long-Term Effectiveness

Alternative #1 provides a high degree of both short-term and long-term effectiveness/permanence for protecting human health by eliminating the exposure pathway with water supply well replacements. The vinyl chloride and other organics in the lower outwash unit are anticipated to continue to decrease in concentration with distance from the landfill as a result of destructive and non-destructive natural attenuation processes. Preliminary projections suggest vinyl chloride may migrate through the lower outwash from 5,400 to 9,000 feet from the unlined portion of the landfill (Appendix C); however, risk to groundwater receptors will be mitigated with deeper replacement wells and routine monitoring. Replacement wells provide long-term protection and would be installed within 2 to 3 years, including access coordination and agreement finalization, which is considerably sooner than the estimated time of travel to the downgradient residences.

The long-term effectiveness may be bolstered with the establishment of institutional controls preventing the future installation of water supply wells in the lower outwash the area downgradient from the landfill; however, prior conversation with Minnesota Department of Health staff suggest conditions do not warrant a Special Well and Boring Construction Area (i.e., well advisory). Nevertheless, local communities may consider adopting ordinance restricting well installation for consumptive use.

⁵ Preliminary projections suggest peak organics concentrations are anticipated to reach well P-334L between 2026 and 2034 due to higher organics inputs at the landfill in the early 1990s (Appendix C).

Implementability

Alternative #1 is considered highly implementable. The installation of deeper water supply wells is highly implementable from the construction and permitting standpoints. Domestic well construction is allowed in the Mt. Simon aquifer in Sherburne County and water quality is anticipated to be suitable for consumption without treatment provided concentrations of naturally occurring elements or compounds unrelated to the landfill are below drinking water criteria. ERL has a successful track record for open communication with area neighbors and developing mutually acceptable access agreements with individuals (without complaint to State, County, or City).

Scoping and implementing a natural attenuation evaluation is also considered highly implementable. MNA applications are widely accepted in Minnesota and throughout the United States and guidance from State, Federal, and non-governmental organizations is readily available. ERL has access to both internal and external technical expertise capable of developing an MNA evaluation and the MPCA has the expertise to review and comment on plans and evaluation results. The locations of new monitoring wells would require the development of an agreement(s) to access to private property for the installation and subsequent monitoring.

Cost

The primary Alternative #1 cost components include capital costs for replacement well/pump installation, connection, and sealing the existing well. There are no operation and maintenance costs associated with Alternative #1 because the residents will assume ownership of the new wells and pumps (which are low maintenance items). The primary MNA cost components include monitoring well installations and long-term monitoring and evaluation costs. The estimated total cost (30 Year, Net Present Value [NPV]) for Alternative 1 – MNA and Residential Water Supply Replacement ranges from \$590,000 to \$1,300,000 (Table 1). Cost estimate details are included as Appendix E.

5.2 Alternative #2: Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement

Alternative #2 includes constructing and operating a groundwater extraction system along the west side of the landfill, in the northern portion of the vinyl chloride plume, and on-site water treatment and discharge, in addition to a focused MNA evaluation and replacement of residential water supply wells (as detailed in Alternative #1). Alternative #2 assumes that three extraction wells would be installed, equipped with submersible pumps, and connected to groundwater forcemains to transmit groundwater to an on-site system for organics treatment and discharge to an infiltration basin located on the east side of the landfill in the extraction system capture zone. For the purpose of this report, the groundwater treatment is assumed to include pre-filtration and air stripping/carbon fixation depending on discharge requirements. Seasonal discharge to RL/TB may be a viable alternative if groundwater extraction is focused between the compliance boundary and property boundary.

Based on the challenges presented by the hydrogeologic conditions, the depth of the organics plume, and the nature of the release from the closed Pre-Subtitle D area, the implementation of this alternative would utilize an observational approach to evaluate performance and Adaptive Site Management

principles that allow for adjustments over the Site's life cycle as new site information and technologies become available (ITRC, 2017). This flexible approach would allow for a more expedient start up to groundwater extraction compared to a 30%/60%/90% design progression and would allow flexibility for ERL to propose modifications to the corrective action approach, adjust the treatment technologies or discharge locations, or to incorporate an alternate corrective action approach as performance data is reviewed and new information or technologies become available. This type of flexible approach is inherent to managing large, ongoing remediation projects and is compatible with the existing reporting cycle.

The replacement of residential water supply wells (as described in Alternative #1) is critical to the protectiveness of this alternative, and would be the initial priority for implementation. The MNA component would be focused on the southern portion of the vinyl chloride plume where decreasing concentrations are present along the compliance boundary (Appendix B).

Overall Protection of Human Health and the Environment

Alternative #2 provides an equally high degree of protectiveness to the health of nearby residents (i.e., groundwater users) and confidence that the groundwater pathway from the landfill to residential wells will be incomplete due to the replacement of water supply wells. Discharge of treated water to RL/TB would potentially affect ground conditions/stability of the floating bog in the discharge area and exacerbate health and safety issues related to accessing the area for monitoring, maintenance, or other reasons (including trespassers).

Meeting Applicable Requirements

Alternative #2 would provide additional means to meet applicable groundwater criteria along the compliance boundary by intercepting and/or stagnating impacted groundwater migrating from the Pre-Subtitle D area. The extraction well(s) zone of influence would extend upgradient (beneath the Pre-Subtitle D portion of the landfill) and to the west to a lesser degree. Long-term operation of the extraction system will remove impacted groundwater and allow for fresh groundwater to in fill west of the extraction area. As previously discussed, the timeframe to meet applicable groundwater criteria is based on many factors and may take decades.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative #2 will provide reduction of toxicity, mobility, or volume with a combination of engineered groundwater extraction/treatment system and natural attenuation processes. South and west of the extraction system, the toxicity, mobility, and volume of vinyl chloride would be reduced by either destructive or non-destructive natural attenuation processes that are occurring in the subsurface. The toxicity of the vinyl chloride (and other organics) in the extracted groundwater would be addressed by a phase change to vapor which would transfer the organics to the air at very low concentrations or by being bound to a carbon media which would be disposed of or thermally regenerated. The mobility of organics in groundwater upgradient of the extraction system would be reduced by intercepting the migration pathway between the unlined portion of the landfill and either the compliance boundary or property boundary. The operation of the groundwater extraction and treatment system would provide a minimal

reduction of the volume of vinyl chloride in the groundwater system. Preliminary annual estimates using existing data and applying an average pumping rate of 40 gpm, approximately 0.2 lbs of vinyl chloride would be treated from approximately 21,000,000 gallons of groundwater. For comparison purposes, the current active gas extraction system is estimated to remove approximately 60 lbs of vinyl chloride from the landfill annually.

Under Alternative #2, the organics in groundwater downgradient of the extraction system would remain in groundwater in the lower outwash until attenuating via destructive or non-destructive processes. The migration of these organics is not anticipated to pose a threat to human health or the environment.

Short-Term and Long-Term Effectiveness

Alternative #2 provides a high degree of short-term and long-term effectiveness/permanence for protecting human health due to the residential well replacements. Alternative #2 is expected to achieve applicable groundwater criteria in the southern portion of the vinyl chloride plume along the landfill via natural attenuation and in the northern portion of the vinyl chloride plume along the landfill via groundwater extraction. For the reasons explained in Section 4.3, providing a reliable timeframe for achieving groundwater criteria at wells along the northern portion of the landfill is not appropriate at this time. In general terms, the anticipated timeframe for achieving criteria may be decades and, should groundwater extraction be maintained as the long-term corrective action approach, it is anticipated to continue until either the source is depleted, another approach or technology is employed using Adaptive Site Management principles, or natural attenuation is demonstrated to be a protective corrective action approach.

Implementability

Alternative #2 is considered moderate to low in terms of implementability based on anticipated challenges regarding discharge of the extracted groundwater and permitting. Pumping along the west side of the landfill would extract groundwater with elevated concentrations of certain compounds that may require a waiver to discharge limits or a higher degree of treatment which would increase the treatment system costs and/or operation and maintenance needs. On-site discharge would also require the construction of an appropriately sized infiltration basin or other infrastructure (e.g., injection wells) to discharge the treated groundwater.

Pumping in RL/TB near the landfill could be conducted seasonally. Pumping would be achieved using the natural hydraulic heads in the lower outwash beneath RL/TB. The concentration of inorganic compounds would not be as high as those encountered closer to the landfill (at least at start-up) but would also likely require a waiver for discharge. Further, discharge of a constant flow of water in RL/TB may adversely affect ground/floating bog conditions in the discharge area and further complicate access.

An engineered onsite groundwater treatment system would require permitting, design, pilot testing, construction, start-up, and long-term system operation and maintenance. Prior to start-up of the groundwater extraction system, discharge to an infiltration basin would likely require National Pollutant Discharge Elimination System (NPDES) permitting with the MPCA. Direct discharge to RL/TB may require a

waiver for certain inorganic constituents, permitting with the MDNR and the U.S. Army Corps of Engineers (401 Certification and 404 Discharge of Fill to Wetlands).

Cost

The primary cost components of Alternative #2 (in addition to those detailed in Alternative #1) include capital costs for installing and connecting the groundwater extraction, conveyance, and treatment system infrastructure and piloting/start-up activities. Operation and maintenance costs include regular well and forcemain maintenance activities; long term monitoring costs; and components previously described in Alternative #2. The estimated total cost (30 Year, NPV) for Alternative #2 – Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement ranges from \$3,400,000 to \$7,000,000 (Table 1). Cost estimate details are included as Appendix E.

5.3 Alternative #3: Pre-subtitle D Landfill Excavation and Placement on Liner

Alternative #3 is being evaluated at the request of the MPCA and includes excavation of the unlined pre-Subtitle D landfill and abutting waste followed by placement on new liner at ERL. This scenario would include the excavation of approximately 4.9 MCY of in-place waste and 1 MCY non-waste soils.

For protectiveness purposes, this alternative would also include the installation and operation of an on-site groundwater extraction/treatment system to manage the anticipated increased leachate flux rate to groundwater during the excavation project and the replacement of residential water supply wells to be protective to downgradient residents because excavating the Pre-Subtitle D portion of the landfill is not expected to improve downgradient water quality in the foreseeable future.

Overall Protection of Human Health and the Environment

Alternative #3 provides an equally high degree of protectiveness to the health of nearby residents (i.e., groundwater users) and confidence that the groundwater pathway from the landfill to residential wells will be incomplete due to the replacement of water supply wells. The excavation of the unlined Pre-Subtitle D portion of the landfill and placement on a lined landfill cell at ERL adds to the high degree of overall protection in the long-term by eliminating the source of organics; however, the introduction and migration of organics in groundwater would likely be increased in the short-term due to removing the final cover and increased leakage during excavation. Longer-term sources to groundwater would include leaching from residual source materials, residual impacts beneath the landfill, and back diffusion from the organics that are sorbed to the aquifer matrix.

Meeting Applicable Requirements

Alternative #3 would provide additional means to meet applicable groundwater criteria along the compliance boundary by intercepting and/or stagnating impacted groundwater migrating from the excavated Pre-Subtitle D area via operation of the groundwater extraction/treatment. The groundwater extraction/treatment system operation would be similar to that in Alternative #2 but would likely not need to be operated as long and the mass of vinyl chloride removed would be anticipated to be higher.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative #3 will not result in a reduction of toxicity because the waste not being treated. A temporary but sustained increase of organics mobility and volume in the groundwater system would be expected during and for some time after waste excavation activities were completed. In the long-term (likely decades), the mobility of organics from the source would be eliminated or greatly reduced by removal of unlined waste.

Under Alternative #3, the organics in groundwater downgradient of the extraction system would remain in groundwater in the lower outwash until attenuating via destructive or non-destructive processes. The migration of these organics is not anticipated to pose a threat to human health or the environment.

Short-Term and Long-Term Effectiveness

Alternative #3 provides a low degree of short-term effectiveness and a high degree of long-term effectiveness/permanence for protecting human health due to the residential well replacements.

Alternative #3 is expected to result in moderate to low short-term effectiveness as a result of the long lead time it would take to plan and construct and high degree of long-term effectiveness/permanence due to unlined waste removal.

Implementability

The excavation of the Pre-Subtitle D portion of the landfill is presently infeasible given that space does not exist in the currently permitted landfill for the excavated waste. In addition, lined landfill cells are built over and adjacent to the unlined waste. Removal of material in the unlined landfill must either be limited to maintain the integrity of the adjacent lined portions or include the excavation of the neighboring lined waste for purposes of stability. If a portion of the unlined waste remains in place, it will remain as source material and long-term groundwater corrective actions may be required. Additional implementability challenges may include: odors and emissions during excavation, increased levels of dust and noise; prolonged exposure of waste to the environment which would lead to generation of additional leachate and landfill gas emissions; and disruption of neighboring lined landfill cells.

Cost

The unit rates used for the cost estimate are based on feasibility study costs for a similar project involving the excavation and relining of a different landfill in the Twin Cities area. It is noted that the excavation at ERL is considered more challenging due to overlying lined phases and adjoining lined waste areas. This cost may underestimate the actual cost, however, detailed cost estimated for this alternative is beyond the scope of this report.

Primary capital costs items include the constructing a new lined footprint to accept the Pre-Subtitle D waste and associated infrastructure to accept the unlined waste, construction costs to excavate and place the waste on liner, increased leachate management, etc. The estimated total cost (30 Year, NPV) for Alternative #4: Pre-subtitle D Landfill Excavation and Placement on Liner ranges from \$64,000,000 to \$140,000,000 (Table 1). Cost estimate details are included as Appendix E. However, again it is important to

note that the ERL does not have enough remaining capacity for MSW waste to accommodate waste from this exhumation.

5.4 Alternative #4: Groundwater Extraction (on and off-site) and Treatment

Alternative #4 is being evaluated at the request of the MPCA and includes constructing and operating an on-site groundwater extraction system, an off-site groundwater extraction system, and a water treatment discharge structure at ERL. This alternative assumes that, in addition to the system discussed in Alternative #2, two extraction wells are installed downgradient of well P-334L and utilized for groundwater extraction. These extraction wells would be equipped with submersible pumps and connected to a groundwater forcemain that conveys water back to the landfill for treatment and discharge at ERL. For the purpose of this report, it is estimated that a combined pumping rate of 80 gpm would be sufficient. Conveying groundwater to the ERL for discharge is considered more implementable than permitting, constructing, operating, and discharging from a groundwater treatment system on privately owned property.

Because the groundwater extraction system is operating downgradient of well P-334L and upgradient of residential wells, replacement residential water supply wells and documenting natural attenuation downgradient of well P-334L would not be included in this alternative. Groundwater extraction at the Site would be required to achieve applicable groundwater criteria.

Overall Protection of Human Health and the Environment

Alternative #4 provides a high to moderate degree of protectiveness to the health of nearby residents (i.e., groundwater users) with less certainty that the groundwater pathway from the landfill to residential wells will be incomplete as compared to Alternative #1.

Meeting Applicable Requirements

Alternative #4 will improve water quality at monitoring wells located along the compliance boundary by intercepting and/or stagnating leachate-impacted groundwater migrating from the northern portion of vinyl chloride plume along the west side of the ERL. The capture zone for the extraction wells will extend upgradient (beneath the Pre-Subtitle D portion of the landfill) and to the west to a lesser degree. Long-term operation of the extraction system will remove leachate-impacted groundwater and allow for fresh groundwater to in fill west of the groundwater extraction area. As previously discussed, the timeframe to meet applicable groundwater criteria is based on many factors and may take decades.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative #4 will provide reduction of toxicity, mobility, or volume in addition to the natural processes already occurring. The mobility and volume/mass of organics in the groundwater system will be reduced by cutting off the pathway both downgradient of the landfill and between well P-334L and the residential wells. Toxicity of organic compounds is addressed through treatment. Preliminary estimates using existing data and applying an average annual pumping rate of 80 gpm, approximately 0.2 lbs of vinyl chloride from approximately 42,000,000 gallons of groundwater.

Alternative #4, is intended to remove the organics in groundwater downgradient of the landfill.

Short-Term and Long-Term Effectiveness

Alternative #4 will provide a moderate degree of short-term effectiveness and a high long-term effectiveness/permanence protecting human health. Alternative #4 has a moderate degree of short-term effectiveness because the implementation timeframe is anticipated to be longer than Alternative #1 due to the need to design and pilot test such a system, negotiate access agreements for installing and operating remedial system components and the time it will take to implement well and forcemain construction activities on privately-owned property. Alternative #4 is expected to achieve applicable groundwater criteria in the long-term.

Implementability

Off-site groundwater extraction with off-site treatment has a low degree of implementability due to the lack of ownership of the property where the alternative would be implemented, the long distance that groundwater forcemain piping would need to be installed for extracted groundwater conveyance, and permitting. The groundwater extraction approach is reliable and effective in the long term if target pumping rates are continuously achieved in a well-maintained and monitored system. After the groundwater extraction system is established, modifications to pumping schemes will be employed to optimize recovery, however the combined flow of the on-site and off-site extraction systems may present unique challenges.

Cost

Major cost components of Alternative #4 (in addition to those detailed associated with on-site groundwater extraction and treatment in Alternative #2) include capital costs for installing and connecting the groundwater extraction and conveyance system to infrastructure from the off-site groundwater extraction wells to the ERL. Significant operation and maintenance costs include third-party treatment fees for the combined flow of the on-site and off-site systems; regular well and forcemain maintenance activities; and long term monitoring costs. The estimated total cost (30 Year, NPV) for Alternative #4 – Groundwater Extraction (on and off-site) and Treatment i ranges from \$6,400,000 to \$14,000,000 (Table 1). Cost estimate details are included as Appendix E.

6.0 Comparison of Alternatives

This section presents a relative comparison of the corrective action alternatives described in Section 5.

The alternatives were evaluated against seven evaluation criteria that are based on CERCLA guidance (USEPA, 1988). Consistent with the NCP, the selected alternative must meet two threshold criteria and achieve the best balance of trade-offs with respect to the balancing criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost) in a cost-effective manner. The NCP says, "a remedy shall be cost-effective if its costs are proportional to its overall effectiveness."

Alternative #1, MNA and Residential Water Supply Replacement achieves the threshold criteria and is judged to be the most cost-effective alternative that achieves the best balance of the evaluation criteria assuming that further evaluation demonstrates MNA is occurring sufficiently and applicable groundwater requirements are met. Based on the refined preliminary analysis presented herein, MNA is anticipated to sufficiently reduce the toxicity, mobility, and volume of vinyl chloride via natural processes and protectiveness to human health would be addressed with water supply well replacements. Alternative #1 would be equally protective in the short-term and long-term, reasonably implementable, and is the lowest cost alternative evaluated in this report.

Alternative #2, Groundwater Extraction and Treatment with MNA and Residential Water Supply Replacement is equally protective as Alternative #1 but is not a cost-effective alternative due to the operation of the groundwater extraction and treatment system. Alternative #2 provides a means to make progress towards achieving groundwater criteria at the compliance boundary (above and beyond natural processes) by intercepting the migration of groundwater with vinyl chloride along the west side of the landfill, however, preliminary estimates suggest that, on an annual basis, removal of 0.2 lbs of vinyl chloride from approximately 21,000,000 gallons of extracted groundwater. This alternative could be considered in the future if MNA is not demonstrated to be protective.

Alternative #3, Pre-Subtitle D Landfill Excavation/Placement on Liner best addresses long-term effectiveness and permanence but is not cost effective. This alternative is not feasible because lined waste is present in cells adjacent to and overlying the Pre-Subtitle D area and capacity does not exist to accommodate the excavated waste.

This alternative is not judged to be effective in the short-term due to the long lead time required to plan and implement it and because excavation of the unlined waste will require removing the landfill cap, resulting in increased contaminant flux to the groundwater system. Incomplete waste removal and/or residual impacts below the closed Pre-Subtitle D area would require long-term operation of a groundwater treatment system and residential water supply well replacements would be needed to protect the downgradient residents to the same extent in Alternatives #1 and #2.

Alternative #4, Groundwater Extraction (on and off-site) and Treatment is equally protective of Alternatives #1 and #2 but offers less certainty than residential water supply well replacement. Implementation of this alternative is considered difficult given the need to negotiate access to construct, operate, and maintain a groundwater extraction system on privately-owned land. This alternative will also entail extracting groundwater with low vinyl chloride concentrations (e.g., at or below the reporting limit), pumping the groundwater to ERL for treatment, and discharge at the Site. The estimated range of combined flows from the two extraction systems would also be challenging to discharge at the Site. Preliminary estimates suggest that, on an annual basis, the removal of approximately 0.21 lbs of vinyl chloride from approximately 42,000,000 gallons of extracted groundwater (assuming a rate of 80 gpm).

All four alternatives meet the threshold criteria of protecting human health and the environment and have the ability to meet appropriate groundwater criteria at the ERL. Alternative #1, MNA and Residential Water Supply Replacement, is judged to achieve the best balance of the other criteria in a cost-effective manner. The components of Alternative #1 are discussed below:

- Residential water supply replacement: replacing lower outwash supply wells with deeper wells will eliminate the exposure pathway and be protective of downgradient receptors. This component is critical to Alternative #1, provides the greatest value for the cost because it will mitigate risk to downgradient residents (i.e., groundwater users) with a high degree of certainty. Replacement of water supply wells would be the initial priority for implementation for this alternative.
- Monitored natural attenuation (on-site): the results of the evaluation in Appendix C project that the groundwater criteria may be achieved in areas along the west side of the landfill in a reasonable timeframe via naturally occurring attenuation processes. One of these areas is southern portion of the vinyl chloride plume in the vicinity of monitoring wells P-314C, P-313C, and P-323L. The focus along the west side of the landfill would include collecting additional data to track vinyl chloride trends and continue to assess geochemical conditions on a regular basis.
- Monitored natural attenuation (off-site): the focus of this compound would be to conduct additional evaluation of MNA to build on the recent screening update (Barr, 2020b). The off-site evaluation would focus on the areas up and downgradient of well P-334L, including installation of additional MNA monitoring points and collecting additional data to evaluate the stability of the vinyl chloride plume, assess daughter-parent compound relationships, and to refine the attenuation rate estimates and the preliminary projections presented in Appendix C of this report. Provided MNA proves to be a fully appropriate corrective action alternative, the data will be used to support a proposal for the establishment of appropriate alternative groundwater criteria for the Pre-Subtitle D portion of the landfill consistent with Minnesota Solid Waste Rules.

7.0 Summary and Next Steps

This report summarizes four corrective action alternatives identified to address vinyl chloride in groundwater at and downgradient of the ERL. Alternative #1, MNA and Residential Water Supply Replacement meets the threshold criteria and is judged to achieve the best balance of the other criteria in a cost-effective manner. Upon receiving concurrence with MPCA on Alternative #1, a work plan including implementation steps and schedule will be submitted under separate cover to MPCA review and approval. Implementation would prioritize the installation of replacement water supply wells and the installation of additional MNA monitoring network points downgradient of the ERL.

8.0 References

- Barr, 2020a. 2019 Water Quality Monitoring Report, Elk River Landfill (SW-74). Prepared for Elk River Landfill, Inc. January 2019.
- Barr, 2020b. Groundwater Natural Attenuation Evaluation Report, Elk River Landfill (SW-74), Elk River, Minnesota. Prepared for Elk River Landfill, Inc. February 2020.
- Barr, 2019. Groundwater Corrective Action Alternatives Screening Report, Elk River Landfill (SW-74), Elk River, Minnesota. Prepared for Elk River Landfill, Inc. July 2019.
- Barr, 2018. Groundwater Investigation and Well Installations Summary Report, Elk River Landfill. Prepared for Elk River Landfill, Inc. June 2018.
- Barr, 2016. Interim Report: 2016 Vertical Groundwater Profiling and Well Installations, Elk River Landfill, August.
- Barr, 2015a. Supplemental Site-Wide Hydrogeologic Evaluation Report, Elk River Landfill. Prepared for Elk River Landfill, Inc. June 2015.
- Barr, 2015b. Work Plan for Additional Groundwater Investigation, Elk River Landfill, April 2015.
- Camp, Dresser & McKee, Inc., 1994. Corrective Action Investigation Report, Volume 1, Elk River Landfill, March 1994.
- Geomatrix, 2000. 1999 P-17C Investigation and Well Installation Report. May 19, 2000.
- Geomatrix, 1999. P-17C Area Follow-up Groundwater Investigation Report, Elk River Landfill.
- Geomatrix, 1998. Groundwater Quality Investigation Report, Elk River Landfill, January, 1998.
- ITRC, 2017. Remediation Management of Complex Sites. RMCS-1. Washington, D.C.: Interstate Technology & Regulatory Council, Remediation Management of Complex Sites Team. <http://rmcs-1.itrcweb.org>
- MPCA, 2020. Closed Landfill Investment Fund, Minnesota Pollution Control Agency. <https://www.pca.state.mn.us/sites/default/files/c-clf1-17.pdf>, February 2020.
- USEPA, 1998. Technical Protocol for Evaluating NA of Chlorinated Solvents in Ground Water. United States Environmental Protection Agency, EPA/600/R-89/128, September 1998.
- USEPA, 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. United States Environmental Protection Agency, EPA/540/G-89/004, October 1988.

Tables

Table 1
Corrective Action Evaluation Summary
Elk River Landfill

CERLCA Criteria		Threshold Criteria	Threshold Criteria	Balancing Criteria	Balancing Criteria	Balancing Criteria	Balancing Criteria	Balancing Criteria	Comments
Alternatives		Overall Protection of Human Health and the Environment	Meeting Applicable Requirements ¹	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Long-Term Effectiveness and Permanence	Implementability	Cost Range (Capital + 30 Year NPV for O&M, +50% / -30%)	
		(CAO #1 - Priority/Initial Objective)	(CAO #2 - Long Term Objective)						
#1	Monitored Natural Attenuation + Residential Water Supply Replacment	Provides the highest degree of protectiveness for human health based on the replacement of water supply wells. Preliminary evaluation / weight of evidence suggest MNA is a protective approach.	Based on preliminary evaluation, this alternative is anticipated to meet applicable alternate groundwater criteria established under MN Rules.	Based on preliminary evaluation, this alternative is anticipated to reduce toxicity and volume of organics upgradient of groundwater users via destructive and non-destructive natural attenuation processes. Relies on natural processes occurring the subsurface for reductions of toxicity, mobility, or volume.	High degree of short-term effectiveness and permanence in protecting human health with well replacements implemented within 2 to 3 years. Provides additional monitoring locations upgradient of residential wells. Provides data required to evaluate plume stability, refine estimate, verify geochemical conditions, and document mass destruction.	High degree of long-term effectiveness and permanence in protecting human health. Provides additional monitoring locations upgradient of residential wells. Provides data required to evaluate plume stability, refine estimate, and verify geochemical conditions. Documents mass reductions via natural attenuation using methods developed by, applied, and accepted by regulatory agencies.	Residential well replacements are highly implementable with owner acceptance and alternatives to well replacements are available. Natural attenuation evaluation and implementation is highly implementable. Preliminary data / weight of evidence suggest MNA is a protective approach.	\$ 590,000 to \$1,300,000	This approach achieves the threshold criteria as discussed in the report, is cost-effective, and is judged to achieve the best balance of the evaluation criteria. If MNA evaluation does not prove to be adequate, additional measures can be considered in the future.
#2	Groundwater Extraction with Treatment with Focused MNA and Residential Water Supply Replacement	Same degree of protectiveness to downgradient residents as Alt. #1 due to replacement of water supply wells. If discharge occurs to RL/TB, the volume of water may affect the ground conditions in the discharge area (e.g., ponding water) and exacerbate health and safety issues relating to access for monitoring, maintenance, and/or trespassers.	This alternative provides additional means to achieve alternate groundwater criteria. The timeframe to meet criteria and may be on the order of decades (but would be better understood after the system is installed and performance data and water quality trend data is generated).	In addition to Alt. #1, vinyl chloride mobility would be reduced at the landfill via groundwater extraction. Toxicity of organic compounds would be reduced by treatment. The operation of the extraction system is estimated to marginally reduce volume of vinyl chloride in the groundwater system. Treatment system wastes (if generated) would require disposal/management.	Permitting, extraction and treatment system design, construction, and start-up would be required prior to starting the extraction and treatment system operations. Well replacement and MNA implementation would be the same as Alt. #1.	Same as Alt. #1 with regard to protecting human health. If MNA proves to be effective, long term (>30 years) pumping and treating would not increase effectiveness and permanence.	Moderately implementable due to water discharge challenges. Infiltration east of landfill may be hindered due to space needed for infiltration basin. Discharge to RL/TB could be conducted seasonally if permitted but access may become problematic. Groundwater extraction along the west side of the landfill would be anticipated to extract groundwater with high inorganic compound concentrations. These concentrations may necessitate discharge waivers or a higher degree of treatment which would substantially increase costs and/or operation and maintenance needs.	\$ 3,400,000 to \$7,000,000	This approach is not cost effective and does not provide additional protection to human health or the environment to a degree greater than Alternative #1. Using an average groundwater extraction rate of 40 gpm, approximately 21,000,000 gallons of groundwater would be extracted annuallyand treatment would remove approximately 0.2 pounds/year of vinyl chloride.

Table 1
Corrective Action Evaluation Summary
Elk River Landfill

CERLCA Criteria		Threshold Criteria	Threshold Criteria	Balancing Criteria	Balancing Criteria	Balancing Criteria	Balancing Criteria	Balancing Criteria	Comments
Alternatives		Overall Protection of Human Health and the Environment	Meeting Applicable Requirements ¹	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Long-Term Effectiveness and Permanence	Implementability	Cost Range (Capital + 30 Year NPV for O&M, +50% / -30%)	
		(CAO #1 - Priority/Initial Objective)	(CAO #2 - Long Term Objective)						
#3	Pre-subtitle D Landfill Excavation and Placement on Liner	Same degree of protectiveness to downgradient residents as Alt. #1 due to replacement of water supply wells. Provides the highest degree of overall protection of human health in the long-term due to removal of unlined waste.	Expected to meet alternate groundwater criteria in the long term but not likely in the foreseeable future due to a long lead time for planning/implementation, increased organics flux during implementation. The possibility of incomplete waste removal or continued organics flux from residual impacts (in addition to increased organics flux during implementation) requires the addition of additional groundwater corrective actions (i.e. gw extraction) for the foreseeable future. The timeframe to meet applicable groundwater criteria would be dependent on completeness of source removal (i.e., waste and residuals) and physical processes (e.g., advective transport, matrix rebound, etc.).	Anticipated to increase mobility in the short-term / foreseeable future due to waste disturbance, increased infiltration, cover removal, etc. (generation of leachate and LFG emissions). Increased mobility would require additional groundwater corrective measures (i.e., gw extraction).	Timeline for planning and implementation would be protracted due to magnitude of the project and need to permit and construct new lined area. High degree of short-term effectiveness and permanence in protecting human health with well replacements implemented within 2 to 3 years.	Provides highest degree of long term effectiveness / permanence. Excavation of the unlined pre-Subtitle D landfill and placement on a lined landfill cell is reliable and effective in the long term provided the entire source is removed.	Infeasible given space for the excavated waste does not exist in the currently permitted landfill. Difficult implementation due to lined phases with leachate collection are built over and adjacent to the Pre-Subtitle D area. Difficulties in removing all off the unlined waste, managing leachate and contact water, managing landfill gas/odors/emmission and dust are anticipated.	\$ 63,000,000 to \$ 140,000,000	This alternative is not not feasible given sufficient permitted air space is not available at ERL to accept excavated waste. This alternative is not considered to be cost effective. The detailed estimation of costs for this alternative and consideration of the are beyond the scope of this evaluation. This alternative would require implementation of groundwater extraction/treatment and water supply replacement to manage anticipated increase in flux to groundwater from implementation. The operation of a groundwater extraction/treatment system (or an alternate technology would be expected to be shorter than without waste removal.
#4	Groundwater Extraction (on and off-site) and Treatment	Provides high degree of protectiveness for human health but less certainty than residential well replacements.	Same as Alt. #2.	Vinyl chloride mobility would be reduced at and downgradient of the landfill via groundwater extraction. Toxicity of organic compounds at and downgradient of the landfill would be reduced by treatment.	Timing based on negotiating access agreements with private property owners. Negotiating access for an active system that would require regular operation and routine maintenance is anticipated to be more difficult than access for monitoring. High degree of short-term effectiveness in protecting human health assuming full plume interception.	If MNA proves to be effective, long term (>30 years) pumping and treating would not increase effectiveness and permanence. Long-term operation would require long-term access agreement with private land owner.	Judged to have low degree of implementability due private property ownership by others, permitting, rate of discharge required, and issues of operating and maintaining a system in RL/TB. Moderate to low implementability assuming seasonal extraction/ treatment/discharge is permitted in RL/TB on ERL property. Infiltration east of landfill may be hindered due to space needed for infiltration basin.	\$ 6,400,000 to \$ 14,000,000	This approach is not cost effective and does not provide additional protection to human health or the environment to a degree greater than Alternative #1. Using an average groundwater extraction rate of 80 gpm , approximately 42,000,000 gallons of groundwater would be extracted annually and treatment would remove approximately 0.2 pounds/year of vinyl chloride.

Notes:

¹ MPCA requested the evaluation to consider meeting Intervention Limits at the Compliance Boundary. ERL is addressing impacts related to the Pre-Subtitle D portion of the site which may necessitate the establishment of alternate limits under 7035.2815 Subpart 4 (H) (2).

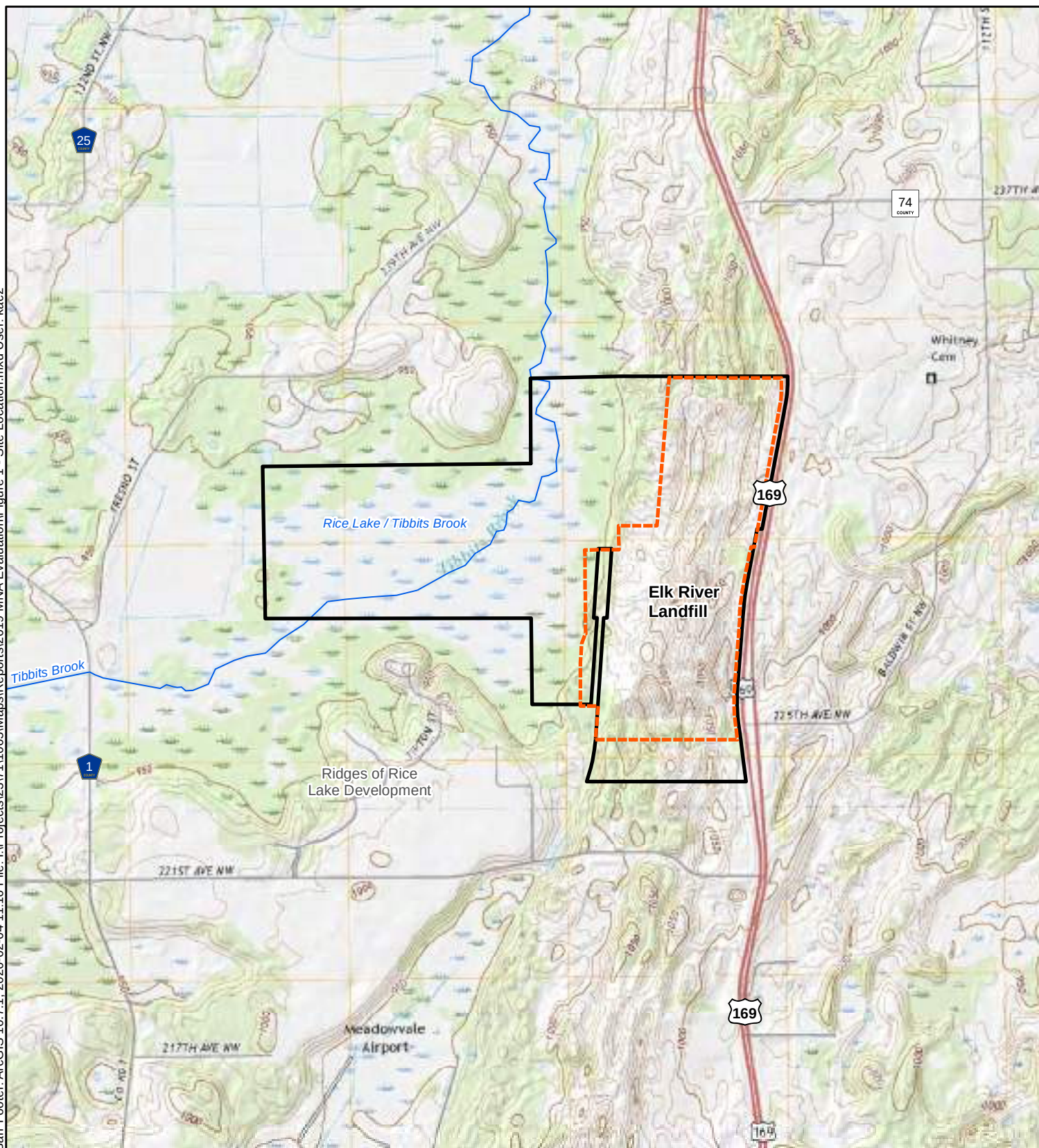
Color Key for this chart is provided to indicate relative degree of achieving listed criteria and/or relative ranking of favorability. Gradient color fills indicate uncertainty.

Favorable / High

Neutral / Moderate

Less Favorable / Low

Figures



- Property Boundary
- Groundwater Compliance Boundary



Feet
0 2,000 4,000

Figure 1

SITE LOCATION
Elk River Landfill
Elk River, Minnesota

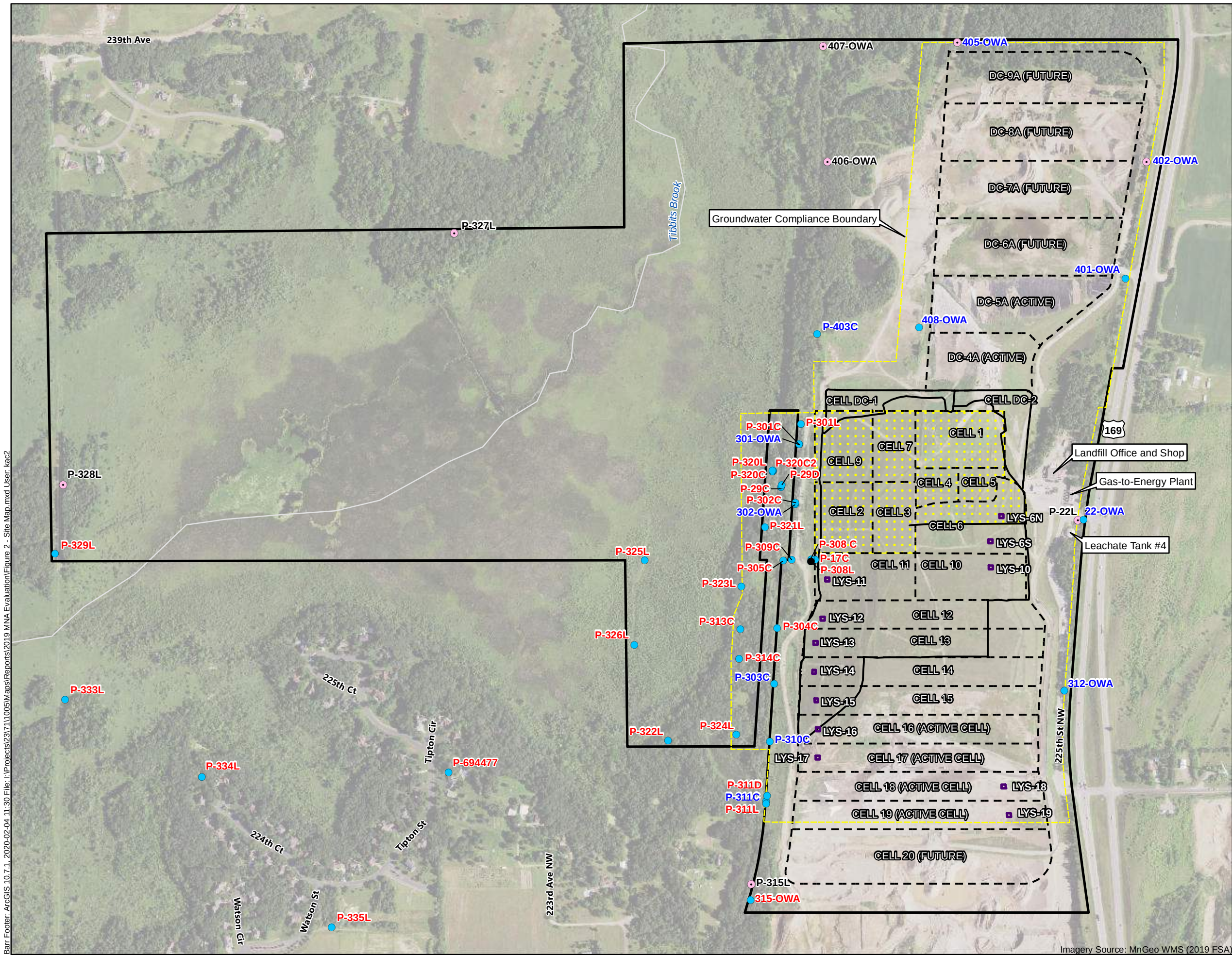
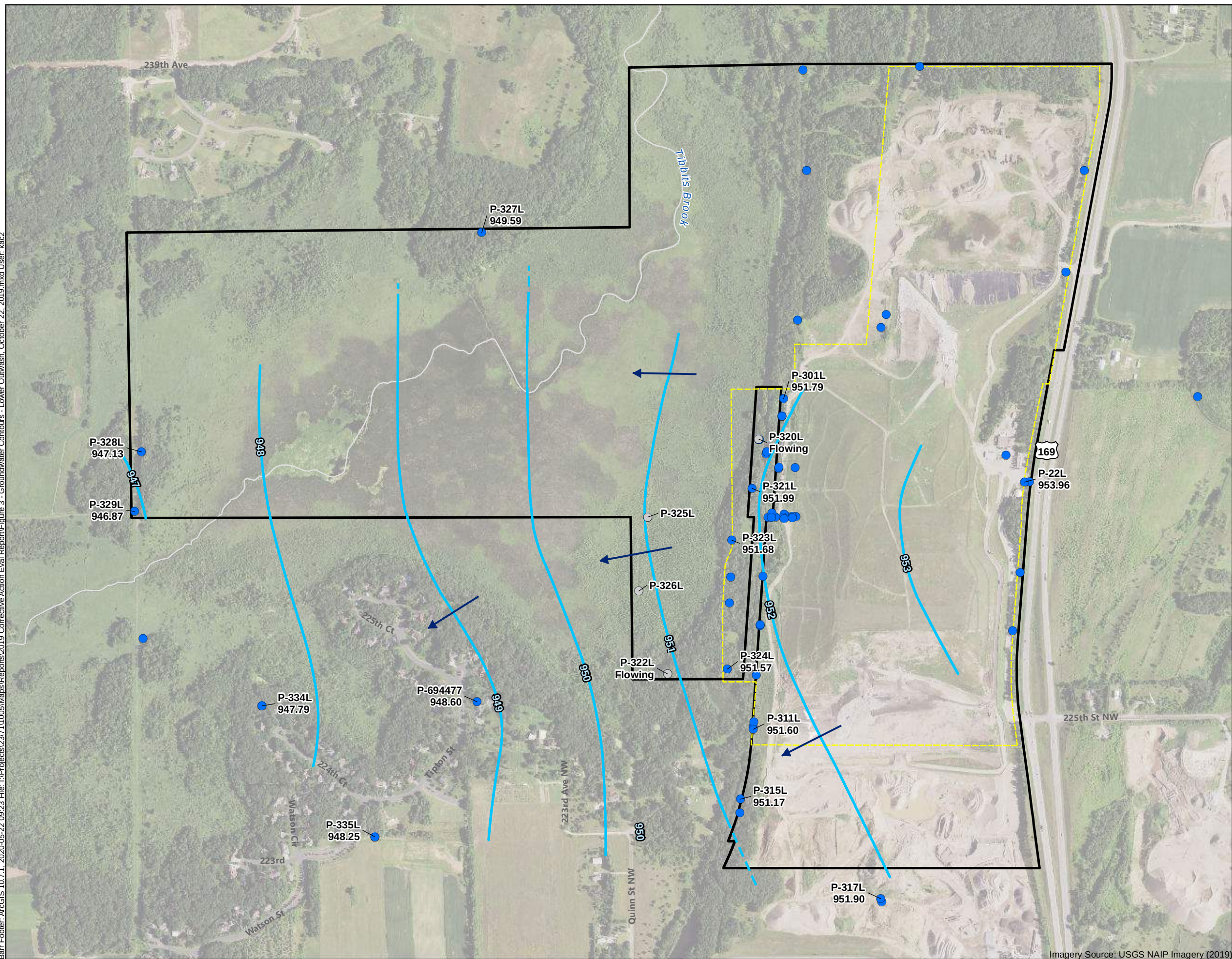


Figure 2
SITE MAP
Elk River Landfill
Elk River, Minnesota





- Property Boundary
- Groundwater Compliance Boundary
- Lower Outwash Monitoring Well
- Lower Outwash Monitoring Well (Not Used for Groundwater Contours)
- Groundwater Contour (feet MSL)
- Flow Line

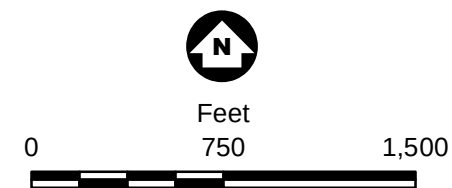
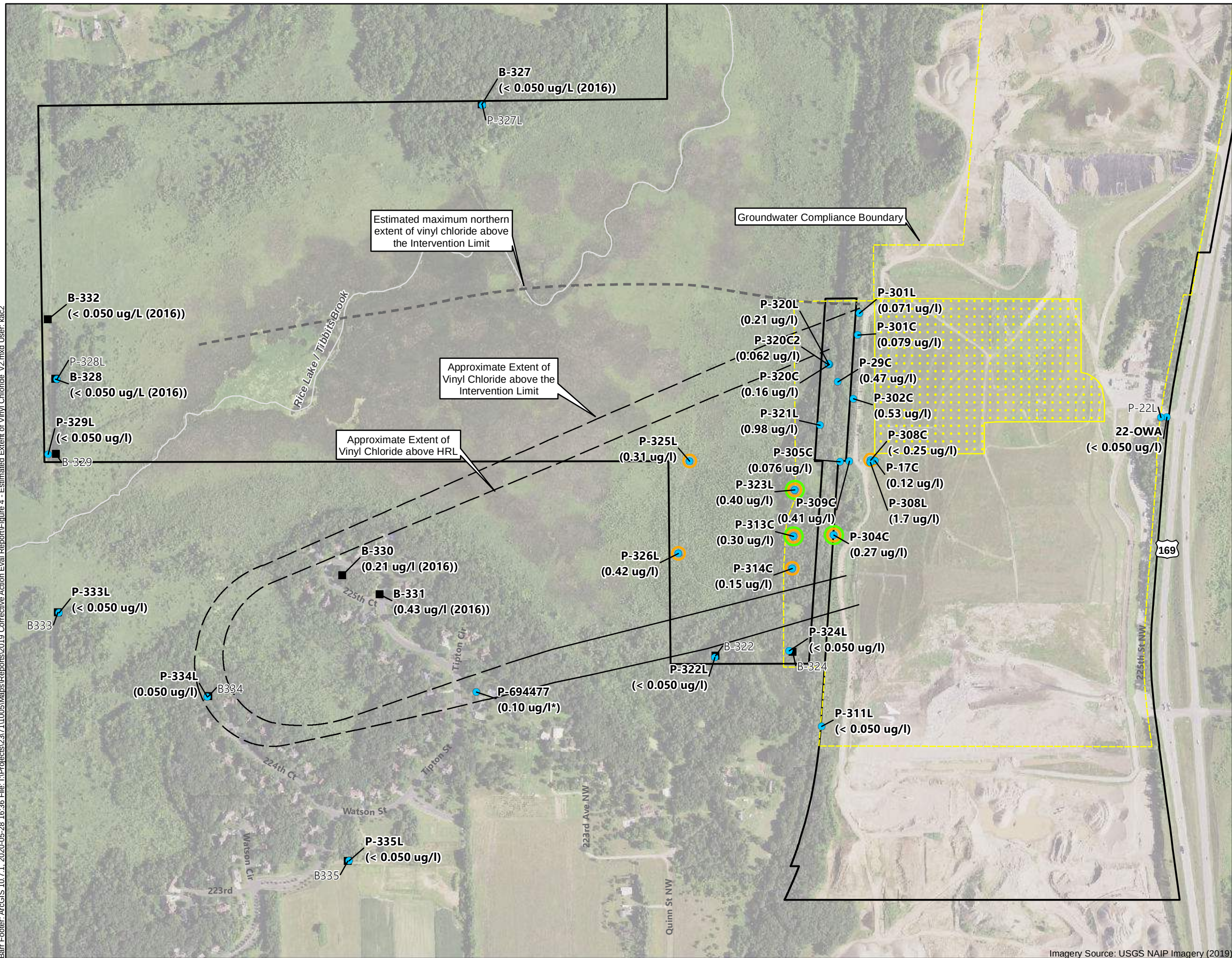


Figure 3
GROUNDWATER CONTOURS -
LOWER OUTWASH
October 22, 2019
Elk River Landfill
Elk River, Minnesota



Barr Footer: ArcGIS 10.7.1, 2020-05-28 16:36 File: I:\Projects\23711005\Maps\Reports\2019 Corrective Action Eval Report\Figure 4 - Estimated Extent of Vinyl Chloride v2.mxd User: kac2



- Property Boundary
- Pre-Subtitle D Area
- Monitoring Well
- Vertical Groundwater Profile Boring (2016/2018)
- TCE detected (>1.0 ug/L) since 2018
- cDCE detected (>1.0 ug/L) since 2018

Note:

- Vinyl chloride extents based on 2019 data and investigation data (Barr, 2018).
- * October 2019 data shown for P-694477 (first detection of vinyl chloride at this location).
- Vinyl chloride was not detected at P-334L (<0.050 ug/L), P-694477 (<0.231) and P-301L (<0.050 ug/L) in April 2020 samples.
- Estimated extents based on lower outwash groundwater contours (2014-2019) and water quality data.
- Locations of vinyl chloride parent product detections shown with green and red circles.

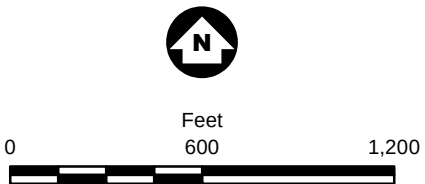
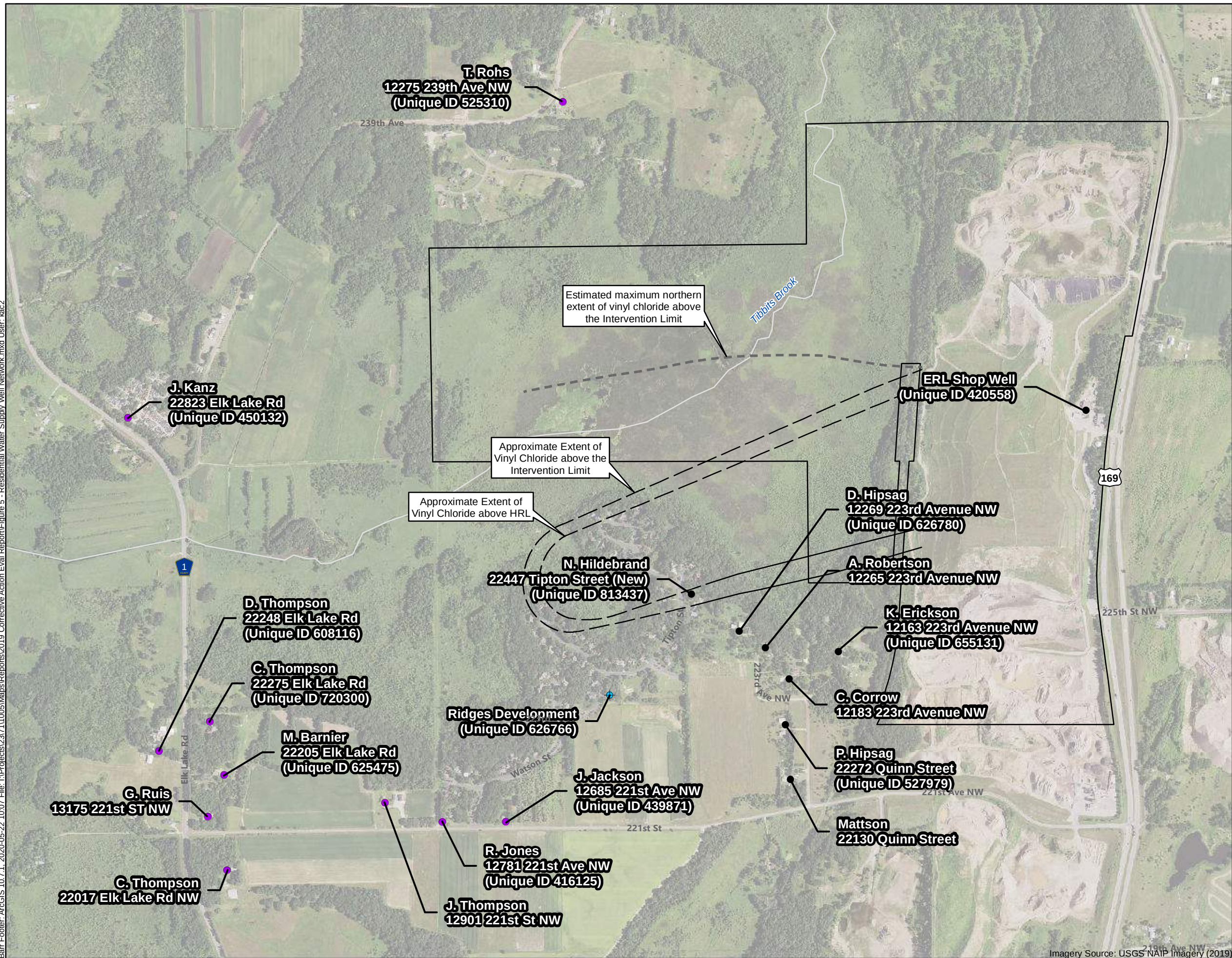


Figure 4
ESTIMATED EXTENT OF
VINYL CHLORIDE
Elk River Landfill
Elk River, Minnesota



Bar Footer: ArcGIS 10.7.1, 2020-05-22 10:07 File: I:\Projects\23711005\Maps\Reports\2019 Corrective Action Eval Report\Figure 5 - Residential Water Supply Well Network.mxd User: kac2



- Property Boundary
- Residential Well Network Location
- Community Water Supply Well
- Residential Well (Expanded Network, 2015-2017)

Notes:
(1) 12265 223rd is listed as 11265 223rd in Permit SW-74.
(2) Upgradient monitoring locations not shown.

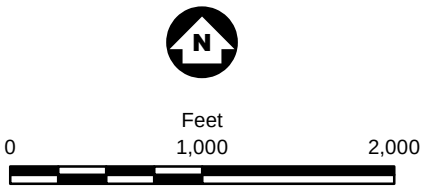
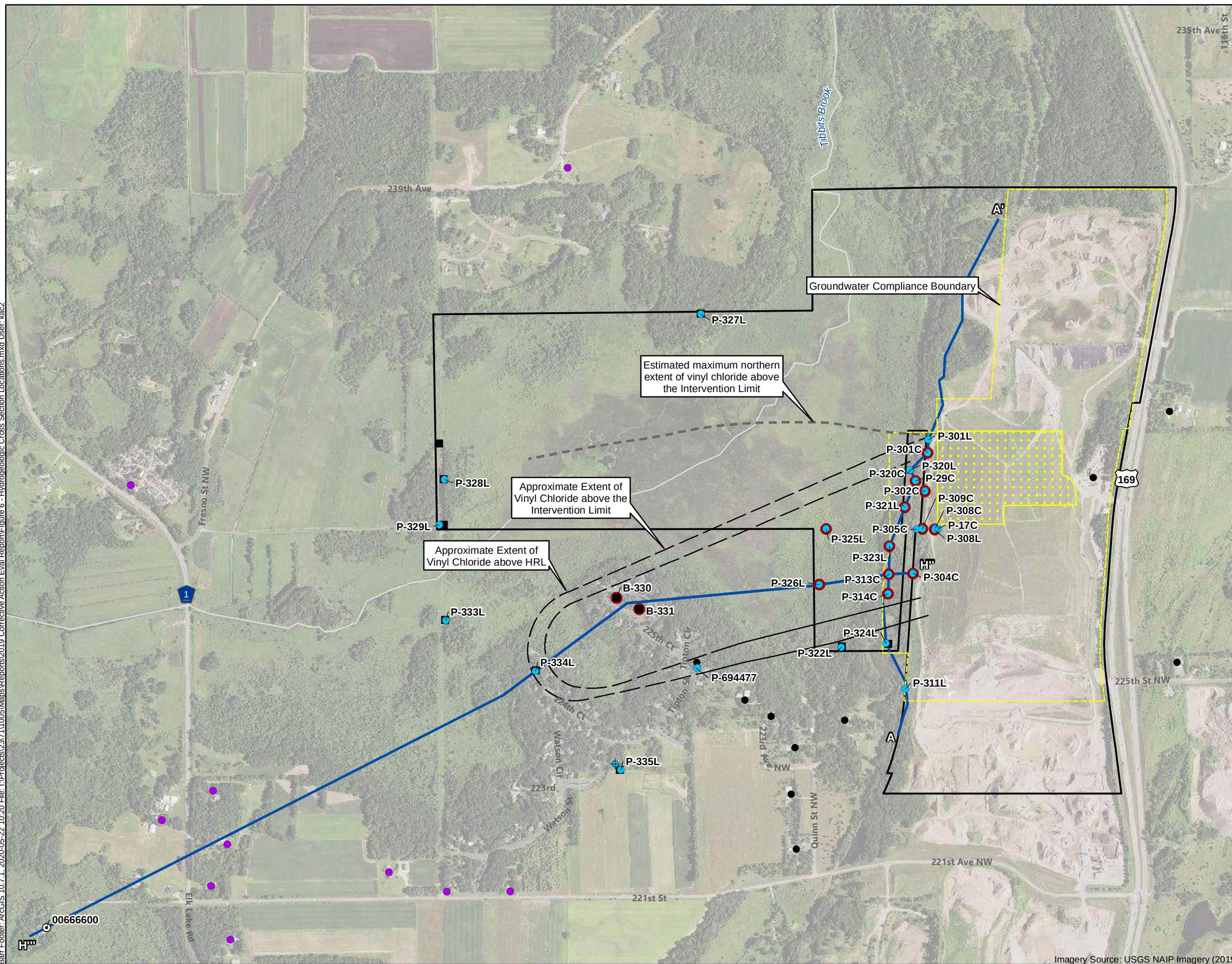


Figure 5
RESIDENTIAL WATER SUPPLY
WELL NETWORK
Elk River Landfill
Elk River, Minnesota





- Property Boundary
- Pre-Subtitle D Area
- Confirmed HRL Exceedance
- Cross Section Location
- Monitoring Well
- Vertical Groundwater Profile Boring (2016/2018)
- Residential Well Network Location
- Community Water Supply Well
- Residential Well (Expanded Network, 2015-2017)
- Other Well

Notes:
- Vinyl chloride extents based on 2019 data and investigation data (Barr, 2018).

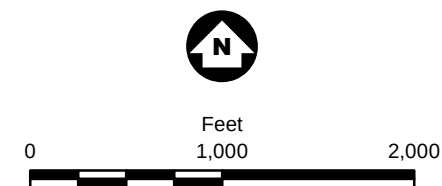
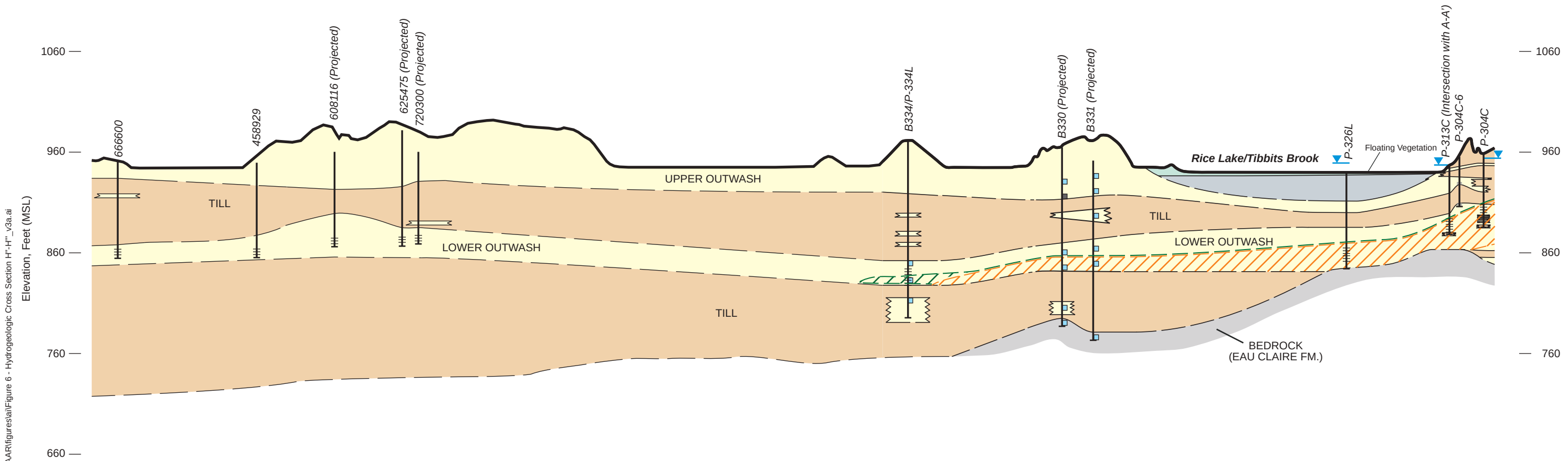


Figure 6
HYDROGEOLOGIC CROSS
SECTION LOCATIONS
Elk River Landfill
Elk River, Minnesota



H'''
WEST

H''
EAST



\\barr.com\projects\mpls\23 MN\17123711005 ERL, GW Netwrok Development\WorkFiles\Corrective Action\CAAR\figures\allFigure 6 - Hydrogeologic Cross Section H''-H'''_v3a.ai

EXPLANATION

OUTWASH	Includes the following soil types: SP: Sand with <5% fines; thin/discontinuous gravel lenses rare to common. SM: (Where in contact with SP); Silty sand; silt content approximately 30 to 50%.
TILL	Includes the following soil types: ML: Sandy silt - diamict with approximately 10 to 50% Sand and Gravel; firm to very hard. CL: Clay textured diamict with varying amounts of sand and gravel; firm to hard. SM: (Where bounded by ML or CL); Silty sand; silt content approximately 30 - 50% ML/CL: Silt or clay, <5% sand, massive to thinly bedded
EAU CLAIRE	Eau Claire Formation: Fine-grained sandstone/siltstone with shale partings present locally.

0 750
Approximate Horizontal Scale in Feet
7.5X Vertical Exaggeration

NOTE:
Data are insufficient to determine if Intervention Limits (IL) exceedences occurred at wells 203-OWA, 202-OWA, 102-OWA, and 101-OWA. Organics were not detected above Intervention Limits at W ells 43-OWA or 201-OWA or in vertical groundwater profile boring P-304C-6.

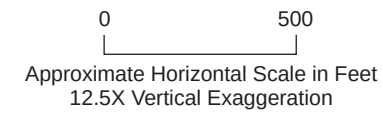
LEGEND

	Ground Surface (Approximate)
	Geologic Contact (Dashed where approximate)
	September 2014 Groundwater Elevation (Measured in deepest nested well shown on figure)
	Existing Well Screen
	Groundwater Sample Locations
	Groundwater Interval Purged Dry
	Approximate/Inferred Extent of Vinyl Chloride Above Health Risk Limits
	Approximate Extent of Vinyl Chloride Above Intervention Limits



Figure 7

HYDROGEOLOGIC CROSS SECTION H''-H'''
Elk River Landfill
Elk River, Minnesota



LEGEND

Includes the following soil types:

- SP: Sand with <5% fines; thin/discontinuous gravel lenses rare to common.
- SM: (Where in contact with SP); Silty sand; silt content approximately 30 to 50%.

Includes the following soil types:

- ML: Sandy silt - diamict with approximately 10 to 50% Sand and Gravel; firm to very hard.
- CL: Clay textured diamict with varying amounts of sand and gravel; firm to hard.
- SM: (Where bounded by ML or CL);
Silty sand; silt content approximately 30 - 50%
- ML/CL: Silt or clay, <5% sand, massive to thinly bedded

Eau Claire Formation:
Fine-grained sandstone/siltstone with shale partings
present locally.

Ground Surface (Approximate)

Geologic Contact (Dashed where approximate)

Groundwater Elevation from Shallowest Well
(2014 unless otherwise noted)

Groundwater Elevation (2014 unless otherwise noted)

Existing Well Screen

Former Well Screen, Vertical Groundwater Profiling Screen Interval

Approximate/Inferred Extent of Vinyl Chloride Above Health Risk Limits

Approximate Extent of Vinyl Chloride Above Intervention Limits

HYDROGEOLOGIC
CROSS SECTION A-A'
Elk River Landfill
Elk River, Minnesota

Appendices

Appendix A

2018 – 2020 (April) Groundwater Monitoring Data

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-17C	P-17C	P-17C	P-17C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-301C	P-301C	P-301C	P-301C
Date				7/19/2018	7/12/2019	10/23/2019	12/19/2019	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/10/2019	10/22/2019	12/19/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/08/2019	10/22/2019	12/19/2019	4/21/2020	4/18/2018	7/17/2018	10/18/2018	4/09/2019		
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																										
Effective Date		04/27/2020	07/23/2015																										
Exceedance Key		Bold	<u>Underline</u>																										
Volatile Organic Compounds																													
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	17.5	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U J4	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	2250.0	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	0.5	< 0.50	< 0.50	< 0.50 H	--	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 1.0	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50		
1,1,2-Trichloroethane	ug/l	3 HRL93	0.75	< 0.75	< 0.75	< 1.0 H	--	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0	--	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	--	< 1.0	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75		
1,1-Dichloroethane	ug/l	80 RAA16 (1)	25.0	< 4.0	< 10	< 1.0 H	--	2.6	2.6	2.5	2.1	3.0	3.4	--	3.45	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,1-Dichloroethylene	ug/l	200 HBV19	50.0	< 4.0	< 10	< 2.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 2.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0			
1,1-Dichloropropene	ug/l			< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2,3-Trichlorobenzene	ug/l			< 4.0	< 10	< 5.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 5.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 5.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	0.00075	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	1.0	< 4.0	< 10	< 5.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 5.0 ^	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2,4-Trimethylbenzene	ug/l	30 HBV19	25.0	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		0.05	< 0.050	< 0.050	< 0.050	--	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	--	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	--	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050		
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	0.001	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2-Dichlorobenzene	ug/l	600 HRL93	150.0	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2-Dichloroethane	ug/l	1 HRL13 (1)	<u>0.25</u>	< 0.25	< 0.25	< 0.25 ^*	--	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 ^*	--	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 ^*	--	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25	
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	12.5	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	10.0	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,2-Dichloropropane	ug/l	5 HRL94	1.25	< 4.0	< 10	< 1.0 H*	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	25.0	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,3-Dichlorobenzene	ug/l			< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0 ^	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,3-Dichloropropane	ug/l			< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	0.5	< 0.50	< 0.50	< 0.25 H	--	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.25	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.25	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50		
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94		< 4.0	< 10	< 5.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 5.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	<u>2.5</u>	< 4.0	< 10	<u>2.6 H</u>	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
2,2-Dichloropropane	ug/l			< 4.0 ^	< 10	< 4.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 4.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H^	< 1.0		
Acetone	ug/l	3000 HBV17 (1)	1000	< 40	< 100	< 10 H	--	< 10	< 10	< 10	< 10	< 10	< 10	--	< 10.0 U	< 10	< 10	< 10	< 10	< 10	--	< 10	< 10.0 U	< 20	< 10	< 10 H	< 10		
Allyl chloride	ug/l	30 HRL94	7.5	< 4.0	< 10	< 2.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 2.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Benzene	ug/l	2 HRL09 (1)	<u>0.5</u>	<u>1.1</u>	<u>1.2</u>	<u>1.5 H*</u>	--	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50		
Bromobenzene	ug/l			< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0 ^	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Bromochloromethane	ug/l			< 4.0	< 10	< 5.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 5.0 ^	< 1.00 U J4	< 2.0	< 1.0	< 1.0 H	< 1.0		
Bromodichloromethane	ug/l	3 HBV18 (1)	1.5	< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Bromoform	ug/l	40 HRL93	10.0	< 4.0	< 10 *F1	< 5.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 5.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Bromomethane	ug/l	10 HRL93	2.5	< 4.0	< 10	< 4.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0 ^	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 4.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Butylbenzene	ug/l			< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Butylbenzene, sec	ug/l			< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0 ^	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Butylbenzene, tert	ug/l			< 4.0	< 10	< 1.0 H	--	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0 ^	< 1.00 U	< 2.0	< 1.0	< 1.0 H	< 1.0		
Carbon tetrachloride	ug/l	1 HRL13 (1)	0.25	< 0.25	< 0.25	< 0.25	--	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	--	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	--	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25		
Chlorobenzene	ug/l	100 HRL93	25.0	6.																									

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-17C	P-17C	P-17C	P-17C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29C	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-29D	P-301C	P-301C	P-301C	P-301C
Date				7/19/2018	7/12/2019	10/23/2019	12/19/2019	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/10/2019	10/22/2019	12/19/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/08/2019	10/22/2019	12/19/2019	4/21/2020	4/18/2018	7/17/2018	10/18/2018	4/09/2019		
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																										
Effective Date		04/27/2020	07/23/2015																										
Exceedance Key		Bold	<u>Underline</u>																										
General Parameters																													
Alkalinity, total, as CaCO3	mg/l			1260	1040	--	--	--	422	--	--	429	--	--	--	--	178	--	--	172	--	--	--	--	--	--	478	--	--
Carbon, total organic	mg/l			--	69.5	56.2	--	--	--	--	--	3.7	2.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cation-Anion balance	%			0.46	2.4	--	--	--	-1.4	--	--	-1.7	--	--	--	--	0.35	--	--	3.3	--	--	--	--	--	-1.4	--	--	
Chloride	mg/l			526	675	--	--	--	49.7	--	--	64.8	--	--	--	--	< 0.50	--	--	< 0.50	--	--	--	--	--	26.6	--	--	
Dissolved oxygen, field	mg/l			9.8	2.4	3.0	5.1	3.5	0.6	1.4	3.5	0.5	2.6	3.1	--	3.6	0.5	0.6	1.5	0.3	0.3	0.7	--	0.2	1.7	1.2	0.7		
Iron, ferrous, FE II, field	mg/l			--	6.5	--	--	--	--	--	--	2.70	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Manganese II, field	mg/l			--	200	--	--	--	--	--	--	18.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, ammonia, as N	mg/l			20.0	2.6	--	--	--	< 0.020	--	--	0.070	--	--	--	--	0.14	--	--	0.17 F1	--	--	--	--	< 0.020	--	--	--	
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	< 0.050 H	< 0.050	--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrite, as N	mg/l			--	< 0.050 H	< 0.050	--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
pH, field	pH units			6.72	6.59	6.60	6.70	7.35	7.53	7.18	7.25	6.85	6.65	680	--	8.56	8.37	8.14	8.00	7.83	8.31	8.17	--	7.63	7.80	7.46	7.42		
Redox (oxidation potential), field	mV			-69	-42	-88	12	20.1	131.1	17.5	194.1	176	181	35	--	-151.3	114.5	27.6	199.9	212.4	209.7	111	--	-101.7	-99	242.6	-32.0		
Solids, total dissolved	mg/l			2130 H	2340	--	--	--	527	--	--	535	--	--	--	--	199	--	--	201	--	--	--	--	--	729	--	--	
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Specific conductance @ 25 °C, field	umhos/cm			3454	3888	3199	3215	911	900	986	1331	802	932	895	--	317	320	315	323	322	320	309	--	917	1017	1037	1199		
Sulfate, as SO4	mg/l			< 2.0	< 40.0	--	--	--	25.8	--	--	22.8	--	--	--	--	3.0	--	--	2.2	--	--	--	--	--	154	--	--	
Sulfide, as S ²⁻ , field	mg/l			--	0.75	--	--	--	--	--	--	0.23	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Temperature, field	deg C			15.3	15.6	147	14.8	9.4	12.3	12.1	11.1	12.2	11.7	10.0	--	10.1	11.9	11.6	10.6	11.9	11.4	10.4	--	9.8	10.7	10.8	10.4		
Turbidity, field	NTU			16.6	22.1	29.1	33.3	14.0	15.5	88.7	61.3	73.1	87.1	71.1	--	10.2	17.1	3.0	3.9	5.1	4.6	4.0	--	16.7	41.7	1.8	4.2		
Dissolved Metals																													
Arsenic	ug/l		2.5	20.6	34.0	--	--	--	< 5.0	--	--	< 1.0	--	--	--	--	< 5.0	--	--	< 1.0	--	--	--	--	--	< 5.0	--	--	
Boron	ug/l	500 RAA17	250.0	5250	3580	--	--	--	39.8	--	--	132	--	--	--	--	< 20.0	--	--	< 20.0	--	--	--	--	--	30.7	--	--	
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Calcium	mg/l			173	174	--	--	--	123	--	--	122	--	--	--	--	42.6	--	--	43.6	--	--	--	--	--	142	--	--	
Chromium	ug/l	100 CR HRL93	25.0	< 4.0	< 4.0	--	--	--	< 4.0	--	--	< 4.0	--	--	--	--	< 4.0	--	--	< 4.0	--	--	--	--	--	< 4.0	--	--	
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Iron	ug/l			17400	21000	--	--	--	1480	--	--	1250	--	--	--	--	232	--	--	342	--	--	--	--	--	841	--	--	
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Magnesium	mg/l			124	131	--	--	--	42	--	--	41.8	--	--	--	--	15.6	--	--	15.9	--	--	--	--	--	68.3	--	--	
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Potassium	mg/l			18.6	10.3	--	--	--	2.65	--	--	2.96	--	--	--	--	1.25	--	--	1.29	--	--	--	--	--	2.43	--	--	
Sodium	mg/l			463	481	--	--	--	7.68	--	--	19.2	--	--	--	--	4.38	--	--	4.31	--	--	--	--	--	7.14	--	--	
Zinc	ug/l	2000 HRL94	500.0	12.3	< 10.0	--	--	--	< 10.0	--	--	< 10.0	--	--	--	--	< 10.0	--	--	< 10.0	--	--	--	--	--	< 10.0	--	--	

Elk River Landfill

Location				P-301C	P-301C	P-301C	P-301C	P-301L	P-301L	P-301L	P-301L	P-301L	P-301L	P-301L	P-301L	P-302C	P-302C	P-302C	P-302C	P-302C	P-302C	P-302C	P-304C	P-304C	P-304C	P-304C	P-304C
Date				7/09/2019	10/22/2019	12/19/2019	4/22/2020	4/18/2018	7/17/2018	10/18/2018	4/11/2019	7/12/2019	10/23/2019	12/19/2019	4/23/2020	4/18/2018	7/17/2018	10/16/2018	4/09/2019	7/10/2019	10/23/2019	4/22/2020	4/17/2018	7/19/2018	10/15/2018	4/09/2019	7/09/2019
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																								
Effective Date		04/27/2020	07/23/2015																								
Exceedance Key		Bold	Underline																								
Volatile Organic Compounds																											
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	17.5	< 1.0	--	< 1.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U J4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U J4	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	2250.0	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	0.5	< 0.50	--	< 1.0	< 0.500 U	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 h	< 0.50 H	--	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 ^A	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	0.75	< 0.75	--	< 1.0	< 0.750 U	< 0.75	< 0.75	< 0.75 h	< 0.75	< 0.75 h	< 1.0 H	--	< 0.750 U	< 0.75 h	< 0.75	< 0.75	< 0.75 h	< 0.75	< 1.0 ^A	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75
1,1-Dichloroethane	ug/l	80 RAA16 (1)	25.0	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	1.5 H	< 2.0	1.5	1.1	1.4
1,1-Dichloroethylene	ug/l	200 HBV19	50.0	< 1.0	--	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 2.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 2.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l			< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l			< 1.0	--	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 5.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	0.00075	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	1.0	< 1.0	--	< 5.0 ^	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	25.0	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		0.05	< 0.050	< 0.050 h	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 0.050	--	< 1.00 U	< 0.050 h	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	0.001	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	150.0	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	0.25	< 0.25	0.40 h	< 0.25	< 0.250 U	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25	< 0.25 ^A	--	< 0.250 U	0.45 h	0.41	0.33	0.46 h	0.38	< 0.25 ^A	0.436	< 0.25	0.25	< 0.25	< 0.25	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	12.5	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	1.0 H	< 2.0	1.1	< 1.0	1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	10.0	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	1.25	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	25.0	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l			< 1.0	--	< 1.0 ^	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l			< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	0.5	< 0.50	--	< 0.25	< 0.500 U	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 h	< 2.0 H	--	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.25 ^A	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94		< 1.0	--	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 5.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	2.5	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l			< 1.0	--	< 4.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H^	< 1.0	< 1.0	< 4.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 4.0	< 1.00 U	< 1.0 H	< 2.0 ^	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	1000	< 10	--	< 10	< 10.0 U	< 10	< 10	< 10 H	< 10	< 10	< 10 H	--	< 10.0 U	< 20	< 20	< 20	< 20	< 10	< 10	< 10.0 U	< 10 H	< 20	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	7.5	< 1.0	--	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 2.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 2.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	0.5	< 0.50 *	--	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 h	< 0.50 H	--	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 ^A	< 0.500 U	< 0.50	0.74	< 0.50	< 0.50	< 0.50 *
Bromobenzene	ug/l			< 1.0	--	< 1.0 ^	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l			< 1.0	--	< 5.0 ^	< 1.00 U J4	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	--	< 1.00 U J4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 5.0 ^	< 1.00 U J4	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	1.5	< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	10.0	< 1.0	--	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0 *	< 5.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 5.0 *	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0 *
Bromomethane	ug/l	10 HRL93	2.5	< 1.0	--	< 4.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 4.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 4.0 *	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l			< 1.0	--	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l			< 1.0	--	< 1.0 ^	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l			< 1.0	--	< 1.0 ^	< 1.00 U	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	--	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.00 U	< 1.0 H	< 2.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	0.25	< 0.25	< 0.25 h	< 0.25	< 0.250 U	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25 h	< 0.25	--	< 0.250 U	< 0.25 h											

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-301C	P-301C	P-301C	P-301C	P-301L	P-301L	P-301L	P-301L	P-301L	P-301L	P-301L	P-301L	P-301L	P-302C	P-302C	P-302C	P-302C	P-302C	P-302C	P-302C	P-304C	P-304C	P-304C	P-304C	P-304C
Date				7/09/2019	10/22/2019	12/19/2019	4/22/2020	4/18/2018	7/17/2018	10/18/2018	4/11/2019	7/12/2019	10/23/2019	12/19/2019	4/23/2020	4/18/2018	7/17/2018	10/16/2018	4/09/2019	7/10/2019	10/23/2019	4/22/2020	4/17/2018	7/19/2018	10/15/2018	4/09/2019	7/09/2019	
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																									
Effective Date		04/27/2020	07/23/2015																									
Exceedance Key		Bold	<u>Underline</u>																									
General Parameters																												
Alkalinity, total, as CaCO3	mg/l			473	--	--	--	--	293	--	--	285	--	--	--	--	692	--	--	651	--	--	--	796	--	--	--	730
Carbon, total organic	mg/l			--	--	--	--	--	--	--	--	1.5	< 1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Cation-Anion balance	%			2.0	--	--	--	--	-0.063	--	--	2.3	--	--	--	--	-1.1	--	--	9.9	--	--	--	2.2	--	--	0.88	
Chloride	mg/l			27.5	--	--	--	--	41.7	--	--	39.0	--	--	--	--	240	--	--	190	--	--	--	80.2	--	--	57.8	
Dissolved oxygen, field	mg/l			0.8	2.2	1.3	--	1.8	3.3	2.0	1.0	0.3	0.4	0.6	--	0.6	2.6	2.4	1.0	2.4	2.1	--	2.4	3.7	5.0	1.1	2.4	
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	--	--	--	0.15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Manganese II, field	mg/l			--	--	--	--	--	--	--	--	8.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, ammonia, as N	mg/l			0.068	--	--	--	--	0.23	--	--	< 0.020	--	--	--	--	0.039	--	--	0.059	--	--	--	0.048	--	--	0.039	
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	--	--	--	< 0.050 H	< 0.050	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	--	--	--	< 0.050 H	< 0.050	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
pH, field	pH units			7.14	7.11	7.29	--	7.68	6.59	7.38	7.41	7.28	7.18	7.20	--	7.20	7.45	7.04	7.12	7.07	7.65	--	6.86	6.63	6.67	6.90	6.65	
Redox (oxidation potential), field	mV			326.5	269	100	--	128.9	-50	303.2	2.6	25	31	59	--	-143.9	-131	-10.8	74.2	326.0	257.1	--	-115.8	-25	59.7	-32.7	283.6	
Solids, total dissolved	mg/l			811	--	--	--	--	379	--	--	347	--	--	--	--	1050	--	--	1050	--	--	--	983 H	--	--	888	
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Specific conductance @ 25 °C, field	umhos/cm			1160	1838	1155	--	740	675	736	724	638	704	680	--	1709	1938	1782	1868	1890	1231	--	1358	1993	1533	1355	1551	
Sulfate, as SO4	mg/l			160	--	--	--	--	23.5	--	--	18.2	--	--	--	--	19.8	--	--	29.5	--	--	--	9.3	--	--	17.9	
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	--	--	--	0.10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Temperature, field	deg C			10.9	12.4	9.9	--	9.0	15.0	10.1	8.7	10.7	9.9	8.8	--	11.9	14.4	13.1	12.9	13.3	10.5	--	9.0	10.5	9.8	8.5	10.2	
Turbidity, field	NTU			9.8	34.7	10.0	--	8.5	3.6	1.4	8.0	3.0	2.1	1.9	--	26.6	6.0	7.0	20.1	42.1	6.9	--	20.1	12.1	3.6	41.2	15.8	
Dissolved Metals																												
Arsenic	ug/l		2.5	<u>5.1</u>	--	--	--	--	< 5.0	--	--	< 1.0	--	--	--	--	<u>8.5</u>	--	--	<u>11.6</u>	--	--	--	< 5.0	--	--	2.9	
Boron	ug/l	500 RAA17	<u>250.0</u>	43.9	--	--	--	--	33.1	--	--	40.7	--	--	--	--	<u>384</u>	--	--	<u>444</u>	--	--	--	<u>1100</u>	--	--	<u>788</u>	
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Calcium	mg/l			156	--	--	--	--	88.4	--	--	91.5	--	--	--	--	152	--	--	180	--	--	--	197	--	--	184	
Chromium	ug/l	100 CR HRL93	25.0	< 4.0	--	--	--	--	< 4.0	--	--	< 4.0	--	--	--	--	< 4.0	--	--	< 4.0	--	--	--	< 4.0	--	--	< 4.0	
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Iron	ug/l			1080	--	--	--	--	175	--	--	238	--	--	--	--	12300	--	--	16100	--	--	--	4440	--	--	4240	
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Magnesium	mg/l			71.7	--	--	--	--	31.5	--	--	32.1	--	--	--	--	125	--	--	127	--	--	--	76.8	--	--	66.1	
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Potassium	mg/l			2.47	--	--	--	--	6.37	--	--	2.38	--	--	--	--	4.85	--	--	5.22	--	--	--	2.51	--	--	2.19	
Sodium	mg/l			6.87	--	--	--	--	7.7	--	--	5.21	--	--	--	--	40.3	--	--	43.6	--	--	--	63	--	--	45.5	
Zinc	ug/l	2000 HRL94	500.0	< 10.0	--	--	--	--	< 10.0	--	--	< 10.0	--	--	--	--	< 10.0	--	--	< 10.0	--	--	--	< 10.0	--	--	< 10.0	

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-304C	P-304C	P-305C	P-305C	P-305C	P-305C	P-305C	P-305C	P-305C	P-308C	P-308C	P-308L	P-308L	P-308L	P-308L	P-309C	P-309C	P-311D	P-311D	P-311D	P-311D	P-311D	P-311D	
Date				10/23/2019	4/22/2020	4/17/2018	7/19/2018	10/16/2018	4/09/2019	7/08/2019	10/23/2019	4/22/2020	7/19/2018	7/11/2019	7/12/2019	10/23/2019	12/19/2019	12/20/2019	7/19/2018	7/09/2019	4/23/2018	7/20/2018	10/22/2018	6/10/2019	7/11/2019	10/22/2019	4/23/2020
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																								
Effective Date		04/27/2020	07/23/2015																								
Exceedance Key		Bold	<u>Underline</u>																								
General Parameters																											
Alkalinity, total, as CaCO3	mg/l			--	--	--	312	--	--	342	--	--	1220	1090	540	--	--	598	560	561	--	198	--	--	172	--	--
Carbon, total organic	mg/l			--	--	--	--	--	--	--	--	--	--	--	4.4	3.9	--	2.2	--	--	--	--	--	--	--	--	
Cation-Anion balance	%			--	--	--	3.4	--	--	1.7	--	--	2.3	1.3	7.8	--	--	--	0.25	0.78	--	-3.9	--	--	1.6	--	--
Chloride	mg/l			--	--	--	53.2	--	--	78.3	--	--	771	702	41.3	--	--	32.1	243	240	--	< 0.50	--	--	< 0.50	--	--
Dissolved oxygen, field	mg/l			4.1	--	2.1	2.3	2.6	0.7	1.1	1.3	--	11.0	9.4	0.6	0.4	0.8	0.8	7.0	2.0	0.1	9.1	0.5	0.2	0.6	0.5	--
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	4.5	--	--	--	--	--	--	--	--	--	--	--	
Manganese II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	187	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, ammonia, as N	mg/l			--	--	--	0.060	--	--	0.068	--	--	3.3	2.8	0.028	--	--	--	0.23	0.29	--	0.20	--	--	0.16	--	--
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	--	--	--	--	--	--	< 0.050 H	< 0.050	--	< 0.050	--	--	--	--	--	--	--	--	
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	< 0.050 H	< 0.050	--	0.066	--	--	--	--	--	--	--	--	
pH, field	pH units			6.66	--	7.62	7.28	7.19	7.44	7.33	7.56	--	6.72	6.72	7.01	7.40	7.50	7.50	6.90	6.79	7.78	7.94	7.47	7.85	7.57	7.60	--
Redox (oxidation potential), field	mV			283.0	--	-68.1	3.0	166.9	135.4	248.6	251.5	--	-70	215.0	-179	-217	-74	-74	-27	352.6	47.2	309.5	359.0	160	76.4	243.7	--
Solids, total dissolved	mg/l			--	--	--	451 H	--	--	481 H	--	--	2490 H	2410	658	--	--	--	1120 H	986	--	190	--	--	179	--	--
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Specific conductance @ 25 °C, field	umhos/cm			1598	--	687	687	712	733	830	721	--	3891	3794	1111	599	1080	1080	1675	1907	492	340	335	305	351	340	--
Sulfate, as SO4	mg/l			--	--	--	9.1	--	--	8.3	--	--	< 40.0	< 40.0	19.9	--	--	38.9	11.9	10.3	--	3.1	--	--	3.2	--	--
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	--	--	--	--	--	--	0.19	--	--	--	--	--	--	--	--	--	--	--	
Temperature, field	deg C			9.9	--	10.3	12.0	12.3	11.4	12.5	11.6	--	15.3	15.3	17.9	14.0	9.9	9.9	13.4	13.2	8.8	9.5	8.7	8.8	8.7	8.6	--
Turbidity, field	NTU			10.8	--	16.3	10.9	4.7	7.1	7.3	6.0	--	6.0	30.9	8.7	10.9	12.2	122	69.3	18.7	0.8	5.1	0.6	1.3	2.0	0.8	--
Dissolved Metals																											
Arsenic	ug/l		<u>2.5</u>	--	--	--	< 5.0	--	--	6.4	--	--	33.4	35.8	< 1.0	--	--	--	13.2	21.5	--	< 5.0	--	--	1.7	--	--
Boron	ug/l	500 RAA17	<u>250.0</u>	--	--	--	519	--	--	613	--	--	3940	4140 ^	126	--	--	--	1270	1220	--	< 20.0	--	--	22.6	--	--
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Calcium	mg/l			--	--	--	69.9	--	--	75.0	--	--	205	181	152	--	--	--	169	166	--	46.0	--	--	44.2	--	--
Chromium	ug/l	100 CR HRL93	25.0	--	--	--	< 4.0	--	--	< 4.0	--	--	< 4.0	< 4.0	< 4.0	--	--	--	< 4.0	< 4.0	--	< 4.0	--	--	< 4.0	--	--
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Iron	ug/l			--	--	--	1530	--	--	1980	--	--	20900	17600	18500	--	--	--	6460	6440	--	1180	--	--	1150	--	--
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Magnesium	mg/l			--	--	--	49.2	--	--	56.9	--	--	157	136	60.6	--	--	--	77.5	74.9	--	14.1	--	--	13.7	--	--
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Potassium	mg/l			--	--	--	2	--	--	2.18	--	--	11.6	11.2	3.55	--	--	--	3.99	4.41	--	1.2	--	--	1.26	--	--
Sodium	mg/l			--	--	--	18.6	--	--	21.8	--	--	546	488	18.2	--	--	--	71.8	82.2	--	3.96	--	--	4.41	--	--
Zinc	ug/l	2000 HRL94	500.0	--	--	--	< 10.0	--	--	< 10.0	--	--	< 10.0	< 10.0	< 10.0	--	--	--	< 10.0	< 10.0	--	< 10.0	--	--	< 10.0	--	--

Elk River Landfill

Location				P-311L	P-311L	P-311L	P-311L	P-311L	P-311L	P-311L	P-311L	P-313C	P-313C	P-313C	P-313C	P-313C	P-313C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-311L	P-311L	P-311L	P-311L	P-311L	P-311L	P-311L	P-311L	P-313C	P-313C	P-313C	P-313C	P-313C	P-313C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-314C	P-320C	P-320C	P-320C
Date				4/20/2018	7/19/2018	10/18/2018	4/11/2019	7/10/2019	10/23/2019	4/23/2020	4/23/2018	7/16/2018	10/15/2018	4/09/2019	7/09/2019	10/22/2019	4/23/2020	4/23/2018	7/17/2018	10/16/2018	4/10/2019	7/09/2019	10/23/2019	4/22/2020	4/17/2018	7/16/2018	10/15/2018	
		MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																									
Parameter	Units																											
Effective Date		04/27/2020	07/23/2015																									
Exceedance Key		Bold	<u>Underline</u>																									
General Parameters																												
Alkalinity, total, as CaCO3	mg/l			--	347	--	--	319	--	--	--	621	--	--	532	--	--	--	810	--	--	--	735	--	--	--	376	--
Carbon, total organic	mg/l			--	--	--	--	--	--	--	--	--	--	--	2.9	4.1	--	--	--	--	--	--	--	--	--	--	--	
Cation-Anion balance	%			--	1.2	--	--	4.1	--	--	--	-2.5	--	--	0.80	--	--	--	-2.8	--	--	--	4.1	--	--	--	-2.4	--
Chloride	mg/l			--	27.0	--	--	28.3	--	--	--	74.7	--	--	72.2	--	--	--	66.5	--	--	--	56.2	--	--	--	72.1	--
Dissolved oxygen, field	mg/l			0.6	2.5	1.7	1.1	0.7	1.5	--	4.2	1.3	4.0	2.3	0.7	0.9	--	0.4	0.3	3.5	1.4	2.1	3.2	--	5.9	0.2	0.9	
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	1.50	--	--	--	--	--	--	--	--	--	--	--	--	
Manganese II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	25.0	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, ammonia, as N	mg/l			--	< 0.020	--	--	< 0.020	--	--	--	< 0.020	--	--	< 0.020	--	--	--	< 0.020	--	--	--	< 0.020	--	--	--	< 0.020	--
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	--	--	--	--	--	--	
pH, field	pH units			7.66	7.36	7.95	7.33	7.19	7.00	--	5.96	7.15	6.95	7.22	6.87	6.84	--	6.95	7.00	6.67	7.00	6.69	6.76	--	7.55	7.42	7.18	
Redox (oxidation potential), field	mV			151.9	54	99.4	338	290.7	271.5	--	176.4	156.9	28.3	266.7	133	89	--	-18.1	213.2	311.4	333.8	307.1	282.1	--	113.7	329.6	329.3	
Solids, total dissolved	mg/l			--	449 H	--	--	413	--	--	--	722	--	--	673	--	--	--	925	--	--	--	895	--	--	--	505	--
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Specific conductance @ 25 °C, field	umhos/cm			734	693	723	761	782	774	--	1161	1289	1306	1168	1119	1220	--	1106	1534	1542	1554	1626	1472	--	861	885	884	
Sulfate, as SO4	mg/l			--	21.5	--	--	21.1	--	--	--	21.3	--	--	20.6	--	--	--	35.5	--	--	--	21.7	--	--	--	33.1	--
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	--	--	--	--	--	--	0.06	--	--	--	--	--	--	--	--	--	--	--	--	
Temperature, field	deg C			8.6	9.4	9.3	7.7	9.9	9.0	--	11.6	9.9	8.5	8.8	11.0	8.3	--	9.5	11.4	8.8	6.4	10.7	8.8	--	9.0	11.4	10.3	
Turbidity, field	NTU			26.3	63.9	58.0	13.5	24.0	29.3	--	13.3	11.9	2.2	4.6	9.9	8.0	--	50.3	156.0	36.4	10.9	34.6	23.8	--	15.3	7.6	5.9	
Dissolved Metals																												
Arsenic	ug/l		<u>2.5</u>	--	< 5.0	--	--	< 1.0	--	--	--	< 5.0	--	--	1.2	--	--	--	< 5.0	--	--	--	< 1.0	--	--	--	<u>5.6</u>	--
Boron	ug/l	500 RAA17	<u>250.0</u>	--	24.5	--	--	21.3	--	--	--	59.1	--	--	61.6	--	--	--	42.5	--	--	--	66.0	--	--	--	25.7	--
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Calcium	mg/l			--	101	--	--	101	--	--	--	168	--	--	157	--	--	--	213	--	--	--	216	--	--	--	115	--
Chromium	ug/l	100 CR HRL93	25.0	--	< 4.0	--	--	< 4.0	--	--	--	< 4.0	--	--	< 4.0	--	--	--	< 4.0	--	--	--	4.6	--	--	--	< 4.0	--
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Iron	ug/l			--	866	--	--	992	--	--	--	308	--	--	469	--	--	--	6530	--	--	--	11400	--	--	--	3330	--
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Magnesium	mg/l			--	36.8	--	--	35.6	--	--	--	64.4	--	--	59.7	--	--	--	76.6	--	--	--	75.8	--	--	--	42.9	--
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Potassium	mg/l			--	1.72	--	--	1.78	--	--	--	2.51	--	--	2.36	--	--	--	2.75	--	--	--	2.76	--	--	--	2.14	--
Sodium	mg/l			--	4.09	--	--	4.59	--	--	--	11	--	--	10.9	--	--	--	9.76	--	--	--	10.1	--	--	--	5.69	--
Zinc	ug/l	2000 HRL94	500.0	--	< 10.0	--	--	< 10.0	--	--	--	< 10.0	--	--	< 10.0	--	--	--	< 10.0	--	--	--	< 10.0	--	--	--	< 10.0	--

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-320C	P-320C	P-320C	P-320C	P-320C2	P-320C2	P-320C2	P-320C2	P-320C2	P-320C2	P-320C2	P-320L	P-320L	P-320L	P-320L	P-320L	P-320L	P-320L	P-321L	P-321L	P-321L	P-321L	P-321L	P-321L
Date				4/08/2019	7/08/2019	10/22/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/08/2019	10/22/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/08/2019	10/23/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/10/2019	10/23/2019
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																								
Effective Date		04/27/2020	07/23/2015																								
Exceedance Key		Bold	<u>Underline</u>																								
Volatile Organic Compounds																											
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	17.5	< 1.0	< 1.0	< 1.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	2250.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	0.5	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50 ^A	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	0.75	< 0.75	< 0.75	< 1.0	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	--	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0 ^A	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75 h	< 0.75	< 1.0
1,1-Dichloroethane	ug/l	80 RAA16 (1)	25.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	1.03	1.5	1.3	1.4	1.3	1.4	2.0 ^A	1.95	5.7	5.5	6.7	5.1	5.1	4.8
1,1-Dichloroethylene	ug/l	200 HBV19	50.0	< 1.0	< 1.0	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,1-Dichloropropene	ug/l			< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l			< 1.0	< 1.0	< 5.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 5.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	0.00075	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	1.0	< 1.0	< 1.0	< 5.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	25.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		0.05	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	0.001	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	150.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	<u>0.25</u>	< 0.25	< 0.25	< 0.25 ^A	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 ^A	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 ^A	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25 *
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	12.5	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	10.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	1.25	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	25.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l			< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	0.5	< 0.50	< 0.50	< 0.25	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.25 ^A	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.25
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94		< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	<u>2.5</u>	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l			< 1.0	< 1.0	< 4.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.00 U	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0
Acetone	ug/l	3000 HBV17 (1)	1000	< 10	< 10	< 10	< 10.0 U	< 10	< 10	< 10	< 10	< 10	--	< 10.0 U	< 10	< 10	< 10	< 10	< 10	< 10	< 10.0 U	< 10	< 10	< 10	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	7.5	< 1.0	< 1.0	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Benzene	ug/l	2 HRL09 (1)	<u>0.5</u>	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50 ^A	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50
Bromobenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l			< 1.0	< 1.0	< 5.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 ^	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0
Bromodichloromethane	ug/l	3 HBV18 (1)	1.5	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	10.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 *	< 1.00 U	< 1.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 ^A
Bromomethane	ug/l	10 HRL93	2.5	< 1.0	< 1.0	< 4.0 ^A	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0
Butylbenzene	ug/l			< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l			< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l			< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.00 U	< 1												

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-320C	P-320C	P-320C	P-320C	P-320C2	P-320C2	P-320C2	P-320C2	P-320C2	P-320C2	P-320C2	P-320L	P-320L	P-320L	P-320L	P-320L	P-320L	P-320L	P-321L	P-321L	P-321L	P-321L	P-321L	P-321L
Date				4/08/2019	7/08/2019	10/22/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/08/2019	10/22/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/08/2019	10/23/2019	4/21/2020	4/17/2018	7/16/2018	10/15/2018	4/08/2019	7/10/2019	10/23/2019
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																								
Effective Date		04/27/2020	07/23/2015																								
Exceedance Key		Bold	Underline																								
General Parameters																											
Alkalinity, total, as CaCO3	mg/l			--	390	--	--	--	351	--	--	368	--	--	--	360	--	--	356	--	--	--	537	--	--	384	--
Carbon, total organic	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.8	2.4
Cation-Anion balance	%			--	-0.44	--	--	--	-1.9	--	--	0.63	--	--	--	-0.33	--	--	0.41	--	--	--	-3.6	--	--	10.6	--
Chloride	mg/l			--	85.4	--	--	--	67.5	--	--	68.1	--	--	--	51.0	--	--	44.5	--	--	--	56.7	--	--	49.7	--
Dissolved oxygen, field	mg/l			0.6	1.0	1.4	--	4.0	2.6	2.0	0.4	1.1	1.9	--	6.1	4.0	3.0	0.5	1.4	1.8	--	2.6	1.2	2.4	1.1	0.9	1.1
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.85	--
Manganese II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	9.9	--
Nitrogen, ammonia, as N	mg/l			--	< 0.020	--	--	--	< 0.020	--	--	< 0.020	--	--	--	< 0.020	--	--	< 0.020	--	--	--	< 0.020	--	--	< 0.020	--
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050
pH, field	pH units			7.59	7.26	7.61	--	7.60	7.58	7.35	7.30	7.41	7.37	--	7.46	7.40	7.17	7.27	7.39	7.48	--	7.28	7.37	7.08	7.23	7.08	7.01
Redox (oxidation potential), field	mV			292.1	214.7	242.1	--	-93.5	200.4	128.4	263.9	215.7	224.7	--	-16.5	227.9	201.3	284.6	195.8	240.2	--	-49.4	192.6	6.3	191.2	166	80
Solids, total dissolved	mg/l			--	658	--	--	--	521	--	--	496 H	--	--	--	457	--	--	440	--	--	--	661	--	--	602	--
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Specific conductance @ 25 °C, field	umhos/cm			928	1015	977	--	829	810	802	849	924	970	--	819	813	820	855	837	827	--	1122	1071	1030	1035	944	1004
Sulfate, as SO4	mg/l			--	27.2	--	--	--	21.3	--	--	21.3	--	--	--	22.3	--	--	21.3	--	--	--	30.3	--	--	27.6	--
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.08	--
Temperature, field	deg C			9.7	11.5	11.0	--	9.6	11.7	10.7	10.5	11.8	11.7	--	8.4	12.0	10.7	10.4	11.8	11.4	--	10.6	11.4	10.6	11.1	11.2	10.6
Turbidity, field	NTU			1.4	1.3	2.9	--	11.7	10.4	10.8	5.5	1.5	10.0	--	22.6	11.2	13.1	8.3	1.5	3.6	--	26.4	11.0	1.5	5.7	13.2	9.0
Dissolved Metals																											
Arsenic	ug/l		2.5	--	< 1.0	--	--	--	< 5.0	--	--	6.7	--	--	--	< 5.0	--	--	1.3	--	--	--	< 5.0	--	--	< 1.0	--
Boron	ug/l	500 RAA17	250.0	--	44.5	--	--	--	28.0	--	--	32.6	--	--	--	< 20.0	--	--	21.0	--	--	--	41.1	--	--	36.6	--
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcium	mg/l			--	128	--	--	--	109	--	--	120	--	--	--	112	--	--	110	--	--	--	146	--	--	143	--
Chromium	ug/l	100 CR HRL93	25.0	--	< 4.0	--	--	--	< 4.0	--	--	< 4.0	--	--	--	< 4.0	--	--	< 4.0	--	--	--	< 4.0	--	--	< 4.0	--
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Iron	ug/l			--	305	--	--	--	318	--	--	436	--	--	--	1980	--	--	762	--	--	--	835	--	--	756	--
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium	mg/l			--	47.8	--	--	--	39.6	--	--	42.9	--	--	--	37.6	--	--	37.9	--	--	--	53.5	--	--	53.7	--
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Potassium	mg/l			--	2.35	--	--	--	2.5	--	--	2.54	--	--	--	2.33	--	--	2.3	--	--	--	2.81	--	--	3.12	--
Sodium	mg/l			--	6.35	--	--	--	5.44	--	--	5.4	--	--	--	4.31	--	--	4.07	--	--	--	5.98	--	--	5.95	--
Zinc	ug/l	2000 HRL94	500.0	--	< 10.0	--	--	--	< 10.0	--	--	< 10.0	--	--	--	< 10.0	--	--	< 10.0	--	--	--	< 10.0	--	--	< 10.0	--

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-321L	P-321L	P-322L	P-322L	P-322L	P-322L	P-322L	P-322L	P-322L	P-322L	P-322L	P-323L	P-323L	P-323L	P-323L	P-323L	P-323L	P-323L	P-323L	P-324L	P-324L	P-324L	P-324L	P-324L	P-324L	P-324L
Date				12/19/2019	4/21/2020	4/23/2018	7/17/2018	10/16/2018	4/10/2019	7/09/2019	10/23/2019	4/22/2020	4/19/2018	7/16/2018	10/15/2018	4/08/2019	7/10/2019	10/23/2019	12/19/2019	4/21/2020	4/19/2018	7/17/2018	10/15/2018	4/09/2019	7/09/2019	10/22/2019	12/19/2019		
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																										
Effective Date		04/27/2020	07/23/2015																										
Exceedance Key		Bold	<u>Underline</u>																										
Volatile Organic Compounds																													
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	17.5	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U J4	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	2250.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	0.5	--	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50 ^	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	
1,1,2-Trichloroethane	ug/l	3 HRL93	0.75	--	< 0.750 U	< 0.75 h	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0 ^	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0	--	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0	< 1.0	--	
1,1-Dichloroethane	ug/l	80 RAA16 (1)	25.0	--	2.87	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	14	17	16	12	11	8.4	--	9.00	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,1-Dichloroethylene	ug/l	200 HBV19	50.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	--	
1,1-Dichloropropene	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,2,3-Trichlorobenzene	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0 ^	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	--	
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	0.00075	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	--	
1,2,4-Trimethylbenzene	ug/l	30 HBV19	25.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0 *	--	
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		0.05	--	< 1.00 U	< 0.050 h	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	--	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	--	
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	0.001	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,2-Dichlorobenzene	ug/l	600 HRL93	150.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,2-Dichloroethane	ug/l	1 HRL13 (1)	<u>0.25</u>	--	< 0.250 U	< 0.25 h	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 ^	< 0.250 U	<u>0.88</u>	<u>0.86</u>	<u>0.78</u>	<u>0.90</u>	<u>0.58</u>	<u>0.58</u>	--	<u>0.604</u>	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 *	< 0.25 *	--
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	12.5	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0 ^	< 1.00 U	5.3	6.5	7.3	5.9	5.2	4.9	--	4.22	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	10.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,2-Dichloropropane	ug/l	5 HRL94	1.25	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	1.0	--	1.03	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	25.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0 *	--
1,3-Dichlorobenzene	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,3-Dichloropropane	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	0.5	--	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.50	< 0.25 ^	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.25	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.25	< 0.25	--
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94		--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	--
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	<u>2.5</u>	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
2,2-Dichloropropane	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 4.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 4.0	--
Acetone	ug/l	3000 HBV17 (1)	1000	--	< 10.0 U	< 10	< 10	< 10	< 10	< 10	< 10	< 10.0 U	< 20	< 20	< 20	< 20	< 20	< 10	--	< 10.0 U	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	--
Allyl chloride	ug/l	30 HRL94	7.5	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	--
Benzene	ug/l	2 HRL09 (1)	<u>0.5</u>	--	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.50 *	< 0.50 ^	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50 *	< 0.50 *	< 0.50	< 0.50	--
Bromobenzene	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
Bromochloromethane	ug/l			--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 ^	< 1.00 U J4	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	--
Bromodichloromethane	ug/l	3 HBV18 (1)	1.5	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
Bromoform	ug/l	40 HRL93	10.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 *	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0 ^	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 5.0	< 5.0	< 5.0	--
Bromomethane	ug/l	10 HRL93	2.5	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0 *	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 4.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0 ^	< 4.0 ^	--
Butylbenzene	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
Butylbenzene, sec	ug/l			--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0 *	--
Butylbenzene, tert	ug/l			--																									

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-321L	P-321L	P-322L	P-322L	P-322L	P-322L	P-322L	P-322L	P-322L	P-322L	P-323L	P-323L	P-323L	P-323L	P-323L	P-323L	P-323L	P-323L	P-324L	P-324L	P-324L	P-324L	P-324L	P-324L	P-324L
Date				12/19/2019	4/21/2020	4/23/2018	7/17/2018	10/16/2018	4/10/2019	7/09/2019	10/23/2019	4/22/2020	4/19/2018	7/16/2018	10/15/2018	4/08/2019	7/10/2019	10/23/2019	12/19/2019	4/21/2020	4/19/2018	7/17/2018	10/15/2018	4/09/2019	7/09/2019	10/22/2019	12/19/2019	
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																									
Effective Date		04/27/2020	07/23/2015																									
Exceedance Key		Bold	<u>Underline</u>																									
General Parameters																												
Alkalinity, total, as CaCO3	mg/l			--	--	--	392	--	--	350	--	--	--	947	--	--	620	--	--	--	--	--	371	--	--	280	--	--
Carbon, total organic	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	11.3 ^	10.2	--	--	--	--	--	--	< 1.0	1.2	--	
Cation-Anion balance	%			--	--	--	-9.2	--	--	0.58	--	--	--	-4.2	--	--	9.4	--	--	--	--	0.57	--	--	-3.7	--	--	
Chloride	mg/l			--	--	--	20.4	--	--	17.5	--	--	--	201	--	--	159	--	--	--	--	25.3	--	--	32.0	--	--	
Dissolved oxygen, field	mg/l			1.1	--	0.2	0.1	1.9	0.7	0.9	1.3	--	0.1	0.7	6.5	1.0	1.9	2.0	0.8	--	0.1	0.2	1.1	0.3	0.7	0.8	0.7	
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	5.0	--	--	--	--	--	--	--	2.03	--	--	
Manganese II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	12.1	--	--	--	--	--	--	--	18.2	--	--	
Nitrogen, ammonia, as N	mg/l			--	--	--	< 0.020	--	--	< 0.020	--	--	--	< 0.020	--	--	< 0.020	--	--	--	--	< 0.020	--	--	0.033	--	--	
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050	--	--	--	--	--	--	< 0.050	< 0.050 H	--	
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050	--	--	--	--	--	--	< 0.050	< 0.050 H	--	
pH, field	pH units			6.95	--	7.54	7.52	7.17	7.20	7.09	7.26	--	6.83	6.91	6.63	6.72	6.78	6.70	6.64	--	7.75	7.84	7.38	7.49	7.40	7.21	7.37	
Redox (oxidation potential), field	mV			329.3	--	193.2	76.4	107.9	306.7	306.1	262.3	--	243.1	196.0	9.6	243.2	144	70	264.0	--	-162.8	-9.1	-30.2	242.3	-43	-30	333.9	
Solids, total dissolved	mg/l			--	--	--	411	--	--	412	--	--	--	1280	--	--	1050	--	--	--	--	375	--	--	309	--	--	
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Specific conductance @ 25 °C, field	umhos/cm			1120	--	750	705	752	753	755	779	--	2034	2052	2024	1896	1611	1683	1704	--	520	509	577	556	567	651	643	
Sulfate, as SO4	mg/l			--	--	--	29.6	--	--	24.9	--	--	--	25.2	--	--	16.0	--	--	--	--	19.2	--	--	< 2.0	--	--	
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	0.14	--	--	--	--	--	--	--	0.26	--	--	
Temperature, field	deg C			10.5	--	8.6	10.4	8.7	7.4	8.7	8.2	--	8.7	10.0	9.5	9.2	9.6	9.4	8.6	--	8.3	9.3	9.1	8.1	9.2	8.9	7.8	
Turbidity, field	NTU			7.9	--	6.7	24.7	7.8	7.8	7.3	0.4	--	236.4	9.6	92.3	19.6	8.7	21.5	157.0	--	13.5	24.5	20.2	30.7	27.3	23.3	58.7	
Dissolved Metals																												
Arsenic	ug/l		2.5	--	--	--	< 5.0	--	--	1.6	--	--	--	< 5.0	--	--	< 1.0	--	--	--	--	--	< 5.0	--	--	< 1.0	--	--
Boron	ug/l	500 RAA17	250.0	--	--	--	< 20.0	--	--	20.3	--	--	--	372	--	--	485	--	--	--	--	--	20.1	--	--	22.5	--	--
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Calcium	mg/l			--	--	--	90.9	--	--	101	--	--	--	257	--	--	215	--	--	--	--	96.2	--	--	54.7	--	--	
Chromium	ug/l	100 CR HRL93	25.0	--	--	--	< 4.0	--	--	< 4.0	--	--	--	< 4.0	--	--	< 4.0	--	--	--	--	< 4.0	--	--	< 4.0	--	--	
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Iron	ug/l			--	--	--	970	--	--	< 50.0	--	--	--	5130	--	--	4870	--	--	--	--	985	--	--	6860	--	--	
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Magnesium	mg/l			--	--	--	33.1	--	--	34.8	--	--	--	91.6	--	--	80.3	--	--	--	--	42.6	--	--	44.9	--	--	
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Potassium	mg/l			--	--	--	1.57	--	--	1.67	--	--	--	4.27	--	--	4.5	--	--	--	--	1.92	--	--	1.93	--	--	
Sodium	mg/l			--	--	--	3.66	--	--	3.5	--	--	--	53.5	--	--	70.1	--	--	--	--	4.96	--	--	4.49	--	--	
Zinc	ug/l	2000 HRL94	500.0	--	--	--	< 10.0	--	--	< 10.0	--	--	--	< 10.0	--	--	< 10.0	--	--	--	--	< 10.0	--	--	< 10.0	--	--	

Elk River Landfill

Location				P-324L	P-325L	P-325L	P-325L	P-325L	P-325L	P-325L	P-325L	P-326L	P-326L	P-326L	P-326L	P-326L	P-326L	P-327L	P-328L	P-329L	P-329L	P-329L	P-329L	P-329L	P-329L	P-329L	
Date				4/22/2020	5/10/2018	7/17/2018	10/17/2018	4/10/2019	7/09/2019	10/22/2019	4/21/2020	5/10/2020	7/17/2018	10/17/2018	5/02/2019	7/09/2019	10/22/2019	4/23/2020	5/10/2018	5/10/2018	5/10/2018	7/20/2018	10/22/2018	4/10/2019	7/12/2019	10/24/2019	4/23/2020
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																								
Effective Date																											
Exceedance Key		Bold	<u>Underline</u>																								
Volatile Organic Compounds																											
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	17.5	< 1.00 U J4	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U J4
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	2250.0	< 1.00 U	< 2.0	< 2.0	< 2.0 ^	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	0.5	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 H	< 0.500 U
1,1,2-Trichloroethane	ug/l	3 HRL93	0.75	< 0.750 U	< 0.75 h	< 0.75	< 0.75	< 0.75 h	< 0.75	< 1.0	< 0.750 U	< 0.75 h	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0	< 0.750 U	< 0.75	< 0.75	< 0.75 h	< 0.75	< 0.75	< 0.75 h	< 0.75	< 1.0 H	< 0.750 U
1,1-Dichloroethane	ug/l	80 RAA16 (1)	25.0	< 1.00 U	4.8	6.5	6.5 ^	5.8	6.3	5.7	6.41	4.6	6.7	7.8 ^	6.7	6.8	7.7	6.52	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,1-Dichloroethylene	ug/l	200 HBV19	50.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 2.0 H^	< 1.00 U
1,1-Dichloropropene	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,2,3-Trichlorobenzene	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	< 1.00 U
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	0.00075	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	1.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	< 1.00 U
1,2,4-Trimethylbenzene	ug/l	30 HBV19	25.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		0.05	< 1.00 U	< 0.050 h	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 1.00 U	< 0.050 h	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 1.00 U
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	0.001	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,2-Dichlorobenzene	ug/l	600 HRL93	150.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,2-Dichloroethane	ug/l	1 HRL13 (1)	<u>0.25</u>	< 0.250 U	< 0.25 h	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25 *	< 0.250 U	< 0.25 h	< 0.25	< 0.25	< 0.25	<u>0.28</u>	<u>0.273</u>	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.250 U
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	12.5	< 1.00 U	< 2.0	2.3	2.1	< 2.0 ^	2.1	1.9	1.42	< 1.0	2.0	2.3	2.0	2.3	1.83	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 1.0	< 1.0 H	< 1.0	< 1.00 U
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	10.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,2-Dichloropropane	ug/l	5 HRL94	1.25	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	25.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,3-Dichlorobenzene	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,3-Dichloropropane	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	0.5	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.25	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.25	< 0.500 U	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 h	< 0.25 h	< 0.500 U
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94		< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	< 1.00 U	
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	<u>2.5</u>	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U	
2,2-Dichloropropane	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0 ^	< 2.0 ^	< 2.0	< 4.0	< 1.00 U	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 4.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 1.0	< 4.0 H	< 1.00 U
Acetone	ug/l	3000 HBV17 (1)	1000	< 10.0 U	< 20	< 20	< 20	< 20	< 20	< 10	< 10.0 U	< 10	< 10	< 10	< 10	< 10	< 10.0 U	< 10	< 10	< 10	< 10	< 10 H	< 10	< 10	< 10 H	< 10.0 U	
Allyl chloride	ug/l	30 HRL94	7.5	< 1.00 U	< 2.0	< 2.0	< 2.0 ^	< 2.0	< 2.0	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 2.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^H	< 1.0	< 1.0	< 2.0 H*	< 1.00 U
Benzene	ug/l	2 HRL09 (1)	<u>0.5</u>	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50 *	< 0.50	< 0.500 U	< 0.50 h	< 0.50	< 0.50	< 0.50 *	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50 h	< 0.50 H	< 0.500 U
Bromobenzene	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U	
Bromochloromethane	ug/l			< 1.00 U J4	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 5.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 5.0 H	< 1.00 U J4	
Bromodichloromethane	ug/l	3 HBV18 (1)	1.5	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U	
Bromoform	ug/l	40 HRL93	10.0	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0 *	< 5.0 H	< 1.00 U	
Bromomethane	ug/l	10 HRL93	2.5	< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 4.0 ^	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0 ^	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 4.0 H	< 1.00 U	
Butylbenzene	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U	
Butylbenzene, sec	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.0	< 1.0 H	< 1.00 U	
Butylbenzene, tert	ug/l			< 1.00 U	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0								

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-324L	P-325L	P-325L	P-325L	P-325L	P-325L	P-325L	P-325L	P-326L	P-326L	P-326L	P-326L	P-326L	P-326L	P-326L	P-327L	P-328L	P-329L	P-329L	P-329L	P-329L	P-329L	P-329L	
Date				4/22/2020	5/10/2018	7/17/2018	10/17/2018	4/10/2019	7/09/2019	10/22/2019	4/21/2020	5/10/2018	7/17/2018	10/17/2018	5/02/2019	7/09/2019	10/22/2019	4/23/2020	5/10/2018	5/10/2018	5/10/2018	7/20/2018	10/22/2018	4/10/2019	7/12/2019	10/24/2019	4/23/2020
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																								
Effective Date		04/27/2020	07/23/2015																								
Exceedance Key		Bold	<u>Underline</u>																								
General Parameters																											
Alkalinity, total, as CaCO3	mg/l			--	--	591	--	--	563	--	--	--	571	--	--	526	--	--	187	184	--	189	--	--	159	--	--
Carbon, total organic	mg/l			--	--	--	--	--	3.8	7.3	--	--	--	--	--	9.9	3.2	--	--	--	--	--	--	--	--	--	
Cation-Anion balance	%			--	--	-2.3	--	--	2.8	--	--	--	-2.4	--	--	2.6	--	--	-2.1	-0.56	--	3.7	--	--	6.0	--	--
Chloride	mg/l			--	--	185	--	--	141	--	--	--	60.1	--	--	52.0	--	--	13.2	2.59	--	1.8	--	--	2.0	--	--
Dissolved oxygen, field	mg/l			--	4.1	1.2	6.7	1.0	1.0	0.8	--	2.1	1.1	5.6	0.8	1.3	1.6	--	0.6	0.5	0.7	0.2	0.2	0.2	0.2	1.8	--
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	1.71	--	--	--	--	--	--	1.89	--	--	--	--	--	--	--	--	--	--	
Manganese II, field	mg/l			--	--	--	--	--	19.7	--	--	--	--	--	--	20.3	--	--	--	--	--	--	--	--	--	--	--
Nitrogen, ammonia, as N	mg/l			--	--	< 0.020	--	--	< 0.020	--	--	--	< 0.020	--	--	< 0.020	--	--	0.18	0.24	--	0.086	--	--	0.10	--	--
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050	--	--	--	--	--	--	
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	--	--	--	--	
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	< 0.050	< 0.050 H	--	--	--	--	--	--	--	--	--	
pH, field	pH units			--	7.29	7.15	7.24	7.32	6.75	6.76	--	7.48	7.12	7.33	7.06	6.76	6.86	--	8.35	8.47	8.91	7.94	8.85	8.08	7.75	7.91	--
Redox (oxidation potential), field	mV			--	-46	-5.1	100.0	330.2	25	45	--	-29	-110.8	287.1	293.4	-95	-35	--	-226	-199	-214	201.6	156.7	274.6	296.2	238.4	--
Solids, total dissolved	mg/l			--	--	578	--	--	808	--	--	--	694	--	--	615	--	--	183	171	--	214	--	--	179	--	--
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 4.0	49.2	--	--	--	--	--	--	
Specific conductance @ 25 °C, field	umhos/cm			--	1532	1444	1121	1539	1343	1299	--	1088	1067	1123	1163	1032	1141	--	390	364	259	378	226	374	358	392	--
Sulfate, as SO4	mg/l			--	--	25.3	--	--	19.3	--	--	--	23.8	--	--	21.1	--	--	9.24	13.6	--	12.8	--	--	7.7	--	--
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	0.01	--	--	--	--	--	--	0.05	--	--	--	--	--	--	--	--	--	--	
Temperature, field	deg C			--	10.0	8.5	8.5	7.0	10.1	8.9	--	10.0	9.1	8.8	8.4	10.8	9.6	--	7.9	7.5	8.0	8.5	9.3	6.2	11.1	8.6	--
Turbidity, field	NTU			--	6.0	3.8	2.7	2.4	4.3	3.9	--	7.3	6.0	3.2	3.0	5.1	8.9	--	7.0	8.2	16.0	1.9	5.8	4.6	11.4	11.2	--
Dissolved Metals																											
Arsenic	ug/l		<u>2.5</u>	--	--	< 5.0	--	--	< 1.0	--	--	--	< 5.0	--	--	< 1.0	--	--	1.8	1.1	--	< 5.0	--	--	< 1.0	--	--
Boron	ug/l	500 RAA17	<u>250.0</u>	--	--	209	--	--	<u>302</u>	--	--	--	20.6	--	--	25.6	--	--	21	22	--	20.2	--	--	22.1	--	--
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 2.0	< 2.0	--	--	--	--	--	--	
Calcium	mg/l			--	--	187	--	--	184	--	--	--	156	--	--	157	--	--	48.3	46.8	--	53.0	--	--	43.2	--	--
Chromium	ug/l	100 CR HRL93	25.0	--	--	< 4.0	--	--	< 4.0	--	--	--	< 4.0	--	--	< 4.0	--	--	< 4.0	< 4.0	--	< 4.0	--	--	< 4.0	--	--
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 10	< 10	--	--	--	--	--	--	--
Iron	ug/l			--	--	1770	--	--	2190	--	--	--	3480	--	--	2640	--	--	2400	3900	--	352	--	--	970	--	--
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 10	< 10	--	--	--	--	--	--	--
Magnesium	mg/l			--	--	71.2	--	--	70.3	--	--	--	57.2	--	--	58.3	--	--	17.4	16.5	--	18.1	--	--	16.4	--	--
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	210	210	--	--	--	--	--	--	--
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.20	< 0.20	--	--	--	--	--	--	--
Potassium	mg/l			--	--	3.17	--	--	3.11	--	--	--	2.14	--	--	2.14	--	--	1.4	1.5	--	1.38	--	--	1.67	--	--
Sodium	mg/l			--	--	32.2	--	--	31.5	--	--	--	5.49	--	--	5.85	--	--	5.6	5.9	--	4.99	--	--	5.19	--	--
Zinc	ug/l	2000 HRL94	500.0	--	--	< 10.0	--	--	< 10.0	--	--	--	< 10.0	--	--	< 10.0	--	--	< 10	37	--	< 10.0	--	--	< 10.0	--	--

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-333L	P-333L	P-333L	P-333L	P-333L	P-333L	P-334L	P-334L	P-334L	P-334L	P-334L	P-334L	P-334L	P-334L	P-335L	P-335L	P-335L	P-335L	P-335L	P-335L	P-335L	P-335L	315-OWA	315-OWA	
Date				3/06/2018	4/19/2018	7/16/2018	4/10/2019	7/12/2019	4/23/2020	4/19/2018	7/16/2018	10/19/2018	4/12/2019	6/10/2019	7/10/2019	10/23/2019	12/19/2019	4/23/2020	4/19/2018	7/16/2018	10/19/2018	4/12/2019	7/11/2019	10/24/2019	4/23/2020	4/18/2018	7/17/2018	
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																									
Effective Date		04/27/2020	07/23/2015																									
Exceedance Key		Bold	<u>Underline</u>																									
Volatile Organic Compounds																												
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	17.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U J4	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	2250.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	0.5	< 0.050	< 0.50	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	0.75	< 0.050	< 0.75	< 0.75	< 0.75	< 0.75	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75 h	< 0.75	< 0.75	< 1.0	--	< 0.750 U	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0	< 0.750 U	< 0.75	< 0.75	
1,1-Dichloroethane	ug/l	80 RAA16 (1)	25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,1-Dichloroethylene	ug/l	200 HBV19	50.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0 ^	--	< 1.0	< 2.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 2.0	< 1.00 U	< 1.0	< 1.0
1,1-Dichloropropene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,2,3-Trichlorobenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0 ^	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 5.0	< 1.00 U	< 1.0	< 1.0	
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	0.00075	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		0.05	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 1.00 U	< 0.050	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	0.001	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,2-Dichlorobenzene	ug/l	600 HRL93	150.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,2-Dichloroethane	ug/l	1 HRL13 (1)	<u>0.25</u>	< 0.050	< 0.25	< 0.25	< 0.25	< 0.25	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25	< 0.25 *	< 0.25	< 0.250 U	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.250 U	< 0.25	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	12.5	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	10.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,2-Dichloropropane	ug/l	5 HRL94	1.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,3-Dichlorobenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,3-Dichloropropane	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	0.5	< 0.050	< 0.50	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.25	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.25	< 0.500 U	< 0.50	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 5.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	<u>2.5</u>	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
2,2-Dichloropropane	ug/l			< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0 ^	--	< 1.0	< 4.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 4.0	< 1.00 U	< 1.0	< 1.0	
Acetone	ug/l	3000 HBV17 (1)	1000	< 10	< 10	< 10	< 10	< 10	< 10.0 U	< 10	< 10	< 10	< 10	--	< 10	< 10	--	< 10.0 U	< 10	< 10	< 10	< 10	< 10	< 10	< 10.0 U	< 10	< 10	
Allyl chloride	ug/l	30 HRL94	7.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 2.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0 ^	< 1.00 U	< 1.0	< 1.0	
Benzene	ug/l	2 HRL09 (1)	<u>0.5</u>	< 0.050	< 0.50	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.50	--	< 0.500 U	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.500 U	< 0.50	< 0.50
Bromobenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
Bromochloromethane	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 5.0	--	< 1.00 U J4	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U J4	< 1.0	< 1.0	
Bromodichloromethane	ug/l	3 HBV18 (1)	1.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
Bromoform	ug/l	40 HRL93	10.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 5.0 ^a	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.00 U	< 1.0	< 1.0	
Bromomethane	ug/l	10 HRL93	2.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 4.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.00 U	< 1.0	< 1.0	
Butylbenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
Butylbenzene, sec	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	
Butylbenzene, tert	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.00 U	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	--	< 1.00 U	< 1.0	< 1.								

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				P-333L	P-333L	P-333L	P-333L	P-333L	P-333L	P-334L	P-334L	P-334L	P-334L	P-334L	P-334L	P-334L	P-334L	P-335L	P-335L	P-335L	P-335L	P-335L	P-335L	P-335L	P-335L	315-OWA	315-OWA
Date				3/06/2018	4/19/2018	7/16/2018	4/10/2019	7/12/2019	4/23/2020	4/19/2018	7/16/2018	10/19/2018	4/12/2019	6/10/2019	7/10/2019	10/23/2019	12/19/2019	4/23/2020	4/19/2018	7/16/2018	10/19/2018	4/12/2019	7/11/2019	10/24/2019	4/23/2020	4/18/2018	7/17/2018
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74																								
Effective Date		04/27/2020	07/23/2015																								
Exceedance Key		Bold	<u>Underline</u>																								
General Parameters																											
Alkalinity, total, as CaCO3	mg/l			--	195	189	172	174	--	213	200	208	--	--	241	--	--	--	184	185	173	--	173	--	--	--	38.9
Carbon, total organic	mg/l			--	--	--	--	--	--	--	--	--	--	--	< 1.0 ^	< 1.0	--	--	--	--	--	--	--	--	--	--	--
Cation-Anion balance	%			--	-2.2	1.6	4.4	4.7	--	-2.6	1.3	0.35	--	--	-2.6	--	--	--	-0.18	0.13	1.4	--	1.5	--	--	--	3.2
Chloride	mg/l			--	1.35	1.32	1.33	1.4	--	3.64	3.94	6.38	--	--	6.8	--	--	--	2.27	2.13	2.04	--	2.5	--	--	--	5.3
Dissolved oxygen, field	mg/l			0.3	2.9	0.6	0.3	0.6	--	1.8	0.4	1.3	1.0	0.6	0.6	0.7	1.1	--	1.4	0.4	0.7	0.5	0.8	0.9	--	0.5	2.3
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	1.14	--	--	--	--	--	--	--	--	--	--	--	--
Manganese II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--	55	--	--	--	--	--	--	--	--	--	--	--	--
Nitrogen, ammonia, as N	mg/l			--	0.071	0.096	< 0.020	0.050	--	< 0.020	< 0.020	< 0.020	--	--	< 0.020 F1	--	--	--	0.050	0.033	< 0.020	--	< 0.020	--	--	--	< 0.020
Nitrogen, nitrate + nitrite, as N	mg/l			--	< 0.050	< 0.050	< 0.050	--	--	< 0.050	< 0.050	< 0.050	--	--	--	--	--	--	< 0.050	< 0.050	< 0.050	--	--	--	--	--	--
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050	--	--	--	--	--	--	--	--	--	--	--
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--	< 0.050	< 0.050	--	--	--	--	--	--	--	--	--	--	--
pH, field	pH units			8.07	7.67	8.13	8.09	7.38	--	7.74	7.80	7.81	7.51	7.64	6.89	7.18	7.18	--	7.78	7.88	7.85	7.99	7.97	8.43	--	6.32	7.03
Redox (oxidation potential), field	mV			-218.5	75	59	282.8	271.6	--	-250	56	97.2	211.1	202	85	88	-10	--	-221	25	209.2	316.0	294.6	242.9	--	328.7	221.6
Solids, total dissolved	mg/l			--	213	177	221	200	--	205	214	260	--	--	256	--	--	--	394	215	226	--	214	--	--	--	89.0
Solids, total suspended	mg/l			--	7.2	< 4.0	< 4.0	--	--	< 4.0	< 4.0	84.4	--	--	--	--	--	--	< 4.0	< 4.0	26.4	--	--	--	--	--	--
Specific conductance @ 25 °C, field	umhos/cm			382	383	350	387	397	--	420	395	446	476	426	446	455	615	--	370	340	367	379	388	359	--	149	131
Sulfate, as SO4	mg/l			--	16.2	14	12.7	13.8	--	20.2	17.4	19.8	--	--	16.3	--	--	--	15	13.5	12.9	--	12.9	--	--	--	13.0
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	--	--	--	--	--	--	0.20	--	--	--	--	--	--	--	--	--	--	--	--
Temperature, field	deg C			6.7	7.7	9.4	7.5	7.9	--	9.0	9.3	9.7	8.3	9.4	9.2	8.8	8.1	--	10.2	10.9	10.2	9.0	10.5	9.4	--	8.0	7.8
Turbidity, field	NTU			161.0	--	7.2	3.5	1.9	--	--	--	86.7	64.0	51	30.7	53.2	19.9	--	--	7.0	20.9	3.2	5.5	19.6	--	51.5	18.3
Dissolved Metals																											
Arsenic	ug/l		2.5	--	< 1.0	< 5.0	< 1.0	< 1.0	--	< 1.0	< 5.0	< 1.0 ^	--	--	< 1.0	--	--	--	< 1.0	< 5.0	< 1.0 ^	--	< 1.0	--	--	--	< 5.0
Boron	ug/l	500 RAA17	<u>250.0</u>	--	< 20	< 20	< 20	22.0	--	< 20	< 20	< 20	--	--	< 20.0	--	--	--	< 20	< 20	< 20	--	< 20.0	--	--	--	< 20.0
Cadmium	ug/l	0.5 HRL15 (1)		--	< 2.0	< 2.0	< 2.0	--	--	< 2.0	< 2.0	< 2.0	--	--	--	--	--	--	< 2.0	< 2.0	< 2.0	--	--	--	--	--	--
Calcium	mg/l			--	48.3	50.9	49.6	50.9	--	52.5	54.4	56.7	--	--	61.0	--	--	--	45.9	47.4	46.1	--	46.9	--	--	--	14.5
Chromium	ug/l	100 CR HRL93	25.0	--	< 4.0	< 4.0	< 4.0	< 4.0	--	< 4.0	< 4.0	< 4.0	--	--	< 4.0	--	--	--	< 4.0	< 4.0	< 4.0	--	< 4.0	--	--	--	< 4.0
Copper	ug/l			--	< 10	< 10	< 10	--	--	< 10	< 10	< 10	--	--	--	--	--	--	< 10	< 10	< 10	--	--	--	--	--	--
Iron	ug/l			--	950	840	1100	790	--	760	300	580	--	--	594	--	--	--	500	510	1500	--	385	--	--	--	99.8
Lead	ug/l			--	< 10	< 10	< 10	--	--	< 10	< 10	< 10	--	--	--	--	--	--	< 10	< 10	< 10	--	--	--	--	--	--
Magnesium	mg/l			--	17.8	18.4	17.5	17.1	--	21.2	21.0	21.7	--	--	22.2	--	--	--	18.1	18.0	16.8	--	16.5	--	--	--	4.18
Manganese	ug/l	100 HBV18		--	170	160	170	--	--	220	150	160	--	--	--	--	--	--	250	170	170	--	--	--	--	--	--
Mercury	ug/l			--	< 0.20	< 0.20	< 0.20	--	--	< 0.20	< 0.20	< 0.20	--	--	--	--	--	--	< 0.20	< 0.20	< 0.20	--	--	--	--	--	--
Potassium	mg/l			--	1.5	1.3	1.3	1.47	--	1.8	1.4	1.6	--	--	1.65	--	--	--	2.3	1.6	1.6	--	1.37	--	--	--	3.12
Sodium	mg/l			--	4.0	3.4	3.1	3.42	--	2.9	2.6	2.9	--	--	2.97	--	--	--	4.6	3.7	3.8	--	3.61	--	--	--	2.86
Zinc	ug/l	2000 HRL94	500.0	--	< 10	< 10	< 10	< 10.0	--	< 10	< 10	< 10	--	--	< 10.0	--	--	--	< 10	< 10	< 10	--	< 10.0	--	--	--	< 10.0

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				315-OWA	315-OWA	P694477	P694477	P694477	P694477	P694477	P694477	P694477	P694477	P694477
Date				10/16/2018	7/10/2019	4/19/2018	7/16/2018	10/22/2018	4/12/2019	5/02/2019	7/11/2019	10/24/2019	12/20/2019	4/24/2020
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74											
Effective Date		04/27/2020	07/23/2015											
Exceedance Key		Bold	<u>Underline</u>											
Volatile Organic Compounds														
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	17.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.190 U
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	2250.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.185 U
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	0.5	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50 H	< 1.0	< 0.139 U
1,1,2-Trichloroethane	ug/l	3 HRL93	0.75	< 0.75	< 0.75	< 0.75 h	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	< 1.0 H	< 1.0	< 0.119 U
1,1-Dichloroethane	ug/l	80 RAA16 (1)	25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	1.2	< 0.0982 U
1,1-Dichloroethylene	ug/l	200 HBV19	50.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 2.0 H^	< 2.0	< 0.121 U
1,1-Dichloropropene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.162 U
1,2,3-Trichlorobenzene	ug/l			< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0 ^	< 5.0 H	< 5.0	< 1.47 U
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	0.00075	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.324 U
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 5.0 H	< 5.0 ^	< 0.880 U
1,2,4-Trimethylbenzene	ug/l	30 HBV19	25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.316 U
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		0.05	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.780 U
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	0.001	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.130 U
1,2-Dichlorobenzene	ug/l	600 HRL93	150.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.0850 U
1,2-Dichloroethane	ug/l	1 HRL13 (1)	<u>0.25</u>	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.130 U
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	12.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.147 U J4
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	10.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.208 U
1,2-Dichloropropane	ug/l	5 HRL94	1.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.284 U
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.400 U
1,3-Dichlorobenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 0.120 U
1,3-Dichloropropane	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.100 U J4
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	0.5	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.25 H	< 0.25	< 0.151 U
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 5.0 H	< 5.0	< 0.228 U
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	<u>2.5</u>	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.140 U
2,2-Dichloropropane	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 4.0 H	< 4.0	< 0.276 U
Acetone	ug/l	3000 HBV17 (1)	1000	< 10	< 10	< 10	< 10	< 10	--	< 10	< 10	< 10 H	< 10	< 7.30 U
Allyl chloride	ug/l	30 HRL94	7.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	--	< 1.0	< 1.0	< 2.0 H*	< 2.0	< 0.800 U
Benzene	ug/l	2 HRL09 (1)	<u>0.5</u>	< 0.50	< 0.50	< 0.50 h	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50 H	< 0.50	< 0.0934 U
Bromobenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 0.180 U
Bromochloromethane	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 5.0 H	< 5.0 ^	< 0.113 U
Bromodichloromethane	ug/l	3 HBV18 (1)	1.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.145 U
Bromoform	ug/l	40 HRL93	10.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 5.0 H	< 5.0	< 0.234 U J0
Bromomethane	ug/l	10 HRL93	2.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 4.0 H	< 4.0	< 0.394 U
Butylbenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 1.05 U
Butylbenzene, sec	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 0.576 U
Butylbenzene, tert	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 0.390 U
Carbon tetrachloride	ug/l	1 HRL13 (1)	0.25	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25 ^	< 0.25	< 0.180 U
Chlorobenzene	ug/l	100 HRL93	25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.0420 U
Chlorodibromomethane	ug/l	10 HRL93	2.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 5.0 H	< 5.0 ^	< 0.122 U
Chloroethane	ug/l	ND RAA16		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 4.0 H	< 4.0	< 0.340 U
Chloroform	ug/l	20 HRL18	7.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 3.0 H	< 3.0	< 0.206 U
Chloromethane	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 3.0 H	< 3.0	< 0.870 U
Chlorotoluene, o	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.173 U
Chlorotoluene, p	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.0900 U J4
Cumene (isopropyl benzene)	ug/l	300 HRL93	75.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 0.0850 U
Cymene p- (toluene isopropyl p-)	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.510 U
Dibromomethane (methylene bromide)	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.150 U
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	175.0	< 1.0	< 1.0	< 1.0	1.3	1.0	--	1.7	2.2	< 3.0 H	< 3.0	< 0.322 U
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17		< 1.0	< 1.0	< 1.0	1.4	1.3	--	1.6	2.0	2.0 H	3.3	3.30
Ethane	ug/l			--	--	--	--	--	--	--	--	--	--	--
Ethyl benzene	ug/l	40 HBV19 (1)	12.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.147 U
Ethyl ether	ug/l	200 RAA16 (1)	<u>50.0</u>	< 1.0	< 1.0	< 1.0	1.5	1.7	--	2.2	2.9	3.4 H	5.2	6.28
Ethylene	ug/l			--	--	--	--	--	--	--	--	--	--	--
Hexachlorobutadiene	ug/l	1 HRL93	0.25	< 0.25	< 0.25	< 0.25 h	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 1.4 H	< 1.4	< 0.243 U
Methane	ug/l			--	--	--	--	--	--	--	--	--	--	--
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	1000.0	< 10	< 10	< 10	< 10	< 10	--	< 10	< 10 ^	< 10 H	< 10	< 12.7 U
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	75.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	--	< 5.0	< 5.0	< 10 H	< 10	< 0.456 U
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	15	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.0700 U
Methylene chloride	ug/l	5 HRLMCL	<u>1.25</u>	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 5.0 H	< 5.0	< 1.33 U
Naphthalene	ug/l	70 HRL13	17.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 5.0 H	< 5.0	< 0.976 U
Propylbenzene	ug/l			< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 0.190 U
Styrene	ug/l		25.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.0458 U
Tetrachloroethylene	ug/l	4 HBV14 (1)	1.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0 ^	< 0.179 U J0 J4
Tetrahydrofuran	ug/l	600 HRL18		< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	--	< 5.0	< 5.0	< 10 H^	< 10	< 0.704 U
Toluene	ug/l	70 HBV19 (1)	50.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 1.0 H	< 1.0	< 0.260 U
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	<u>0.1</u>	< 0.10	< 0.10	< 0.10 h	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.117 U
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	500.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 4.0 H	< 4.0	< 0.165 U
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	50000.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--	< 1.0	< 1.0	< 2.0 H*	< 2.0	< 0.151 U
Vinyl chloride	ug/l	0.2 HRL18 (1)	<u>0.05</u>	< 0.050	< 0.050	< 0.050 h	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	<u>0.10</u>	<u>0.075</u>	< 0.231 U
Xylene, total	ug/l	300 XYL HBV19 (1)	75	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	--	< 2.0	< 2.0	< 3.0 H	< 3.0	< 0.176 U

Appendix A
Groundwater Data Compared to Groundwater-Based Intervention Limits (2018-April 2020)
Corrective Action Summary
Elk River Landfill

Location				315-OWA	315-OWA	P694477	P694477	P694477	P694477	P694477	P694477	P694477	P694477	P694477
Date				10/16/2018	7/10/2019	4/19/2018	7/16/2018	10/22/2018	4/12/2019	5/02/2019	7/11/2019	10/24/2019	12/20/2019	4/24/2020
Parameter	Units	MDH Human Health-Based Water Guidance Table	Elk River Groundwater Limits Table - SW-74											
Effective Date		04/27/2020	07/23/2015											
Exceedance Key		Bold	<u>Underline</u>											
General Parameters														
Alkalinity, total, as CaCO3	mg/l			--	36.9	--	245	--	--	--	259	--	--	--
Carbon, total organic	mg/l			--	--	--	--	--	--	--	--	--	--	--
Cation-Anion balance	%			--	1.2	--	-2.7	--	--	--	-3.6	--	--	--
Chloride	mg/l			--	2.4	--	6.3	--	--	--	9.0	--	--	--
Dissolved oxygen, field	mg/l			4.9	5.0	1.4	0.6	0.7	0.9	0.2	0.7	2.0	0.2	0.5
Iron, ferrous, FE II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--
Manganese II, field	mg/l			--	--	--	--	--	--	--	--	--	--	--
Nitrogen, ammonia, as N	mg/l			--	< 0.020	--	0.23	--	--	--	< 0.020	--	--	--
Nitrogen, nitrate + nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--
Nitrogen, nitrate, as N	mg/l	10 HRLMCL		--	--	--	--	--	--	--	--	--	--	--
Nitrogen, nitrite, as N	mg/l			--	--	--	--	--	--	--	--	--	--	--
pH, field	pH units			6.79	7.35	7.60	7.59	7.50	7.71	7.38	7.67	7.71	7.41	7.74
Redox (oxidation potential), field	mV			198.8	319.1	-102	75	176.6	215.3	290.1	269.8	256.4	308.4	219.6
Solids, total dissolved	mg/l			--	61.0	--	297	--	--	--	338	--	--	--
Solids, total suspended	mg/l			--	--	--	--	--	--	--	--	--	--	--
Specific conductance @ 25 °C, field	umhos/cm			157	103	462	445	484	506	508	534	529	573	602
Sulfate, as SO4	mg/l			--	4.8	--	19.8	--	--	--	19.4	--	--	--
Sulfide, as S ²⁻ , field	mg/l			--	--	--	--	--	--	--	--	--	--	--
Temperature, field	deg C			8.1	6.8	9.4	9.7	9.5	9.8	10.0	10.6	10.2	9.9	11.4
Turbidity, field	NTU			145.0	78.6	1.3	6.0	4.8	1.9	5.9	11.4	2.6	0.6	5.0
Dissolved Metals														
Arsenic	ug/l		<u>2.5</u>	--	< 1.0	--	< 5.0	--	--	--	< 1.0	--	--	--
Boron	ug/l	500 RAA17	<u>250.0</u>	--	< 20.0	--	24.7	--	--	--	27.0	--	--	--
Cadmium	ug/l	0.5 HRL15 (1)		--	--	--	--	--	--	--	--	--	--	--
Calcium	mg/l			--	10.1	--	62.7	--	--	--	65.6	--	--	--
Chromium	ug/l	100 CR HRL93	25.0	--	< 4.0	--	< 4.0	--	--	--	< 4.0	--	--	--
Copper	ug/l			--	--	--	--	--	--	--	--	--	--	--
Iron	ug/l			--	57.3	--	431	--	--	--	718	--	--	--
Lead	ug/l			--	--	--	--	--	--	--	--	--	--	--
Magnesium	mg/l			--	3.03	--	22.7	--	--	--	23.3	--	--	--
Manganese	ug/l	100 HBV18		--	--	--	--	--	--	--	--	--	--	--
Mercury	ug/l			--	--	--	--	--	--	--	--	--	--	--
Potassium	mg/l			--	2.91	--	1.41	--	--	--	1.38	--	--	--
Sodium	mg/l			--	2.2	--	3.31	--	--	--	3.64	--	--	--
Zinc	ug/l	2000 HRL94	500.0	--	< 10.0	--	< 10.0	--	--	--	< 10.0	--	--	--

Data Footnotes and Qualifiers

Barr Standard Footnotes and Qualifiers

--	Not analyzed/Not available.
U	The analyte was analyzed for, but was not detected.
*	Estimated value, QA/QC criteria not met.
h	EPA recommended sample preservation, extraction or analysis holding time was exceeded.

TestAmerica Qualifiers

*	LCS or LCSD is outside acceptance limits.
^	ICV,CCV,ICB,CCB, ISA, ISB, CRI, CRA, DLCK or MRL standard: Instrument related QC is outside acceptance limits.
F1	MS and/or MSD Recovery is outside acceptance limits.
H	Sample was prepped or analyzed beyond the specified holding time
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Pace Qualifiers - 2020

J0	The identification of the analyte is acceptable, but the reported concentration is an estimate. The calibration met method criteria.
J4	The associated batch QC was outside the established quality control range for accuracy.
Q	Sample was prepared and/or analyzed past holding time as defined in the method. Concentrations should be considered minimum values.

MDH Human Health-Based Water Guidance Table

CR	Value represents the criteria for Chromium, hexavalent.
DCP	Value shown is 1,3-dichloropropene in the MDH criterion, however, the laboratory reports cis and trans isomers individually.
(1)	Health Based Value 2014; Value is representative of the lowest exposure duration published in the Minnesota Department of Health Human Health Advisory Table.
HBV14	Health Based Value 2014.
HBV17	Health Based Value 2017.
HBV18	Health Based Value 2018.
HBV19	Health Base Value 2019.
HRL09	Health Risk Limit 2009.
HRL13	Health Risk Limit 2013.
HRL15	Health Risk Limit 2015
HRL18	Health Risk Limit 2018.
HRL20	Health Risk Limit 2020.
HRL93	Health Risk Limit 1993.
HRL94	Health Risk Limit 1994.
***	Dual guidance applies: See Dual Guidance for Drinking Water (https://www.health.state.mn.us/communities/environment/risk/guidance/dualguidance.html)
HRLMCL	Health Risk Limit; Maximum Contaminant Level.
ND	Not derived due to insufficient information.
RAA13	Risk Assessment Advice 2013.
RAA16	Risk Assessment Advice 2016.
RAA17	Risk Assessment Advice 2008.
XYL	Value shown is for the sum of the mixed o,m and p Xylene isomers.

Appendix B

Concentrations Trend Plots

Appendix B

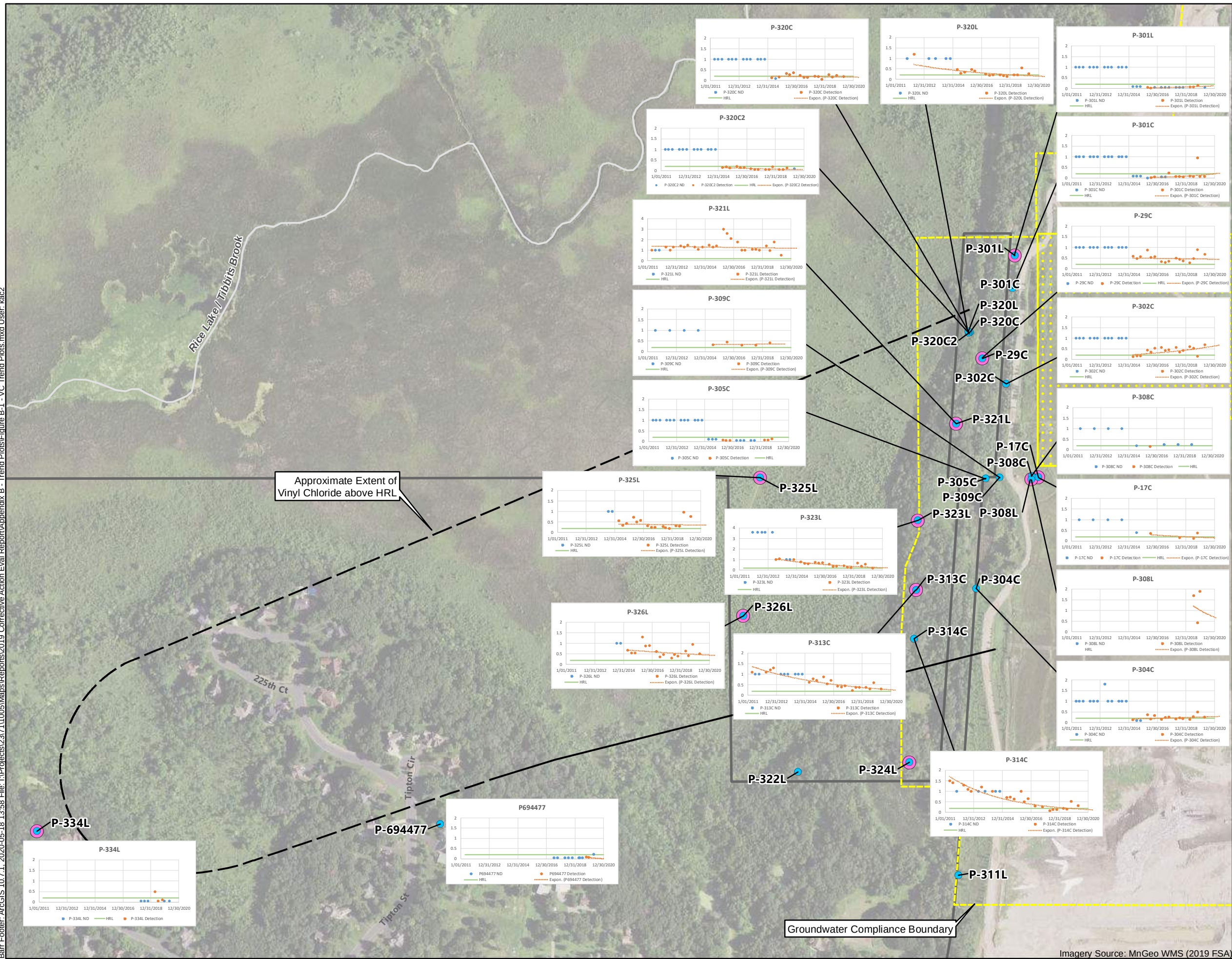
Trend Plots – Overall Summary

This appendix shows vinyl chloride and parent compound concentration trends since 2011 at wells where vinyl chloride has recently been detected. Data from the April 2020 sampling event are included in the plots and are subject to quality assurance review presented in the spring 2020 quarterly monitoring report. The trends for the displayed wells indicate the following:

1. The central and southern portion of vinyl chloride extents nearing the Compliance Boundary (P-313C, P-314C, P-323L) is attenuating steadily over time. The reductive dechlorination progression from TCE to vinyl chloride is evident in this area.
2. Limited attenuation is occurring in the northern portion of vinyl chloride extents near the landfill and Compliance Boundary. Wells P-321L and P-302C have shown stable to increasing trends, respectively. Precursor compounds TCE and cis-DCE are not typically observed in this area.
3. In general, an uptick in vinyl chloride concentrations were observed in 2019 but draft April 2020 data indicate concentrations have returned to levels observed prior to 2019.
4. Vinyl chloride was detected for the first time at distal wells P-334L and P-694477 in 2019. Draft April 2020 vinyl chloride data for these locations are non-detect, although the reporting limit for the P-694477 sample was elevated.
5. Concentrations of chlorinated compounds down the centerline of the plume show attenuation of these compounds with distance from the source area. Vinyl chloride plots alone do not encapsulate the entirety of attenuation with distance (or time) due to the reductive dechlorination process transforming TCE and, more prominently cDCE, to vinyl chloride.
6. Based on theoretical molar mass transformations via a reductive dechlorination pathway, 1 µg/L of cDCE is estimated to produce approximately 0.6 µg/L of vinyl chloride. As shown on Figure 4 of the report, cDCE is present in groundwater at wells P-325L and P-326L and not present in groundwater at P-334L. The limited extent of cDCE, coupled with decreasing vinyl chloride concentrations with distance, suggest that natural attenuation is occurring and that the extent of vinyl chloride may be extended downgradient due to sequential dechlorination reactions producing vinyl chloride via the degradation of cDCE.
7. Vinyl chloride concentrations have dramatically decreased in concentration downgradient of former well P-43B. See attached historic trend plots (and map showing well locations).

Attachments:

Figure B-1	Vinyl Chloride Trends Map
Figure B-2	Vinyl Chloride Trends with Regression (2011-2020)
Figure B-3	Vinyl Chloride, Potential Precursor Compound (TCE, DCE), and Total Molar Chlorinated Ethene Trends (2011-2020)
Figure B-4	Vinyl Chloride and Total Molar Chlorinated Ethene Concentrations along Plume Centerline
Figure B-5	Historic Trend Plots (and map showing historic boring/well locations)



- Property Boundary
- Pre-Subtitle D Area
- Monitoring Well
- MNA Monitoring Well

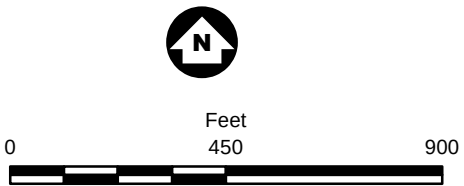


Figure B-1
VINYL CHLORIDE TRENDS
Elk River Landfill
Elk River, Minnesota



Figure B-2 Vinyl Chloride Trends with Regression (2011-2019)

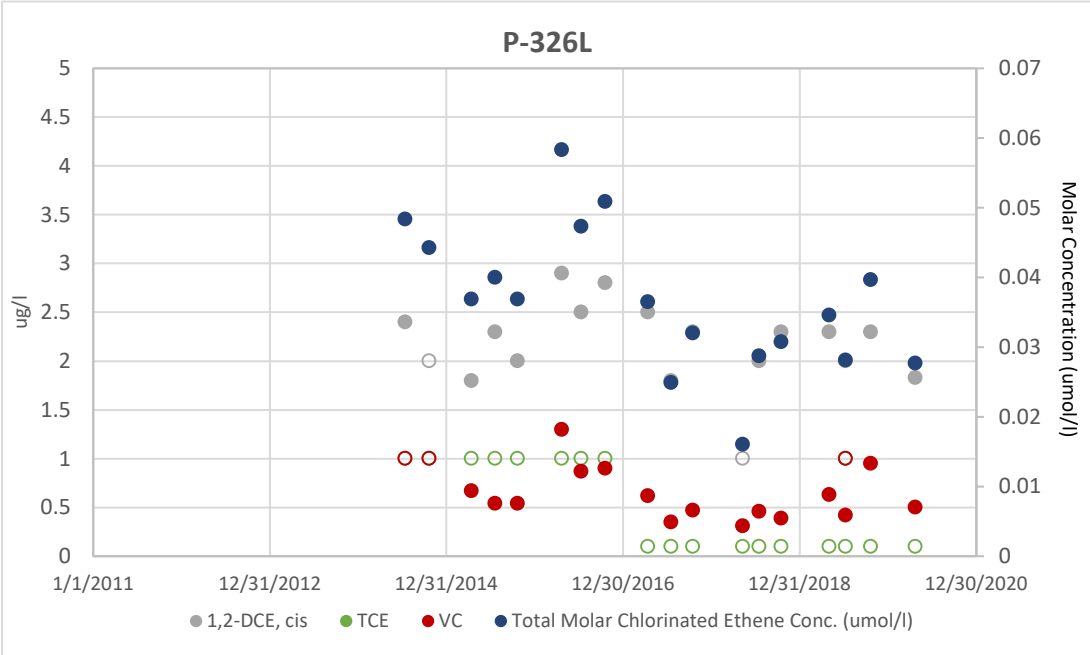
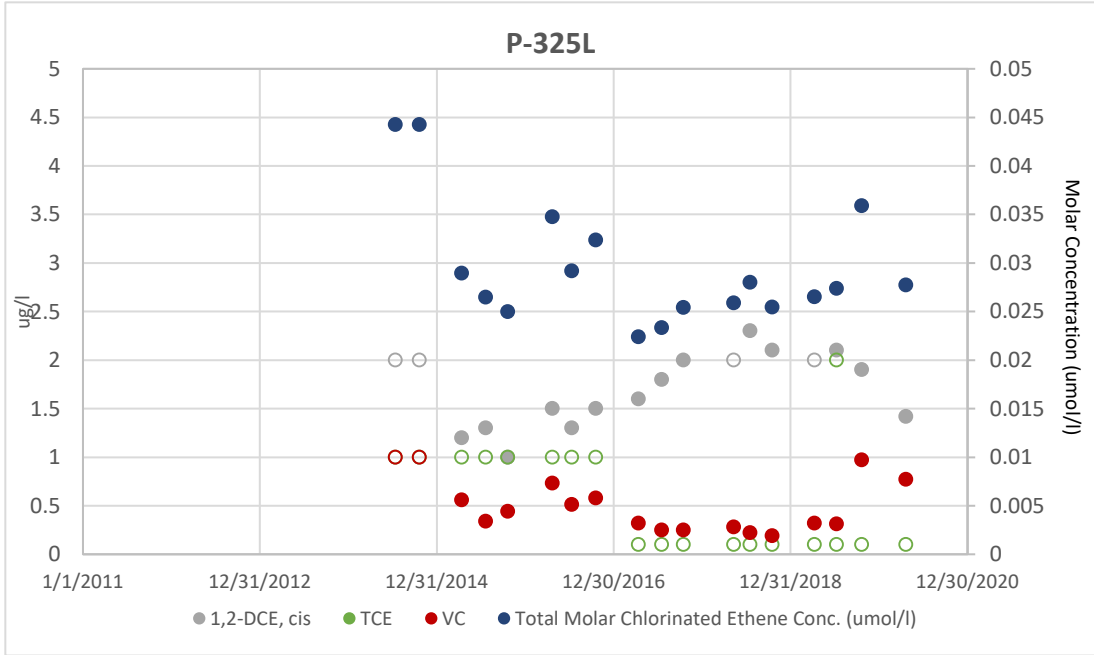
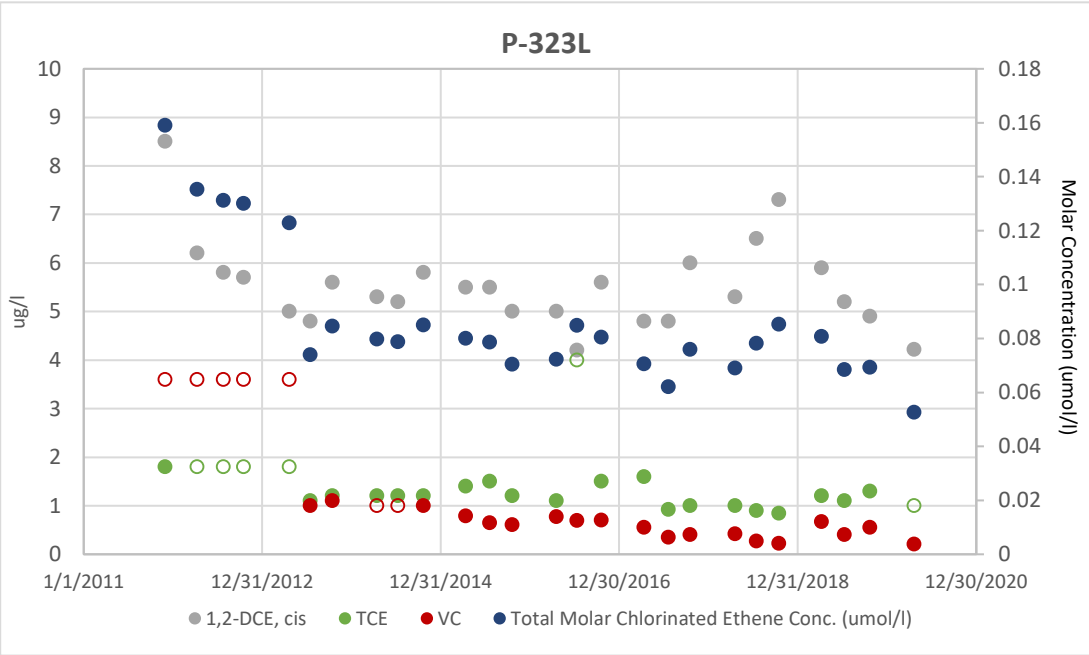
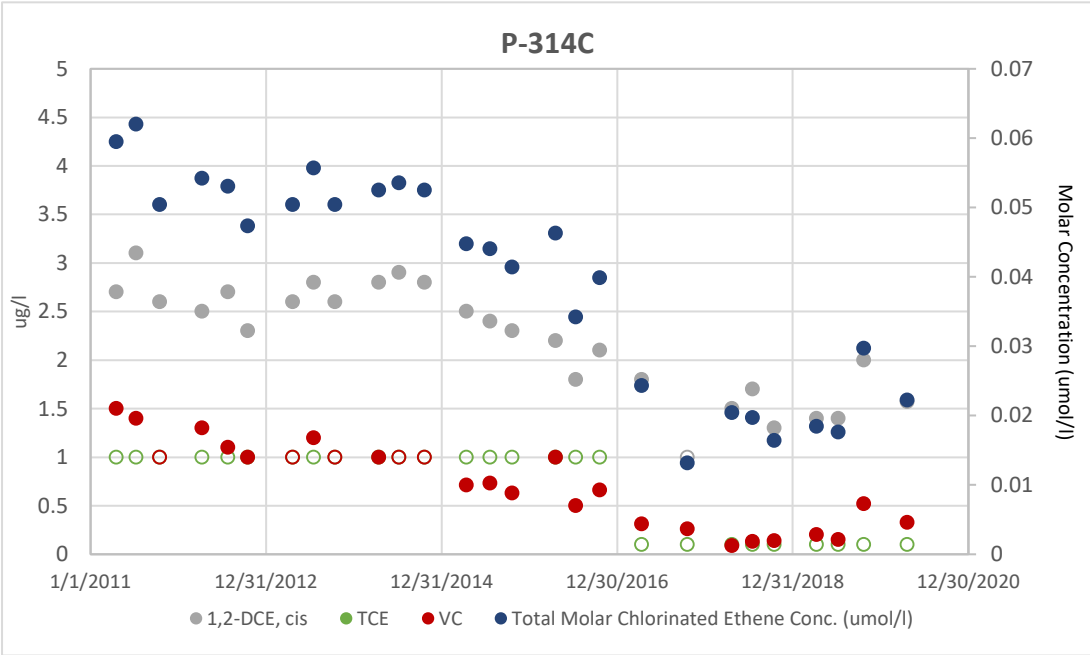
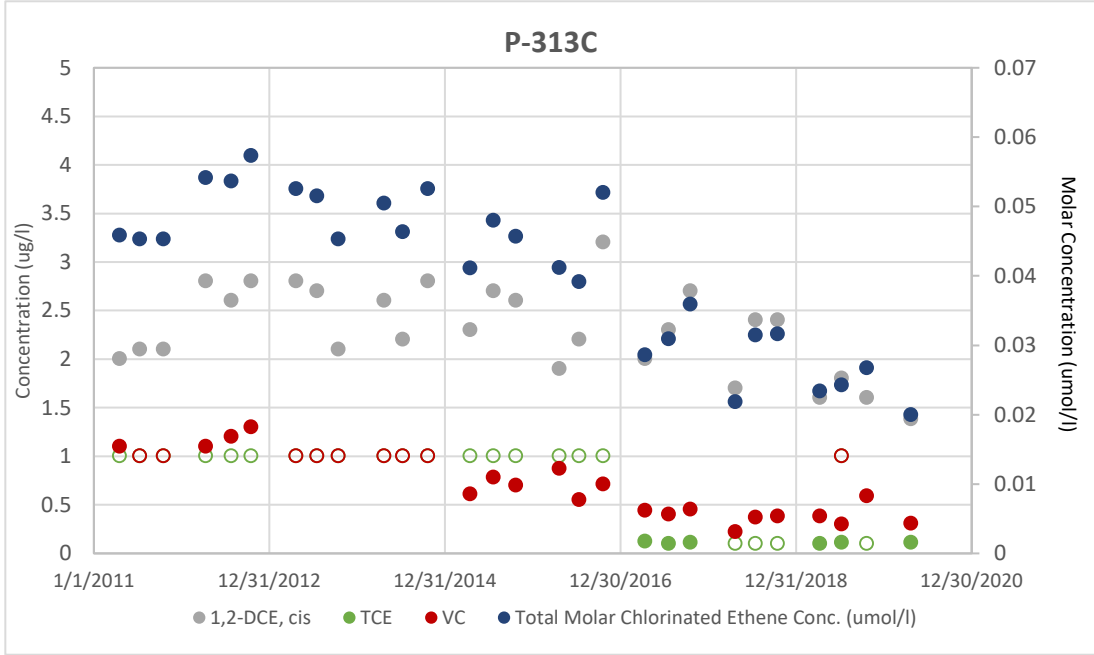
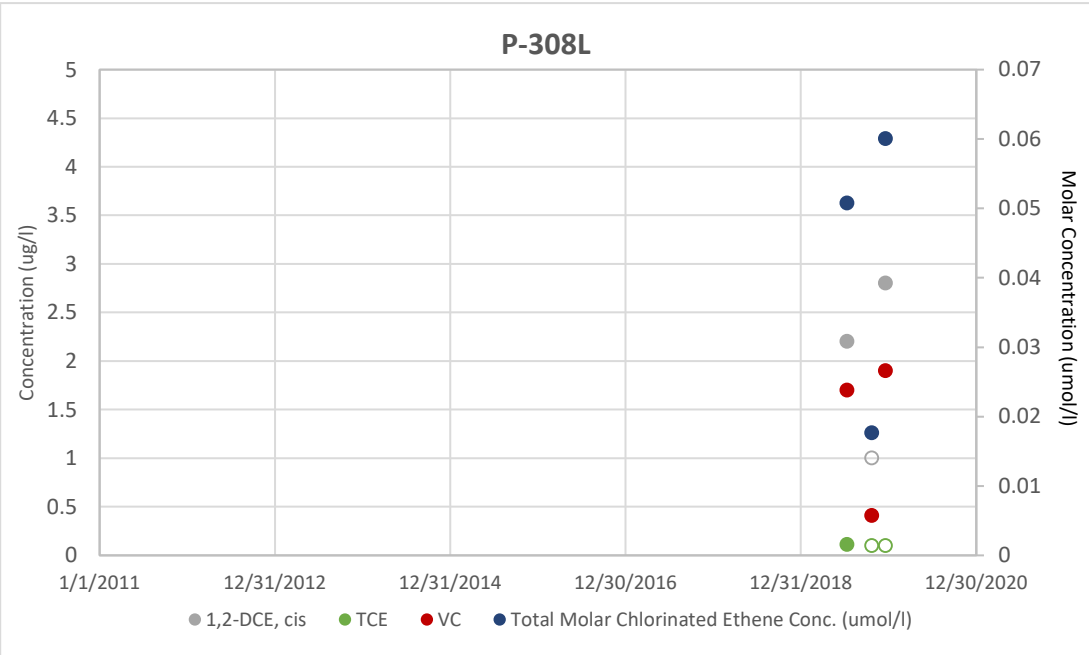
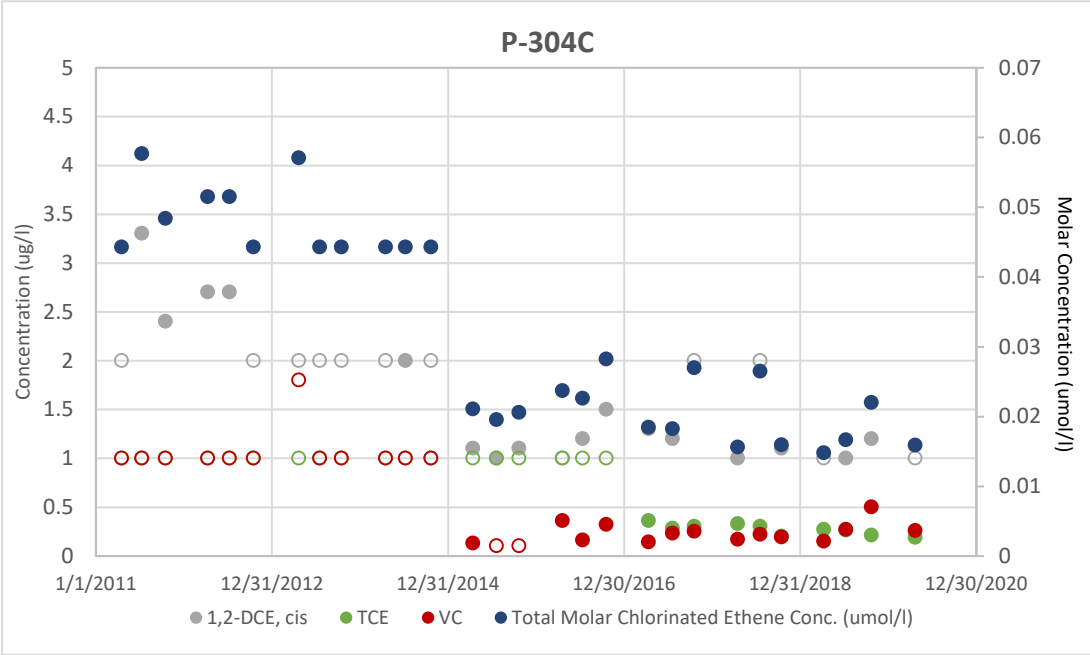


Figure B-2 Vinyl Chloride Trends with Regression (2011-2019)



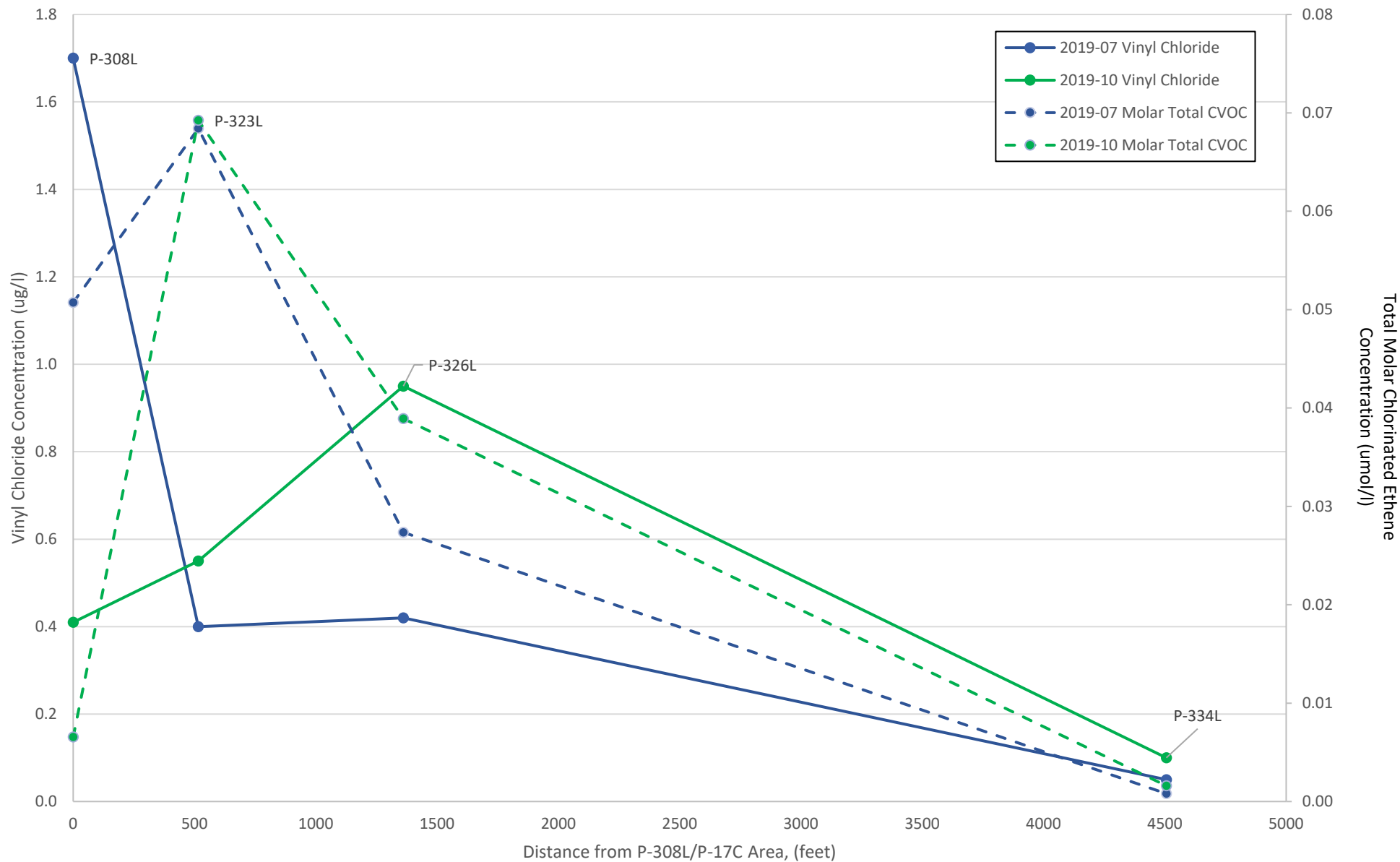
Note: Only locations where vinyl chloride has been detected in recent are displayed.

Figure B-3 Vinyl Chloride, Potential Precursor Compound (TCE, DCE), and Total Molar Chlorinated Ethene Trends (2011-2019)



Notes: Only wells where TCE or cis-DCE detected in 2019 are displayed (PCE not detected).
Open symbol indicats sample was non-detect.

Figure B-4 Vinyl Chloride and Total Molar Chlorinated Ethene Concentrations along Plume Centerline



Note: Only monitoring events following P-308L installation plotted.

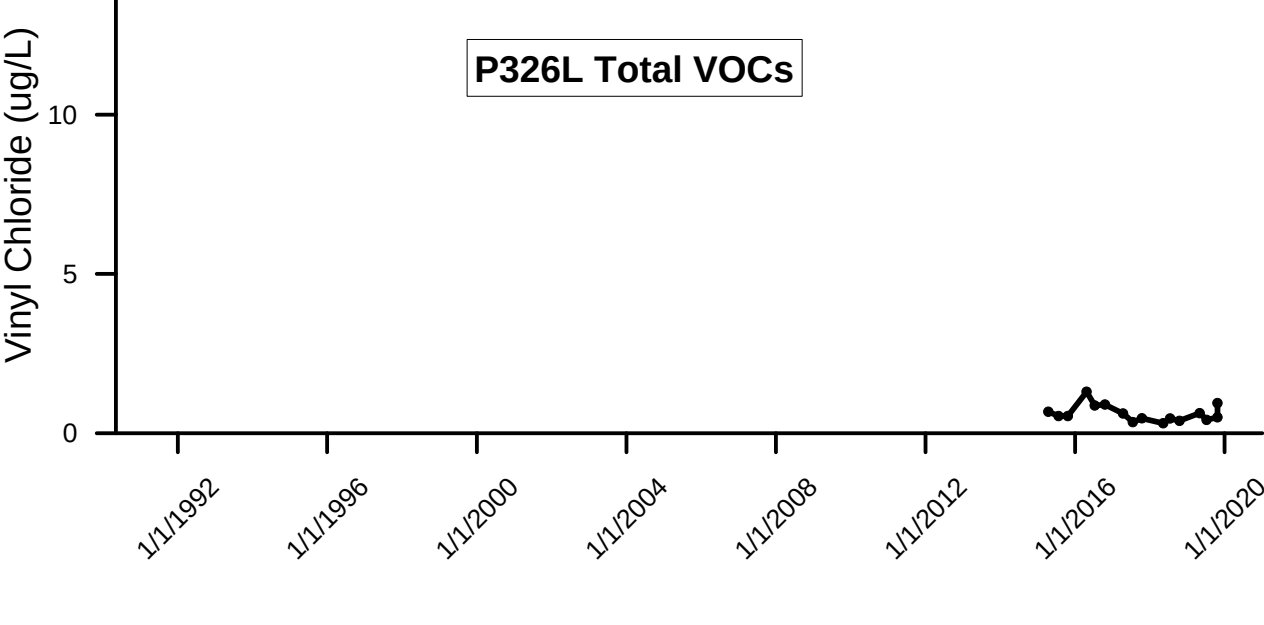
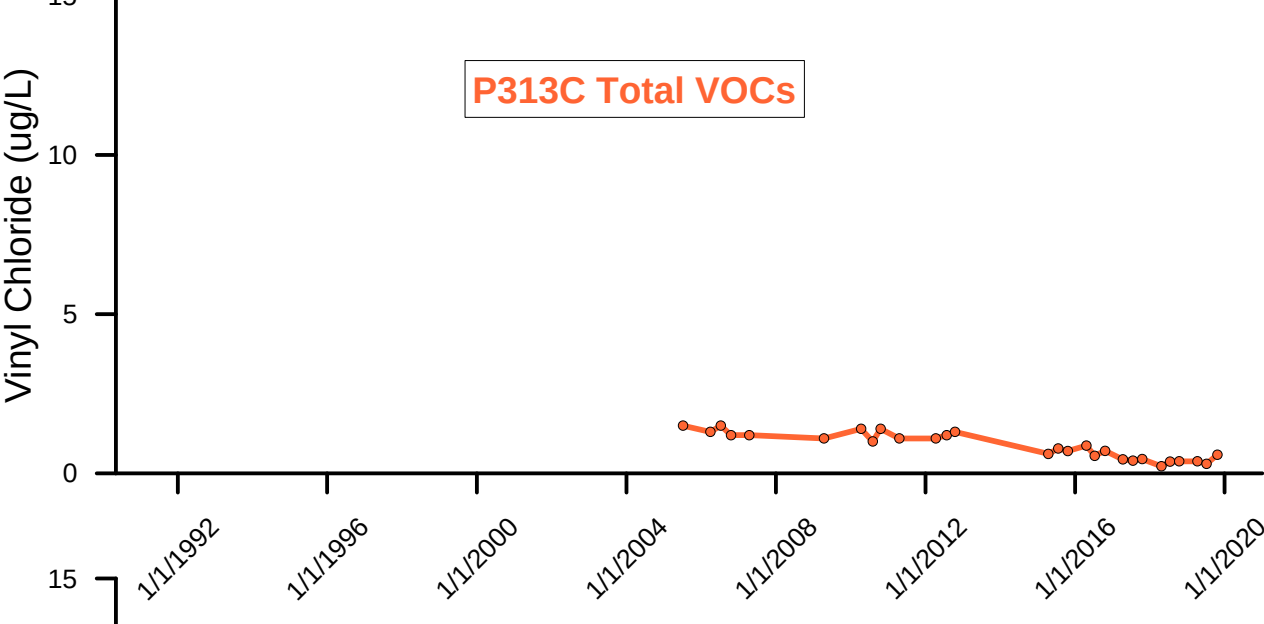
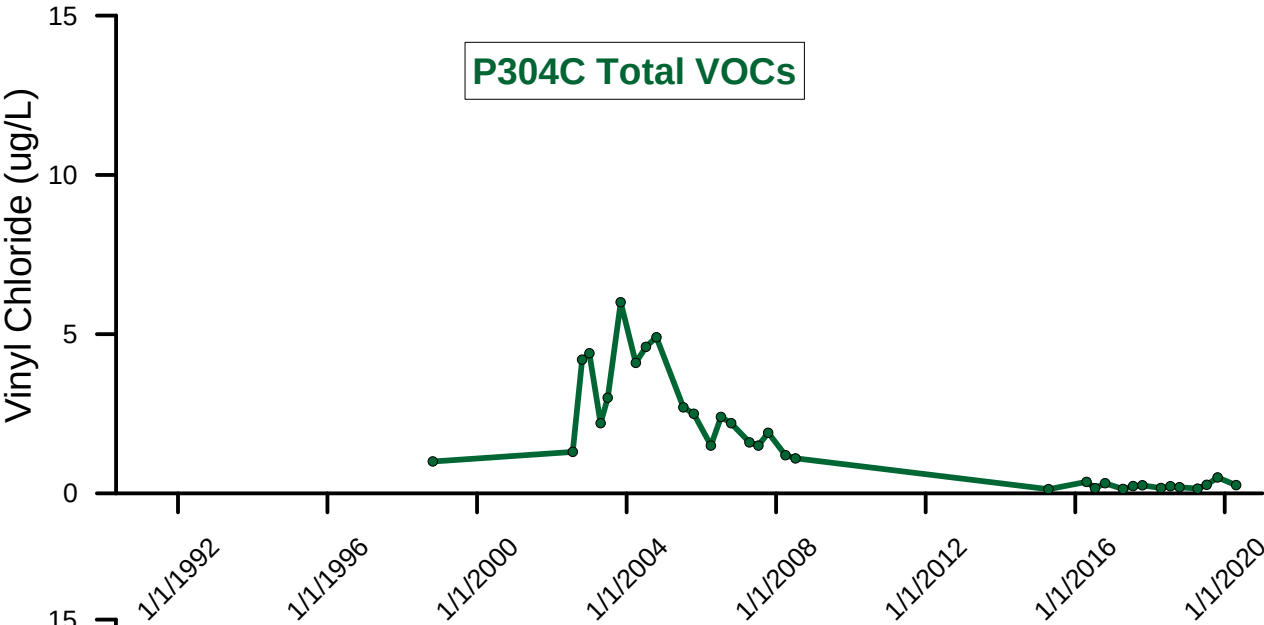
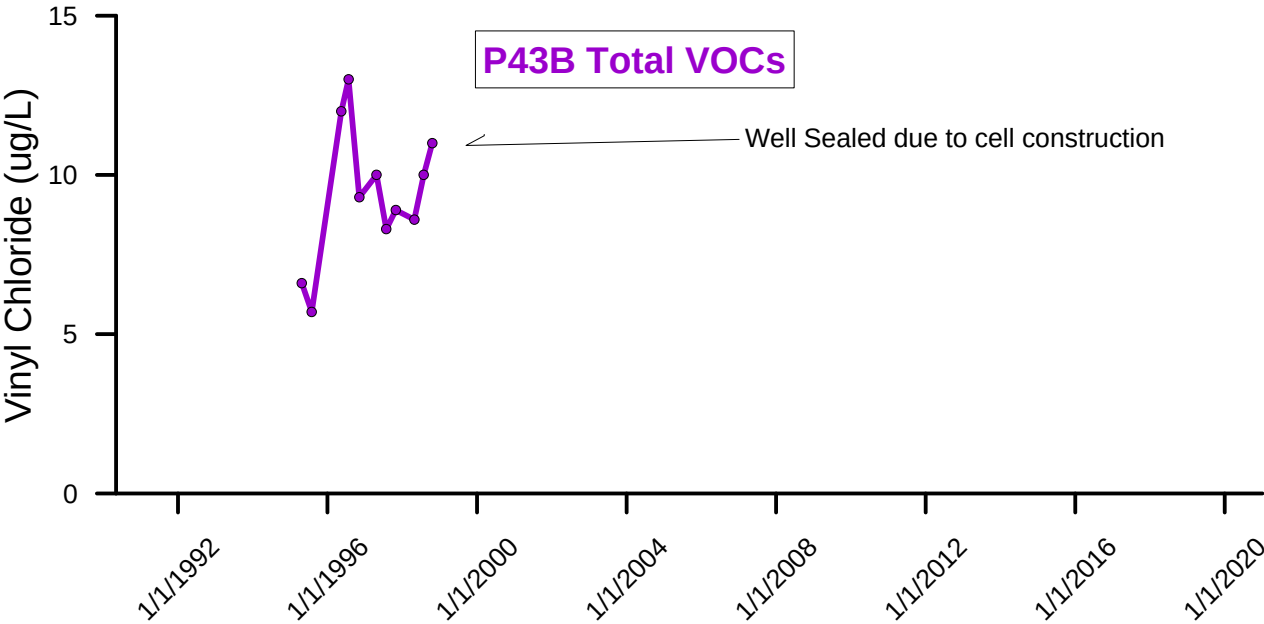
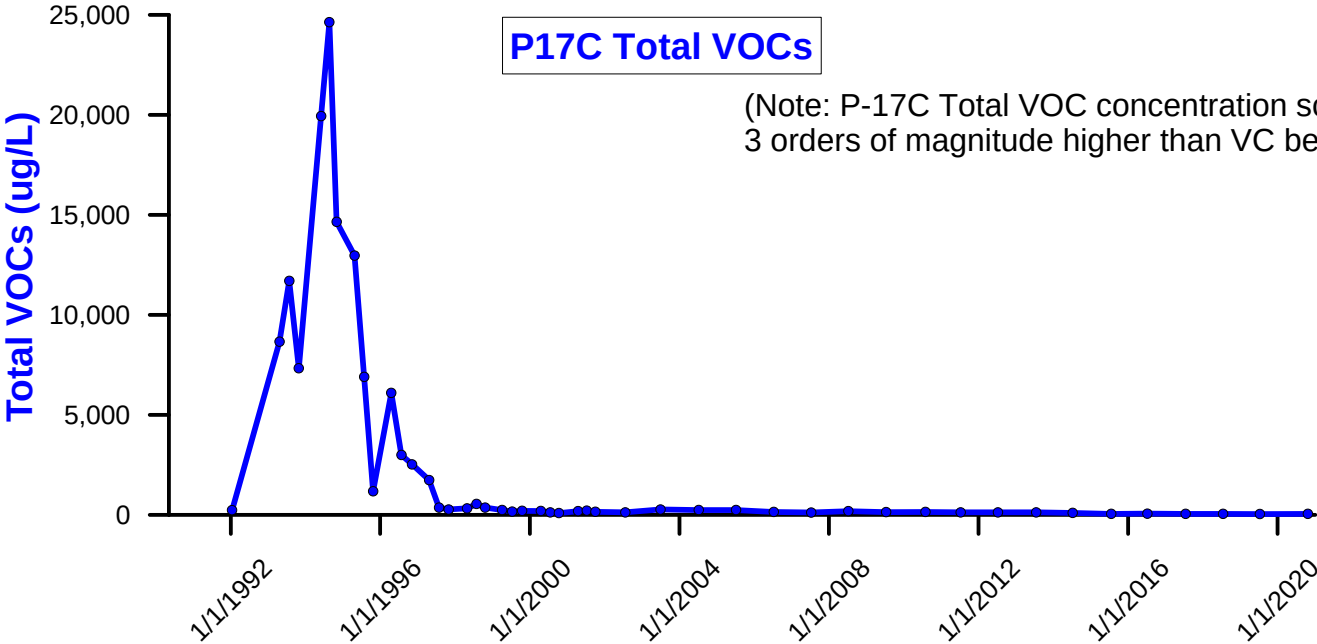


Figure B-5
Historic Trend Plots
Elk River Landfill Elk
River, Minnesota

Appendix C

Preliminary Attenuation Rate Calculations

Appendix C

Estimated Attenuation Rates and Projections

This appendix documents the inputs, assumptions, and methodology for developing A) estimated groundwater flow velocity, B) attenuation rates and resulting projections of vinyl chloride concentrations (and travel distance) downgradient of ERL, and C) vinyl chloride mass and input (flux) from the western edge of ERL into the groundwater system.

A) Vinyl Chloride Transport Velocity and Approximated Arrival Times at Downgradient Monitoring Wells

The vinyl chloride transport velocity (V_{VC}) the lower outwash aquifer (where organics mass transport is predominantly occurring west of ERL) is estimated to be approximately 106 feet/year (Equation 1). The 106 feet/year value is based on the observed extent of vinyl chloride downgradient of the facility at P-334L (detected for the first time at this location in 2019) and the beginning of landfill operations (estimated to be 1972).

Applying a retardation factor (R) of 1.052 for vinyl chloride (Equation 2), the groundwater flow velocity (V_{GW}) is calculated to be approximately 112 feet/year (Equation 3). This calculated V_{GW} is approximately twice the calculated velocity from an aquifer test at P-308L performed in 2019 (Equation 4). This discrepancy is attributed to the heterogeneity in the lower outwash (e.g., coarse gravel was more abundant at wells P-325L and P-326L than at the wells along the west side of the landfill).

Note that the vinyl chloride transport velocity would be higher if the release did not occur for years after landfill operations began. In the estimates provided in this Appendix, a +25% multiplier is applied to represent an alternative higher end estimate for vinyl chloride transport velocity ($V_{VC,HI} = 133$ ft/yr) and groundwater flow velocity ($V_{GW,HI} = 140$ ft/yr) to account for this uncertainty.

Using these velocity values, the estimated arrival times for the slug of elevated organics concentrations (observed at P-17C in 1994) to arrive at downgradient monitoring points was calculated (See Table C1). Based on this estimation, the slug of elevated organics concentrations is predicted to have reached the borings B-330/B-331 in the period of 2017 to 2023 and is projected to reach well P-334L between 2026 and 2034. Vinyl chloride was detected in groundwater from one sample interval at a concentration of 0.43 micrograms per liter ($\mu\text{g/L}$) at B-331 in 2016.

B) Attenuation Rates

Location-specific (k_{POINT}) and bulk overall attenuation rates (k_{BULK}) and were calculated to further assess attenuation and develop projections based on existing data. Location-specific attenuation rates provide a gauge of the degree of attenuation is occurring at the evaluated location. For example, a value of 0.07/year represents a half-life of approximately 10 years. Bulk overall attenuation rates provide an overall assessment of attenuation across the entire length of a plume. Details are provided below.

Location-Specific Attenuation Rates (k_{POINT})

Location-specific vinyl chloride attenuation rates are useful in assessing trends and projecting time until concentrations reach a certain level (i.e. Intervention Limits) at well locations. This evaluation was only applied to vinyl chloride in the central and southern portions of the plume (where decreasing vinyl chloride trends are occurring near the Compliance Boundary) and not the northern half of the plume (i.e., well P-321L and northward) due to mixed trends. See Appendix B for trend data. Attenuation rates were also not calculated for locations P-334L and P694477 due to too few detections at these locations.

Appendix C

Estimated Attenuation Rates and Projections

This approach should not be used to make projections across an entire plume (Newell & Rifai et. al, 2002).

Vinyl chloride concentration data from 2011 to 2019 was reviewed to calculate k_{POINT} values (Newell & Rifai et. al, 2002) for six wells located near (P-313C, P-314C, P-321L, P-323L), and beyond (P-325L, P-326L) the Compliance Boundary (see Equation 6).

Calculated k_{POINT} values ranged from 0.081 (P-326L) to 0.269 (P-314C). These values indicate the following:

- Attenuation is occurring at a greater rate near the Compliance Boundary compared to the downgradient Property boundary.
- In recent years, the central and southern areas of the vinyl chloride extents near the landfill are naturally attenuating over time and attenuation near P-321L is more stagnant.

Note that the location-specific attenuation rates may be biased low as they do not account for conversion of precursor compounds (PCE, TCE, and DCE) to vinyl chloride. Using first order kinetics and k_{POINT} values, projections for when each of these wells may approach Intervention Limits (ILs) were calculated. These projections range from approximately 4 (i.e., 2024 at P-314C) to 28 years (i.e., 2048 at P-326L) and are shown in Table C2.

Bulk Attenuation Rates (k_{BULK})

Bulk attenuation rates describe the behavior of the entire plume at one point in time and can be useful to project how far along a flow path a plume will expand (Newell & Rifai et. al, 2002).

Overall bulk attenuation rates (k_{BULK}) were estimated using trend line analysis methods outlined in MPCA guidance (MPCA, 2006). A primary assumption in applying this method is that vinyl chloride and other organics have achieved steady state (i.e., not expanding). Late 2019 monitoring results showed first-time confirmed detections of vinyl chloride in samples from monitoring wells P-334L and P-694477. Vinyl chloride was not detected in the spring 2020 samples at wells P-334L ($<0.05 \mu\text{g/L}$) or P-694477 (<0.231 ; i.e., the reporting limit was elevated). The sporadic detections at concentrations near the reporting limit and non-detections suggest these wells are located near the plume fringe and that further monitoring is necessary to assess the overall stability of the organics downgradient of the ERL. Note that if the extents of vinyl chloride are expanding, the attenuation rates presented below are overestimated.

Three approaches were applied to develop a range of potential overall attenuation rates along the plume centerline (P-308L, P-323L, P-326L, and P-334L) using the trend line analysis method. July and October 2019 datasets were used in the review for the first two approaches with the objective of including both wells P-308L (installed in 2019) and P-334L (installed in 2018).

- 1) July and October 2019 datasets (vinyl chloride only). This approach likely represents a low estimate of attenuation rates as conversion from precursor compounds (PCE, TCE, DCE) to vinyl chloride are not considered.
- 2) July and October 2019 datasets (total molar concentration of vinyl chloride and precursor compounds PCE, TCE, DCE). This approach includes precursor compounds to capture transformation to vinyl chloride and likely represents a high estimate of attenuation rates as

Appendix C

Estimated Attenuation Rates and Projections

precursor compounds are present at several locations and generally attenuate more rapidly than vinyl chloride.

- 3) Maximum reported concentrations at each well since 2015 (vinyl chloride only). This approach estimates rates at the highest reported concentrations at each well since 2015 when reporting limits were lowered to current standards.

Based on these varying approaches (Equation 5), estimated overall attenuation rates are summarized in the following table:

Method	Bulk Overall Att. Rate at $V_{GW} = 112 \text{ ft/yr}$		Bulk Overall Att. Rate at $V_{GW} = 145 \text{ ft/yr}$	
	$K_{BULK, JULY} \text{ (/yr)}$	$K_{BULK, OCT} \text{ (/yr)}$	$K_{BULK, JULY, HI} \text{ (/yr)}$	$K_{BULK, OCT, HI} \text{ (/yr)}$
1. Vinyl chloride (2019)	0.078	0.045	0.102	0.058
2. Molar (2019)	0.112	0.067	0.145	0.087
3. Vinyl chloride (max since 2015)	0.067		0.087	
4. Overall average	0.074		0.096	

The estimated vinyl chloride travel velocities and k_{BULK} are applied to evaluate the following scenarios. See Table C2 for details.

- A) Scenario A: What is the estimated highest vinyl concentration at the Compliance Boundary that would naturally attenuate before reaching nearest residential water supply user in the direct downgradient flowpath of the mapped vinyl chloride extent.
 - a. Range: 1 to 90 $\mu\text{g/l}$
 - b. Average: 7 $\mu\text{g/l}$

This scenario suggests that, on average, vinyl chloride concentrations at or below 7 $\mu\text{g/l}$ at the Compliance Boundary will attenuate before reaching the nearest residential well downgradient of P-334L.

- B) Scenario B: What is the estimated highest vinyl chloride concentration at monitoring well P-334L that would naturally attenuate below the IL or detection limit (0.05 $\mu\text{g/l}$) before reaching nearest residential water supply user in the direct downgradient flow path of the mapped vinyl chloride extent.
 - a. Range: 0.21 to 1.8 $\mu\text{g/l}$
 - b. Average: 0.54 $\mu\text{g/l}$

This scenario suggests that, on average, vinyl chloride concentrations at or below 0.54 $\mu\text{g/l}$ in groundwater at well P-334L will attenuate before reaching the nearest residential well downgradient of P-334L.

- C) Scenario C: How far is vinyl chloride projected to travel downgradient of the Compliance Boundary considering peak 2019 concentrations reported near Compliance Boundary (1.8 $\mu\text{g/l}$ at P-321L)?
 - a. Range: 3,500 to 9,000 feet
 - b. Average: 5,400 feet

Appendix C

Estimated Attenuation Rates and Projections

This scenario suggests that, on average, the vinyl chloride detected in groundwater at well P-321L will travel a distance of 5,400 feet. For context the nearest residential water supply user in the direct downgradient flow path of the mapped vinyl chloride extent is approximately 7,500 feet downgradient of the Compliance Boundary.

C) Mass Estimates of Vinyl Chloride

The change in vinyl chloride inputs from western edge of the landfill into the groundwater system over time were estimated using a mass flux approach that applies principles of Darcy's Law. The Approximate Extent of Vinyl Chloride Above Intervention Limits shown on Cross Section A-A' (Figure 8 of the Report) represents the evaluated transect of flow. This transect of flow was evaluated using datasets from April 2010 and 2019. The April 2010 dataset was selected as it represents the passage of approximately 10 years. Data inputs, assumptions, and calculated values are included in Table C4.

Using the mass flux approach, in 2019, vinyl chloride flowed from the western edge of ERL (represented by Cross Section A-A') into the downgradient groundwater system at a rate of 0.065 lb/yr. This is a 42% reduction compared to April 2010 (0.11 lb/yr). Consistent with the k_{POINT} values, the zones showing the greatest decrease in mass flux over that time period were in the central and southern areas while the northern area remained similar over that time period.

For context, the estimated total mass of vinyl chloride in the plume downgradient of the unlined area is estimated to be approximately 1 lb. Data inputs and calculated values are included in Table C5.

Summary

The estimates above suggest that natural attenuation to meet ILs in the short term along the southern portion of the organics plume is plausible and less likely in the northern area. Assuming the plume is stable, vinyl chloride concentrations along the Compliance Boundary from are anticipated to attenuate under natural conditions before reaching the nearest residential well downgradient of well P-334L (using average k_{BULK} value).

Mass flux calculations show the overall input of vinyl chloride into the downgradient groundwater system is declining over time. This reduction of inputs is expected to result in lower downgradient concentrations and have a positive effect on the overall plume extents in coming years.

Reliance on Rates and Projections

The attenuation rates and the resulting projections above should be considered as approximations based on existing data (at this time) and the stated assumptions (i.e., not definitive estimates). Further long-term monitoring at current vinyl chloride reporting limits and at wells installed in the last decade are necessary to improve confidence in and refine these estimates as appropriate. This variability and need for additional data is further emphasized by the variability in the values derived using k_{BULK} .

References

Appendix C

Estimated Attenuation Rates and Projections

MPCA, 2006. Guidelines, Natural Attenuation of Chlorinated Solvents in Groundwater. Minnesota Pollution Control Agency, Site Remediation Section, Revised June 2006.

Newell & Rifai et. al, 2002. Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies. United States Environmental Protection Agency Groundwater Issue. EPA/540/S-02/500. November 2002.

Appendix C
Vinyl Chloride Transport Velocity and Attenuation Rate Estimates
Elk River Landfill

1) Vinyl Chloride Velocity Estimate → $V_{VC}=x/t_{LF}$

<u>Variable</u>	<u>Value</u>	<u>Units</u>	<u>Source/Comment</u>
x	5000	ft	Estimated distance vinyl chloride has traveled from source
t_{LF}	47	years	Years from beginning of landfill operations (est. 1972) to detection of vinyl chloride at P-334L in 2019.
V_{VC}	106	ft/yr	Vinyl chloride velocity $V_{VC,HI}$ 133 ft/yr +25% higher end estimate

2) Retardation Factor → $R=1+r_b k_d/n$

<u>Variable</u>	<u>Value</u>	<u>Units</u>	<u>Source/Comment</u>
r_s	2.65	kg/L	Quartz solids density
r_b	1.9875	kg/L	Bulk Density → $r_b=r_s(1-n)$
f_{oc}	0.00035		Fractional organic carbon - https://www.itrcweb.org/DNAPL-ISC_tools-selection/Content/Appendix%20I.%20Foc%20Tables.htm
k_{oc}	18.6	L/kg	MPCA Risk-Based Guidance for Soil Leaching Pathway, Working Draft Guidelines (1998)
k_d	0.00651	L/kg	Soil Distribution Coefficient → $k_d=f_{oc}k_{oc}$
n	0.25		2015 Hydro Report (Barr)
R	1.052		Retardation Factor - Vinyl chloride 5.2% retarded

3) Groundwater Velocity → $V_{GW}=V_{VC}R$

<u>Variable</u>	<u>Value</u>	<u>Units</u>	<u>Source/Comment</u>
V_{GW}	112	ft/yr	Velocity of Groundwater at Base of Lower Outwash Unit $V_{GW,HI}$ 140 +25% higher end estimate

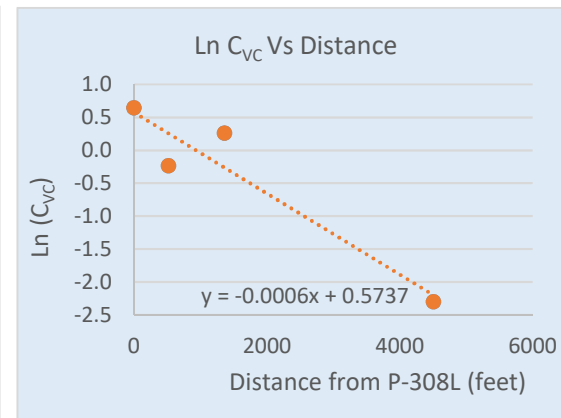
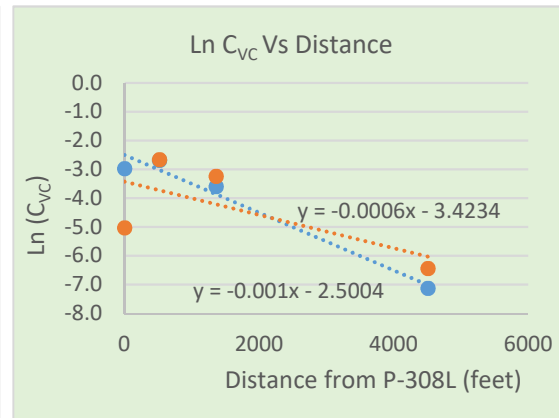
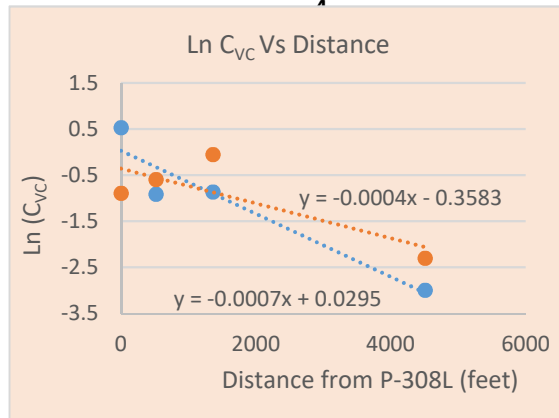
4) ALTERATE Groundwater Velocity → $V_{GW}=Ki/n$

<u>Variable</u>	<u>Value</u>	<u>Units</u>	<u>Source/Comment</u>
K	41.99	ft/day	P-308L Step Test (2019) ALTERNATE IS 5.67 ft/d (0.002 cm/s from 2015 Hydro Report)
n	0.25		2015 Hydro Report
$x_{P323L-P334L}$	3990	ft	Distance from P-323L to P-334L
i	0.00097	ft/ft	Avg water Levels 2018-2019 (P-323L, P-334L), Distance between the locations (3990 ft)
V_{GW}	59.7	ft/yr	Not utilized for attenuation rate calculations as it does not align with vinyl chloride presence at well P-334L

Appendix C
Vinyl Chloride Transport Velocity and Attenuation Rate Estimates
Elk River Landfill

5) **Overall Bulk Attenuation Rate (Solve for k_{BULK}) $\rightarrow -k/V_{GW}$ =Regression Slope (see MPCA, 2006 - Appendix A for methodology)**

Distance	July 2019		October 2019		Molar July 2019		Molar October 2019		Max Conc. (since 2015)		
	C _{VC} (ug/l)	Ln C _{VC}	C _{VC} (ug/l)	Ln C _{VC}	C _{MOL} (umol/l)	Ln C _{MOL} (umol)	C _{MOL} (umol/l)	Ln C _{MOL} (umol)	C _{VC} (ug/l)	Ln C _{VC}	
P-308L	0	1.7	0.53	0.41	-0.89	0.051	-2.981	0.0066	-5.027	1.9	0.641853886
P-323L	516	0.4	-0.92	0.55	-0.60	0.068	-2.682	0.0692	-2.670	0.79	-0.235722334
P-326L	1361	0.42	-0.87	0.95	-0.05	0.027	-3.599	0.0389	-3.246	1.3	0.262364264
P-334L	4506	0.05	-3.00	0.1	-2.30	0.001	-7.131	0.0016	-6.438	0.1	-2.302585093
Reg. Slope	-7E-04 Plot Slope		-0.0004 Plot Slope		-0.001 Plot Slope		-0.0006 Plot Slope		-0.0006 Plot Slope		AVERAGE
k _{BULK}	0.078 /yr		0.045 /yr		0.112 /yr		0.067 /yr		0.067 /yr		0.074
k _{BULK,HI-VELO}	0.098 /yr		0.056		0.140		0.084		0.084		0.092



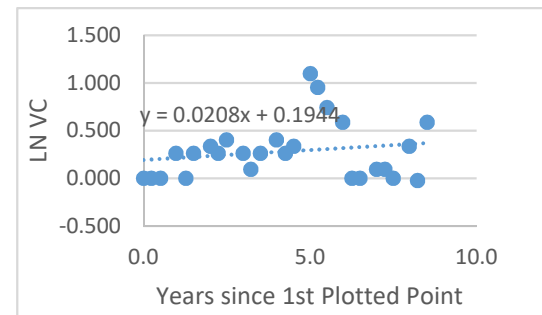
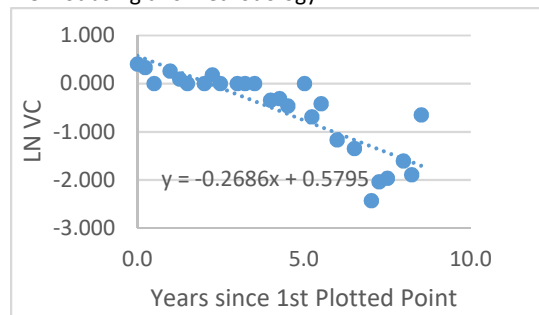
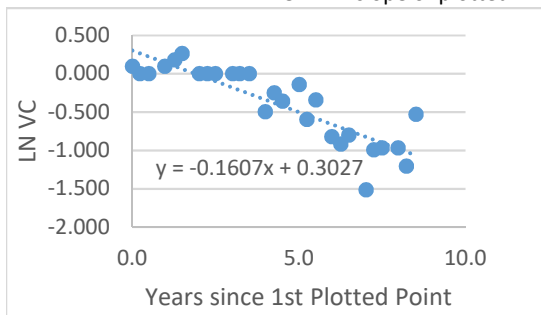
Overall attenuation rates indicate attenuation is occurring over the length of the plume, but there is high variability in rates based on calculation methods

Appendix C
Vinyl Chloride Transport Velocity and Attenuation Rate Estimates
Elk River Landfill

6) **Location-specific Attenuation Rates (see Newell & Rifai et al., 2002 for calculation methods)** red values are non-detect

P-313C	VC (ug/l)	ln VC	Yrs	P-314C	VC (ug/l)	ln VC	Yrs	P-321L	VC (ug/l)	ln VC	Yrs
4/19/2011	1.1	0.095	0.0	4/19/2011	1.5	0.405	0.0	4/19/2011	1.0	0.000	0.0
7/11/2011	1.0	0.000	0.2	7/11/2011	1.4	0.336	0.2	7/12/2011	1.0	0.000	0.2
10/17/2011	1.0	0.000	0.5	10/17/2011	1.0	0.000	0.5	10/24/2011	1.0	0.000	0.5
4/10/2012	1.1	0.095	1.0	4/10/2012	1.3	0.262	1.0	4/10/2012	1.3	0.262	1.0
7/26/2012	1.2	0.182	1.3	7/26/2012	1.1	0.095	1.3	7/26/2012	1.0	0.000	1.3
10/16/2012	1.3	0.262	1.5	10/16/2012	1.0	0.000	1.5	10/17/2012	1.3	0.262	1.5
4/22/2013	1.0	0.000	2.0	4/22/2013	1.0	0.000	2.0	4/22/2013	1.4	0.336	2.0
7/18/2013	1.0	0.000	2.2	7/18/2013	1.2	0.182	2.2	7/17/2013	1.3	0.262	2.2
10/14/2013	1.0	0.000	2.5	10/14/2013	1.0	0.000	2.5	10/15/2013	1.5	0.405	2.5
4/22/2014	1.0	0.000	3.0	4/15/2014	1.0	0.000	3.0	4/15/2014	1.3	0.262	3.0
7/9/2014	1.0	0.000	3.2	7/9/2014	1.0	0.000	3.2	7/9/2014	1.1	0.095	3.2
10/22/2014	1.0	0.000	3.5	10/22/2014	1.0	0.000	3.5	10/22/2014	1.3	0.262	3.5
4/15/2015	0.61	-0.494	4.0	4/15/2015	0.71	-0.342	4.0	4/14/2015	1.5	0.405	4.0
7/21/2015	0.78	-0.248	4.3	7/21/2015	0.73	-0.315	4.3	7/21/2015	1.3	0.262	4.3
10/22/2015	0.7	-0.357	4.5	10/22/2015	0.63	-0.462	4.5	10/21/2015	1.4	0.336	4.5
4/20/2016	0.87	-0.139	5.0	4/20/2016	1.0	0.000	5.0	4/19/2016	3.0	1.099	5.0
7/12/2016	0.55	-0.598	5.2	7/12/2016	0.5	-0.693	5.2	7/11/2016	2.6	0.956	5.2
10/20/2016	0.71	-0.342	5.5	10/20/2016	0.66	-0.416	5.5	10/19/2016	2.1	0.742	5.5
4/12/2017	0.44	-0.821	6.0	4/12/2017	0.31	-1.171	6.0	4/11/2017	1.8	0.588	6.0
7/20/2017	0.4	-0.916	6.3	10/19/2017	0.26	-1.347	6.5	7/21/2017	1.0	0.000	6.3
10/17/2017	0.45	-0.799	6.5	4/23/2018	0.088	-2.430	7.0	10/17/2017	1.0	0.000	6.5
4/23/2018	0.22	-1.514	7.0	7/17/2018	0.13	-2.040	7.2	4/17/2018	1.1	0.095	7.0
7/16/2018	0.37	-0.994	7.2	10/16/2018	0.14	-1.966	7.5	7/16/2018	1.1	0.095	7.2
10/15/2018	0.38	-0.968	7.5	4/10/2019	0.2	-1.609	8.0	10/15/2018	1.0	0.000	7.5
4/9/2019	0.38	-0.968	8.0	7/9/2019	0.15	-1.897	8.2	4/8/2019	1.4	0.336	8.0
7/9/2019	0.3	-1.204	8.2	10/23/2019	0.52	-0.654	8.5	7/10/2019	0.98	-0.020	8.2
10/22/2019	0.59	-0.528	8.5					10/23/2019	1.8	0.588	8.5
k_{P313C} 0.1607				k_{P314C} 0.2686				k_{P321L} NA (not decreasing)			

NOTE: k=slope of plotted LN VC vs Time Plot using this methodology



Appendix C
Vinyl Chloride Transport Velocity and Attenuation Rate Estimates
Elk River Landfill

6) continued

<u>P-323L</u>	<u>VC (ug/l)</u>	<u>ln VC</u>	<u>Yrs</u>	<u>P-325L</u>	<u>VC (ug/l)</u>	<u>ln VC</u>	<u>Yrs</u>	<u>P-326L</u>	<u>VC (ug/l)</u>	<u>ln VC</u>	<u>Yrs</u>
12/1/2011	3.6			7/14/2014	1.0			7/14/2014	1.0		
4/10/2012	3.6			10/21/2014	1.0			10/21/2014	1.0		
7/26/2012	3.6			4/14/2015	0.56	-0.580	0	4/14/2015	0.67	-0.400	0
10/16/2012	3.6			7/22/2015	0.34	-1.079	0.3	7/22/2015	0.54	-0.616	0.3
4/22/2013	3.6			10/22/2015	0.44	-0.821	0.5	10/22/2015	0.54	-0.616	0.5
7/17/2013	1.0	0.000	0	4/22/2016	0.73	-0.315	1.0	4/22/2016	1.3	0.262	1.0
10/14/2013	1.1	0.095	0.2	7/11/2016	0.51	-0.673	1.2	7/11/2016	0.87	-0.139	1.2
4/15/2014	1.0	0.000	0.7	10/19/2016	0.58	-0.545	1.5	10/19/2016	0.9	-0.105	1.5
7/10/2014	1.0	0.000	1.0	4/13/2017	0.32	-1.139	2.0	4/13/2017	0.62	-0.478	2.0
10/22/2014	1.0	0.000	1.3	7/18/2017	0.25	-1.386	2.3	7/18/2017	0.35	-1.050	2.3
4/14/2015	0.79	-0.236	1.7	10/16/2017	0.25	-1.386	2.5	10/16/2017	0.47	-0.755	2.5
7/21/2015	0.65	-0.431	2.0	5/10/2018	0.28	-1.273	3.1	5/10/2018	0.31	-1.171	3.1
10/21/2015	0.61	-0.494	2.3	7/17/2018	0.22	-1.514	3.3	7/17/2018	0.46	-0.777	3.3
4/19/2016	0.77	-0.261	2.8	10/17/2018	0.19	-1.661	3.5	10/17/2018	0.39	-0.942	3.5
7/11/2016	0.69	-0.371	3.0	4/10/2019	0.32	-1.139	4.0	5/2/2019	0.63	-0.462	4.0
10/20/2016	0.7	-0.357	3.3	7/9/2019	0.31	-1.171	4.2	7/9/2019	0.42	-0.868	4.2
4/11/2017	0.55	-0.598	3.7	10/22/2019	0.97	-0.030	4.5	10/22/2019	0.95	-0.051	4.5
7/21/2017	0.35	-1.050	4.0								
10/17/2017	0.4	-0.916	4.3								
4/19/2018	0.42	-0.868	4.8								
7/16/2018	0.27	-1.309	5.0								
10/15/2018	0.22	-1.514	5.2								
4/8/2019	0.67	-0.400	5.7								
7/10/2019	0.4	-0.916	6.0								
10/23/2019	0.55	-0.598	6.3								
k_{P323L}		0.1832		k_{P325L}		0.0859		k_{P326L}		0.0811	

NOTE: k=slope of plotted LN VC vs Time Plot using this methodology

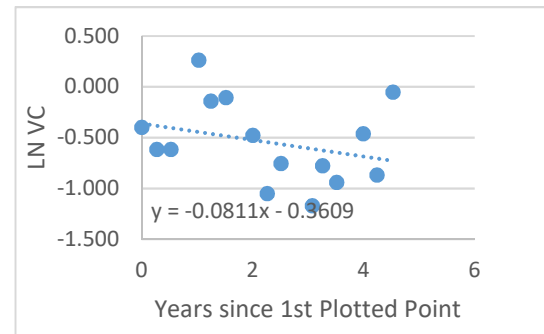
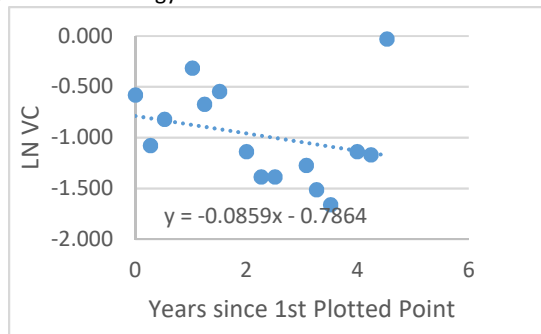
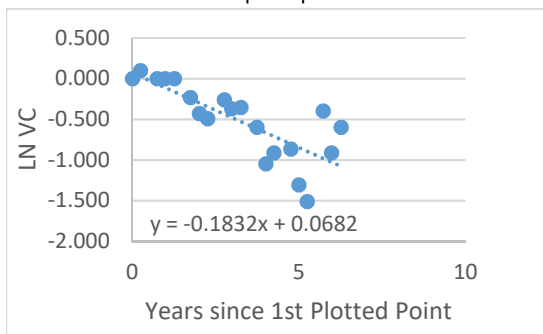


Table C1
Organics Plug Travel Projections

Projections/Estimated timing of when the 1992 organics slug arrived/will arrive downgradient of ERL

Location	Distance from P-17C (feet)	Est. Year (using V_{VC})	Est. Year (using $V_{VC,HI}$)	Observed Maximum Vinyl Chloride Concentration (ug/l)	Observed Maximum Vinyl Chloride Concentration Date	Notes
P-325L	1175	<u>2003</u>	<u>2001</u>	0.97	10/22/2019	P-325L was installed in 2014.
P-326L	1375	<u>2005</u>	<u>2002</u>	1.3	4/22/2016	P-326L was installed in 2014.
B-330 / B-331	3300	<u>2023</u>	<u>2017</u>	0.43	5/2/2016	Temporary boring B-331 was completed in 2016.
P-334L	4500	<u>2034</u>	<u>2026</u>	0.10	10/23/2019	P-334L was installed in 2018.

Inputs

V_{VC}	106 ft/yr	Vinyl Chloride Travel Velocity (estimated)
$V_{VC,HI}$	133 ft/yr	Vinyl Chloride Travel Velocity (high estimate)
Year	1992 Starting Year of Organics Concentration Spike at P-17C (1992-1994)	

Table C2
Projecting Time to Achieve ILs at Wells

Well	k _{POINT}	C ₀	C ₀ Date	C _{IL}	Projected Year C _{IL} Achieved
P-313C	0.161	1.1	4/19/2011	0.05	2031
P-314C	0.269	1.5	4/19/2011	0.05	2024
P-321L	NA (not decreasing)	1.0	4/19/2011	0.05	
P-323L	0.183	1.0	7/17/2013	0.05	2030
P-325L	0.086	0.56	4/14/2015	0.05	2044
P-326L	0.081	0.67	4/14/2015	0.05	2048

Notes: -Projected Year C_{IL} Achieved is based on application of first order kinetics using calculated overall attenuation rate and dataset shown in attached calculations.

-Locations nearest to the Compliance Boundary and Property Boundary are shown.

Variables

$$C_{IL} = C_0 e^{-kt}$$

t = time (years)

k_{POINT} = Calculated overall attenuation rate at well (/year)

x = distance

C_{IL} = Vinyl chloride intervention limit (0.05 ug/l)

V_{VC} = Vinyl chloride velocity (ft/year)

C₀ = Vinyl chloride concentration at date listed. Listed date based on first detections at well since 2011 (or installation date)

Table C3
Bulk Attenuation Projections

ID	Description	Guiding Equation	Overall Attenuation Rate		Vinyl Chloride Travel Distance, Velocity, and Time					Vinyl Chloride Concentration	
			Variable	Overall Attenuation Rate (/yr)	Start Point	End Point	Distance (feet)	V _{GW} (ft / year)	Travel Time (years)	C _{IL} (ug/l)	C _{CB} (ug/l)
A	Calculate the maximum vinyl chloride concentration at the Compliance Boundary that would naturally attenuate below ILs before reaching nearest residential water supply user downgradient of mapped extent?	$C_{CB} = \frac{C_{IL}}{e^{-k \frac{x}{V_{GW}}}}$	k _{JUL, VC}	0.078	Compliance Boundary	Nearest Directly Downgradient Residential Water Supply User	7500	112	67	0.05	10
			k _{OCT, VC}	0.045							1.0
			k _{JUL, MOL}	0.112							90
			k _{OCT, MOL}	0.067							4.5
			k _{MAX, VC}	0.067							4.5
			k _{AVG}	0.074							<u>7.1</u>
B	Calculate the maximum vinyl chloride concentration at P-334L that would naturally attenuate before reaching nearest residential water supply user downgradient of mapped extent (C. Thompson)?	$C_{P-334L} = \frac{C_{IL}}{e^{-k \frac{x}{V_{GW}}}}$	k _{JUL, VC}	0.078	P-334L	Nearest Directly Downgradient Residential Water Supply User	3600	112	34	0.05	0.62
			k _{OCT, VC}	0.045							0.21
			k _{JUL, MOL}	0.112							1.8
			k _{OCT, MOL}	0.067							0.43
			k _{MAX, VC}	0.067							0.43
			k _{AVG}	0.074							<u>0.54</u>
C	How far is vinyl chloride projected to travel downgradient of the Compliance Boundary considering peak 2019 concentrations reported near Compliance Boundary (1.8 ug/l at P-321L) ?	$x = \left(\frac{\ln \frac{C_{IL}}{C_{CB}}}{-k} \right) V_{GW}$	k _{JUL, VC}	0.078	Compliance Boundary	NA	5124	112	46	0.05	1.8
			k _{OCT, VC}	0.045			8968		80		
			k _{JUL, MOL}	0.112			3587		32		
			k _{OCT, MOL}	0.067			5978		53		
			k _{MAX, VC}	0.067			5978		53		
			k _{AVG}	0.074			<u>5435</u>		49		

Assumptions/Notes:

- Overall attenuation rates may be conservatively biased low due to observed presence of parent compounds to vinyl chloride upgradient of P-334L.
- The extent of vinyl chloride is stable and no longer expanding.
- First order kinetics applied, i.e. C_x=C₀e^{-kt}
- The higher end groundwater velocities (+25%) do not yield different results than what is shown above. A change in groundwater velocities yields a proportional change in attenuation rates. This results in no change to results in bolded text above.
- NA = Not applicable or not analyzed
- Inputs in Standard Text
- Results in Bolded Text**
- Value calculated using average attenuation rate, or estimated groundwater velocity, is underlined.

Variables

- C_{CB} = Vinyl chloride concentration at Compliance Boundary.
- t = time
- k = overall attenuation rate
- x = distance
- C_{IL} = Vinyl chloride intevention limit (0.05 ug/l)
- V_{VC} = Vinyl chloride velocity
- C_{P334L} = Vinyl chloride concentration at P-334L

Table C4
Mass of Vinyl Chloride Leaving the Source Area Estimates (April 2010 / 2019)

Mass Flux Leaving Source Area Estimate - April 2010											
Box ID	Wells Included in "Box"	"Box" Depth (feet)	"Box" Width (feet)	"Box" Area (sq feet)	K (ft/day)	GW Elev u/g (ft MSL)	GW Elev d/g (ft MSL)	i (ft/ft)	VC Conc (µg/L)	VC Flux (g/day)	VC Flux (lb/yr)
A - south	P-314C	27	500	13500	41.99	952	951	0.0013	2.00	0.04	0.03
B	P-313C	27	250	6750	41.99	952	951	0.0013	1.40	0.01	0.01
C	P-323L	20	400	8000	41.99	952	951	0.0013	1.00	0.01	0.01
D	P-321L	50	400	20000	41.99	952	951	0.0013	1.20	0.04	0.03
E	4 Wells	55	400	22000	41.99	952	951	0.0013	0.85	0.03	0.02
F - north	2 Wells	55	500	27500	41.99	952	951	0.0013	0.03	0.00	0.00
Total										0.14	0.11
Distance u/g to d/g contour (feet)						750					

Mass Flux Leaving Source Area Estimate - 2019											
Box ID	Wells Included in "Box"	"Box" Depth (feet)	"Box" Width (feet)	"Box" Area (sq feet)	K (ft/day)	GW Elev u/g (ft MSL)	GW Elev d/g (ft MSL)	i (ft/ft)	VC Conc (µg/L)	VC Flux (g/day)	VC Flux (lb/yr)
A - south	P-314C	27	500	13500	41.99	952	951	0.0013	0.29	0.01	0.00
B	P-313C	27	250	6750	41.99	952	951	0.0013	0.42	0.00	0.00
C	P-323L	20	400	8000	41.99	952	951	0.0013	0.54	0.01	0.01
D	P-321L	50	400	20000	41.99	952	951	0.0013	1.4	0.04	0.04
E	4 Wells	55	400	22000	41.99	952	951	0.0013	0.29	0.01	0.01
F - north	2 Wells	55	500	27500	41.99	952	951	0.0013	0.20	0.01	0.01
Total										0.08	0.065
Distance u/g to d/g contour (feet)						750					
Decrease in VC flux in 2019 compared to April 2010:											42%

Notes:

Mass flux estimated using transect/box model method by application of Darcy's Law.

Estimated areas are based on Approximate Extent of Vinyl Chloride above IL on Figure 8 of CAER.

Hydraulic conductivity (K) data based on P-308L step test (2019)

Wells P-29C, P-320C, P-320C2, and P-321L included in Box E. Wells P-301C and P-301L included in Box F.

2019 groundwater elevations/horizontal gradient (i) are based on 952 ft MSL (u/g) and 951 ft MSL (d/g) contours on Figure 3 of CAER.

For consistency, the 2010 groundwater elevations/horizontal gradient (i) were kept consistent with 2019. The current downgradient well network was not yet established.

2019 Average Vinyl Chloride and Total Organics concentrations are average values from wells located in each "box".

2010 Average Vinyl Chloride concentrations are from the April 2010 monitoring event from wells located in each "box". For locations with no data or where non-detect values were reported due to higher reporting limits, data from the nearest date where a detection was reported is applied. These data points are *italicized*.

Table C5
Total Plume Mass Estimate

Zone Description (start/end)	Est. Plume Thickness (ft)	Within Approximate Extent of VC Limits (Fig. 4)				Within Max Estimated Northern Extent of VC above ILs (Fig. 4)				Est. Mass of Vinyl Chloride in Plume Incl. North Area (ug/l)
		Vinyl Chloride Conc. (ug/l)	Est. Area of Plume (Acres)	Groundwater Volume (cubic feet)	Est. Mass of Vinyl Chloride in Plume (lbs)	North Area Vinyl Chloride Conc. (ug/l)	Est. North Area (Acres)	Est. North Area Groundwater Volume (cubic feet)	Est. North Area Mass of Vinyl Chloride (lbs)	
1 - Western Edge of Unlined Area / Midpoint between Compliance and Property Boundaries	40	0.39	35.7	15550920	0.38	0.05	4.1	1785960	0.01	0.38
2 - Midpoint between Compliance and Property Boundaries / Midpoint between Property Boundary and Plume Toe	20	0.41	96.3	20974140	0.54	0.05	36.7	7993260	0.02	0.56
3 - Midpoint between Property Boundary and Toe of Plume / Toe of Plume	15	0.05	43.3	7073055	0.02	0.05	51.6	8428860	0.03	0.05
<u>TOTAL</u>			175.3	43598115	0.94		92.4	18208080.00	0.06	0.99

Notes

Estimated plume areas based on Approximate Extent of Vinyl Chloride above IL and Maximum Estimated Northern Extent of VC above ILs on Figure 4 of CAER.

Estimated Plume Thickness based on Figure 7 and Figure 8 of CAER.

Porosity value of 0.25 from Supplemental Site-Wide Hydrogeologic Evaluation Report (Barr, 2015a).

Average vinyl chloride concentrations based on average concentration values from wells located in each zone. North Area vinyl chloride concentration assumed to be 0.05 ug/l for this calculation.

Appendix D

Area Water Supply Wells

Technical Memorandum

To: File
From: Jim Eidem
Subject: 2020 Well Search Update
Date: May 2020
Project: Elk River Landfill

This technical memorandum summarizes the 2014 update to the Elk River Landfill (ERL) well search. The following subsections describe the well search update methods and results.

Methods

The Minnesota Well Index (MWI) was queried to identify water wells located in the vicinity of ERL (Figure D1). Well records from the MWI are attached.

Results

The construction details for the wells located west of the landfill are summarized in Table D1. Table D1 also summarizes the years the residential wells were sampled dating back to 2011. Data are included in Table D2. No organics have been detected.

Attachments:

- Table D1, Well Construction Summary
- Table D2, Residential Water Supply Well Data (2011-2019)
- Figure D1, Well Search Results
- Well Records

Table D1
Well Construction Summary
Elk River Landfill
Elk River, Minnesota

Approximate Distance (feet) and Direction from ERL		MN Unique Number	Name of Well Record (and on Fig D1 if different)	Address	Attached Data	Use	Approximate Elevation (feet MSL)	Well Depth (feet bgs)	Base of Casing (feet bgs)	Aquifer	Estimated Completion Interval (feet MSL)
5000'	SW	00416125	JONES, RANDY	12781 221st Ave NW	2015-2016	Domestic	989	135	131	Quaternary	858 - 854
4300'	SW	00439871	JACKSON, JERRY	12685 221st Ave NW	2015-2016	Domestic	990	137	133	Quaternary	857 - 853
2800'	SW	00455265	LAFSON, ELOF	see unique ID# on figure (12210 221st Ave NW)	--	Domestic	957	101	88	Quaternary	869 - 856
8400'	SW	00458929	THOMPSON, MATTHEW	see unique ID # on figure (22112 Elk Lake Rd)	--	Domestic	951	92	81	Quaternary	870 - 859
1200'	SW	00527979	Unnamed (P. Hipsag)	22272 Quinn St	2011-2019	Domestic	992	140	135	Quaternary	857 - 852
8000'	SW	00535970	THOMPSON, CLAY	22017 Elk Lake Rd NW	2016	Domestic	979	170	160	Quaternary	819 - 809
8000'	SW	00608116	THOMPSON, DICK	22248 Elk Lake Rd	2017	Domestic	961	94	85	Quaternary	876 - 867
7000'	SW	00625475	BARNIER, MARK	22205 Elk Lake Rd	2015-2016	Domestic	981	113	104	Quaternary	877 - 868
3000'	SW	00626766	RIDGES OF RICE LAKE 1	Ridges Development	2011-2019	Community	987	325	294	Quaternary	693 - 662
1800'	SW	00626780	HIPSAG, DOUG	12269 223rd Ave NW (St.)	2011-2019	Domestic	987	150	147	Quaternary	840 - 837
600'	SW	00655131	ERICKSON, KEVIN & SHAVON (K. Erickson)	12163 223rd Ave NW	2011-2019	Domestic	974	132	122	Quaternary	852 - 842
2000'	SW	00694477	HILDENBRAND, DEBBIE & NA (22447 Tipton St)	HILDENBRAND, DEBBIE & NA (22447 Tipton St)		Domestic	1000	145	142	Quaternary	858 - 855
7400'	SW	00720300	THOMPSON, COREY	22275 Elk Lake Rd	2017	Domestic	960	91	82	Quaternary	878 - 869
2000'	SW	00813437	HILDENBRAND, DEBBIE & NA (22447 Tipton St)	22447 Tipton Ave	2016-2019	Domestic	1000	300	254	Mt. Simon	746 - 700
1500'	SW	00638355*	AIRHART, DONNA & STEVE (Mattson)	22130 Quinn St	2011-2019	Domestic	991	105	95	Quaternary	896 - 886
1400'	SW	None	None (A. Robertson)	12265 223rd Ave (formerly listed as 11265 223rd Ave)	2011-2019	Domestic	--	--	--	--	-- - --
1100'	SW	None	None (C. Corrow)	12183 223rd Ave	2011-2019	Domestic	--	--	--	--	-- - --
8000'	SW	None	None (G. Ruis)	13175 221st Ave NW	2016	Domestic	--	--	--	--	-- - --
5300'	SW	None	None (J. Thompson)	12901 221st Ave NW	2016	Domestic	--	--	--	--	-- - --
8400'	W	00450132	CATO, NANCY (J. Kanz)	22824 Elk Lake Rd	2015	Domestic	961	127	113	Quaternary	848 - 834
7500'	W	00508127	PERL SOD	see unique ID# on figure	--	Undefined	948	210	135	Mt. Simon	813 - 738
7500'	W	00562960	ED FIELDS & SONS, INC	see unique ID# on figure (13000 238th Ave NW)	--	Domestic	949	130	123	Quaternary	826 - 819
8200'	W	00606204	DUNHAM, HOWARD	22722 Elk Lake Rd	--	Domestic	955	89	84	Quaternary	871 - 866
4600'	NW	00525310	SHERPER, DON (T. Rohs)	1227 239th Ave NW	2011-2019	Domestic	984	110	105	Quaternary	879 - 874
4200'	NW	00672355	DRUK, TIM	23115 128th St	--	Domestic	948	89	89	Quaternary	859 - 859
5200'	NW	00672356	DRUK, TIM	23255 128th St	--	Domestic	961	89	84	Quaternary	877 - 872
4200'	NW	00676075	GWYNN, MIKE	23128 128th St	--	Domestic	949	100	91	Quaternary	858 - 849
4500'	NW	00676082	Unnamed	--	--	Domestic	951	93	84	Quaternary	867 - 858
5600'	NW	00676434	Unnamed	23282 128th St NW	--	Domestic	957	210	141	CMTS	816 - 747
5500'	NW	00676922	OLSON, MATT	12876 232nd Ave NW	--	Domestic	951	104	99	Quaternary	852 - 847
5000'	NW	00681344	Unnamed	12821 232nd Ave	--	Domestic	958	90	86	Quaternary	872 - 868
5100'	NW	00703235	Unnamed	12845 232nd Ave	--	Domestic	953	94	90	Quaternary	863 - 859
5000'	NW	00704785	HARTUNGS, JESSE	23195 128th St NW	--	Domestic	951	105	95	Quaternary	856 - 846
5300'	NW	00706000	Unnamed	12875 232nd Av NW	--	Domestic	953	105	95	Quaternary	858 - 848
5200'	NW	00706665	Unnamed	12861 232nd Ave	--	Domestic	953	103	99	Quaternary	854 - 850
4850'	NW	00709882	ISRAELSON, JOAN	12280 239th Av NW	--	Domestic	963	97	87	Quaternary	876 - 866
3500'	NW	00731676	KINGERY, BRIAN & ST. MARIE, TANYA	23105 128th St NW	--	Domestic	958	104	94	Quaternary	864 - 854
5400'	NW	00734477	HANLON, CHRIS	12818 232nd Av NW	--	Domestic	954	110	100	Quaternary	854 - 844

Notes:

Well construction and elevations from Minnesota Well Index (Minnesota Department of Health and Minnesota Geological Survey, 2014, 2020).

-- not available

bgs - below ground surface

MSL - Mean sea level

* - Noted as sealed in County Well Index. Residential well at 22130 Quinn St. is included in ERL residential well monitoring network.

Monitoring wells 696665-696667, 770880, 770881; irrigation well 126512; scientific boring 272081; ERL monitoring wells not included in table.

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	22447 Tipton St. New	22447 Tipton St. New	22447 Tipton St. New
Date			10/20/2011	10/18/2012	10/15/2013	10/20/2014	10/23/2015	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/23/2015	4/25/2016	10/21/2016
Alt. Name (2020)			ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	N. Hildenbrand	N. Hildenbrand	N. Hildenbrand
Unique Well ID# (or MPCA ID)			00420558	00420558	00420558	00420558	00420558	00420558	00420558	00420558	00420558	00813437	00813437	00813437
Parameter	Units	MDH Human Health-Based Water Guidance Table												
Effective Date		04/27/2020												
Exceedance Key		No Exceed												
Volatile Organic Compounds														
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 1.0	< 1.0	< 1.0
1,1,2-Trichloroethane	ug/l	3 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 0.050	< 0.050	< 0.050	< 1.0	< 1.0	< 1.0
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 20	< 20	< 20	< 20	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 2.0	< 2.0	< 2.0 *	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 1.0	< 1.0	< 1.0
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 2.0	< 2.0	< 2.0	< 2.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0
Chlorobenzene	ug/l	100 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0
Hexachlorobutadiene	ug/l	1 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 0.25	< 0.25	< 1.4	< 1.0	< 1.0	< 1.0
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 20	< 20	< 20	< 20	< 10 ^	< 10	< 10	< 10 ^	< 10	< 10 ^	< 10	< 10
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 5.0 ^	< 5.0	< 10	< 5.0	< 5.0	< 5.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	22447 Tipton St. New	22447 Tipton St. New	22447 Tipton St. New
Date			10/20/2011	10/18/2012	10/15/2013	10/20/2014	10/23/2015	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/23/2015	4/25/2016	10/21/2016
Alt. Name (2020)			ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	ERL Shop Well	N. Hildenbrand	N. Hildenbrand	N. Hildenbrand
Unique Well ID# (or MPCA ID)			00420558	00420558	00420558	00420558	00420558	00420558	00420558	00420558	00420558	00813437	00813437	00813437
Parameter	Units	MDH Human Health-Based Water Guidance Table												
Effective Date		04/27/2020												
Exceedance Key		No Exceed												
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Methylene chloride	ug/l	5 HRLMCL	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0 ^	< 5.0	< 10	< 5.0	< 5.0	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 4.0	< 1.0 ^	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.050	< 0.050	< 0.050	< 0.050	< 0.10	< 0.0040	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0
General Parameters														
Alkalinity, total, as CaCO3	mg/l		214	149	148	3520	174	167	175	177	216	172	--	168
Chemical Oxygen Demand	mg/l		< 5.0	< 5.0	< 5.0	< 5.0	< 10.0 F1	< 10.0	< 10.0	< 10.0	< 10.0	< 10.0	--	< 10.0
Chloride	mg/l		< 1.0	< 1	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.5	< 1.0	0.527	--	< 0.5
Dissolved oxygen	mg/l		--	--	--	--	--	0.8	0.6	0.5	1.5	--	0.4	0.6
Nitrogen, ammonia, as N	mg/l		0.18	0.14	0.099	0.15 F1	0.13	0.13	0.13	0.13	0.15	0.17	--	0.22 F1
Nitrogen, nitrate + nitrite, as N	mg/l		< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	--	< 0.050
pH	pH units		7.70	7.20	7.18	7.59	8.13	7.97	7.93	7.83	7.60	8.02	7.89	7.98
Redox (oxidation potential)	mV		--	--	--	--	--	-200.0	-180	-101	-39	--	-173	-210.0
Solids, total dissolved	mg/l		157	184	158	179	164	194	202	184	165	130	--	174
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	--	< 4.0
Specific conductance @ 25 °C	umhos/cm		307	418	409	356	325	328	326	326	327	333	337	328
Sulfate, as SO4	mg/l		--	--	--	--	--	--	--	--	--	--	--	--
Temperature	deg C		10.0	10.2	10.0	11.8	11.4	11.3	11.0	10.8	11.0	10.0	9.2	9.5
Turbidity	NTU		--	--	--	--	--	--	1.7	0.9	1.4	--	--	--
Total Metals														
Calcium	mg/l		--	--	--	--	43.7	40.6	41.7	44.5	42.0	43.0	--	40.2
Magnesium	mg/l		--	--	--	--	13.7	13.7	13.7	13.7	13.5	13.4	--	13.6
Potassium	mg/l		--	--	--	--	1.4	1.4	1.4	1.4	1.4	1.5	--	1.6
Sodium	mg/l		--	--	--	--	6.4	6.4	6.5	6.1	6.0	5.9	--	5.9

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22447 Tipton St. New	22447 Tipton St. New	22447 Tipton St. New	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd St
Date			10/18/2017	10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/22/2014	4/23/2015	12/14/2015	4/25/2016	10/20/2016	10/18/2017
Alt. Name (2020)			N. Hildenbrand	N. Hildenbrand	N. Hildenbrand	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag
Unique Well ID# (or MPCA ID)			00813437	00813437	00813437	00626780	00626780	00626780	00626780	00626780	00626780	00626780	00626780	00626780
Parameter	Units	MDH Human Health-Based Water Guidance Table												
Effective Date		04/27/2020												
Exceedance Key		No Exceed												
Volatile Organic Compounds														
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 0.50	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	< 0.75	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 0.050	< 0.050	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 0.50	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 10	< 20	< 20	< 20	< 20	< 10	< 10	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *
Benzene	ug/l	2 HRL09 (1)	< 0.50	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 1.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0 ^	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Hexachlorobutadiene	ug/l	1 HRL93	< 0.25	< 0.25	< 1.4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10	< 10 ^	< 10	< 20	< 20	< 20	< 20	<				

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22447 Tipton St. New	22447 Tipton St. New	22447 Tipton St. New	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave	12269 223rd Ave
Date			10/18/2017	10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/22/2014	4/23/2015	12/14/2015	4/25/2016	10/20/2016
Alt. Name (2020)			N. Hildenbrand	N. Hildenbrand	N. Hildenbrand	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag	D. Hipsag
Unique Well ID# (or MPCA ID)			00813437	00813437	00813437	00626780	00626780	00626780	00626780	00626780	00626780	00626780	00626780
Parameter	Units	MDH Human Health-Based Water Guidance Table											
Effective Date		04/27/2020											
Exceedance Key		No Exceed											
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0 ^	< 1.0	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *
Tetrahydrofuran	ug/l	600 HRL18	< 5.0 ^	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0 ^
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 0.10	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.050	< 0.050	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.0040	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters													
Alkalinity, total, as CaCO3	mg/l		175	181	217	240	238	228	254 B	247	270	--	279
Chemical Oxygen Demand	mg/l		< 10.0	< 10.0	< 10.0	5.1	11.7 B	< 5.0	< 5.0	--	< 10.0	--	< 10.0
Chloride	mg/l		< 0.5	< 0.5	< 1.0	7.9	8.33	10.1	9.69	11.4	12.1	--	11.4
Dissolved oxygen	mg/l		0.3	0.6	0.7	--	--	--	--	--	--	1.7	2.5
Nitrogen, ammonia, as N	mg/l		0.23	0.23 F1	0.23	< 0.050	< 0.050	< 0.050	< 0.050	--	< 0.020	--	< 0.020
Nitrogen, nitrate + nitrite, as N	mg/l		< 0.050	< 0.050	< 0.050	0.98	1.2	1.2	1.3	--	1.4	--	1.4
pH	pH units		7.93	7.82	7.55	7.44	6.90	7.24	7.86	7.41	7.60	7.51	7.52
Redox (oxidation potential)	mV		-100	-129	-20	--	--	--	--	--	--	-84	60.0
Solids, total dissolved	mg/l		194	194	161	247	297	297	304	--	316	--	349
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	--	< 4.0	--	< 4.0
Specific conductance @ 25 °C	umhos/cm		327	328	325	471	613	487	474	523	566	550	570
Sulfate, as SO4	mg/l		--	--	--	--	--	--	--	20.8	--	--	--
Temperature	deg C		9.6	9.8	10.0	11.0	10.5	10.5	10.2	9.7	10.1	11.0	11.2
Turbidity	NTU		2.5	2.0	2.2	--	--	--	--	--	--	--	--
Total Metals													
Calcium	mg/l		40.5	45.6	43.2	--	--	--	--	78.7	74.3	--	74.9
Magnesium	mg/l		13.2	13.9	13.8	--	--	--	--	27.4	26.5	--	27.6
Potassium	mg/l		1.4	1.5	1.4	--	--	--	--	1.5	1.5	--	1.6
Sodium	mg/l		5.7	5.7	5.5	--	--	--	--	3.2	3.3	--	3.5

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12269 223rd Ave	12269 223rd St	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	
Date			10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/23/2015	4/25/2016	10/20/2016	10/18/2017
Alt. Name (2020)			D. Hipsag	D. Hipsag	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson
Unique Well ID# (or MPCA ID)			00626780	00626780	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)
Parameter	Units	MDH Human Health-Based Water Guidance Table											
Effective Date		04/27/2020											
Exceedance Key		No Exceed											
Volatile Organic Compounds													
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 0.050	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 20	< 20	< 20	< 20	< 10	< 10	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Hexachlorobutadiene	ug/l	1 HRL93	< 0.25	< 1.4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10 ^	< 10	< 20	< 20	< 20	< 20	< 10	< 10 ^	< 10	< 10	< 10
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 5.0	< 10	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12269 223rd Ave	12269 223rd St	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	12265 223rd Ave ¹	
Date			10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/23/2015	4/25/2016	10/20/2016	10/18/2017
Alt. Name (2020)			D. Hipsag	D. Hipsag	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson	A. Roberson
Unique Well ID# (or MPCA ID)			00626780	00626780	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)	(ZW00214)
Parameter	Units	MDH Human Health-Based Water Guidance Table											
Effective Date		04/27/2020											
Exceedance Key		No Exceed											
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.050	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.0040	< 0.050	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters													
Alkalinity, total, as CaCO3	mg/l		277	312	197	158	186	206	166	169	--	165	168
Chemical Oxygen Demand	mg/l		< 10.0	< 10.0	18.1	< 5.0	6.1	< 5.0	--	< 10.0	--	< 10.0	< 10.0
Chloride	mg/l		11.7	12.6	14.3	13.7	18.6	16.3	17.2	15.5	--	15.4	13
Dissolved oxygen	mg/l		2.1	2.5	--	--	--	--	--	--	0.3	0.6	0.4
Nitrogen, ammonia, as N	mg/l		< 0.020	< 0.020	0.12	0.094	0.055	0.41	--	0.061	--	0.072	0.069
Nitrogen, nitrate + nitrite, as N	mg/l		1.0	0.86	< 0.050	< 0.050	< 0.050	< 0.050	--	< 0.050	--	< 0.050	< 0.050
pH	pH units		7.58	7.50	7.62	7.45	7.60	7.61	7.49	7.94	7.83	7.78	7.76
Redox (oxidation potential)	mV		99	111	--	--	--	--	--	--	-99	-102.0	-50
Solids, total dissolved	mg/l		343	320	231	287	277	337	--	248	--	289	288
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	--	< 4.0	--	< 4.0	< 4.0
Specific conductance @ 25 °C	umhos/cm		560	555	421	474	452	442	434	422	436	453	448
Sulfate, as SO4	mg/l		--	--	--	--	--	--	48.6	--	--	--	--
Temperature	deg C		11.5	11.2	9.7	10.7	9.6	9.4	9.7	11.0	10.0	11.3	9.7
Turbidity	NTU		1.0	1.3	--	--	--	--	--	--	--	--	1.7
Total Metals													
Calcium	mg/l		80.8	81.8	--	--	--	--	65.2	63.1	--	58.9	58.1
Magnesium	mg/l		27.3	29.0	--	--	--	--	18.8	18.0	--	18.4	17.3
Potassium	mg/l		1.5	1.5	--	--	--	--	1.5	1.5	--	1.6	1.4
Sodium	mg/l		3.4	3.5	--	--	--	--	4.3	4.6	--	4.7	4.4

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12265 223rd Ave ¹	12265 223rd Ave ¹	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave
Date			10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/23/2015	4/25/2016	10/20/2016	10/18/2017
Alt. Name (2020)			A. Roberson	A. Roberson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson
Unique Well ID# (or MPCA ID)			(ZW00214)	(ZW00214)	00655131	00655131	00655131	00655131	00655131	00655131	00655131	00655131	00655131
Parameter	Units	MDH Human Health-Based Water Guidance Table											
Effective Date		04/27/2020											
Exceedance Key		No Exceed											
Volatile Organic Compounds													
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 0.050	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 20	< 20	< 20	< 20	< 10	< 10 ^	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Hexachlorobutadiene	ug/l	1 HRL93	< 0.25	< 1.4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10 ^	< 10	< 20	< 20	< 20	< 20	< 10	< 10 ^	< 10	< 10	< 10 ^
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 5.0	< 10	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12265 223rd Ave ¹	12265 223rd Ave ¹	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave	12163 223rd Ave
Date			10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/23/2015	4/25/2016	10/20/2016	10/18/2017
Alt. Name (2020)			A. Roberson	A. Roberson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson	K. Erickson
Unique Well ID# (or MPCA ID)			(ZW00214)	(ZW00214)	00655131	00655131	00655131	00655131	00655131	00655131	00655131	00655131	00655131
Parameter	Units	MDH Human Health-Based Water Guidance Table											
Effective Date		04/27/2020											
Exceedance Key		No Exceed											
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.050	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.0040	< 0.050	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters													
Alkalinity, total, as CaCO3	mg/l		166	196	271	265	297	7120	270	283 4	--	287	307
Chemical Oxygen Demand	mg/l		< 10.0	< 10.0	10.8	5.0	< 5.0	< 5.0	--	< 10.0	--	< 10.0	< 10.0
Chloride	mg/l		11.8	11.6	10.7	10.1	10.7	10.1	12.1	11.3	--	14.1	16.3
Dissolved oxygen	mg/l		0.7	0.8	--	--	--	--	--	--	0.9	1.2	0.7
Nitrogen, ammonia, as N	mg/l		0.072	0.063	< 0.050	< 0.050	< 0.050	0.098	--	< 0.020	--	< 0.020	< 0.020
Nitrogen, nitrate + nitrite, as N	mg/l		< 0.050	< 0.050	1.8	1.9	1.4	1.3	--	1.2	--	1.5	1.4
pH	pH units		7.72	7.50	7.48	7.52	7.60	7.47	7.44	7.78	7.59	7.58	7.56
Redox (oxidation potential)	mV		-20	20	--	--	--	--	--	--	-85	138.0	68
Solids, total dissolved	mg/l		276	287	272	337	329	336	--	315	--	358	372
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	--	< 4.0	--	< 4.0	< 4.0
Specific conductance @ 25 °C	umhos/cm		432	427	516	573	555	530	537	517	544	599	628
Sulfate, as SO4	mg/l		--	--	--	--	--	--	22.3	--	--	--	--
Temperature	deg C		9.6	9.5	9.3	9.5	9.6	9.4	9.6	9.0	9.0	9.2	9.3
Turbidity	NTU		1.1	1.3	--	--	--	--	--	--	--	--	--
Total Metals													
Calcium	mg/l		62.2	58.6	--	--	--	--	79.1	78.5	--	79.4	83.9
Magnesium	mg/l		17.3	16.9	--	--	--	--	27.9	27.3	--	29.5	30.8
Potassium	mg/l		1.5	1.4	--	--	--	--	1.5	1.6	--	1.6	1.6
Sodium	mg/l		4.1	3.9	--	--	--	--	3.0	3.3	--	3.6	3.7

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12163 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	22272 Quinn St	
Date			10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/22/2015	4/25/2016	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/20/2011
Alt. Name (2020)			K. Erickson	C. Corrow	C. Corrow	C. Corrow	C. Corrow	C. Corrow	C. Corrow	C. Corrow	C. Corrow	C. Corrow	C. Corrow	C. Corrow	P. Hipsag
Unique Well ID# (or MPCA ID)			00655131	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	00527979
Parameter	Units	MDH Human Health-Based Water Guidance Table													
Effective Date		04/27/2020													
Exceedance Key		No Exceed													
Volatile Organic Compounds															
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 2.0
1,1,2-Trichloroethane	ug/l	3 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75	< 0.75	< 1.0	< 1.0
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,2,3-Trichlorobenzene	ug/l		< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 0.050	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.050	< 0.050	< 0.050	< 3.0
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0
1,3-Dichloropropane	ug/l		< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.25	< 1.0
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
2,2-Dichloropropane	ug/l		< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 20	< 20	< 20	< 20	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 20
Allyl chloride	ug/l	30 HRL94	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0
Benzene	ug/l	2 HRL09 (1)	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 2.0
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0
Bromomethane	ug/l	10 HRL93	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0
Butylbenzene	ug/l		< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Butylbenzene, sec	ug/l		< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Butylbenzene, tert	ug/l		< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Chlorodibromomethane	ug/l	10 HRL93	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0
Chloroethane	ug/l	ND RAA16	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0
Chloroform	ug/l	20 HRL18	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0
Chloromethane	ug/l		< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12163 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	12183 223rd Ave	22272 Quinn St	
Date			10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/22/2015	4/25/2016	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/20/2011
Alt. Name (2020)			K. Erickson	C.Corrow	C.Corrow	C.Corrow	C.Corrow	C.Corrow	C.Corrow	C.Corrow	C.Corrow	C.Corrow	C.Corrow	C.Corrow	P. Hipsag
Unique Well ID# (or MPCA ID)			00655131	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	(ZW00215)	00527979
Parameter	Units	MDH Human Health-Based Water Guidance Table													
Effective Date		04/27/2020													
Exceedance Key		No Exceed													
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 3.0
Methylene chloride	ug/l	5 HRLMCL	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0
Naphthalene	ug/l	70 HRL13	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0
Propylbenzene	ug/l		< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Styrene	ug/l		< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 10	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.10	< 1.0
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.0040	< 0.050	< 0.050	< 0.050	< 0.050	< 1.0
Xylene, total	ug/l	300 XYL HBV19 (1)	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 3.0	< 2.0
General Parameters															
Alkalinity, total, as CaCO3	mg/l		350	186	173	195	4030	219	202	--	232	227	214	246	217
Chemical Oxygen Demand	mg/l		< 10.0	6.4	< 5.0	7.1	5.4 B	--	< 10.0	--	< 10.0	< 10.0	11.8	< 10.0	12.7
Chloride	mg/l		18.3	2.3	3.74	4.33	5.71	6.6	5.71	--	6.04	5.5	5.32	5.8	16.2
Dissolved oxygen	mg/l		1.1	--	--	--	--	--	--	0.3	0.7	0.5	0.5	0.9	--
Nitrogen, ammonia, as N	mg/l		< 0.020	< 0.050	< 0.050	< 0.050	0.084	--	< 0.020	--	< 0.020	< 0.020	< 0.020	< 0.020	< 0.050
Nitrogen, nitrate + nitrite, as N	mg/l		1.3	< 0.050	< 0.050	< 0.050	< 0.050	--	< 0.050	--	< 0.050	< 0.050	< 0.050	< 0.050	1.8
pH	pH units		7.42	7.54	7.51	7.58	7.45	7.54	7.82	7.65	7.69	7.66	7.63	7.39	7.47
Redox (oxidation potential)	mV		87	--	--	--	--	--	--	-98	-124.0	-55	-25	11	--
Solids, total dissolved	mg/l		390	163	242	222	258	--	233	--	279	285	259	289	223
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	--	< 4.0	--	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
Specific conductance @ 25 °C	umhos/cm		639	352	395	379	431	432	413	450	502	456	454	452	446
Sulfate, as SO4	mg/l		--	--	--	--	--	25.6	--	--	--	--	--	--	--
Temperature	deg C		9.4	10.5	10.1	10.2	12.0	9.9	9.9	9.7	11.5	10.8	10.3	10.4	10.6
Turbidity	NTU		1.5	--	--	--	--	--	--	--	--	2.3	1.8	2.4	--
Total Metals															
Calcium	mg/l		90.6	--	--	--	--	62.3	61.3	--	60.4	58.9	62.7	62.1	--
Magnesium	mg/l		31.9	--	--	--	--	20.1	19.8	--	21.2	20.4	20.9	21.5	--
Potassium	mg/l		1.6	--	--	--	--	1.7	1.7	--	1.8	1.6	1.7	1.6	--
Sodium	mg/l		3.7	--	--	--	--	4.9	5.4	--	5.4	4.9	4.7	4.7	--

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St
Date			10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/22/2015	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015
Alt. Name (2020)			P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	Mattson	Mattson	Mattson	Mattson	Mattson
Unique Well ID# (or MPCA ID)			00527979	00527979	00527979	00527979	00527979	00527979	00527979	00527979	00527979	00638355	00638355	00638355	00638355	00638355
Parameter	Units	MDH Human Health-Based Water Guidance Table														
Effective Date		04/27/2020														
Exceedance Key		No Exceed														
Volatile Organic Compounds																
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,1,2-Trichloroethane	ug/l	3 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 0.050	< 0.050	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0
1,3-Dichloropropane	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
2,2-Dichloropropane	ug/l		< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 20	< 20	< 20	< 10	< 10	< 10	< 10	< 10	< 10	< 20	< 20	< 20	< 20	< 10
Allyl chloride	ug/l	30 HRL94	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 2.0	< 2.0	< 2.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 1.0
Butylbenzene	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Butylbenzene, sec	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Butylbenzene, tert	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorobenzene	ug/l	100 HRL93	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^
Chloroethane	ug/l	ND RAA16	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^
Ethyl benzene	ug/l	40 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Hexachlorobutadiene	ug/l	1 HRL93	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 1.4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 20	< 20	< 20	< 10	< 10	< 10	< 10	< 10 ^	< 10	< 20	< 20	< 20	< 20	< 10
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 5.0	< 5.0 ^	< 5.0	< 10	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22272 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St
Date			10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/22/2015	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015
Alt. Name (2020)			P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	P. Hipsag	Mattson	Mattson	Mattson	Mattson	Mattson
Unique Well ID# (or MPCA ID)			00527979	00527979	00527979	00527979	00527979	00527979	00527979	00527979	00527979	00638355	00638355	00638355	00638355	00638355
Parameter	Units	MDH Human Health-Based Water Guidance Table														
Effective Date		04/27/2020														
Exceedance Key		No Exceed														
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0
Methylene chloride	ug/l	5 HRLMCL	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0
Propylbenzene	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Styrene	ug/l		< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0 ^	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.050	< 0.050	< 0.050	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters																
Alkalinity, total, as CaCO3	mg/l		218	190	3960	210	201	195	207	209	266	238	186	173	4270	196
Chemical Oxygen Demand	mg/l		6.9	< 5.0	< 5.0	--	< 10.0	< 10.0	< 10.0	15.1	< 10.0	< 5.0	< 5.0	8.3	< 5.0	--
Chloride	mg/l		15.8	20.4	19.3	22.2	21.6	21.9	23.5	23.9	27.3	5.8	5.27	6.02	5.83	6.3
Dissolved oxygen	mg/l		--	--	--	--	--	1.9	1.4	1.5	0.9	--	--	--	--	--
Nitrogen, ammonia, as N	mg/l		< 0.050	< 0.050	< 0.050 F1	--	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.050	< 0.050	< 0.050	< 0.050	--
Nitrogen, nitrate + nitrite, as N	mg/l		2.1	2.0	2.1	--	2.1	2.1	2.0	2.0	1.6	< 0.050	< 0.050	< 0.050	< 0.050	--
pH	pH units		7.20	7.25	7.50	7.37	7.77	7.60	7.63	7.58	7.60	7.57	7.71	7.74	7.57	7.34
Redox (oxidation potential)	mV		--	--	--	--	--	130.0	25	80	99	--	--	--	--	--
Solids, total dissolved	mg/l		275	250	296	--	238	259	314	308	290	225	266	254	245	--
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	--	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	--
Specific conductance @ 25 °C	umhos/cm		496	487	467	482	443	479	482	497	520	438	432	428	459	471
Sulfate, as SO4	mg/l		--	--	--	20.1	--	--	--	--	--	--	--	--	--	25.6
Temperature	deg C		10.5	10.1	10.2	9.5	10.2	10.6	10.7	10.6	10.4	10.0	9.8	9.9	9.9	9.3
Turbidity	NTU		--	--	--	--	--	--	1.4	1.0	0.8	--	--	--	--	--
Total Metals																
Calcium	mg/l		--	--	--	62.2	61.1	58.9	60.2	70.2	71.2	--	--	--	--	57.7
Magnesium	mg/l		--	--	--	21.5	20.6	21.8	21.3	23.2	24.7	--	--	--	--	21.2
Potassium	mg/l		--	--	--	1.3	1.4	1.5	1.3	1.5	1.4	--	--	--	--	1.5
Sodium	mg/l		--	--	--	2.6	2.8	2.9	2.8	3.0	3.1	--	--	--	--	3.7

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.
Date			10/22/2015	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/23/2015	10/20/2016	10/18/2017
Alt. Name (2020)			Mattson	Mattson	Mattson	Mattson	Mattson	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.
Unique Well ID# (or MPCA ID)			00638355	00638355	00638355	00638355	00638355	00626766	00626766	00626766	00626766	00626766	00626766	00626766	00626766
Parameter	Units	MDH Human Health-Based Water Guidance Table													
Effective Date		04/27/2020													
Exceedance Key		No Exceed													
Volatile Organic Compounds															
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	< 1.0	< 1.0	< 0.75	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 1.0	< 1.0	< 0.050	< 0.050	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 0.50	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 10	< 10	< 10	< 20	< 20	< 20	< 20	< 10	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 0.50
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0 ^
Hexachlorobutadiene	ug/l	1 HRL93	< 1.0	< 1.0	< 0.25	< 0.25	< 1.4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 0.25
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10	< 10	< 10	< 10 ^	< 10	< 20	< 20	< 20	< 20	< 10	< 10 ^	< 10	< 10
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 5.0	< 5.0	< 5.0	< 5.0	< 10	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 5.0	< 5.0 ^

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	22130 Quinn St	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.
Date			10/22/2015	10/20/2016	10/18/2017	10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/20/2014	4/23/2015	10/23/2015	10/20/2016	10/18/2017
Alt. Name (2020)			Mattson	Mattson	Mattson	Mattson	Mattson	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.	Ridges Develop.
Unique Well ID# (or MPCA ID)			00638355	00638355	00638355	00638355	00638355	00626766	00626766	00626766	00626766	00626766	00626766	00626766	00626766
Parameter	Units	MDH Human Health-Based Water Guidance Table													
Effective Date		04/27/2020													
Exceedance Key		No Exceed													
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0 ^
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 1.0	< 1.0	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 5.0	< 5.0	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0 ^
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 1.0	< 1.0	< 0.10	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.10	< 0.050	< 0.050	< 0.050	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.050	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters															
Alkalinity, total, as CaCO3	mg/l		208	208	218	219	239	202	176	182	3890	172	185	183	187
Chemical Oxygen Demand	mg/l		< 10.0	< 10.0	< 10.0	< 10.0	< 10.0	10.8	< 5.0	< 5.0	6.1 B	--	< 10.0	< 10.0	< 10.0
Chloride	mg/l		6.11	5.9	4.54	4.08	4.3	< 1.0	< 1	< 1	< 1	< 1.0	< 0.5	< 0.5	< 0.5
Dissolved oxygen	mg/l		--	0.4	0.6	0.8	0.3	--	--	--	--	--	--	6.9	2.9
Nitrogen, ammonia, as N	mg/l		< 0.020	0.038	< 0.020	< 0.020	< 0.020	0.27	0.23	0.18	0.51	--	0.18	0.23	0.23
Nitrogen, nitrate + nitrite, as N	mg/l		< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050 F1	--	< 0.050	< 0.050	< 0.050
pH	pH units		7.96	7.72	7.74	7.25	7.08	7.82	8.25	8.19	7.58	7.53	7.97	7.87	7.80
Redox (oxidation potential)	mV		--	143.0	-35	65	85	--	--	--	--	--	--	-10.0	25
Solids, total dissolved	mg/l		214	249	257	271	258	196	202	191	209	--	168	207	232
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	--	< 4.0	< 4.0	< 4.0
Specific conductance @ 25 °C	umhos/cm		419	424	430	432	428	326	350	352	344	342	319	348	344
Sulfate, as SO4	mg/l		--	--	--	--	--	--	--	--	--	< 4.0	--	--	--
Temperature	deg C		9.9	9.9	10.2	10.0	10.0	10.2	10.0	10.0	9.9	9.4	10.0	10.2	10.5
Turbidity	NTU		--	--	1.3	1.7	1.2	--	--	--	--	--	--	--	3.0
Total Metals															
Calcium	mg/l		57.4 4	53.8	52.3	57.3	58.3	--	--	--	--	46.4	45.7 4	44.0	46.8
Magnesium	mg/l		20.2	20.2	19.6	20.3	21.4	--	--	--	--	14.9	14.3	15.1	15.4
Potassium	mg/l		1.5	1.5	1.4	1.5	1.5	--	--	--	--	1.2	1.2	1.3	1.3
Sodium	mg/l		3.8	3.8	3.7	3.5	3.6	--	--	--	--	5.4	5.7	6.0	6.2

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			Ridges Develop.	Ridges Develop.	12685 221st Ave NW	12685 221st Ave NW	12685 221st Ave NW	12781 221st Ave NW	12781 221st Ave NW	12781 221st Ave NW	12901 221st Ave NW	12901 221st Ave NW
Date			10/16/2018	10/24/2019	5/29/2015	10/23/2015	11/07/2016	5/29/2015	10/23/2015	11/07/2016	7/07/2016	10/21/2016
Alt. Name (2020)			Ridges Develop.	Ridges Develop.	J. Jackson	J. Jackson	J. Jackson	R. Jones	R. Jones	R. Jones	J. Thompson	J. Thompson
Unique Well ID# (or MPCA ID)			00626766	00626766	00439871	00439871	00439871	00416125	00416125	00416125	--	--
Parameter	Units	MDH Human Health-Based Water Guidance Table										
Effective Date		04/27/2020										
Exceedance Key		No Exceed										
Volatile Organic Compounds												
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 0.50	< 0.50	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2-Trichloroethane	ug/l	3 HRL93	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 5.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 0.050	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 1.0	< 4.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 0.50	< 0.50	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 5.0	< 1.0 ^	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Hexachlorobutadiene	ug/l	1 HRL93	< 0.25	< 1.4	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10 ^	< 10	< 10	< 10 ^	< 10	< 10	< 10 ^	< 10	< 10	< 10
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			Ridges Develop.	Ridges Develop.	12685 221st Ave NW	12685 221st Ave NW	12685 221st Ave NW	12781 221st Ave NW	12781 221st Ave NW	12781 221st Ave NW	12901 221st Ave NW	12901 221st Ave NW
Date			10/16/2018	10/24/2019	5/29/2015	10/23/2015	11/07/2016	5/29/2015	10/23/2015	11/07/2016	7/07/2016	10/21/2016
Alt. Name (2020)			Ridges Develop.	Ridges Develop.	J. Jackson	J. Jackson	J. Jackson	R. Jones	R. Jones	R. Jones	J. Thompson	J. Thompson
Unique Well ID# (or MPCA ID)			00626766	00626766	00439871	00439871	00439871	00416125	00416125	00416125	--	--
Parameter	Units	MDH Human Health-Based Water Guidance Table										
Effective Date		04/27/2020										
Exceedance Key		No Exceed										
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 4.0	< 1.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.050	< 0.050	< 0.10	< 0.10	< 0.050	< 0.10	< 0.10	< 0.050	< 0.0040	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters												
Alkalinity, total, as CaCO3	mg/l		182	225	153	152 4	152	171	165	172	172	170
Chemical Oxygen Demand	mg/l		< 10.0	< 10.0	--	< 10.0	< 10.0	--	< 10.0	< 10.0	--	117
Chloride	mg/l		< 0.5	< 1.0	15.9	17.3	17.3	2.0	2.38	5.09	3.2	1.74
Dissolved oxygen	mg/l		3.0	3.5	--	--	0.2	--	--	0.2	0.8	0.2
Nitrogen, ammonia, as N	mg/l		0.80	0.24	--	0.035	< 0.020	--	0.098	0.091 F1	--	0.086
Nitrogen, nitrate + nitrite, as N	mg/l		< 0.050	< 0.050	--	< 0.050	< 0.050	--	< 0.050	< 0.050	--	< 0.050
pH	pH units		7.58	7.48	7.94	8.19	7.50	7.88	8.26	7.81	7.95	8.03
Redox (oxidation potential)	mV		36	58	--	--	-89.0	--	--	-148.0	-103.0	-144.0
Solids, total dissolved	mg/l		185	210	--	232	281	--	169	227	--	191
Solids, total suspended	mg/l		< 4.0	5.6	--	< 4.0	5.2	--	< 4.0	< 4.0	--	< 4.0
Specific conductance @ 25 °C	umhos/cm		366	352	460	403	435	379	309	384	380	357
Sulfate, as SO4	mg/l		--	--	51.0	--	--	24.6	--	--	21.9	--
Temperature	deg C		9.9	9.6	11.0	12.0	11.8	9.7	10.0	10.0	10.4	10.9
Turbidity	NTU		2.5	5.2	--	--	--	--	--	--	--	--
Total Metals												
Calcium	mg/l		47.9	45.2	59.4	60.1	57.2	48.7	45.4	49.2	45.8	43.1
Magnesium	mg/l		14.8	14.5	16.4	15.9	15.7	14.3	14.2	15.5	14.9	15.0
Potassium	mg/l		1.2	1.2	1.2	1.3	1.3	1.6	1.5	1.7	1.5	1.4
Sodium	mg/l		5.6	5.4	3.3	3.5	3.7	9.3	6.8	7.2	5.8	6.2

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22017 Elk Lake Rd NW	22017 Elk Lake Rd NW	13175 221st Ave NW	13175 221st Ave NW	22205 Elk Lake Rd	22205 Elk Lake Rd	22205 Elk Lake Rd	22275 Elk Lake Rd NW	22275 Elk Lake Rd NW	22248 Elk Lake Rd
Date			7/07/2016	10/21/2016	7/07/2016	10/21/2016	5/29/2015	10/23/2015	11/07/2016	4/10/2017	10/18/2017	4/10/2017
Alt. Name (2020)			C. Thompson	C. Thompson	G. Ruis	G. Ruis	M. Barnier	M. Barnier	M. Barnier	C. Thompson	C. Thompson	D. Thompson
Unique Well ID# (or MPCA ID)			00535970	00535970	--	--	00625475	00625475	00625475	00720300	00720300	00608116
Parameter	Units	MDH Human Health-Based Water Guidance Table										
Effective Date		04/27/2020										
Exceedance Key		No Exceed										
Volatile Organic Compounds												
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75	< 0.75	< 0.75
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.050	< 0.050	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 0.50	< 0.50
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 0.25	< 0.25
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0	< 1.0 *
Chloroform	ug/l	20 HRL18	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0
Hexachlorobutadiene	ug/l	1 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 0.25	< 0.25	< 0.25
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10	< 10	< 10	< 10	< 10	< 10 ^	< 10	< 10	< 10	< 10
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0 ^	< 5.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22017 Elk Lake Rd NW	22017 Elk Lake Rd NW	13175 221st Ave NW	13175 221st Ave NW	22205 Elk Lake Rd	22205 Elk Lake Rd	22205 Elk Lake Rd	22275 Elk Lake Rd NW	22275 Elk Lake Rd NW	22248 Elk Lake Rd
Date			7/07/2016	10/21/2016	7/07/2016	10/21/2016	5/29/2015	10/23/2015	11/07/2016	4/10/2017	10/18/2017	4/10/2017
Alt. Name (2020)			C. Thompson	C. Thompson	G. Ruis	G. Ruis	M. Barnier	M. Barnier	M. Barnier	C. Thompson	C. Thompson	D. Thompson
Unique Well ID# (or MPCA ID)			00535970	00535970	--	--	00625475	00625475	00625475	00720300	00720300	00608116
Parameter	Units	MDH Human Health-Based Water Guidance Table										
Effective Date		04/27/2020										
Exceedance Key		No Exceed										
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0 *	< 5.0 ^	< 5.0 *
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.10	< 0.10
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.0040	< 0.050	< 0.0040	< 0.050	< 0.10	< 0.10	< 0.050	< 0.050	< 0.050	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters												
Alkalinity, total, as CaCO3	mg/l		174	176	164	161	154	139	147	--	193	--
Chemical Oxygen Demand	mg/l		--	< 10.0	--	< 10.0	--	< 10.0	< 10.0	--	< 10.0	--
Chloride	mg/l		2.8	3.21	19.2	21.8	14.7	14.4	15.5	--	3.66	--
Dissolved oxygen	mg/l		0.6	0.4	0.6	0.3	--	--	0.2	1.5	0.5	1.2
Nitrogen, ammonia, as N	mg/l		--	0.030	--	0.054	--	0.15	0.17	--	0.34	--
Nitrogen, nitrate + nitrite, as N	mg/l		--	< 0.050	--	< 0.050	--	< 0.050	< 0.050	--	< 0.050	--
pH	pH units		7.91	7.97	7.93	7.93	7.87	8.13	7.81	8.24	7.99	8.19
Redox (oxidation potential)	mV		-102.0	-145.0	-79.0	-142.0	--	--	-83.0	-20.0	20	-15.0
Solids, total dissolved	mg/l		--	232	--	285	--	248	283	--	262	--
Solids, total suspended	mg/l		--	8.0	--	< 4.0	--	< 4.0	< 4.0	--	< 4.0	--
Specific conductance @ 25 °C	umhos/cm		386	381	420	451	431	387	435	397	396	405
Sulfate, as SO4	mg/l		24.7	--	59.1	--	49.8	--	--	--	--	--
Temperature	deg C		9.9	9.9	10.9	10.5	9.7	9.9	9.8	9.3	9.6	9.1
Turbidity	NTU		--	--	--	--	--	--	--	--	2.6	--
Total Metals												
Calcium	mg/l		53.4	54.2	65.0	67.9	59.5	61.9	59.9 4	--	50.6	--
Magnesium	mg/l		11.5	12.6	14.6	16.2	14.7	15.0	14.9	--	16.7	--
Potassium	mg/l		1.1	1.1	1.4	1.5	1.3	1.4	1.4	--	1.6	--
Sodium	mg/l		3.3	3.4	3.3	3.4	3.3	3.8	3.8	--	4.8	--

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22248 Elk Lake Rd	22823 Elk Lake Rd	22823 Elk Lake Rd	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW
Date			10/18/2017	5/29/2015	10/23/2015	11/03/2011	10/18/2012	10/15/2013	10/20/2014	10/23/2015	10/20/2016	10/18/2017
Alt. Name (2020)			D. Thompson	J. Kanz	J. Kanz	Sherper	Sherper	Sherper	Sherper	Sherper	Sherper	Sherper
Unique Well ID# (or MPCA ID)			00608116	00450132	00450132	00525310	00525310	00525310	00525310	00525310	00525310	00525310
Parameter	Units	MDH Human Health-Based Water Guidance Table										
Effective Date		04/27/2020										
Exceedance Key		No Exceed										
Volatile Organic Compounds												
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 0.50	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 0.50
1,1,2-Trichloroethane	ug/l	3 HRL93	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 0.050	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 0.050
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 0.50	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
2,2-Dichloropropane	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 10	< 20	< 20	< 20	< 20	< 10	< 10	< 10
Allyl chloride	ug/l	30 HRL94	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Benzene	ug/l	2 HRL09 (1)	< 0.50	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 0.50
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 1.0	< 1.0	< 1.0
Butylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 1.0 ^	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Chloroform	ug/l	20 HRL18	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 1.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 1.0 ^	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 1.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0 ^	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0 ^
Hexachlorobutadiene	ug/l	1 HRL93	< 0.25	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 0.25
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10	< 10	< 10 ^	< 20	< 20	< 20	< 20	< 10 ^	< 10	< 10
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 5.0 ^	< 5.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 5.0 ^

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22248 Elk Lake Rd	22823 Elk Lake Rd	22823 Elk Lake Rd	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW	12275 239th Ave NW
Date			10/18/2017	5/29/2015	10/23/2015	11/03/2011	10/18/2012	10/15/2013	10/20/2014	10/23/2015	10/20/2016	10/18/2017
Alt. Name (2020)			D. Thompson	J. Kanz	J. Kanz	Sherper	Sherper	Sherper	Sherper	Sherper	Sherper	Sherper
Unique Well ID# (or MPCA ID)			00608116	00450132	00450132	00525310	00525310	00525310	00525310	00525310	00525310	00525310
Parameter	Units	MDH Human Health-Based Water Guidance Table										
Effective Date		04/27/2020										
Exceedance Key		No Exceed										
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0 ^	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0 ^
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Styrene	ug/l		< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0 ^	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0 ^
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 1.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.050	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.050	< 0.050
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters												
Alkalinity, total, as CaCO3	mg/l		178	166	172 4	234 B	285	198	202	208	216	225
Chemical Oxygen Demand	mg/l		< 10.0	--	< 10.0	< 5.0	6.6	11.8	8.0	< 10.0	< 10.0	< 10.0
Chloride	mg/l		6.01	< 0.50	< 0.5	6.8	9.56	14.5	16.6	20.4	20.5	21.2
Dissolved oxygen	mg/l		0.7	--	--	--	--	--	--	--	1.4	0.8
Nitrogen, ammonia, as N	mg/l		0.55	--	0.22	0.11	0.11	0.069	0.19	0.093	0.11	0.095
Nitrogen, nitrate + nitrite, as N	mg/l		< 0.050	--	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050
pH	pH units		7.94	7.86	8.29	7.98	8.11	8.07	7.74	8.11	7.95	7.93
Redox (oxidation potential)	mV		-20	--	--	--	--	--	--	--	68.0	68
Solids, total dissolved	mg/l		260	--	146	273	288	292	295	235	309	328
Solids, total suspended	mg/l		< 4.0	--	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
Specific conductance @ 25 °C	umhos/cm		405	338	325	440	467	460	456	412	509	509
Sulfate, as SO4	mg/l		--	4.4	--	--	--	--	--	--	--	--
Temperature	deg C		10.2	9.1	10.2	9.4	8.9	9.0	9.9	9.2	9.2	9.2
Turbidity	NTU		7.0	--	--	--	--	--	--	--	--	3.3
Total Metals												
Calcium	mg/l		52.1	41.8	42.8	--	--	--	--	62.7	59.2	61.8
Magnesium	mg/l		15.5	13.2	13.4	--	--	--	--	25.0	25.8	25.9
Potassium	mg/l		1.7	1.2	1.4	--	--	--	--	1.6	1.6	1.6
Sodium	mg/l		4.5	6.0	6.7	--	--	--	--	4.1	4.2	4.1

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12275 239th Ave NW	12275 239th Ave	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	22191 Hwy 169 ²	22191 Hwy 169 ²	22191 Hwy 169 ²	22191 Hwy 169 ²
Date			10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/21/2014	10/23/2015	10/16/2018	10/20/2011	10/18/2012	10/15/2013	10/21/2014
Alt. Name (2020)			Sherper	T. Rohs	T. Schulze	T. Schulze	T. Schulze	T. Schulze	T. Schulze	T. Schulze	E. Toth	E. Toth	E. Toth	E. Toth
Unique Well ID# (or MPCA ID)			00525310	00525310	(ZW00217)	(ZW00217)	(ZW00217)	(ZW00217)	(ZW00217)	(ZW00217)	00437275	00437275	00437275	00437275
Parameter	Units	MDH Human Health-Based Water Guidance Table												
Effective Date		04/27/2020												
Exceedance Key		No Exceed												
Volatile Organic Compounds														
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0
1,1,2-Trichloroethane	ug/l	3 HRL93	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2,3-Trichlorobenzene	ug/l		< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 5.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 0.050	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,3-Dichlorobenzene	ug/l		< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0
1,3-Dichloropropane	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 0.50	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
2,2-Dichloropropane	ug/l		< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0 ^	< 2.0	< 2.0	< 2.0	< 2.0
Acetone	ug/l	3000 HBV17 (1)	< 10	< 10	< 20	< 20	< 20	< 20	< 10	< 10	< 20	< 20	< 20	< 20
Allyl chloride	ug/l	30 HRL94	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0 *	< 2.0
Benzene	ug/l	2 HRL09 (1)	< 0.50	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
Bromomethane	ug/l	10 HRL93	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0 *
Butylbenzene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Butylbenzene, sec	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Butylbenzene, tert	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 0.25	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0
Chlorobenzene	ug/l	100 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Chlorodibromomethane	ug/l	10 HRL93	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Chloroethane	ug/l	ND RAA16	< 1.0	< 4.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Chloroform	ug/l	20 HRL18	< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Cymene p- (toluene isopropyl p-)	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Dibromomethane (methylene bromide)	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 1.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0 ^	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Ethyl ether	ug/l	200 RAA16 (1)	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Hexachlorobutadiene	ug/l	1 HRL93	< 0.25	< 1.4	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 0.25	< 2.0	< 2.0	< 2.0	< 2.0
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 10 ^	< 10	< 20	< 20	< 20	< 20	< 10 ^	< 10 ^	< 20	< 20	< 20	< 20
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 5.0	< 10	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			12275 239th Ave NW	12275 239th Ave	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	11611 225th Ave ²	22191 Hwy 169 ²	22191 Hwy 169 ²	22191 Hwy 169 ²	22191 Hwy 169 ²
Date			10/16/2018	10/24/2019	10/20/2011	10/18/2012	10/15/2013	10/21/2014	10/23/2015	10/16/2018	10/20/2011	10/18/2012	10/15/2013	10/21/2014
Alt. Name (2020)			Sherper	T. Rohs	T. Schulze	T. Schulze	T. Schulze	T. Schulze	T. Schulze	T. Schulze	E. Toth	E. Toth	E. Toth	E. Toth
Unique Well ID# (or MPCA ID)			00525310	00525310	(ZW00217)	(ZW00217)	(ZW00217)	(ZW00217)	(ZW00217)	(ZW00217)	00437275	00437275	00437275	00437275
Parameter	Units	MDH Human Health-Based Water Guidance Table												
Effective Date		04/27/2020												
Exceedance Key		No Exceed												
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 1.0	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0 ^	< 3.0	< 3.0	< 3.0	< 3.0
Methylene chloride	ug/l	5 HRLMCL	< 1.0	< 5.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Naphthalene	ug/l	70 HRL13	< 1.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
Propylbenzene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Styrene	ug/l		< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 10	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 0.10	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 4.0	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 0.050	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 3.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters														
Alkalinity, total, as CaCO3	mg/l		230	275	195	144	185	207	176	173	201	182	202	206
Chemical Oxygen Demand	mg/l		11.2	< 10.0	14.6	5.0	< 5.0	< 5.0	< 10.0 F1	< 10.0	14.9	6.0	< 5.0	7.4
Chloride	mg/l		19.6	22.0	< 1.0	< 1	< 1	< 1	0.748	1.19	27.8	27.3	30.8	32.3
Dissolved oxygen	mg/l		0.6	0.4	--	--	--	--	--	0.6	--	--	--	--
Nitrogen, ammonia, as N	mg/l		0.097	0.12	0.27	0.23	0.17	0.27	0.19	0.21	< 0.050	< 0.050	< 0.050	< 0.050
Nitrogen, nitrate + nitrite, as N	mg/l		< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050
pH	pH units		7.82	7.65	7.99	7.98	8.00	7.94	8.40	7.98	7.80	7.83	7.82	8.27
Redox (oxidation potential)	mV		65	101	--	--	--	--	--	-73	--	--	--	--
Solids, total dissolved	mg/l		312	314	171	197	179	173	170	177	259	305	277	321
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
Specific conductance @ 25 °C	umhos/cm		504	512	318	346	340	325	316	333	445	497	490	455
Sulfate, as SO4	mg/l		--	--	--	--	--	--	--	--	--	--	--	--
Temperature	deg C		9.2	9.7	9.6	9.8	9.6	10.5	9.4	9.7	9.2	9.4	9.4	9.2
Turbidity	NTU		0.9	1.5	--	--	--	--	--	0.8	--	--	--	--
Total Metals														
Calcium	mg/l		69.8	65.6	--	--	--	--	39.0	40.6	--	--	--	--
Magnesium	mg/l		27.6	26.8	--	--	--	--	15.1	15.3	--	--	--	--
Potassium	mg/l		1.7	1.6	--	--	--	--	1.5	1.5	--	--	--	--
Sodium	mg/l		4.2	4.1	--	--	--	--	8.3	8.2	--	--	--	--

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22715 Baldwin ²	22715 Baldwin ²	22715 Baldwin ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	23385 Hwy 169 ²	23385 Hwy 169 ²	23385 Hwy 169 ²	23385 Hwy 169 ²
Date			10/20/2011	10/18/2012	10/21/2014	10/20/2011	10/18/2012	10/15/2013	10/21/2014	10/23/2015	10/16/2018	10/20/2011	10/18/2012	10/15/2013	10/21/2014
Alt. Name (2020)			J. Lawson	J. Lawson	J. Lawson	J. Toth	J. Toth	J. Toth	J. Toth	J. Toth	J. Toth	J. Spencer	J. Spencer	J. Spencer	J. Spencer
Unique Well ID# (or MPCA ID)			(ZW00216)	(ZW00216)	(ZW00216)	00545375	00545375	00545375	00545375	00545375	00545375	00531397	00531397	00531397	00531397
Parameter	Units	MDH Human Health-Based Water Guidance Table													
Effective Date		04/27/2020													
Exceedance Key		No Exceed													
Volatile Organic Compounds															
1,1,1,2-Tetrachloroethane	ug/l	70 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,1,1-Trichloroethane	ug/l	5000 HRL18 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,1,2,2-Tetrachloroethane	ug/l	2 HRL94	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0
1,1,2-Trichloroethane	ug/l	3 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.75	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloroethane	ug/l	80 RAA16 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,1-Dichloroethylene	ug/l	200 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,1-Dichloropropene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2,3-Trichlorobenzene	ug/l		< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
1,2,3-Trichloropropane	ug/l	0.003 HRL13 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2,4-Trichlorobenzene	ug/l	4 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2,4-Trimethylbenzene	ug/l	30 HBV19	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dibromo-3-chloropropane (DBCP)	ug/l		< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 0.050	< 3.0	< 3.0	< 3.0	< 3.0
1,2-Dibromoethane (EDB)	ug/l	0.004 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2-Dichlorobenzene	ug/l	600 HRL93	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethane	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0
1,2-Dichloroethylene, cis	ug/l	6 HRL18 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2-Dichloroethylene, trans	ug/l	9 HRL20 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,2-Dichloropropane	ug/l	5 HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
1,3,5-Trimethylbenzene	ug/l	30 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,3-Dichlorobenzene	ug/l		< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 1.0	< 1.0	< 5.0	< 5.0	< 5.0	< 5.0
1,3-Dichloropropane	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
1,3-Dichloropropene, cis	ug/l	2 DCP HRL94	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.50	< 1.0	< 1.0	< 1.0	< 1.0
1,3-Dichloropropene, trans	ug/l	2 DCP HRL94	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
1,4-Dichlorobenzene	ug/l	10 HRL94 (1) ***	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
2,2-Dichloropropane	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Acetone	ug/l	3000 HBV17 (1)	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 10 ^	< 10	< 20	< 20	< 20	< 20
Allyl chloride	ug/l	30 HRL94	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0 *	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0 *	< 2.0
Benzene	ug/l	2 HRL09 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 0.50	< 2.0	< 2.0	< 2.0	< 2.0
Bromobenzene	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromochloromethane	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Bromodichloromethane	ug/l	3 HBV18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bromoform	ug/l	40 HRL93	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
Bromomethane	ug/l	10 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Butylbenzene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Butylbenzene, sec	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Butylbenzene, tert	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Carbon tetrachloride	ug/l	1 HRL13 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.25	< 1.0	< 1.0	< 1.0	< 1.0
Chlorobenzene	ug/l	100 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Chlorodibromomethane	ug/l	10 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Chloroethane	ug/l	ND RAA16	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Chloroform	ug/l	20 HRL18	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chloromethane	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, o	ug/l		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chlorotoluene, p	ug/l		< 4.0	< 4.0	< 2.0	< 4.0	< 4.0	< 4.0	< 2.0	< 1.0	< 1.0	< 4.0	< 4.0	< 4.0	< 2.0
Cumene (isopropyl benzene)	ug/l	300 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Cymene p- (toluene isopropyl p-)	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Dibromomethane (methylene bromide)	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Dichlorodifluoromethane (Freon-12)	ug/l	500 RAA17	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Dichlorofluoromethane (Freon-21)	ug/l	20 RAA17	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Ethyl benzene	ug/l	40 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Ethyl ether	ug/l	200 RAA16 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Hexachlorobutadiene	ug/l	1 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 0.25	< 2.0	< 2.0	< 2.0	< 2.0
Methyl ethyl ketone (2-butanone)	ug/l	4000 HRL94	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 10 ^	< 10 ^	< 20	< 20	< 20	< 20
Methyl isobutyl ketone (MIBK)	ug/l	300 HRL94	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 5.0	< 5.0	< 3.0	< 3.0	< 3.0	< 3.0

Table D2
Residential Water Supply Well Data (2011-2019)
Elk River Landfill
Elk River, Minnesota

Location			22715 Baldwin ²	22715 Baldwin ²	22715 Baldwin ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	22915 Hwy 169 ²	23385 Hwy 169 ²	23385 Hwy 169 ²	23385 Hwy 169 ²	23385 Hwy 169 ²
Date			10/20/2011	10/18/2012	10/21/2014	10/20/2011	10/18/2012	10/15/2013	10/21/2014	10/23/2015	10/16/2018	10/20/2011	10/18/2012	10/15/2013	10/21/2014
Alt. Name (2020)			J. Lawson	J. Lawson	J. Lawson	J. Toth	J. Toth	J. Toth	J. Toth	J. Toth	J. Toth	J. Spencer	J. Spencer	J. Spencer	J. Spencer
Unique Well ID# (or MPCA ID)			(ZW00216)	(ZW00216)	(ZW00216)	00545375	00545375	00545375	00545375	00545375	00545375	00531397	00531397	00531397	00531397
Parameter	Units	MDH Human Health-Based Water Guidance Table													
Effective Date		04/27/2020													
Exceedance Key		No Exceed													
Methyl tertiary butyl ether (MTBE)	ug/l	60 RAA13 (1)	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
Methylene chloride	ug/l	5 HRLMCL	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Naphthalene	ug/l	70 HRL13	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 1.0	< 1.0	< 3.0	< 3.0	< 3.0	< 3.0
Propylbenzene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Styrene	ug/l		< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Tetrachloroethylene	ug/l	4 HBV14 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 *	< 1.0
Tetrahydrofuran	ug/l	600 HRL18	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Toluene	ug/l	70 HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Trichloroethylene (TCE)	ug/l	0.4 HRL15 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 1.0	< 1.0	< 1.0	< 1.0
Trichlorofluoromethane (Freon-11)	ug/l	2000 HRL93	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0 ^	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0 ^
Trichlorotrifluoroethane (Freon 113)	ug/l	200000 HRL93	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0	< 2.0
Vinyl chloride	ug/l	0.2 HRL18 (1)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 0.10	< 0.050	< 1.0	< 1.0	< 1.0	< 1.0
Xylene, total	ug/l	300 XYL HBV19 (1)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
General Parameters															
Alkalinity, total, as CaCO3	mg/l		265	216	233	247	188	213	206	206	205	217	196	170	165
Chemical Oxygen Demand	mg/l		12.7	< 5.0	< 5.0	13.0	< 5.0	< 5.0	< 5.0	11.6	10.5	6.7	< 5.0	< 5.0	5.8
Chloride	mg/l		12.5	10.9	12.7	28.4	24.3	28.9	27.1	30.7	30.2	< 1.0	< 1	< 1	< 1 F1
Dissolved oxygen	mg/l		--	--	--	--	--	--	--	--	0.6	--	--	--	--
Nitrogen, ammonia, as N	mg/l		< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.020	< 0.020	0.076	0.13	0.10	0.16
Nitrogen, nitrate + nitrite, as N	mg/l		9.6	9.6	9.8	0.19	0.49	0.81	0.93	0.84	0.34	< 0.050	< 0.050	< 0.050	< 0.050 F1
pH	pH units		7.60	8.09	7.73	7.67	7.96	7.92	7.67	7.92	7.62	8.17	8.26	8.19	8.04
Redox (oxidation potential)	mV		--	--	--	--	--	--	--	--	80	--	--	--	--
Solids, total dissolved	mg/l		316	347	316	256	302	294	330	265	318	159	183	169	190
Solids, total suspended	mg/l		< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
Specific conductance @ 25 °C	umhos/cm		562	566	495	472	518	503	479	450	532	318	347	350	330
Sulfate, as SO4	mg/l		--	--	--	--	--	--	--	--	--	--	--	--	--
Temperature	deg C		11.0	9.6	9.3	10.6	10.6	9.6	9.8	9.4	9.4	9.5	9.8	10.1	9.5
Turbidity	NTU		--	--	--	--	--	--	--	--	4.7	--	--	--	--
Total Metals															
Calcium	mg/l		--	--	--	--	--	--	--	73.6	71.3	--	--	--	--
Magnesium	mg/l		--	--	--	--	--	--	--	25.0	24.4	--	--	--	--
Potassium	mg/l		--	--	--	--	--	--	--	1.7	1.7	--	--	--	--
Sodium	mg/l		--	--	--	--	--	--	--	3.2	3.1	--	--	--	--

Data Footnotes and Qualifiers

Barr Standard Footnotes and Qualifiers

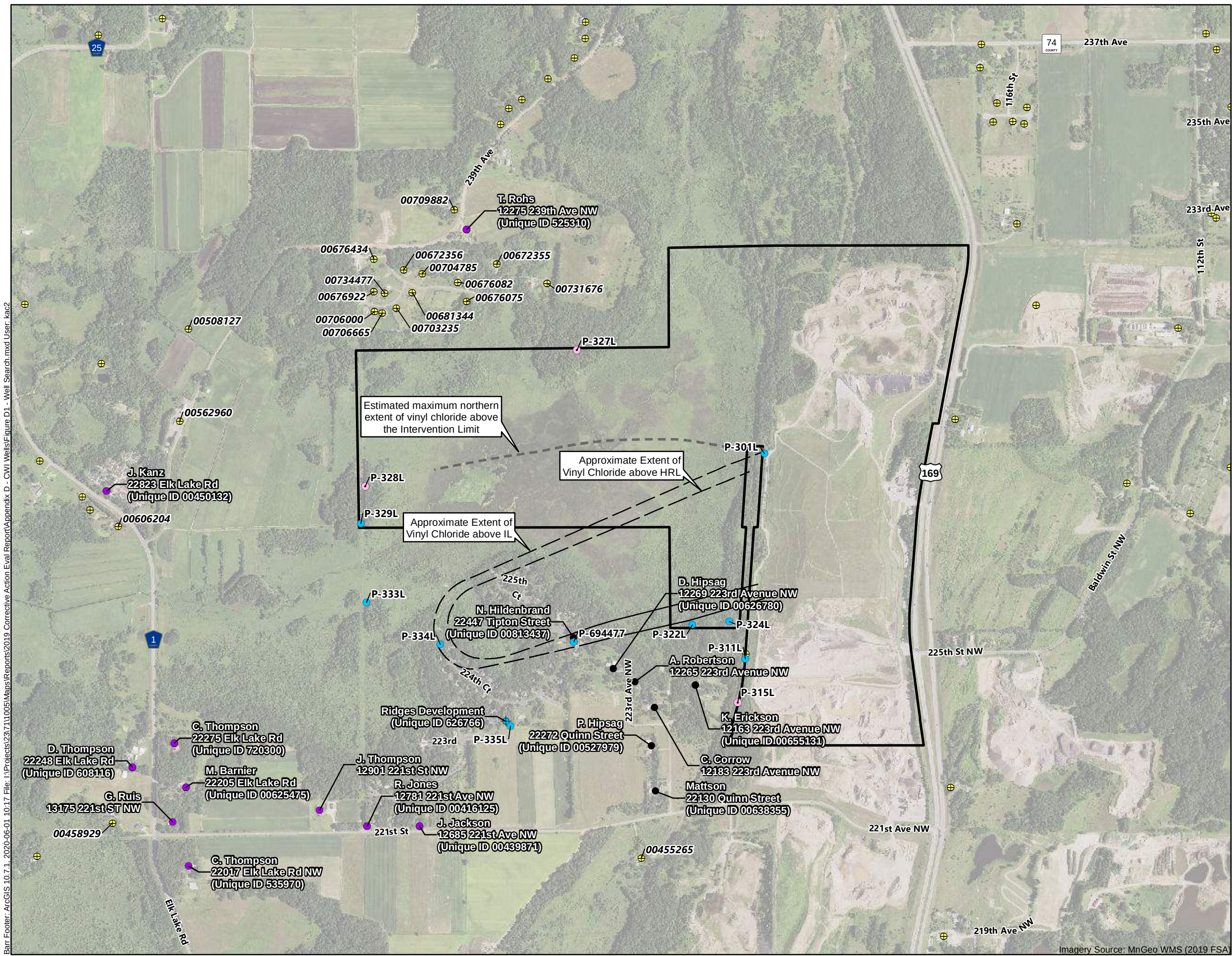
--	Not analyzed/Not available.
*	Estimated value, QA/QC criteria not met.
1	Well 12265 223rd was incorrectly listed as 11265 223rd in Permit SW-74
2	Upgradient well located east of Hwy 169 NW

TestAmerica Qualifiers

*	LCS or LCSD is outside acceptance limits.
^	ICV,CCV,ICB,CCB, ISA, ISB, CRI, CRA, DLCK or MRL standard: Instrument related QC is outside acceptance limits.
4	MS, MSD: The analyte present in the original sample is greater than 4 times the matrix spike concentration; therefore, control limits are not applicable.
B	Compound was found in the blank and sample.
F1	MS and/or MSD Recovery is outside acceptance limits.

MDH Human Health-Based Water Guidance Table

DCP	Value shown is 1,3-dichloropropene in the MDH criterion, however, the laboratory reports cis and trans isomers individually.
(1)	Value is representative of the lowest exposure duration published in the Minnesota Department of Health Human Health Advisory Table.
HBV14	Health Based Value 2014
HBV17	Health Based Value 2017
HBV18	Health Based Value 2018
HBV19	Health Base Value 2019.
HRL09	Health Risk Limit 2009
HRL13	Health Risk Limit 2013.
HRL15	Health Risk Limit 2015
HRL18	Health Risk Limit 2018.
HRL20	Health Risk Limit 2020
HRL93	Health Risk Limit 1993.
HRL94	Health Risk Limit 1994.
***	Dual guidance applies: See Dual Guidance for Drinking Water (https://www.health.state.mn.us/communities/environment/risk/guidance/dualguidance.html)
HRLMCL	Health Risk Limit; Maximum Contaminant Level.
ND	Not derived due to insufficient information.
RAA13	Risk Assessment Advice 2013
RAA16	Risk Assessment Advice 2016
RAA17	Risk Assessment Advice 2017.
XYL	Value shown is for the sum of the mixed o,m and p Xylene isomers.



- Property Boundary
- Domestic
- Residential Well Location
- Community Water Supply Well
- Residential Well (Expanded Sampling Location, 2015-2017)

Existing Monitoring Locations

- Monitoring Well
- Piezometer

Notes:
1) Pertinent ERL lower outwash monitoring locations shown.

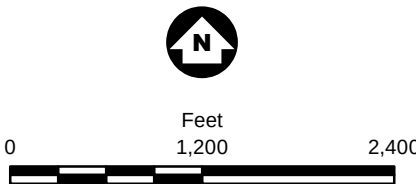


Figure D1
WELL SEARCH
Elk River Landfill
Elk River, Minnesota



Minnesota Unique Well No.

416125

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 12/01/1990
Update Date 02/14/2014
Received Date

Minnesota Statutes Chapter 103I

Well Name JONES, RANDY		Well Depth 135 ft.		Depth Completed 135 ft.		Date Well Completed 08/29/1986	
Township Range Dir Section Subsections Elevation 33 26 W 4 CCCCCC		989 ft.		7.5 minute topographic map (+/- 5 feet)		Drilling Method Non-specified Rotary	
Well Address 12781 221ST AV NW ELK RIVER MN 55330		Drilling Fluid --		Well Hydrofractured? ☐ Yes ☐ No From Ft. to Ft.			
Geological Material		Color		Hardness		From To	
FINE SAND		BROWN		0		41	
CLAY		BROWN		41		57	
MEDIUM SAND		YELLOW		57		60	
CLAY		BROWN		60		63	
CLAY		GRAY		63		66	
ROCKY CLAY		RED		66		75	
MEDIUM SAND		YEL/BRN		75		90	
CLAY		BROWN		90		100	
MEDIUM SAND		BROWN		100		105	
CLAY		RED		105		116	
SAND		BROWN		116		120	
SAND		GRAY		120		135	
Use Domestic		Casing Type Steel (black or low carbon)		Joint Threaded		Drive Shoe? ☐ Yes ☒ No	
Casing Diameter 4 in. to 131 ft.		Weight 10.79 lbs./ft.		Hole Diameter			
Open Hole from ft. to ft.		Screen YES		Make JOHNSON 304		Type stainless steel	
Diameter 3.3		Slot/Gauze 18		Length 4		Set Between 131 ft. and 135 ft.	
Static Water Level 50 ft. from Land surface		Date Measured 08/29/1986		PUMPING LEVEL (below land surface)			
60 ft. after 2 hrs. pumping		30 g.p.m.		Well Head Completion			
Pitless adapter manufacturer BAKER		Model SNAPPY		☐ Casing Protection ☐ 12 in. above grade			
☐ At-grade (Environmental Wells and Borings ONLY)		Grouting Information		Well Grouted? ☒ Yes ☐ No ☐ Not Specified		Grout Material: Bentonite from 0 to 131 ft.	
Nearest Known Source of Contamination 105 feet E direction		Septic tank/drain field type		Well disinfected upon completion? ☒ Yes ☐ No			
Pump ☒ Not Installed		Date Installed 09/09/1986		Manufacturer's name GRUNDFOS			
Model number SP4-8		HP 0.75		Volts 230		Length of drop Pipe 72 ft.	
Capacity 15 g.p.m.		Type Submersible		Material Galvanized		Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No	
Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No		Well Contractor Certification		Renner E.H. Well		71015	
PRAUGHT, V.		License Business Name		Lic. Or Reg. No.		Name of Driller	
First Bedrock		Aquifer Quat. Buried Artes. Aquifer		Last Strat sand-gray		Depth to Bedrock ft.	
County Well Index Online Report		416125		Printed 11/30/2014 HE-01205-07			

Minnesota Unique Well No.

439871

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 08/19/1992
Update Date 02/14/2014
Received Date

Minnesota Statutes Chapter 103I

Well Name JACKSON, JERRY		Well Depth 138 ft.	Depth Completed 137 ft.	Date Well Completed 06/09/1988
Township Range Dir Section Subsections Elevation 990 ft.				
33 26 W 4 CCDCCB Elevation Method topographic map (+/- 5 feet)		Drilling Method Non-specified Rotary		
Well Address 12723 221 AV NW ELK RIVER MN 55330		Drilling Fluid Bentonite	Well Hydrofractured? ☐ Yes ☐ No From Ft. to Ft.	
Geological Material		Use Domestic		
DRY SAND	BROWN	Casing Type Steel (black or low carbon) Joint Threaded Drive Shoe? ☐ Yes ☒ No Above/Below 1 ft.		
CLAY	BROWN			
CLAY	GRAY			
FINE SAND	BROWN			
CLAY	BROWN			
SAND	BROWN			
CLAY	GRAY			
MEDIUM SAND	GRAY			
		Casing Diameter	Weight	Hole Diameter
		4 in. to 133 ft.	10.79 lbs./ft.	
		Open Hole from ft. to ft.		
		Screen YES Make JOHNSON 304 Type stainless steel		
		Diameter	Slot/Gauze	Length
		4.5	18	4
		Set Between 133 ft. and 137 ft.		
		Static Water Level		
		50 ft. from Land surface Date Measured 06/09/1988		
		PUMPING LEVEL (below land surface)		
		70 ft. after 3 hrs. pumping 30 g.p.m.		
		Well Head Completion		
		Pitless adapter manufacturer BAKER Model SNAPPY		
		☐ Casing Protection ☒ 12 in. above grade		
		☐ At-grade (Environmental Wells and Borings ONLY)		
NO REMARKS		Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified		
Located by: Minnesota Geological Survey		Grout Material: Bentonite from 0 to 133 ft.		
Method: Digitized - scale 1:24,000 or larger (Digitizing Table)				
Unique Number Verification: Address verification		Nearest Known Source of Contamination		
Input Date: 04/12/1995		105 feet South East direction Septic tank/drain field type		
System: UTM - Nad83, Zone15, Meters X: 453856 Y: 5024487		Well disinfected upon completion? ☒ Yes ☐ No		
		Pump ☒ Not Installed Date Installed 07/08/1988		
		Manufacturer's name GRUNDFOS Model number 16S07-8 HP 0.75 Volts 230		
		Length of drop Pipe 84 ft. Capacity g.p.m. Type Submersible Material Galvanized		
		Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No		
		Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No		
		Well Contractor Certification		
First Bedrock		Renner E.H. Well 71015 PRAUGHT, V.		
Aquifer Quat. Buried Artes. Aquifer		License Business Name Lic. Or Reg. No. Name of Driller		
Last Strat sand-gray		Depth to Bedrock ft.		
County Well Index Online Report		439871		Printed 11/30/2014 HE-01205-07

Minnesota Unique Well No.		County	Sherburne	MINNESOTA DEPARTMENT OF HEALTH		Entry Date	05/21/1991
450132		Quad	Lake Fremont	WELL AND BORING RECORD		Update Date	02/14/2014
		Quad ID	137A	Minnesota Statutes Chapter 103I		Received Date	
Well Name CATO, NANCY				Well Depth		Date Well Completed	
Township Range Dir Section Subsections Elevation				127 ft.		07/12/1988	
33 26 W 5 BAACCB Elevation Method topographic map (+/- 5 feet)				Depth Completed		127 ft.	
				Drilling Method		Non-specified Rotary	
Well Address				Drilling Fluid		Well Hydrofractured? ☐ Yes ☐ No	
22824 ELK LAKE RD				Bentonite		From Ft. to Ft.	
ELK RIVER MN				Use		Domestic	
Geological Material				Casing Type		Joint No Information Drive Shoe? ☐ Yes ☒ No	
SAND BROWN SOFT 0 9				Plastic		Above/Below 1 ft.	
CLAY GRAY SOFT 9 12				Casing Diameter		Weight	
SAND GRAY SOFT 12 17				4 in. to 113 ft.		lbs./ft.	
CLAY GRAY SOFT 17 28				Hole Diameter		6.25 in. to 127 ft.	
SAND BROWN SOFT 28 33				Open Hole		from ft. to ft.	
CLAY & GRAVEL BROWN HARD 33 113				Screen YES		Make JOHNSON Type stainless steel	
SAND & GRAVEL BROWN SOFT 113 127				Diameter		Slot/Gauze	
				2 15		Length	
				2 12		Set Between	
				2 15		ft. and 127 ft.	
						113 ft. and ft.	
						ft. and ft.	
				Static Water Level			
				4 ft. from Land surface		Date Measured 07/12/1988	
				PUMPING LEVEL (below land surface)			
				110 ft. after 1 hrs. pumping		75 g.p.m.	
				Well Head Completion			
				Pitless adapter manufacturer		Model	
				☐ Casing Protection		☐ 12 in. above grade	
				☐ At-grade (Environmental Wells and Borings ONLY)			
NO REMARKS				Grouting Information		Well Grouted? ☒ Yes ☐ No ☐ Not Specified	
Located by:				Grout Material: Neat Cement		from 0 to 30 ft. 3 bags	
Method: GPS SA Off (averaged)				Nearest Known Source of Contamination		56 feet direction type	
Unique Number Verification: Address verification				Well disinfected upon completion? ☒ Yes ☐ No			
Input Date: 02/02/2011				Pump ☐ Not Installed		Date Installed 07/14/1988	
System: UTM - Nad83, Zone15, Meters				Manufacturer's name AERMOTOR		Model number SD20150 HP 1.5 Volts 230	
				Length of drop Pipe 69 ft.		Capacity 25 g.p.m. Type Submersible Material Steel (black or low carbon)	
				Abandoned Wells		Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No	
				Variance		Was a variance granted from the MDH for this well? ☐ Yes ☐ No	
First Bedrock				Well Contractor Certification			
Aquifer Quat. Buried Artes. Aquifer				Mork Well Co.		02133 LAWRENCE, R.	
Last Strat sand +larger-brown				License Business Name		Lic. Or Reg. No.	
Depth to Bedrock ft.						Name of Driller	
County Well Index Online Report				450132		Printed 12/5/2014	
						HE-01205-07	

455265

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date05/15/1991

Update Date02/14/2014

Received Date

Well Name LAFSON, ELOF					Township 33	Range 26	Dir W	Section 9	Subsection ABABDD	Well Depth 101 ft.					Depth Completed 101 ft.					Date Well Completed 12/06/1988																																		
Elevation 957 ft.					Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary					Drill Fluid Bentonite																																							
Address C/W12210 221ST AV NW ELK RIVER MN										Use domestic					Status Active																																							
										Well Hydrofractured? Yes ☐ No ☐					From To																																							
Stratigraphy Information <table><tr><td>Geological Material</td><td>From</td><td>To (ft.)</td><td>Color</td><td>Hardness</td></tr><tr><td>SAND GRAVEL & CLAY</td><td>0</td><td>15</td><td>BROWN</td><td>HARD</td></tr><tr><td>CLAY & GRAVEL</td><td>15</td><td>22</td><td>GRAY</td><td>SOFT</td></tr><tr><td>SAND & GRAVEL</td><td>22</td><td>30</td><td>BROWN</td><td>SOFT</td></tr><tr><td>CLAY & GRAVEL</td><td>30</td><td>37</td><td>BROWN</td><td>SOFT</td></tr><tr><td>CLAY & GRAVEL</td><td>37</td><td>83</td><td>BROWN</td><td>HARD</td></tr><tr><td>SAND & GRAVEL</td><td>83</td><td>101</td><td>BROWN</td><td>SOFT</td></tr></table>										Geological Material	From	To (ft.)	Color	Hardness	SAND GRAVEL & CLAY	0	15	BROWN	HARD	CLAY & GRAVEL	15	22	GRAY	SOFT	SAND & GRAVEL	22	30	BROWN	SOFT	CLAY & GRAVEL	30	37	BROWN	SOFT	CLAY & GRAVEL	37	83	BROWN	HARD	SAND & GRAVEL	83	101	BROWN	SOFT	Casing Type Single casing					Joint				
										Geological Material	From	To (ft.)	Color	Hardness																																								
										SAND GRAVEL & CLAY	0	15	BROWN	HARD																																								
										CLAY & GRAVEL	15	22	GRAY	SOFT																																								
										SAND & GRAVEL	22	30	BROWN	SOFT																																								
										CLAY & GRAVEL	30	37	BROWN	SOFT																																								
										CLAY & GRAVEL	37	83	BROWN	HARD																																								
										SAND & GRAVEL	83	101	BROWN	SOFT																																								
										Drive Shoe? Yes ☐ No ☒					Above/Below 1 ft.																																							
										Casing Diameter 4 in. To 88 ft.					Weight lbs./ft.					Hole Diameter 6.2 in. To 101 ft.																																		
Open Hole Fromft.Toft.																																																						
Screen? ☒					Type stainless					Make JOHNSON																																												
Diameter 2 in. To 12 ft.					Slot/Gauze Length					Set ft. 101 ft.																																												
2 in. To 12 ft.					12 ft. To 88 ft.					88 ft. To 101 ft.																																												
Static Water Level 15 ft. land surface					Measure 12/06/1988																																																	
Pumping Level (below land surface) 84 ft. 1 hrs. Pumping at 50 g.p.m.																																																						
Wellhead Completion Pitless adapter manufacturer MONITOR Model 8PL41UC1 ☐ Casing Protection ☐ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)																																																						
Grouting Information Material Amount From To neat cement 3 Sacks 0 ft. 30 ft.										Well Grouted? ☒ Yes ☐ No ☐ Not Specified																																												
Nearest Known Source of Contamination 61 feet Southeast Direction Well disinfected upon completion? ☒ Yes ☐ No										Septic tank/drain field Type																																												
Pump ☐ Not Installed Date Installed 12/20/1988 Manufacturer's name LOWARA Model Number 11AM05412 HP 0.5 Volt 230 Length of drop pipe 40 ft Capacity 10 g.p. Typ Submersible																																																						
Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No																																																						
Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No																																																						
Miscellaneous First Bedrock Aquifer Quat. buried Last Strat sand +larger-brown Depth to Bedrock ft Located by Minnesota Geological Survey Locate Method GPS SA Off (averaged) (15 meters) System UTM - NAD83, Zone 15, Meters X 454726 Y 5024353 Unique Number Verification Address verification Input Date 02/02/2011																																																						
Angled Drill Hole																																																						
Well Contractor Mork Well Co. 02133 LAWRENCE, R. Licensee Business Lic. or Reg. No. Name of Driller																																																						

Minnesota Well Index Report

455265

Printed on 05/31/2020
HE-01205-15

Minnesota Unique Well No.

458929

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 01/25/1991
Update Date 02/14/2014
Received Date

Minnesota Statutes Chapter 103I

Well Name THOMPSON, MATTHEW		Well Depth 92 ft.	Depth Completed 92 ft.	Date Well Completed 01/17/1990
Township Range Dir Section Subsections Elevation 33 26 W 5 CDDCBD Elevation Method topographic map (+/- 5 feet)		Drilling Method Non-specified Rotary		
Well Address 22112 ELK LAKE RD ELK RIVER MN		Drilling Fluid Bentonite	Well Hydrofractured? ☐ Yes ☐ No From Ft. to Ft.	
Geological Material SANDY CLAY CLAY SAND		Use Domestic		
Color BROWN GRAY ORANGE	Hardness SOFT MEDIUM SOFT	From 0 48 75	To 48 75 92	Casing Type Plastic Joint No Information Drive Shoe? ☐ Yes ☒ No Above/Below 1 ft.
		Casing Diameter 4 in. to 81 ft.	Weight lbs./ft.	Hole Diameter 6.25 in. to 92 ft.
		Open Hole from ft. to ft.		
		Screen YES Make JOHNSON Type stainless steel		
		Diameter 2	Slot/Gauze 12	Length 12 Set Between 81 ft. and 92 ft.
		Static Water Level 25 ft. from Land surface Date Measured 01/17/1990		
		PUMPING LEVEL (below land surface) 78 ft. after 1 hrs. pumping 25 g.p.m.		
		Well Head Completion Pitless adapter manufacturer MONITOR Model 8PL41UC1 ☐ Casing Protection ☐ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)		
NO REMARKS		Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified Grout Material: Neat Cement from 0 to 30 ft.		
Located by: Method: GPS SA Off (averaged) Unique Number Verification: Address verification Input Date: 02/02/2011 System: UTM - Nad83, Zone15, Meters X: 452651 Y: 5024511		Nearest Known Source of Contamination 101 feet W direction Sewer type Well disinfected upon completion? ☒ Yes ☐ No		
		Pump ☐ Not Installed Date Installed 01/19/1990 Manufacturer's name LOWARA Model number 11AM07B12 HP 0.75 Volts 230 Length of drop Pipe 60 ft. Capacity 10 g.p.m. Type Submersible Material Plastic		
		Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No		
		Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No		
First Bedrock Last Strat sand-orange		Well Contractor Certification Mork Well Co. 02133 AESHLIMAN, S. License Business Name Lic. Or Reg. No. Name of Driller		
County Well Index Online Report		458929		Printed 12/5/2014 HE-01205-07

508127

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date12/01/1990

Update Date06/02/2014

Received Date

Well Name PERL SOD					Township 34	Range 26	Dir W	Section 32	Subsection DBCDBA	Well Depth 210 ft.	Depth Completed 210 ft.	Date Well Completed 08/21/1989				
Elevation 948 ft.					Elev. Method 7.5 minute topographic map (+/- 5 feet)		Drill Method Non-specified Rotary						Drill Fluid Qwik gel			
Address										Use irrigation			Status Active			
										Well Hydrofractured? Yes ☐ No ☐				From To		
										Casing Type Single casing			Joint Welded			
										Drive Shoe? Yes ☐ No ☐			Above/Below			
Stratigraphy Information										Casing Diameter 12 in. To			Weight 135 ft. lbs./ft.		Hole Diameter 18 in. To 135 ft. 11 in. To 210 ft.	
Geological Material					From	To (ft.)	Color	Hardness								
PEAT DIRT					0	5	BLACK	SOFT								
PEAT DIRT					5	10	BLACK	SOFT								
CLAY					10	35	GRAY	SOFT								
SAND & COARSE					35	45	VARIED	MEDIUM								
CLAY & SAND					45	105	RED	MED-HRD								
CLAY					105	125	GRAY	SOFT								
SANDSTONE-SHALE					125	130	VARIED	MED-HRD								
SANDSTONE					130	190	WHT/TAN	MED-HRD								
SANDSTONE					190	205		HARD								
SANDSTONE					205	210		HARD								
										Static Water Level -1.5 ft. land surface Measure 08/21/1989						
										Pumping Level (below land surface) 18 ft. 6 hrs. Pumping at 1000 g.p.m.						
										Wellhead Completion Pitless adapter manufacturer Model ☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)						
										Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified Material Amount From To bentonite 0 ft. 90 ft. neat cement 1.25 Cubic yards 90 ft. 135 ft.						
										Nearest Known Source of Contamination 500 feet West Direction Volatile organic compounds Type Well disinfected upon completion? ☒ Yes ☐ No						
										Pump ☒ Not Installed Date Installed Manufacturer's name Model Number HP Volt Length of drop pipe ft Capacity g.p. Typ						
										Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No						
										Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No						
										Miscellaneous First Bedrock Mt.Simon Sandstone Aquifer Mt.Simon- Last Strat Hinckley Sandstone Depth to Bedrock 125 ft Located by Minnesota Geological Survey Locate Method Digitization (Screen) - Map (1:24,000) (15 meters or System UTM - NAD83, Zone 15, Meters X 452971 Y 5026449 Unique Number Verification Information from Input Date 04/12/1995						
										Angled Drill Hole						
										Well Contractor Bergerson-Caswell 27058 HOLMEN, G. Licensee Business Lic. or Reg. No. Name of Driller						

525310

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date 03/28/1996
Update Date 03/10/2014
Received Date

Well Name SHERPER, DON Township 34 Range 26 Dir Section W 33 Subsection BDCCBC Elevation 984 ft. Elev. Method 7.5 minute topographic map (+/- 5 feet)					Well Depth 110 ft. Depth Completed 110 ft. Date Well Completed 07/07/1995 Drill Method Non-specified Rotary Drill Fluid Bentonite																													
Address C/W 12275 239TH AV NW ELK RIVER MN 55330					Use domestic Status Active																													
Stratigraphy Information <table><thead><tr><th>Geological Material</th><th>From</th><th>To (ft.)</th><th>Color</th><th>Hardness</th></tr></thead><tbody><tr><td>SAND</td><td>0</td><td>25</td><td></td><td></td></tr><tr><td>CLAY</td><td>25</td><td>55</td><td></td><td></td></tr><tr><td>GRAVEL/ CLAY</td><td>55</td><td>85</td><td></td><td></td></tr><tr><td>WATERSAND</td><td>85</td><td>110</td><td></td><td></td></tr></tbody></table>					Geological Material	From	To (ft.)	Color	Hardness	SAND	0	25			CLAY	25	55			GRAVEL/ CLAY	55	85			WATERSAND	85	110			Well Hydrofractured? Yes ☐ No ☐ From To				
					Geological Material	From	To (ft.)	Color	Hardness																									
					SAND	0	25																											
					CLAY	25	55																											
					GRAVEL/ CLAY	55	85																											
					WATERSAND	85	110																											
					Casing Type Single casing Joint																													
					Drive Shoe? Yes ☐ No ☒ Above/Below																													
					Casing Diameter 4 in. To 105 ft. 2 lbs./ft. Weight Hole Diameter 8 in. To 36 ft. 6.7 in. To 110 ft.																													
					Open Hole From ft. To ft.																													
Screen? ☒ Type stainless Make JOHNSON Diameter Slot/Gauze Length Set 2 in. 15 5 ft. 105 ft. 110 ft.																																		
Static Water Level 19 ft. land surface Measure 07/11/1995																																		
Pumping Level (below land surface) 60 ft. 1 hrs. Pumping at 40 g.p.m.																																		
Wellhead Completion Pitless adapter manufacturer MOINTOR Model SNAPPY ☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)																																		
Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified Material Amount From To bentonite 2 Sacks 6 ft. 36 ft.																																		
Nearest Known Source of Contamination 53 feet North Direction Septic tank/drain field Type Well disinfected upon completion? ☒ Yes ☐ No																																		
Pump ☐ Not Installed Date Installed 07/11/1995 Manufacturer's name AERMOTOR Model Number 7T12 HP 0.75 Volt 230 Length of drop pipe 60 ft Capacity 12 g.p. Typ Submersible																																		
Abandoned Does property have any not in use and not sealed well(s)? ☒ Yes ☐ No																																		
Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No																																		
Miscellaneous First Bedrock sand Aquifer Quat. buried Last Strat sand Depth to Bedrock ft Located by Minnesota Geological Survey Locate Method GPS SA Off (averaged) (15 meters) System UTM - NAD83, Zone 15, Meters X 454067 Y 5026827 Unique Number Verification Address verification Input Date 11/12/2010																																		
Angled Drill Hole																																		
Well Contractor Mac's Well Co. 86596 TORGERSON, S. Licensee Business Lic. or Reg. No. Name of Driller																																		

Remarks
OLD WELL SEALED #H58730.

Minnesota Unique Well No.

527979

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 10/13/1993
Update Date 02/14/2014
Received Date

Minnesota Statutes Chapter 103I

Well Name Township Range Dir Section Subsections Elevation 992 ft. 33 26 W 4 DCAACB Elevation Method topographic map (+/- 5 feet)		Well Depth 140 ft.		Depth Completed 140 ft.		Date Well Completed 06/21/1993	
		Drilling Method Non-specified Rotary					
Well Address 22272 QUINN ST ELK RIVER MN 55330		Drilling Fluid Other		Well Hydrofractured? ☐ Yes ☐ No From Ft. to Ft.			
		Use Domestic					
Geological Material CLAY & SAND SILTY SAND & CLAY CLAY CLAY & ROCKS SAND		Color BROWN LT. BRN GRAY BROWN YELLOW		Hardness SOFT SOFT HARD HARD SOFT		From To 0 10 10 74 74 90 90 126 126 140	
		Casing Type Plastic Joint Welded Drive Shoe? ☒ Yes ☐ No Above/Below ft.					
		Casing Diameter 4 in. to 135 ft.		Weight lbs./ft.		Hole Diameter 8 in. to 30 ft.	
		Open Hole from ft. to ft.					
		Screen YES Make JOHNSON Type stainless steel					
		Diameter 2		Slot/Gauze 10		Length Set Between 5 135 ft. and 140 ft.	
		Static Water Level 50 ft. from Land surface Date Measured 06/21/1993					
		PUMPING LEVEL (below land surface) 100 ft. after 3 hrs. pumping 15 g.p.m.					
		Well Head Completion Pitless adapter manufacturer MONITOR BD Model 4A05.5 ☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)					
NO REMARKS		Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified Grout Material: Neat Cement from 0 to 30 ft. 3 bags Grout Material: Bentonite from 30 to 135 ft. 4 bags					
Located by: Method: GPS SA Off (averaged) Unique Number Verification: Address verification Input Date: 02/02/2011 System: UTM - Nad83, Zone15, Meters X: 454759 Y: 5024764		Nearest Known Source of Contamination 50 feet W direction Septic tank/drain field type Well disinfected upon completion? ☒ Yes ☐ No					
		Pump ☐ Not Installed Date Installed 06/22/1993 Manufacturer's name AERMOTOR Model number SD1250 HP 0.5 Volts 230 Length of drop Pipe 105 ft. Capacity 12 g.p.m. Type Submersible Material Plastic					
		Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No					
		Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No					
First Bedrock Last Strat sand-yellow		Aquifer Quat. Buried Artes. Aquifer Depth to Bedrock ft.		Well Contractor Certification Mc Alpine's Well Co. 27186 MCALPINE, T. License Business Name Lic. Or Reg. No. Name of Driller			
County Well Index Online Report		527979		Printed 11/30/2014 HE-01205-07			

535970

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date02/15/1995

Update Date02/14/2014

Received Date

Well Name THOMPSON,	Township 33	Range 26	Dir W	Section 8	Subsection ABBCDB	Well Depth 170 ft.	Depth Completed 170 ft.	Date Well Completed 11/30/1994
Elevation 979 ft.	Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary	Drill Fluid Other	
Address C/W12901 221ST AV ELK RIVER MN						Use domestic	Status Active	
Stratigraphy Information Geological MaterialFromTo (ft.)ColorHardness FINE SAND065BROWNMEDIUM CLAY65160BROWNHARD SAND160170GRAYMEDIUM						Well Hydrofractured? Yes ☐ No ☐ From To		
						Casing Type Single casing Joint		
						Drive Shoe? Yes ☐ No ☐ Above/Below		
						Casing Diameter Weight Hole Diameter 4 in. To 160 ft. lbs./ft.8.8 in. To 30 ft. 6.5 in. To 170 ft.		
						Open Hole Fromft.Toft.		
						Screen? ☒ Type stainless Make JOHNSON DiameterSlot/GauzeLengthSet 2.5 in. 12 10 ft. 160 ft. 170 ft.		
						Static Water Level 45 ft. land surfaceMeasure11/30/1994		
						Pumping Level (below land surface) 170 ft. 2 hrs. Pumping at18 g.p.m.		
						Wellhead Completion Pitless adapter manufacturerMERRILLModelSPP ☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)		
						Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified MaterialAmountFromTo bentonite3 Sacks0 ft. 30 ft.		
Nearest Known Source of Contamination 100 feetEast DirectionSeptic tank/drain field Type Well disinfected upon completion? ☒ Yes ☐ No								
Pump ☐ Not InstalledDate Installed11/30/1994 Manufacturer's nameAERMOTOR Model NumberSD12HP0.5Volt220 Length of drop pipe80 ftCapacity10 g.p. TypSubmersible								
Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No								
Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No								
Miscellaneous First BedrockAquiferQuat. buried Last Stratsand-grayDepth to Bedrockft Located byMinnesota Geological Survey Locate MethodGPS SA Off (averaged) (15 meters) SystemUTM - NAD83, Zone 15, MetersX 452882Y 5024294 Unique Number VerificationAddress verificationInput Date02/02/2011								
Angled Drill Hole								
Well Contractor Drillco27264URAN, J. Licensee BusinessLic. or Reg. No.Name of Driller								

Minnesota Unique Well No.		County	Sherburne	MINNESOTA DEPARTMENT OF HEALTH		Entry Date	11/21/1996
562960		Quad	Lake Fremont	WELL AND BORING RECORD		Update Date	02/14/2014
		Quad ID	137A	Minnesota Statutes Chapter 103I		Received Date	
Well Name ED FIELDS & SONS, INC				Well Depth	Depth Completed	Date Well Completed	
Township Range Dir Section Subsections Elevation				130 ft.	130 ft.	08/03/1996	
34 26 W 32 DCCACC Elevation Method topographic map (+/- 5 feet)				Drilling Method Non-specified Rotary			
Well Address				Drilling Fluid	Well Hydrofractured? ☐ Yes ☐ No		
13000 238TH AV NW				Bentonite	From Ft. to Ft.		
MN				Use Domestic			
Geological Material				Casing Type	Joint Threaded Drive Shoe? ☐ Yes ☒ No Above/Below ft.		
SANDY							
CLAY & ROCKS				Casing Diameter	Weight	Hole Diameter	
CLAY				4 in. to 123 ft.	10.79 lbs./ft.	8.8 in. to 30 ft.	
MEDIUM SAND				Open Hole from ft. to ft.			
GRAVEL & SANDSTONE MIX				Screen YES Make JOHNSON Type stainless steel			
				Diameter	Slot/Gauze	Length	Set Between
				4.5	25	8	121 ft. and 130 ft.
				Static Water Level			
				9 ft. from Land surface Date Measured 08/03/1996			
				PUMPING LEVEL (below land surface)			
				19 ft. after 3 hrs. pumping 30 g.p.m.			
				Well Head Completion			
				Pitless adapter manufacturer BAKER Model SNAPPY			
				☐ Casing Protection ☒ 12 in. above grade			
				☐ At-grade (Environmental Wells and Borings ONLY)			
NO REMARKS				Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified			
Located by:				Grout Material: Bentonite from 0 to 121 ft. 1.3 yds.			
Unique Number Verification: Address verification				Nearest Known Source of Contamination			
System: UTM - Nad83, Zone15, Meters				50 feet E direction Septic tank/drain field type			
				Well disinfected upon completion? ☐ Yes ☐ No			
				Pump ☐ Not Installed Date Installed 08/07/1996			
				Manufacturer's name GRUDFOS Model number 25S10-7 HP 1 Volts 230			
				Length of drop Pipe 42 ft. Capacity 25 g.p.m. Type Submersible Material			
				Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No			
				Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No			
First Bedrock				Well Contractor Certification			
Last Strat gravel (+larger)-brown				Renner E.H. Well 71015 PRAUGHT, V.			
Aquifer Quat. Buried Artes. Aquifer				License Business Name Lic. Or Reg. No. Name of Driller			
Depth to Bedrock ft.							
County Well Index Online Report				562960		Printed 12/5/2014 HE-01205-07	

Minnesota Unique Well No.		County		Sherburne		MINNESOTA DEPARTMENT OF HEALTH			Entry Date		06/04/1998		
606204		Quad		Lake Fremont		WELL AND BORING RECORD			Update Date		02/14/2014		
		Quad ID		137A		Minnesota Statutes Chapter 103I			Received Date				
Well Name DUNHAM, HOWARD						Well Depth		Depth Completed		Date Well Completed			
Township Range Dir Section Subsections Elevation						89 ft.		89 ft.		11/25/1997			
33 26 W 5 BADCAB Elevation Method						topographic map (+/- 5 feet)		Drilling Method		Non-specified Rotary			
Well Address						Drilling Fluid		Well Hydrofractured?		☐ Yes ☐ No			
22722 ELK LAKE RD						Bentonite		From Ft. to Ft.					
ELK RIVER MN 55330						Use		Domestic					
Geological Material						Color		Hardness		From		To	
SAND						BROWN		SOFT		0		40	
CLAY						GRAY		MEDIUM		40		74	
CLAY & GRAVEL						BROWN		MEDIUM		74		80	
GRAVEL						BROWN		SOFT		80		89	
Casing Type						Plastic		Joint		No Information		Drive Shoe?	
No Above/Below						ft.				☐ Yes ☒			
Casing Diameter						Weight		Hole Diameter					
4 in. to						84 ft.		1.9 lbs./ft.		6.5 in. to		89 ft.	
Open Hole						from ft. to		ft.					
Screen YES						Make		JOHNSON		Type		stainless steel	
Diameter						Slot/Gauze		Length		Set Between			
2						12		5		84 ft. and		89 ft.	
Static Water Level						12 ft. from Land surface		Date Measured		11/25/1997			
PUMPING LEVEL (below land surface)						84 ft. after 2 hrs. pumping		50 g.p.m.					
Well Head Completion						Pitless adapter manufacturer		MONITOR		Model		BULLDOG	
☐ Casing Protection						☒ 12 in. above grade							
☐ At-grade (Environmental Wells and Borings ONLY)													
REMARKS						Grouting Information		Well Grouted?		☒ Yes ☐ No ☐ Not Specified			
HOWARD DUNHAM						Grout Material: High solids bentonite		from 0 to 30 ft.		0.17 yds.			
Located by:						Method: GPS SA Off (averaged)							
Unique Number Verification: Address verification						Input Date: 02/02/2011							
System: UTM - Nad83, Zone15, Meters						X: 452686 Y: 5025676							
Nearest Known Source of Contamination						33 feet		South West		direction		Septic tank/drain field type	
Well disinfected upon completion?						☒ Yes ☐ No							
Pump						☐ Not Installed		Date Installed		12/01/1997			
Manufacturer's name						AERMOTOR		Model number		T12-50		HP 0.5 Volts 230	
Length of drop Pipe						40 ft.		Capacity		10 g.p.m.		Type Submersible Material Plastic	
Abandoned Wells						Does property have any not in use and not sealed well(s)?		☐ Yes ☒ No					
Variance						Was a variance granted from the MDH for this well?		☐ Yes ☒ No					
Well Contractor Certification						McAlpine Bros., Inc.		27270		GOODIN, G.			
License Business Name						Lic. Or Reg. No.		Name of Driller					
First Bedrock						Aquifer		Quat. Buried Artes. Aquifer					
Last Strat gravel (+larger)-brown						Depth to Bedrock		ft.					
County Well Index Online Report						606204				Printed 12/5/2014		HE-01205-07	

Minnesota Unique Well No.

608116

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 06/04/1998
Update Date 05/19/2014
Received Date

Minnesota Statutes Chapter 103I

Well Name THOMPSON, DICK		Well Depth 94 ft.		Depth Completed 94 ft.		Date Well Completed 11/01/1997	
Township Range Dir Section Subsections Elevation		961 ft.					
33 26 W 5 CDADBB Elevation Method		7.5 minute topographic map (+/- 5 feet)					
Well Address		Drilling Fluid		Well Hydrofractured?			
22248 ELK LAKE RD		Bentonite		From Ft. to Ft.		☐ Yes ☐ No	
ELK RIVER MN 55330		Use Domestic					
Geological Material		Color		Hardness		From To	
SAND		TAN		SOFT		0 38	
CLAY		TAN		SOFT		38 46	
CLAY		GRAY		SOFT		46 62	
SAND, GRAVEL		TAN		SOFT		62 68	
CLAY, GRAVEL		BROWN		SOFT		68 71	
SAND		TAN		SOFT		71 94	
		Casing Type		Plastic Joint Glued Drive Shoe?		☐ Yes ☒ No Above/Below ft.	
		Casing Diameter		Weight		Hole Diameter	
		4 in. to 85 ft.		lbs./ft.		8.5 in. to 30 ft.	
		Open Hole		from ft. to ft.			
		Screen YES		Make COOK		Type stainless steel	
		Diameter		Slot/Gauze		Length Set Between	
		2		10		8 85 ft. and 94 ft.	
		Static Water Level					
		23 ft. from Land surface		Date Measured 11/01/1997			
		PUMPING LEVEL (below land surface)					
		ft. after 1 hrs. pumping 40 g.p.m.					
		Well Head Completion					
		Pitless adapter manufacturer MONITOR		Model 8PL41UC1			
		☐ Casing Protection		☒ 12 in. above grade			
		☐ At-grade (Environmental Wells and Borings ONLY)					
NO REMARKS		Grouting Information		Well Grouted?		☒ Yes ☐ No ☐ Not Specified	
Located by:		Grout Material: High solids bentonite		from 0 to 30 ft.			
Method: GPS SA Off (averaged)		Grout Material: Cuttings		from 30 to 85 ft.			
Unique Number Verification: Address verification		Input Date: 02/02/2011					
System: UTM - Nad83, Zone15, Meters		X: 452730 Y: 5024730					
		Nearest Known Source of Contamination					
		52 feet W direction Septic tank/drain field type					
		Well disinfected upon completion?		☐ Yes ☐ No			
		Pump		☐ Not Installed Date Installed 11/05/1997			
		Manufacturer's name RED JACKET		Model			
		number 75SESW1-12SBC		HP 0.75 Volts 230			
		Length of drop Pipe 60 ft.		Capacity 15 g.p.m.		Type Submersible Material	
		Abandoned Wells		Does property have any not in use and not sealed well(s)?		☐ Yes ☒ No	
		Variance		Was a variance granted from the MDH for this well?		☐ Yes ☒ No	
		Well Contractor Certification					
First Bedrock		Mork Well Co.		02658		THOMPSON, S	
Last Strat sand-brown		License Business Name		Lic. Or Reg. No.		Name of Driller	
Aquifer Quat. Buried Artes. Aquifer							
Depth to Bedrock ft.							
County Well Index Online Report		608116				Printed 12/5/2014 HE-01205-07	

Minnesota Unique Well No.

625475

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 09/14/1999
Update Date 03/29/2011
Received Date

Minnesota Statutes Chapter 103I

Well Name BARNIER, MARK		Well Depth 113 ft.		Depth Completed 113 ft.		Date Well Completed 02/24/1999	
Township Range Dir Section Subsections Elevation		981 ft.					
33 26 W 5 DCBDCC Elevation Method		7.5 minute topographic map (+/- 5 feet)					
Well Address		Drilling Fluid		Well Hydrofractured?			
22205 ELK LAKE RD		Bentonite		From Ft. to Ft.		☐ Yes ☒ No	
ELK RIVER MN		Use Domestic					
Geological Material		Color		Hardness		From To	
SAND		TAN		SOFT		0 55	
CLAY		GRAY		SOFT		55 85	
CLAY, GRAVEL		BROWN		SOFT		85 96	
SAND		TAN		SOFT		96 113	
		Casing Type		Plastic Joint Glued Drive Shoe?		☐ Yes ☒ No Above/Below ft.	
		Casing Diameter		Weight		Hole Diameter	
		4 in. to 104 ft.		lbs./ft.		8.5 in. to 30 ft.	
		Open Hole		from ft. to ft.			
		Screen YES		Make JOHNSON		Type stainless steel	
		Diameter		Slot/Gauze		Length Set Between	
		2		10		8 104 ft. and 113 ft.	
		Static Water Level					
		48 ft. from Land surface		Date Measured 02/24/1999			
		PUMPING LEVEL (below land surface)					
		ft. after 1 hrs. pumping		30 g.p.m.			
		Well Head Completion					
		Pitless adapter manufacturer		MONITOR		Model 8PL41UC1	
		☐ Casing Protection		☒ 12 in. above grade			
		☐ At-grade (Environmental Wells and Borings ONLY)					
NO REMARKS		Grouting Information		Well Grouted?		☒ Yes ☐ No ☐ Not Specified	
Located by:		Grout Material: High solids bentonite		from 0 to 30 ft.			
Method: GPS SA Off (averaged)		Grout Material: Cuttings		from 30 to 104 ft.			
Unique Number Verification: Address verification		Input Date: 02/02/2011					
System: UTM - Nad83, Zone15, Meters		X: 452941 Y: 5024649					
		Nearest Known Source of Contamination					
		60 feet W direction		Septic tank/drain field type			
		Well disinfected upon completion?		☒ Yes ☐ No			
		Pump		☐ Not Installed		Date Installed 02/24/1999	
		Manufacturer's name		RED JACKET		Model	
		number 75SESW1-12SBC		HP 0.75		Volts 220	
		Length of drop Pipe 80 ft.		Capacity 15 g.p.m.		Type Submersible Material	
		Abandoned Wells		Does property have any not in use and not sealed well(s)?		☒ Yes ☐ No	
		Variance		Was a variance granted from the MDH for this well?		☐ Yes ☒ No	
		Well Contractor Certification					
First Bedrock		Mork Well Co.		02658		THOMPSON, S.	
Last Strat sand-brown		License Business Name		Lic. Or Reg. No.		Name of Driller	
Aquifer Quat. Buried Artes. Aquifer							
Depth to Bedrock ft.							
County Well Index Online Report		625475				Printed 11/30/2014 HE-01205-07	

Minnesota Unique Well No.		County	Sherburne	MINNESOTA DEPARTMENT OF HEALTH		Entry Date	02/06/2002
626766		Quad	Lake Fremont	WELL AND BORING RECORD		Update Date	03/10/2014
		Quad ID	137A	Minnesota Statutes Chapter 103I		Received Date	
Well Name RIDGES OF RICE LAKE 1				Well Depth	Depth Completed	Date Well Completed	
Township Range Dir Section Subsections Elevation				325 ft.	325 ft.	08/23/2001	
33 26 W 4 CACDDB Elevation Method topographic map (+/- 5 feet)				Drilling Method Non-specified Rotary			
Well Address 22323 WATSON ST NW ELK RIVER MN 55330				Drilling Fluid Bentonite	Well Hydrofractured? ☐ Yes ☒ No From Ft. to Ft.		
Geological Material				Use Community Supply PWS ID 1710013 Source S01			
SAND BROWN SOFT 0 50				Casing Type Steel (black or low carbon) Joint Welded Drive Shoe? ☐ Yes ☐ No Above/Below 2 ft.			
CLAY BROWN SOFT 50 70				Casing Diameter Weight Hole Diameter			
SANDY CLAY BROWN SOFT 70 80				8 in. to 294 ft. 28.55 lbs./ft. 16 in. to 325 ft.			
MEDIUM SAND BROWN SOFT 80 85				Open Hole from ft. to ft.			
SAND & CLAY GRY/WHT SOFT 85 110				Screen YES Make JOHNSON Type stainless steel			
GRAVEL BROWN MEDIUM 110 120				Diameter Slot/Gauze Length Set Between			
CLAY BROWN MEDIUM 120 130				6 25 20 295 ft. and 315 ft.			
MEDIUM SAND BROWN MEDIUM 130 170				6 40 10 315 ft. and 325 ft.			
SANDY CLAY GRAY MEDIUM 170 285				Static Water Level			
CLAY & SAND GRAY MEDIUM 285 310				55 ft. from Land surface Date Measured 08/23/2001			
MEDIUM SAND GRAY MEDIUM 310 325				PUMPING LEVEL (below land surface)			
SANDSTONE & SHALE (MEDIUM) MEDIUM 325 325				84 ft. after 8 hrs. pumping 400 g.p.m.			
REMARKS ABB VFD CONTROLLER ACH401602532. WITH DV/DT FILTER.				Well Head Completion			
Located by: Minnesota Department of Health Method: GPS SA Off (averaged)				Pitless adapter manufacturer Model			
Unique Number Verification: N/A Input Date: 05/14/2003				☐ Casing Protection ☒ 12 in. above grade			
System: UTM - Nad83, Zone15, Meters X: 454203 Y: 5024894				☐ At-grade (Environmental Wells and Borings ONLY)			
				Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified			
				Grout Material: Neat Cement from 0 to 120 ft. 95 bags			
				Nearest Known Source of Contamination			
				100 feet E direction Septic tank/drain field type			
				Well disinfected upon completion? ☒ Yes ☐ No			
				Pump ☐ Not Installed Date Installed 10/02/2001			
				Manufacturer's name GRUNDFOS Model number 300S300-7 HP 30 Volts 460			
				Length of drop Pipe 106 ft. Capacity 400 g.p.m. Type Submersible Material			
First Bedrock Mt.Simon Sandstone Aquifer Quat. Buried Artes. Aquifer				Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes			
Last Strat Mt.Simon Sandstone Depth to Bedrock 325 ft.				☒ No			
				Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No			
				Well Contractor Certification			
				Renner E.H. Well 71015 PRAUGHT, V.			
				License Business Name Lic. Or Reg. No. Name of Driller			
County Well Index Online Report				626766		Printed 11/30/2014 HE-01205-07	

Minnesota Unique Well No.		County		Sherburne		MINNESOTA DEPARTMENT OF HEALTH		Entry Date		06/04/2002	
626780		Quad		Lake Fremont		WELL AND BORING RECORD		Update Date		03/29/2011	
		Quad ID		137A		Minnesota Statutes Chapter 103I		Received Date			
Well Name HIPSAG, DOUG						Well Depth		Depth Completed		Date Well Completed	
Township Range Dir Section Subsections Elevation						151 ft.		150 ft.		09/21/2001	
33 26 W 4 DBBDAB Elevation Method topographic map (+/- 5 feet)						Drilling Method Non-specified Rotary					
Well Address						Drilling Fluid		Well Hydrofractured? ☐ Yes ☒ No			
12269 223RD AV NW						Bentonite		From Ft. to Ft.			
ELK RIVER MN 55330						Use Domestic					
Geological Material						Casing Type		Joint Threaded Drive Shoe? ☐ Yes ☒ No			
SAND						Steel (black or low carbon)		Above/Below ft.			
CLAY						Casing Diameter		Weight		Hole Diameter	
CLAY						4 in. to 147 ft.		10.79 lbs./ft.		9 in. to 30 ft.	
MEDIUM SAND						Open Hole from ft. to ft.					
CLAY						Screen YES Make JOHNSON Type stainless steel					
GRAVEL						Diameter		Slot/Gauze		Length Set Between	
						4		15		4 146 ft. and 150 ft.	
						Static Water Level					
						50 ft. from Land surface Date Measured 09/21/2001					
						PUMPING LEVEL (below land surface)					
						ft. after hrs. pumping 20 g.p.m.					
						Well Head Completion					
						Pitless adapter manufacturer BAKER Model SNAPPY					
						☐ Casing Protection ☒ 12 in. above grade					
						☐ At-grade (Environmental Wells and Borings ONLY)					
NO REMARKS						Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified					
Located by:						Grout Material: High solids bentonite from 0 to 30 ft. 4 bags					
Unique Number Verification: Address verification						Nearest Known Source of Contamination					
System: UTM - Nad83, Zone15, Meters						50 feet W direction Septic tank/drain field type					
						Well disinfected upon completion? ☒ Yes ☐ No					
						Pump ☐ Not Installed Date Installed 01/14/2002					
						Manufacturer's name GRUNDFOS Model number 22SQE10-190 HP 1 Volts 230					
						Length of drop Pipe 84 ft. Capacity 22 g.p.m. Type Submersible Material					
						Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No					
						Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No					
First Bedrock						Well Contractor Certification					
Last Strat gravel (+larger)-brown						Renner E.H. Well		71015		PRAUGHT, V.	
Aquifer Quat. Buried Artes. Aquifer						License Business Name		Lic. Or Reg. No.		Name of Driller	
Depth to Bedrock ft.						626780		Printed 11/30/2014			
County Well Index Online Report								HE-01205-07			

Minnesota Unique Well No.

638355

County Sherburne
Quad Elk River
Quad ID 137D

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 04/20/2000
Update Date 03/29/2011
Received Date

Minnesota Statutes Chapter 103I

Well Name AIRHART, DONNA & STEVE		Well Depth 105 ft.		Depth Completed 105 ft.		Date Well Completed 11/21/1999	
Township Range Dir Section Subsections Elevation		991 ft.					
33 26 W 4 DCDACA Elevation Method		7.5 minute topographic map (+/- 5 feet)					
Well Address 22130 QUINN ST NW ELK RIVER MN 55330		Drilling Fluid Bentonite		Well Hydrofractured? ☐ Yes ☒ No		From Ft. to Ft.	
Geological Material GRAVEL CLAY WATERSAND		Color		Hardness		From To	
						0 60 60 80 80 105	
		Use Domestic					
		Casing Type Plastic Joint No Information Drive Shoe? ☐ Yes ☒ No				Above/Below ft.	
		Casing Diameter 4 in. to 95 ft.		Weight 2 lbs./ft.		Hole Diameter 8 in. to 30 ft.	
		Open Hole from ft. to ft.					
		Screen YES Make BIG FOOT Type plastic					
		Diameter 4		Slot/Gauze 12		Length 10	
				Set Between 95 ft. and 105 ft.			
		Static Water Level 35 ft. from Land surface		Date Measured 11/22/1999			
		PUMPING LEVEL (below land surface)					
		80 ft. after 1 hrs. pumping 30 g.p.m.					
		Well Head Completion					
		Pitless adapter manufacturer MONITOR Model SNAPPY 4X1					
		☐ Casing Protection ☒ 12 in. above grade					
		☐ At-grade (Environmental Wells and Borings ONLY)					
REMARKS ABANDONED WELL PERMANENTLY SEALED REPORT NO. H-65542.		Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified					
Located by: Method: GPS SA Off (averaged)		Grout Material: Bentonite		from 6 to 36 ft.		2 bags	
Unique Number Verification: Address verification Input Date: 02/02/2011		Nearest Known Source of Contamination		70 feet S direction Septic tank/drain field type			
System: UTM - Nad83, Zone15, Meters X: 454794 Y: 5024581		Well disinfected upon completion? ☒ Yes ☐ No					
		Pump ☐ Not Installed Date Installed 11/22/1999					
		Manufacturer's name AERMOTOR Model number T12-75 HP 0.75 Volts 230					
		Length of drop Pipe 80 ft. Capacity 12 g.p.m. Type Submersible Material					
		Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No					
		Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No					
		Well Contractor Certification					
First Bedrock		Mac's Well Co.		86596		MCALPINE, D.	
Last Strat sand		License Business Name		Lic. Or Reg. No.		Name of Driller	
County Well Index Online Report		638355				Printed 11/30/2014 HE-01205-07	

Minnesota Unique Well No.

655131

County Sherburne
 Quad Lake Fremont
 Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Entry Date 05/29/2001
 Update Date 03/29/2011
 Received Date

Minnesota Statutes Chapter 103I

Well Name ERICKSON, KEVIN & SHAVON		Well Depth	Depth Completed	Date Well Completed
Township Range Dir Section Subsections Elevation		132 ft.	132 ft.	01/09/2001
33	26 W 4 DABCDC	Elevation Method topographic map (+/- 5 feet)		
Well Address 12163 223RD AV NW ELK RIVER MN 55330		Drilling Fluid Bentonite		
Geological Material ROCKY CLAY-FIRM SAND & GRAVEL CLAY CLAY-FIRM SAND ROCKY SAND & GRAVEL ROCKY CLAY-FIRM ROCKY SAND		Well Hydrofractured? ☐ Yes ☒ No From Ft. to Ft.		
Color	Hardness	From	To	
RED		0	18	
BROWN	SOFT	18	22	
TAN	SOFT	22	40	
GRAY		40	70	
BROWN	SOFT	70	79	
BROWN	SOFT	79	89	
BROWN		89	116	
TAN	SOFT	116	132	
		Use Domestic		
		Casing Type Plastic Joint No Information Drive Shoe? ☐ Yes ☒ No No Above/Below ft.		
		Casing Diameter	Weight	Hole Diameter
		4 in. to 122 ft.	lbs./ft.	6.5 in. to 132 ft.
		Open Hole from ft. to ft.		
		Screen YES Make MONOFLEX Type plastic		
		Diameter	Slot/Gauze	Length
		4	8	10
		Set Between 122 ft. and 132 ft.		
		Static Water Level		
		43 ft. from Land surface Date Measured 01/04/2001		
		PUMPING LEVEL (below land surface)		
		53 ft. after 2 hrs. pumping 20 g.p.m.		
		Well Head Completion		
		Pitless adapter manufacturer MONITOR Model SNAPPY		
		☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)		
NO REMARKS		Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified		
Located by:		Method: GPS SA Off (averaged)		
Unique Number Verification: Address verification		Input Date: 02/02/2011		
System: UTM - Nad83, Zone15, Meters		X: 454945 Y: 5025028		
		Nearest Known Source of Contamination		
		60 feet N direction Septic tank/drain field type		
		Well disinfected upon completion? ☒ Yes ☐ No		
		Pump ☐ Not Installed Date Installed 01/09/2001		
		Manufacturer's name RED JACKET Model number 75F211-12G12		
		HP 0.75 Volts 230		
		Length of drop Pipe 60 ft. Capacity 12 g.p.m. Type Submersible Material		
		Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No		
		Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No		
		Well Contractor Certification		
First Bedrock		Praught M. Well Co. 86576 PRAUGHT, S.		
Last Strat sand +larger-brown		License Business Name Lic. Or Reg. No. Name of Driller		
County Well Index Online Report		655131		
		Printed 11/30/2014 HE-01205-07		

672355

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date 05/13/2002
Update Date 03/28/2011
Received Date

Well Name DRUK, TIM					Township 34	Range 26	Dir W	Section 33	Subsection CABACB	Well Depth 89 ft.					Depth Completed 89 ft.					Date Well Completed 02/06/2002									
Elevation 948 ft.					Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary										Drill Fluid Bentonite									
Address Well 23115 128TH ST ELK RIVER MN										Use domestic										Status Active									
Stratigraphy Information Geological Material From To (ft.) Color Hardness SAND 0 14 BROWN SOFT GRAVEL 14 26 BROWN SOFT CLAY 26 43 GRAY MEDIUM CLAY & GRAVEL 43 69 BROWN MEDIUM GRAVEL 69 89 YELLOW SOFT										Well Hydrofractured? Yes ☐ No ☒										From To									
										Casing Type Single casing										Joint Unknown									
										Drive Shoe? Yes ☐ No ☒										Above/Below									
										Casing Diameter 4 in.					Weight To 89 ft. 1.9 lbs./ft.					Hole Diameter 6.5 in.					To 89 ft.				
										Open Hole From ft. To ft.																			
										Screen? ☒					Type stainless					Make JOHNSON									
										Diameter 2 in.					Slot/Gauze Length 12 ft.					Set 84 ft.					89 ft.				
										Static Water Level 9 ft. land surface										Measure 02/06/2002									
										Pumping Level (below land surface) 84 ft. 2 hrs. Pumping at										100 g.p.m.									
										Wellhead Completion Pitless adapter manufacturer MONITOR Model 1IN BULLDO ☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)																			
Grouting Information Material Amount From To high solids bentonite 0.17 Cubic yards 0 ft. 30 ft. cuttings 30 ft. 84 ft.										Well Grouted? ☒ Yes ☐ No ☐ Not Specified																			
Nearest Known Source of Contamination 35 feet Northeas Direction Well disinfected upon completion? ☒ Yes ☐ No <u>Other</u> Type																													
Pump ☐ Not Installed Date Installed <u>02/18/2002</u> Manufacturer's name AERMOTOR Model Number <u>T12-50</u> HP <u>0.5</u> Volt <u>230</u> Length of drop pipe <u>40</u> ft Capacity <u>10</u> g.p. Typ <u>Submersible</u>																													
Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No																													
Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No																													
Miscellaneous First Bedrock Aquifer Quat. buried Last Strat gravel (+larger)-yellow Depth to Bedrock ft Located by Minnesota Geological Survey Locate Method GPS SA Off (averaged) (15 meters) System UTM - NAD83, Zone 15, Meters X 454183 Y 5026690 Unique Number Verification Address verification Input Date 11/12/2010																													
Angled Drill Hole																													
Well Contractor Mc Alpine Brothers 27636 GOODIN, G. Licensee Business Lic. or Reg. No. Name of Driller																													
Remarks																													

672356

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date 05/30/2002
Update Date 03/28/2011
Received Date

Well Name DRUK, TIM					Township 34		Range 26		Dir Section W 33		Subsection CBBADC		Well Depth 89 ft.				Depth Completed 89 ft.				Date Well Completed 03/08/2002			
Elevation 961 ft.					Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary				Drill Fluid Bentonite										
Address Well 23255 128TH ST ELK RIVER MN												Use domestic				Status Active								
Stratigraphy Information												Well Hydrofractured? Yes ☐ No ☒				From To								
Geological Material												Casing Type Single casing				Joint Unknown								
SAND												Drive Shoe? Yes ☐ No ☒				Above/Below								
CLAY												Casing Diameter 4 in. To 84 ft. 1.9 lbs./ft.				Hole Diameter 6.5 in. To 89 ft.								
CLAY, GRAVEL												Open Hole From ft. To ft.												
GRAVEL												Screen? ☒				Type stainless				Make JOHNSON				
												Diameter 2 in. 12				Slot/Gauze 5 ft.				Set 84 ft. 89 ft.				
												Static Water Level 20 ft. land surface				Measure 03/08/2002								
												Pumping Level (below land surface) 84 ft. 2 hrs. Pumping at				100 g.p.m.								
												Wellhead Completion Pitless adapter manufacturer				MONITOR				Model 1 INCH BUL				
												☐ Casing Protection				☒ 12 in. above grade								
												☐ At-grade (Environmental Wells and Borings ONLY)												
												Grouting Information Material				Well Grouted? ☒ Yes ☐ No ☐ Not Specified								
												Amount high solids bentonite				From 0.17 Cubic yards				To 0 ft. 30 ft.				
												cuttings				30				ft. 84 ft.				
												Nearest Known Source of Contamination 33 feet				North Direction				Septic tank/drain field Type				
												Well disinfected upon completion? ☒ Yes ☐ No												
												Pump ☐ Not Installed				Date Installed 03/22/2002								
												Manufacturer's name AERMOTOR												
												Model Number T12-50				HP 0.5				Volt 230				
												Length of drop pipe 40 ft				Capacity 10 g.p.				Typ Submersible				
												Abandoned Does property have any not in use and not sealed well(s)?				☐ Yes ☒ No								
												Variance Was a variance granted from the MDH for this well?				☐ Yes ☒ No								
												Miscellaneous First Bedrock				Aquifer Quat. buried								
												Last Strat gravel (+larger)-yellow				Depth to Bedrock				ft				
												Located by Minnesota Geological Survey												
												Locate Method GPS SA Off (averaged) (15 meters)												
												System UTM - NAD83, Zone 15, Meters				X 453817				Y 5026672				
												Unique Number Verification				Address verification				Input Date 11/12/2010				
												Angled Drill Hole												
												Well Contractor Mc Alpine Brothers				27636				GOODIN, G.				
												Licensee Business				Lic. or Reg. No.				Name of Driller				
Remarks																								
Minnesota Well Index Report												672356								Printed on 05/31/2020 HE-01205-15				

676075

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date11/01/2002

Update Date03/28/2011

Received Date

Well NameTownshipRangeDir SectionSubsectionGWYNN, MIKE3426W 33CACBBB Elevation949 ft. Elev. Method7.5 minute topographic map (+/- 5 feet) AddressWell23128 128TH ST ELK RIVER MN 55330 Stratigraphy Information<table><thead><tr><th>Geological Material</th><th>From</th><th>To (ft.)</th><th>Color</th><th>Hardness</th></tr></thead><tbody><tr><td>SAND</td><td>0</td><td>6</td><td>BLACK</td><td>SOFT</td></tr><tr><td>SAND, GRAVEL</td><td>6</td><td>20</td><td>TAN</td><td>SOFT</td></tr><tr><td>CLAY</td><td>20</td><td>49</td><td>GRAY</td><td>SOFT</td></tr><tr><td>SAND, GRAVEL</td><td>49</td><td>61</td><td>GRAY</td><td>SOFT</td></tr><tr><td>CLAY, GRAVEL</td><td>61</td><td>76</td><td>BROWN</td><td>SOFT</td></tr><tr><td>SAND</td><td>76</td><td>85</td><td>TAN</td><td>SOFT</td></tr><tr><td>CLAY</td><td>85</td><td>87</td><td>TAN</td><td>SOFT</td></tr><tr><td>SAND</td><td>87</td><td>100</td><td>TAN</td><td>SOFT</td></tr></tbody></table>	Geological Material	From	To (ft.)	Color	Hardness	SAND	0	6	BLACK	SOFT	SAND, GRAVEL	6	20	TAN	SOFT	CLAY	20	49	GRAY	SOFT	SAND, GRAVEL	49	61	GRAY	SOFT	CLAY, GRAVEL	61	76	BROWN	SOFT	SAND	76	85	TAN	SOFT	CLAY	85	87	TAN	SOFT	SAND	87	100	TAN	SOFT	Well DepthDepth CompletedDate Well Completed100 ft.100 ft.07/09/2002 Drill MethodNon-specified RotaryDrill FluidBentonite Use domesticStatusActive Well Hydrofractured?YesNoFromTo Casing TypeSingle casingJointGlued Drive Shoe?YesNoAbove/Below Casing DiameterWeightHole Diameter4 in. To 91 ft. lbs./ft.8.5 in. To 30 ft.6.5 in. To 100 ft. Open HoleFromft.Toft. Screen?TypestainlessMakeJOHNSONDiameterSlot/GauzeLengthSet2 in.128 ft.91 ft.100 ft. Static Water Level9 ft. land surfaceMeasure07/09/2002 Pumping Level (below land surface)ft.1 hrs. Pumping at60 g.p.m. Wellhead Completion Pitless adapter manufacturerMONITORModelSNAPPY Casing Protection12 in. above grade At-grade (Environmental Wells and Borings ONLY) Grouting InformationWell Grouted?YesNoNot SpecifiedMaterialAmountFromTohigh solids bentonite3 Sacks0 ft. 30 ft.cuttings30 ft. 91 ft. Nearest Known Source of Contamination50 feetWest DirectionSeptic tank/drain field TypeWell disinfected upon completion?YesNo PumpNot InstalledDate Installed07/16/2002Manufacturer's nameRED JACKETModel Number75F211-HP0.75Volt230Length of drop pipe40 ftCapacity15 g.p. TypSubmersible AbandonedDoes property have any not in use and not sealed well(s)?YesNo VarianceWas a variance granted from the MDH for this well?YesNo MiscellaneousFirst BedrockAquiferQuat. buriedLast Strat sand-brownDepth to BedrockftLocated byMinnesota Geological SurveyLocate MethodGPS SA Off (averaged) (15 meters)SystemUTM - NAD83, Zone 15, MetersX 454063Y 5026546Unique Number VerificationAddress verificationInput Date11/12/2010 Angled Drill Hole Well ContractorMork Well Co., Inc.02730THOMPSON, S.Licensee BusinessLic. or Reg. No.Name of Driller
Geological Material	From	To (ft.)	Color	Hardness																																										
SAND	0	6	BLACK	SOFT																																										
SAND, GRAVEL	6	20	TAN	SOFT																																										
CLAY	20	49	GRAY	SOFT																																										
SAND, GRAVEL	49	61	GRAY	SOFT																																										
CLAY, GRAVEL	61	76	BROWN	SOFT																																										
SAND	76	85	TAN	SOFT																																										
CLAY	85	87	TAN	SOFT																																										
SAND	87	100	TAN	SOFT																																										
Remarks																																														

676082

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date 08/20/2002
Update Date 03/18/2014
Received Date

Well Name					Township					Range					Dir Section					Subsection					Well Depth					Depth Completed					Date Well Completed														
34					26					W 33					CBADAC					93 ft.					93 ft.					05/13/2002																			
Elevation					951 ft.					Elev. Method					7.5 minute topographic map (+/- 5 feet)					Drill Method					Non-specified Rotary					Drill Fluid					Bentonite														
Address																									Use					domestic					Status					Active									
Stratigraphy Information																									Well Hydrofractured?					Yes ☐ No ☒					From					To									
Casing Type																									Single casing					Joint					Glued														
Drive Shoe?																									Yes ☐ No ☒					Above/Below																			
Casing Diameter																									Weight					Hole Diameter																			
Geological Material																									From					To (ft.)					Color					Hardness									
FILL SAND																									0					4					BLACK					SOFT									
SAND																									4					11					BROWN					SOFT									
SANDY CLAY																									11					19					TAN					SOFT									
SAND, GRAVEL																									19					31					TAN					SOFT									
CLAY																									31					44					GRAY					SOFT									
CLAY, GRAVEL																									44					63					BROWN					SOFT									
SAND, GRAVEL																									63					72					GRAY					SOFT									
CLAY																									72					76					BROWN					SOFT									
SAND, GRAVEL																									76					93					TAN					SOFT									
Open Hole																									From					ft.					To					ft.									
Screen?																									☒					Type					stainless					Make					JOHNSON				
Diameter																									Slot/Gauze					Length					Set														
2 in.																									10					8 ft.					84 ft.					93 ft.									
Static Water Level																									10 ft.					land surface					Measure					05/13/2002									
Pumping Level (below land surface)																									ft.					1 hrs.					Pumping at					40 g.p.m.									
Wellhead Completion																									Pitless adapter manufacturer					MONITOR					Model					SNAPPY									
☐ Casing Protection																									☒ 12 in. above grade																								
☐ At-grade (Environmental Wells and Borings ONLY)																																																	
Grouting Information																									Well Grouted?					☒ Yes ☐ No ☐ Not Specified																			
Material																									Amount					From					To														
high solids bentonite																									3 Sacks					0 ft.					30 ft.														
cuttings																														30 ft.					84 ft.														
Nearest Known Source of Contamination																									56 feet					Northeas Direction					Septic tank/drain field Type														
Well disinfected upon completion?																									☒ Yes ☐ No																								
Pump																									☐ Not Installed					Date Installed					05/21/2002														
Manufacturer's name																									RED JACKET																								
Model Number																									75F211					HP					0.75					Volt					230				
Length of drop pipe																									40 ft					Capacity					15 g.p.					Typ					Submersible				
Abandoned																									Does property have any not in use and not sealed well(s)?					☐ Yes ☒ No																			
Variance																									Was a variance granted from the MDH for this well?					☐ Yes ☒ No																			
Miscellaneous																									First Bedrock					Aquifer					Quat. buried														
Last Strat																									sand +larger-brown					Depth to Bedrock					ft														
Located by																									Minnesota Geological Survey																								
Locate Method																									GPS SA Off (averaged) (15 meters)																								
System																									UTM - NAD83, Zone 15, Meters					X 454029					Y 5026620														
Unique Number Verification																									Address verification					Input Date					11/12/2010														
Angled Drill Hole																																																	
Well Contractor																									Mork Well Co., Inc.					02730					THOMPSON, S.														
Licensee Business																									Lic. or Reg. No.					Name of Driller																			
Minnesota Well Index Report															676082										Printed on 05/31/2020 HE-01205-15																								

676434

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date02/28/2003

Update Date07/15/2011

Received Date

Well Name					Township					Range					Dir Section					Subsection					Well Depth					Depth Completed					Date Well Completed														
					34					26					W 33					CBBBAC					210 ft.					210 ft.					12/12/2002														
Elevation					957 ft.					Elev. Method					7.5 minute topographic map (+/- 5 feet)					Drill Method					Non-specified Rotary					Drill Fluid					Bentonite														
Address																									Use					domestic					Status					Active									
Well23282 128TH ST NW MN																									Well Hydrofractured?					Yes ☐					No ☒					From					To				
Stratigraphy Information																									Casing Type					Single casing					Joint					Threaded									
Drive Shoe?																									Yes ☒					No ☐					Above/Below														
Casing Diameter																									Weight										Hole Diameter														
Geological Material																									From					To (ft.)					Color					Hardness									
FILL																									0					4					TAN					MEDIUM									
SAND																									4					17					BROWN					SOFT									
CLAY																									17					38					GRAY					MEDIUM									
CLAY & GRAVEL																									38					64					GRAY					MEDIUM									
SAND																									64					68					BROWN					SOFT									
CLAY & GRAVEL																									68					137					RED					HARD									
SANDSTONE																									137					210					TAN					HARD									
Open Hole																									From					139 ft.					To					210 ft.									
Screen?																									☐					Type					Make														
Static Water Level																									10 ft.					land surface					Measure					12/12/2002									
Pumping Level (below land surface)																									ft.					hrs.					Pumping at					25 g.p.m.									
Wellhead Completion																									Pitless adapter manufacturer					BAKER					Model					SNAPPY									
☐ Casing Protection																									☐ 12 in. above grade																								
☐ At-grade (Environmental Wells and Borings ONLY)																																																	
Grouting Information																									Well Grouted?					☒ Yes					☐ No					☐ Not Specified									
Material																									Amount					From					To														
well grouted, type unknown																									4 Sacks					0 ft.					30 ft.														
Nearest Known Source of Contamination																									50 feet					West Direction					Septic tank/drain field					Type									
Well disinfected upon completion?																									☒ Yes					☐ No																			
Pump																									☐ Not Installed					Date Installed					01/19/2003														
Manufacturer's name																									GRUNDFOS																								
Model Number																									16S07-8					HP					0.75					Volt					230				
Length of drop pipe																									42 ft					Capacity					16 g.p.					Typ					Submersible				
Abandoned																									Does property have any not in use and not sealed well(s)?					☐ Yes					☒ No														
Variance																									Was a variance granted from the MDH for this well?					☐ Yes					☒ No														
Miscellaneous																									First Bedrock					Mt.Simon Sandstone					Aquifer					Mt.Simon									
Last Strat																									Mt.Simon Sandstone					Depth to Bedrock					137 ft														
Located by																									Minnesota Geological Survey																								
Locate Method																									GPS SA Off (averaged) (15 meters)																								
System																									UTM - NAD83, Zone 15, Meters					X 453701					Y 5026714														
Unique Number Verification																									Address verification					Input Date					11/12/2010														
Angled Drill Hole																																																	
Well Contractor																									Renner E.H. Well					71015					ECKLAND, B.														
Licensee Business																									Lic. or Reg. No.					Name of Driller																			
Minnesota Well Index Report															676434										Printed on 05/31/2020 HE-01205-15																								

676922

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date 09/09/2002
Update Date 03/28/2011
Received Date

Well Name OLSON, MATT					Township 34	Range 26	Dir W	Section 33	Subsection CBBADB
Elevation 951 ft.		Elev. Method 7.5 minute topographic map (+/- 5 feet)							
Address Well 12876 232ND AV NW ELK RIVER MN									
Stratigraphy Information									
Geological Material		From	To (ft.)	Color	Hardness				
GRAVEL		0	32	BROWN	SOFT				
CLAY		32	38	GRAY	MEDIUM				
CLAY & GRAVEL		38	92	BROWN	MEDIUM				
GRAVEL		92	104	YELLOW	SOFT				
Well Depth 104 ft.									
Depth Completed 104 ft.									
Date Well Completed 07/29/2002									
Drill Method Non-specified Rotary		Drill Fluid Bentonite							
Use domestic		Status Active							
Well Hydrofractured? Yes ☐ No ☒ From To									
Casing Type Single casing Joint									
Drive Shoe? Yes ☐ No ☒ Above/Below									
Casing Diameter 4 in.		Weight 99 lbs./ft.		Hole Diameter 6.5 in.					
To		ft.		1.9		ft.		104 ft.	
Open Hole From ft. To ft.									
Screen? ☒ Type stainless Make JOHNSON									
Diameter		Slot/Gauze		Length		Set			
2 in.		12		5 ft.		99 ft.		104 ft.	
Static Water Level 20 ft. land surface Measure 07/29/2002									
Pumping Level (below land surface) 99 ft. 2 hrs. Pumping at 100 g.p.m.									
Wellhead Completion Pitless adapter manufacturer MONITOR Model 1 INCH BUL ☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)									
Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified									
Material		Amount		From		To			
high solids bentonite		0.17 Cubic yards		0		ft. 30		ft.	
cuttings				30		ft. 99		ft.	
Nearest Known Source of Contamination 35 feet West Direction Septic tank/drain field Type									
Well disinfected upon completion? ☒ Yes ☐ No									
Pump ☐ Not Installed Date Installed 08/05/2002									
Manufacturer's name AERMOTOR									
Model Number		T12-75		HP 0.75		Volt 230			
Length of drop pipe		40 ft		Capacity 15 g.p.		Typ Submersible			
Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No									
Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No									
Miscellaneous First Bedrock Aquifer Quat. buried Last Strat gravel (+larger)-yellow Depth to Bedrock ft Located by Minnesota Geological Survey Locate Method GPS SA Off (averaged) (15 meters) System UTM - NAD83, Zone 15, Meters X 453700 Y 5026587 Unique Number Verification Address verification Input Date 11/12/2010									
Angled Drill Hole									
Well Contractor Mc Alpine Brothers 27636 GOODIN, G Licensee Business Lic. or Reg. No. Name of Driller									
Remarks									

Minnesota Well Index Report

676922

Printed on 05/31/2020
HE-01205-15

681344

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date 10/31/2002
Update Date 03/28/2011
Received Date

Well Name 34 26 W 33 CBBDDA					Well Depth 90 ft.		Depth Completed 90 ft.		Date Well Completed 09/04/2002																													
Elevation 958 ft. Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary		Drill Fluid Qwik gel																															
Address Well 12821 232ND AV ELK RIVER MN					Use domestic		Status Active																															
Stratigraphy Information <table><tr><td>Geological Material</td><td>From</td><td>To (ft.)</td><td>Color</td><td>Hardness</td></tr><tr><td>SANDY CLAY</td><td>0</td><td>5</td><td>BROWN</td><td>SOFT</td></tr><tr><td>SAND & GRAVEL</td><td>5</td><td>25</td><td>BRN/BLK</td><td>SOFT</td></tr><tr><td>CLAY</td><td>25</td><td>40</td><td>GRAY</td><td>SOFT</td></tr><tr><td>CLAY, SAND & GRAVEL</td><td>40</td><td>70</td><td>BRN/BLK</td><td>MED-HRD</td></tr><tr><td>GRAVEL</td><td>70</td><td>90</td><td>YELLOW</td><td>SOFT</td></tr></table>					Geological Material	From	To (ft.)	Color	Hardness	SANDY CLAY	0	5	BROWN	SOFT	SAND & GRAVEL	5	25	BRN/BLK	SOFT	CLAY	25	40	GRAY	SOFT	CLAY, SAND & GRAVEL	40	70	BRN/BLK	MED-HRD	GRAVEL	70	90	YELLOW	SOFT	Well Hydrofractured? Yes ☐ No ☐		From To	
					Geological Material	From	To (ft.)	Color	Hardness																													
					SANDY CLAY	0	5	BROWN	SOFT																													
					SAND & GRAVEL	5	25	BRN/BLK	SOFT																													
					CLAY	25	40	GRAY	SOFT																													
					CLAY, SAND & GRAVEL	40	70	BRN/BLK	MED-HRD																													
					GRAVEL	70	90	YELLOW	SOFT																													
					Casing Type Single casing		Joint Welded																															
					Drive Shoe? Yes ☐ No ☐		Above/Below																															
					Casing Diameter 4 in. To 86 ft. lbs./ft.		Hole Diameter 4 in. To 86 ft.																															
Open Hole From ft. To ft.																																						
Screen? ☒		Type stainless		Make JOHNSON																																		
Diameter Slot/Gauze		Length		Set																																		
2 in. 12		4 ft.		86 ft. 90 ft.																																		
Static Water Level 15 ft. land surface Measure 09/04/2002																																						
Pumping Level (below land surface) 60 ft. 2 hrs. Pumping at 50 g.p.m.																																						
Wellhead Completion Pitless adapter manufacturer MERRILL Model MCK6.5 ☒ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)																																						
Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified Material Amount From To high solids bentonite 2 Sacks 0 ft. 30 ft. cuttings 30 ft. 86 ft.																																						
Nearest Known Source of Contamination 50 feet Southeast Direction Septic tank/drain field Type Well disinfected upon completion? ☒ Yes ☐ No																																						
Pump ☐ Not Installed Date Installed 09/09/2002 Manufacturer's name AERMOTOR Model Number 12T75 HP 0.75 Volt 230 Length of drop pipe 60 ft Capacity 12 g.p. Typ Submersible																																						
Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No																																						
Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No																																						
Miscellaneous First Bedrock Aquifer Quat. buried Last Strat gravel (+larger)-yellow Depth to Bedrock ft Located by Minnesota Geological Survey Locate Method GPS SA Off (averaged) (15 meters) System UTM - NAD83, Zone 15, Meters X 453851 Y 5026583 Unique Number Verification Address verification Input Date 11/12/2010																																						
Angled Drill Hole																																						
Well Contractor McAlpine Well Drilling 27695 MCALPINE, T. Licensee Business Lic. or Reg. No. Name of Driller																																						
Remarks																																						

Minnesota Well Index Report

681344

Printed on 05/31/2020
HE-01205-15

703235

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date

Update Date 03/28/2011

Received Date 11/10/2003

Well Name 34 26 W 33 CBCABD					Well Depth 94 ft.		Depth Completed 94 ft.		Date Well Completed 10/01/2003																																				
Elevation 953 ft. Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary		Drill Fluid Qwik gel																																						
Address Well 12845 232ND AV ELK RIVER MN					Use domestic		Status Active																																						
Stratigraphy Information <table><tr><td>Geological Material</td><td>From</td><td>To (ft.)</td><td>Color</td><td>Hardness</td></tr><tr><td>SANDY CLAY</td><td>0</td><td>5</td><td>BROWN</td><td>SOFT</td></tr><tr><td>CLAY, SAND & GRAVEL</td><td>5</td><td>19</td><td>BRN/BLK</td><td>SOFT</td></tr><tr><td>CLAY</td><td>19</td><td>34</td><td>GRAY</td><td>MEDIUM</td></tr><tr><td>CLAY, SAND & GRAVEL</td><td>34</td><td>50</td><td>BRN/BLK</td><td>MED-HRD</td></tr><tr><td>CLAY & SAND</td><td>50</td><td>83</td><td>BROWN</td><td>SOFT</td></tr><tr><td>SAND</td><td>83</td><td>94</td><td>BRN/YEL</td><td>SOFT</td></tr></table>					Geological Material	From	To (ft.)	Color	Hardness	SANDY CLAY	0	5	BROWN	SOFT	CLAY, SAND & GRAVEL	5	19	BRN/BLK	SOFT	CLAY	19	34	GRAY	MEDIUM	CLAY, SAND & GRAVEL	34	50	BRN/BLK	MED-HRD	CLAY & SAND	50	83	BROWN	SOFT	SAND	83	94	BRN/YEL	SOFT	Well Hydrofractured? Yes ☐ No ☐		From		To	
					Geological Material	From	To (ft.)	Color	Hardness																																				
					SANDY CLAY	0	5	BROWN	SOFT																																				
					CLAY, SAND & GRAVEL	5	19	BRN/BLK	SOFT																																				
					CLAY	19	34	GRAY	MEDIUM																																				
					CLAY, SAND & GRAVEL	34	50	BRN/BLK	MED-HRD																																				
					CLAY & SAND	50	83	BROWN	SOFT																																				
					SAND	83	94	BRN/YEL	SOFT																																				
					Casing Type Single casing		Joint Welded																																						
					Drive Shoe? Yes ☐ No ☐		Above/Below																																						
Casing Diameter		Weight		Hole Diameter																																									
4 in. To 90 ft.		lbs./ft.		6.5 in. To 90 ft.																																									
Open Hole		From ft.		To ft.																																									
Screen? ☒		Type stainless		Make JOHNSON																																									
Diameter		Slot/Gauze Length		Set																																									
2 in. 12		4 ft.		90 ft. 94 ft.																																									
Static Water Level					20 ft. land surface		Measure		10/01/2003																																				
Pumping Level (below land surface)					60 ft. 2 hrs.		Pumping at		50 g.p.m.																																				
Wellhead Completion					Pitless adapter manufacturer		MERRILL		Model MCK6.5																																				
☒ Casing Protection					☒ 12 in. above grade																																								
☐ At-grade (Environmental Wells and Borings ONLY)																																													
Grouting Information					Well Grouted?		☒ Yes ☐ No ☐ Not Specified																																						
Material					Amount		From		To																																				
cuttings							30 ft.		90 ft.																																				
high solids bentonite					2 Sacks		ft.		30 ft.																																				
Nearest Known Source of Contamination					50 feet		Northeas Direction		Septic tank/drain field Type																																				
Well disinfected upon completion?					☒ Yes ☐ No																																								
Pump ☐ Not Installed					Date Installed		10/22/2003																																						
Manufacturer's name					AERMOTOR																																								
Model Number					12T50		HP 0.5		Volt 230																																				
Length of drop pipe					60 ft		Capacity 12 g.p.		Typ Submersible																																				
Abandoned					Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No																																								
Variance					Was a variance granted from the MDH for this well? ☐ Yes ☒ No																																								
Miscellaneous					First Bedrock																																								
Last Strat					sand		Aquifer		Quat. buried																																				
Located by					Minnesota Geological Survey																																								
Locate Method					GPS SA Off (averaged) (15 meters)																																								
System					UTM - NAD83, Zone 15, Meters		X 453788		Y 5026522																																				
Unique Number Verification					Address verification		Input Date		11/12/2010																																				
Angled Drill Hole																																													
Well Contractor					McAlpine Well Drilling																																								
Licensee Business					27695		Lic. or Reg. No.		MCALPINE, T.																																				
							Name of Driller																																						

Minnesota Well Index Report

703235

Printed on 05/31/2020
HE-01205-15

704785

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date
Update Date 03/28/2011
Received Date 04/23/2004

Well Name HARTUNGS,	Township 34	Range 26	Dir W	Section 33	Subsection CBABCD	Well Depth 105 ft.	Depth Completed 105 ft.	Date Well Completed 02/11/2004																				
Elevation 951 ft.	Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary	Drill Fluid Bentonite																					
Address Well 23195 128TH ST NW ELK RIVER MN 55330						Use domestic	Status Active																					
Stratigraphy Information						Well Hydrofractured? Yes ☐ No ☒	From To																					
<table><tr><td>Geological Material</td><td>From</td><td>To (ft.)</td><td>Color</td><td>Hardness</td></tr><tr><td>SAND & GRAVEL</td><td>0</td><td>25</td><td>BROWN</td><td>SOFT</td></tr><tr><td>CLAY & GRAVEL</td><td>25</td><td>42</td><td>TAN</td><td>SOFT</td></tr><tr><td>SAND & GRAVEL</td><td>42</td><td>105</td><td>BROWN</td><td>SOFT</td></tr></table>						Geological Material	From	To (ft.)	Color	Hardness	SAND & GRAVEL	0	25	BROWN	SOFT	CLAY & GRAVEL	25	42	TAN	SOFT	SAND & GRAVEL	42	105	BROWN	SOFT	Casing Type Single casing	Joint Above/Below	
Geological Material	From	To (ft.)	Color	Hardness																								
SAND & GRAVEL	0	25	BROWN	SOFT																								
CLAY & GRAVEL	25	42	TAN	SOFT																								
SAND & GRAVEL	42	105	BROWN	SOFT																								
						Drive Shoe? Yes ☐ No ☒																						
						Casing Diameter 4 in.	Weight 95 lbs./ft.	Hole Diameter 6.7 in.																				
						Open Hole From ft. To ft.																						
						Screen? ☒	Type plastic	Make BIG FOOT																				
						Diameter 4 in.	Slot/Gauze 15	Length 10 ft.																				
							Set 95 ft.	ft. 105 ft.																				
						Static Water Level 6 ft.	land surface	Measure 02/11/2004																				
						Pumping Level (below land surface) 45 ft.	3 hrs.	Pumping at 40 g.p.m.																				
						Wellhead Completion Pitless adapter manufacturer MAASS Model JC-4																						
						☐ Casing Protection	☒ 12 in. above grade																					
						☐ At-grade (Environmental Wells and Borings ONLY)																						
						Grouting Information Material high solids bentonite cuttings	Well Grouted? ☒ Yes ☐ No ☐ Not Specified																					
							Amount 4 Sacks	From 0 ft.																				
								To 40 ft.																				
								ft. 95 ft.																				
						Nearest Known Source of Contamination 50 feet South Direction		Sewer Type																				
						Well disinfected upon completion? ☒ Yes ☐ No																						
						Pump ☐ Not Installed	Date Installed 02/11/2004																					
						Manufacturer's name STA-RITE																						
						Model Number HP 1	Volt 230																					
						Length of drop pipe 60 ft	Capacity 12 g.p.	Typ Submersible																				
						Abandoned Does property have any not in use and not sealed well(s)?	☐ Yes ☒ No																					
						Variance Was a variance granted from the MDH for this well?	☐ Yes ☒ No																					
						Miscellaneous First Bedrock Last Strat sand +larger-brown Located by Minnesota Geological Survey	Aquifer Quat. buried	Depth to Bedrock ft																				
						Locate Method GPS SA Off (averaged) (15 meters)																						
						System UTM - NAD83, Zone 15, Meters	X 453891	Y 5026656																				
						Unique Number Verification Address verification	Input Date 11/12/2010																					
						Angled Drill Hole																						
						Well Contractor A. Ruppert Well	30714	RUPPERT, C																				
						Licensee Business	Lic. or Reg. No.	Name of Driller																				

706000

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date
Update Date 03/28/2011
Received Date 05/13/2004

Well Name 34 26 W 33 CBCBAC					Well Depth 105 ft.		Depth Completed 105 ft.		Date Well Completed 02/24/2004		
Elevation 953 ft. Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary		Drill Fluid Bentonite				
Address Well 12875 232ND AV NW ELK RIVER MN 55330					Use domestic		Status Active				
Stratigraphy Information Geological Material From To (ft.) Color Hardness SAND 0 15 BROWN SOFT SANDY CLAY 15 30 GRAY MEDIUM CLAY 30 57 BROWN MEDIUM SANDY CLAY 57 90 VARIED SOFT SAND & GRAVEL 90 105 VARIED SOFT					Well Hydrofractured? Yes ☐ No ☒		From		To		
					Casing Type Single casing		Joint Welded				
					Drive Shoe? Yes ☐ No ☒		Above/Below				
					Casing Diameter 4 in. To 95 ft.		Weight lbs./ft.		Hole Diameter 8.7 in. To 30 ft. 6.2 in. To 105 ft.		
					Open Hole From ft. To ft.						
					Screen? ☒		Type slotted pipe		Make PVC		
					Diameter Slot/Gauze Length Set						
					4 in. 15 10 ft. 95 ft. 105 ft.						
					Static Water Level						
					15 ft. land surface		Measure		02/24/2004		
Pumping Level (below land surface)											
90 ft. 2 hrs. Pumping at		30 g.p.m.									
Wellhead Completion											
Pitless adapter manufacturer		WHITEWATER		Model							
☐ Casing Protection		☐ 12 in. above grade									
☐ At-grade (Environmental Wells and Borings ONLY)											
Grouting Information						Well Grouted? ☒ Yes ☐ No ☐ Not Specified					
Material		Amount		From To							
high solids bentonite		3 Sacks		ft. 30 ft.							
Nearest Known Source of Contamination											
20 feet		Southeas Direction		Septic tank/drain field Type							
Well disinfected upon completion?		☒ Yes ☐ No									
Pump ☐ Not Installed						Date Installed		03/12/2004			
Manufacturer's name		AERMOTOR		HP 1		Volt 220					
Model Number		Length of drop pipe 60 ft		Capacity 20 g.p.		Typ Submersible					
Abandoned											
Does property have any not in use and not sealed well(s)?						☐ Yes ☒ No					
Variance											
Was a variance granted from the MDH for this well?						☐ Yes ☒ No					
Miscellaneous											
First Bedrock		sand +larger		Aquifer Quat. buried							
Last Strat		Depth to Bedrock		ft							
Located by		Minnesota Geological Survey									
Locate Method		GPS SA Off (averaged) (15 meters)									
System		UTM - NAD83, Zone 15, Meters		X 453701		Y 5026509					
Unique Number Verification		Address verification		Input Date		11/12/2010					
Angled Drill Hole											
Well Contractor											
Bergerson-Caswell		27058		LESTER, T.							
Licensee Business		Lic. or Reg. No.		Name of Driller							
Minnesota Well Index Report					706000		Printed on 05/31/2020 HE-01205-15				

706665

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date
Update Date 03/28/2011
Received Date 03/11/2004

Well Name 34 26 W 33 CBCBDA					Well Depth 103 ft.		Depth Completed 103 ft.		Date Well Completed 02/25/2004	
Elevation 953 ft. Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary		Drill Fluid Qwik gel			
Address Well 12861 232ND AV ZIMMERMAN MN					Use domestic		Status Active			
Stratigraphy Information Geological Material From To (ft.) Color Hardness SANDY CLAY 0 15 BROWN SOFT CLAY 15 25 GRAY MEDIUM CLAY 25 30 BROWN MEDIUM CLAY, GRAVEL, & 30 62 BRN/BLK M.HARD CLAY, SAND, & 62 83 BRN/BLK SFT-MED SAND 83 103 BRN/YEL SOFT					Well Hydrofractured? Yes ☐ No ☐		From		To	
					Casing Type Single casing		Joint Welded			
					Drive Shoe? Yes ☐ No ☐		Above/Below			
					Casing Diameter 4 in. To 99 ft.		Weight lbs./ft.		Hole Diameter 6.5 in. To 99 ft.	
					Open Hole From ft. To ft.					
					Screen? ☒ Type stainless		Make JOHNSON			
					Diameter Slot/Gauze Length Set					
					2 in. 12 8 ft. 99 ft. 103 ft.					
					Static Water Level					
					20 ft. land surface		Measure		02/25/2004	
Pumping Level (below land surface)					60 ft. 4 hrs. Pumping at		25 g.p.m.			
Wellhead Completion					Pitless adapter manufacturer MERRILL		Model MCK6.5			
☐ Casing Protection					☒ 12 in. above grade					
☐ At-grade (Environmental Wells and Borings ONLY)										
Grouting Information					Well Grouted? ☒ Yes ☐ No ☐ Not Specified					
Material Amount From To					cuttings 30 ft. 99 ft.					
high solids bentonite 2 Sacks					ft. 30 ft.					
Nearest Known Source of Contamination					50 feet Southeast Direction		Septic tank/drain field Type			
Well disinfected upon completion? ☒ Yes ☐ No										
Pump ☐ Not Installed					Date Installed 02/26/2004					
Manufacturer's name AERMOTOR										
Model Number 20T100 HP 1					Volt 230					
Length of drop pipe 60 ft Capacity 20 g.p.					Typ Submersible					
Abandoned					Does property have any not in use and not sealed well(s)?		☐ Yes ☒ No			
Variance					Was a variance granted from the MDH for this well?		☐ Yes ☒ No			
Miscellaneous					First Bedrock		Aquifer Quat. buried			
Last Strat sand					Depth to Bedrock		ft			
Located by Minnesota Geological Survey										
Locate Method GPS SA Off (averaged) (15 meters)										
System UTM - NAD83, Zone 15, Meters					X 453731 Y 5026503					
Unique Number Verification					Address verification		Input Date 11/12/2010			
Angled Drill Hole										
Well Contractor					McAlpine Well Drilling		27695		MCALPINE, T.	
Licensee Business					Lic. or Reg. No.		Name of Driller			
Minnesota Well Index Report					706665				Printed on 05/31/2020 HE-01205-15	

Minnesota Unique Well No.

720300

County Sherburne
Quad Lake Fremont
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH

**WELL AND BORING
RECORD**

Minnesota Statutes Chapter 103I

Entry Date
Update Date 03/29/2011
Received Date 11/01/2004

Well Name THOMPSON, COREY		Well Depth	Depth Completed	Date Well Completed
Township Range Dir Section Subsections Elevation		91 ft.	91 ft.	09/25/2004
33	26 W 5 DCBBAB	Elevation Method topographic map (+/- 5 feet)		
Well Address 22275 ELK LAKE RD NW ELK RIVER MN 55330		Drilling Method Non-specified Rotary		
Geological Material		Drilling Fluid Qwik gel	Well Hydrofractured? ☐ Yes ☒ No From Ft. to Ft.	
Color		Use Domestic		
Hardness		Casing Type Plastic Joint Glued Drive Shoe? ☐ Yes ☒ No Above/Below ft.		
From		Casing Diameter		
To		Weight		
SAND	TAN	Hole Diameter		
CLAY	TAN	4 in. to 82 ft.		
SAND	GRAY	lbs./ft.		
CLAY	GRAY	8.5 in. to 30 ft.		
SAND	TAN	ft.		
		Open Hole from ft. to ft.		
		Screen YES Make JOHNSON Type stainless steel		
		Diameter		
		Slot/Gauze		
		Length		
		Set Between		
		2 10 8 82 ft. and 91 ft.		
		Static Water Level		
		30 ft. from Land surface Date Measured 09/22/2004		
		PUMPING LEVEL (below land surface)		
		ft. after 1 hrs. pumping 30 g.p.m.		
		Well Head Completion		
		Pitless adapter manufacturer BAKER Model SNAPPY		
		☐ Casing Protection ☒ 12 in. above grade		
		☐ At-grade (Environmental Wells and Borings ONLY)		
NO REMARKS		Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified		
Located by:		Grout Material: High solids bentonite from 0 to 30 ft. 4 bags		
Method: GPS SA Off (averaged)		Grout Material: Cuttings from 30 to 82 ft.		
Unique Number Verification: Address verification		Input Date: 02/02/2011		
System: UTM - Nad83, Zone15, Meters		X: 452896 Y: 5024823		
		Nearest Known Source of Contamination		
		60 feet N direction Other type		
		Well disinfected upon completion? ☒ Yes ☐ No		
		Pump ☐ Not Installed Date Installed 09/23/2004		
		Manufacturer's name GRUNDFOS Model number SQE15C-220 HP 1.5 Volts 220		
		Length of drop Pipe 60 ft. Capacity 22 g.p.m. Type Submersible Material		
		Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No		
		Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No		
		Well Contractor Certification		
First Bedrock		Thompson, Scott A 71710 BECKWORTH, D		
Last Strat sand-brown		License Business Name Lic. Or Reg. No. Name of Driller		
Aquifer Quat. Buried Artes. Aquifer				
Depth to Bedrock ft.				
County Well Index Online Report		720300		
		Printed 11/30/2014 HE-01205-07		

731676

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date
Update Date 03/28/2011
Received Date 11/17/2005

Well Name KINGERY,	Township 34	Range 26	Dir W	Section 33	Subsection CAADBC	Well Depth 104 ft.	Depth Completed 104 ft.	Date Well Completed 11/14/2005	
Elevation 958 ft.	Elev. Method 7.5 minute topographic map (+/- 5 feet)					Drill Method Non-specified Rotary	Drill Fluid Bentonite		
Address Well 23105 128TH ST NW ELK RIVER MN 55330						Use domestic	Status Active		
Stratigraphy Information						Well Hydrofractured? Yes ☐ No ☒	From To		
Geological Material						Casing Type Single casing	Joint Above/Below		
SAND						Drive Shoe? Yes ☐ No ☒	Casing Diameter 4 in. To 94 ft.	Weight lbs./ft.	Hole Diameter 6.5 in. To 104 ft.
CLAY									
CLAY									
SAND GRAVEL									
						Open Hole From ft. To ft.			
						Screen? ☒	Type plastic	Make BIG FOOT	
						Diameter 4 in.	Slot/Gauze 8	Length 10 ft.	Set 94 ft. 104 ft.
						Static Water Level 13 ft.	land surface	Measure	11/10/2005
						Pumping Level (below land surface)			
						90 ft.	2 hrs.	Pumping at	40 g.p.m.
						Wellhead Completion			
						Pitless adapter manufacturer ☐ Casing Protection	MONITOR ☒ 12 in. above grade	Model SNAPPY	
						☐ At-grade (Environmental Wells and Borings ONLY)			
						Grouting Information Material cuttings	Well Grouted? Yes ☒ No ☐ Not Specified	Amount 30 ft.	From To
						high solids bentonite	2 Sacks	ft. 30 ft.	
						Nearest Known Source of Contamination			
						50 feet	South Direction	Sewer Type	
						Well disinfected upon completion?	Yes ☒ No ☐		
						Pump ☐ Not Installed	Date Installed	11/14/2005	
						Manufacturer's name AERMOTOR	Model Number T12-75	HP 0.75	Volt 230
						Length of drop pipe 60 ft	Capacity 12 g.p.	Typ Submersible	
						Abandoned			
						Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No			
						Variance			
						Was a variance granted from the MDH for this well? ☐ Yes ☒ No			
						Miscellaneous			
						First Bedrock	Aquifer	Quat. buried	
						Last Strat sand +larger-brown	Depth to Bedrock	ft	
						Located by Minnesota Geological Survey			
						Locate Method GPS SA Off (averaged) (15 meters)			
						System UTM - NAD83, Zone 15, Meters	X 454380	Y 5026612	
						Unique Number Verification	Address verification	Input Date	11/12/2010
						Angled Drill Hole			
						Well Contractor			
						Praught M. Well Co.	86576	PRAUGHT, S	
						Licensee Business	Lic. or Reg. No.	Name of Driller	

734477

County Sherburne
Quad Lake
Quad ID 137A

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date
Update Date 03/28/2011
Received Date 12/21/2005

Well Name HANLON, CHRIS					Township 34	Range 26	Dir W	Section 33	Subsection CBBFDA
Elevation 954 ft.					Elev. Method 7.5 minute topographic map (+/- 5 feet)				
Address Well 12818 232ND AV NW ELK RIVER MN 55330									
Stratigraphy Information									
Geological Material		From	To (ft.)	Color	Hardness				
GRAVEL & SAND		0	37	BROWN	SOFT				
CLAY		37	42	GRAY	MEDIUM				
CLAY & GRAVEL		42	85	BROWN	MEDIUM				
SAND & GRAVEL		85	110	YELLOW	SOFT				
Well Depth 110 ft.									
Depth Completed 110 ft.									
Date Well Completed 10/08/2005									
Drill Method Non-specified Rotary									
Drill Fluid Bentonite									
Use domestic									
Status Active									
Well Hydrofractured? Yes ☐ No ☒									
From To									
Casing Type Single casing									
Joint Glued									
Drive Shoe? Yes ☐ No ☒									
Above/Below									
Casing Diameter 4 in. To 100 ft. 1.9 lbs./ft.									
Weight 6.5 in. To 110 ft.									
Hole Diameter									
Open Hole From ft. To ft.									
Screen? ☒ Type plastic Make BIGFOOT									
Diameter Slot/Gauze Length Set									
4 in. 15 10 ft. 100 ft. 110 ft.									
Static Water Level 17 ft. land surface Measure 10/08/2005									
Pumping Level (below land surface) 100 ft. 2 hrs. Pumping at 100 g.p.m.									
Wellhead Completion Pitless adapter manufacturer MONITOR Model SNAPPY									
☐ Casing Protection ☒ 12 in. above grade									
☐ At-grade (Environmental Wells and Borings ONLY)									
Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified									
Material Amount From To									
cuttings 0 30 ft. 100 ft.									
high solids bentonite 2 Sacks ft. 30 ft.									
Nearest Known Source of Contamination 32 feet North Direction Sewer Type									
Well disinfected upon completion? ☒ Yes ☐ No									
Pump ☐ Not Installed Date Installed 11/23/2005									
Manufacturer's name GRUNDFOS									
Model Number 22SQE10C- HP 1 Volt 230									
Length of drop pipe 60 ft Capacity 22 g.p. Typ Submersible									
Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No									
Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No									
Miscellaneous First Bedrock Aquifer Quat. buried									
Last Strat sand +larger-yellow Depth to Bedrock ft									
Located by Minnesota Geological Survey									
Locate Method GPS SA Off (averaged) (15 meters)									
System UTM - NAD83, Zone 15, Meters X 453742 Y 5026582									
Unique Number Verification Address verification Input Date 11/12/2010									
Angled Drill Hole									
Well Contractor Alberg Water Services, LLC. 71701 MCALPINE, J.									
Licensee Business Lic. or Reg. No. Name of Driller									

813437

County Sherburne
Quad
Quad ID

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING REPORT
Minnesota Statutes Chapter 1031

Entry Date

Update Date02/23/2016

Received Date11/19/2015

Well Name HILDENBRAND, 33	Township 26	Range W 4	Dir DBB	Subsection	Well Depth 300 ft.	Depth Completed 300 ft.	Date Well Completed 09/11/2015	
Elevation	Elev. Method				Drill Method Non-specified Rotary	Drill Fluid Qwik gel		
Address C/W22447 TIPTON ST NW ELK RIVER MN 55330					Use domestic	Status Active		
					Well Hydrofractured? Yes ☐ No ☒ FromTo			
Stratigraphy Information					Casing Type Single casing	Joint Threaded		
					Drive Shoe? Yes ☒ No ☐ Above/Below			
Geological Material					From	To (ft.)	Color	Hardness
TOPSOIL					0	2	BROWN	SOFT
SAND					2	38	TAN	SOFT
SANDY CLAY					38	59	TAN	SOFT
CLAY W/ GRAVEL					59	75	GRAY	SOFT
GRAVEL					75	76	GRAY	SOFT
CLAY					76	85	GRAY	MEDIUM
CLAY W/ GRAVEL					85	89	BROWN	MEDIUM
SAND + GRAVEL					89	93	BROWN	SOFT
CLAY W/ GRAVEL					93	127	BROWN	MEDIUM
CLAY					127	136	TAN	MEDIUM
SAND					136	146	TAN	SOFT
CLAY W/ GRAVEL					146	191	BROWN	MEDIUM
SAND + GRAVEL					191	198	BROWN	SOFT
SANDY CLAY					198	230	GRAY	MEDIUM
SHALE + SANDROCK					230	240	TAN/BLU	MEDIUM
SANDROCK					240	300	WHT/YEL	MED-HRD
Remarks					Open Hole From254 ft. To300 ft.			
					Screen? ☐ TypeMake			
					Static Water Level 40 ft. land surface Measure09/11/2015			
					Pumping Level (below land surface) ft.3 hrs. Pumping at75 g.p.m.			
					Wellhead Completion Pitless adapter manufacturerAQUA SEAL ModelT4X125 ☐ Casing Protection ☒ 12 in. above grade ☐ At-grade (Environmental Wells and Borings ONLY)			
					Grouting Information Well Grouted? ☒ Yes ☐ No ☐ Not Specified MaterialAmountFromTo neat cement50 Sacks7 ft. 254 ft.			
					Nearest Known Source of Contamination 100 feetSoutheas DirectionSeptic tank/drain field Type Well disinfected upon completion? ☒ Yes ☐ No			
					Pump ☐ Not Installed Date Installed09/11/2015 Manufacturer's nameGRUNDFOS Model Number22SRE-190 HP1 Volt230 Length of drop pipe60 ft Capacity22 g.p. TypSubmersible			
					Abandoned Does property have any not in use and not sealed well(s)? ☐ Yes ☒ No			
					Variance Was a variance granted from the MDH for this well? ☐ Yes ☒ No			
Miscellaneous First BedrockAquifer Last StratDepth to Bedrockft Located by Locate Method SystemUTM - NAD83, Zone 15, MetersXY Unique Number VerificationInput Date								
Angled Drill Hole								
Well Contractor Able Well, Inc.1377THOMPSON, S. Licensee BusinessLic. or Reg. No.Name of Driller								

Appendix E

Cost Estimate Details

**Cost Estimate Summary
Corrective Action Evaluation Report**

ID	Alternative	Capital Cost	O&M (30 Year NPV)	Total Estimated Cost (2020 NPV)	Low Range (-30%)	High Range (+50%)
1	Residential Water Supply Replacement + Monitored Natural Attenuation	\$ 690,000	\$ 150,000	<u>\$ 840,000</u>	\$ 590,000	\$ 1,300,000
2	Groundwater Extraction (ERL Property) with Onsite Treatment + Residential Water Supply + MNA	\$ 2,100,000	\$ 2,700,000	<u>\$ 4,800,000</u>	\$ 3,400,000	\$ 7,000,000
3	Pre-subtitle D Landfill Excavation and Placement on Liner	\$ 84,000,000	\$ 6,000,000	<u>\$ 90,000,000</u>	\$ 63,000,000	\$ 140,000,000
4	Groundwater Extraction (on-site & off-site) and Treatment (on-site)	\$ 2,900,000	\$ 6,200,000	<u>\$ 9,100,000</u>	\$ 6,400,000	\$ 14,000,000

The opinion of probable remedial action cost is made on the basis of Barr's experience and qualifications and represents our best judgment as experienced and qualified professionals familiar with the project. The cost opinion is based on project-related information available to Barr at this time and includes a Detailed Analysis of Alternatives level of project definition. The opinion of cost may change as more information becomes available and regulatory negotiations proceed. In addition, since we have no control over the cost of labor, materials, equipment, or services furnished by others, or over the contractor's methods of determining prices, or over competitive bidding or market conditions, Barr cannot and does not guarantee that proposals, bids, or actual remedial action costs will not vary from the opinion of probable remedial action cost prepared by Barr.

Alt 1
Monitored Natural Attenuation + Residential Water Supply Replacement
Corrective Action Evaluation Report

No.	Item	Quantity	Unit	Unit Cost	Cost
1	Mobilization / Demobilization	1	LS	\$ 32,000	\$ 32,000
2	Drinking Water Well Installation & Connection	10	Ea	\$ 20,000	\$ 200,000
3	Drinking Water Quality Testing	10	Ea	\$ 1,000	\$ 10,000
4	Monitoring Well Site Preparation	1	LS	\$ 30,000	\$ 30,000
5	Monitoring Well Installation	2	Ea	\$ 40,000	\$ 80,000
6	Construction Contingency			25%	\$ 88,000
Construction Cost Subtotal					\$ 440,000
7	Well Installation Coordination with Residents	10	Ea	\$ 10,000	\$ 100,000
8	Engineering and Construction Administration			33%	\$ 150,000
Engineering Cost Subtotal					\$ 150,000
Estimated Capital Cost					\$ 690,000
Operation and Maintenance		1	ANNUAL	\$ 10,000	\$ 150,000
ESTIMATED TOTAL					\$ 840,000
High Range (+50%)					\$ 1,260,000
Low Range (-30%)					\$ 590,000

Primary Assumptions:

- Engineering and construction administration based on A Guide to Developing and Documenting Cost Estimates During
- Assumes two distal monitoring wells to be installed in the wetland area.
- Assumes ten wells have increased analytical monitoring for continued tracking of natural attenuation processes.
- Total well completion depth will be approximately 300 feet below ground surface in Mt. Simon Aquifer
- Costs shown do not include any additive alternatives (i.e. Alternate Water Supply)

Alt 2
Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement
Corrective Action Evaluation Report

No.	Item	Quantity	Unit	Unit Cost	Cost
1	Mobilization / Demobilization	1	LS	\$ 72,540	\$ 72,540
2	Site Preparation	1	LS	\$ 10,000	\$ 10,000
3	Extraction Well Installation - Mud Rotary Methods	3	Ea	\$ 26,067	\$ 78,200
4	Piezometer Installation - Sonic Methods	3	Ea	\$ 15,000	\$ 45,000
5	Trench Excavation and Backfill (to extraction wells)	1000	LF	\$ 20.00	\$ 20,000
6	Utility Bedding Soil	1000	LF	\$ 2.00	\$ 2,000
7	HDPE Forcemain - 2" Dia., SDR11 (well lines)	1000	LF	\$ 3.50	\$ 3,500
8	Directional Drilling 4" Dia. Line 8' Deep	7700	LF	\$ 10.00	\$ 77,000
9	HDPE Forcemain - 4" Dia. SDR11 (pipe around LF to east infilt. basin)	7700	LF	\$ 6.00	\$ 46,200
10	Pressure Testing and Quality Control	1	LS	\$ 20,000	\$ 20,000
11	Well Power Supply and Conduit	1000	LF	\$ 11.00	\$ 11,000
12	Forcemain Sheet Insulation	1000	LF	\$ 12.50	\$ 12,500
13	Water Treatment Structure	1	LS	\$ 58,000	\$ 58,000
14	Water Treatment Units	1	LS	\$ 140,000	\$ 140,000
15	Water Treatment Plumbing	1	LS	\$ 20,000	\$ 20,000
16	Equalization Tank, Controls, and Transfer Pumps	1	LS	\$ 47,000	\$ 47,000
17	Extraction Well Controls, Well Pumps, and Instrumentation	1	LS	\$ 100,000	\$ 100,000
18	Rapid Infiltration Basin	1	LS	\$ 15,000	\$ 15,000
19	Startup / Commissioning	1	LS	\$ 20,000	\$ 20,000
20	Construction Contingency			25%	\$ 199,485
Construction Cost Subtotal					\$ 997,425
21	Discharge Permitting	1	LS	\$ 20,000	\$ 20,000
22	Model Application	1	LS	\$ 20,000	\$ 20,000
23	Treatment Pilot Test	1	LS	\$ 100,000	\$ 100,000
24	Design Investigation	1	LS	\$ 50,000	\$ 50,000
25	Engineering and Construction Administration			26%	\$ 260,000
Engineering Cost Subtotal					\$ 450,000
Groundwater Extraction and Treatment Estimated Capital Cost					\$ 1,400,000
Total Est. Capital Cost (incl. Res. Water Supply + MNA)					\$ 2,100,000

Alt 2
Groundwater Extraction and Treatment with Focused MNA and Residential Water Supply Replacement
Corrective Action Evaluation Report

30 YR NPV, 5% interest rate			
Groundwater Extraction and Treatment Operation and Maintenance	1 ANNUAL	\$ 165,000	\$ 2,500,000
Total Operation and Maintenance (incl. Res. Water Supply + MNA)	1 ANNUAL	\$ 175,000	\$ 2,700,000
ESTIMATED TOTAL (incl. Res. Water Supply + MNA)			\$ 4,800,000
		High Range (+50%)	\$ 7,200,000
		Low Range (-30%)	\$ 3,400,000

Primary Assumptions:

- Engineering and construction administration based on A Guide to Developing and Documenting Cost Estimates During the Feasibility Study (EPA 540-R-00-002)
- Three extraction wells will operate to achieve remedial goals.
- Total depth of extraction wells and piezometers will average 90 feet below ground surface.
- Infiltration basin will be installed on eastern side of ERL property within downgradient plume extents.

Alt 3
Pre-subtitle D Landfill Excavation and Placement on Liner
Corrective Action Evaluation Report

No.	Item	Quantity	Unit	Unit Cost	Cost
1	Waste Removal and Relining (Eng. Fees Included)	4900000	CY	\$ 12.75	\$ 62,483,221
2	Excavate and Fill Cover Soils	1000000	CY	\$ 4.00	\$ 4,000,000
3	Construction Contingency			25%	\$ 15,620,805
Construction Cost Subtotal					\$ 82,104,027
Landfill Excavation and Relining Capital Cost					\$ 82,000,000
Total Est. Capital Cost (incl. Res. Water Supply + MNA + Grounwater Ext. & Treat)					\$ 84,000,000
30 YR NPV, 5% interest rate					
Landfill Excavation and Relining Operation and Maintenance Cost					\$ 3,300,000
Total Operation and Maintenance Cost (incl. Res. Water Supply + MNA + Groundwater Ext & Treat.)					\$ 6,000,000
ESTIMATED TOTAL					\$ 90,000,000
High Range (+50%)					\$ 140,000,000
Low Range (-30%)					\$ 63,000,000

Primary Assumptions:

- Engineering and construction administration based on A Guide to Developing and Documenting Cost Estimates During the Feasibility Study (EPA 540-R-00-002)
- There is an estimated 4,900,000 CY of waste in the pre-Subtitle D unlined portion of the landfill.
- There is an estimated 1,000,000 CY of additional soil to be excavated and placed (i.e. cover).
- Unit costs obtained from *Focused Feasibility Study Report, Freeway Landfill and Freeway Dump*, October 2019, Prepared by Barr Engineering for the Minnesota Pollution Control Agency. Moderate height, moderate footprint alternative (2C).

Alt 4
Groundwater Extraction (on off-site) and Treatment
Corrective Action Evaluation Report

No.	Item	Quantity	Unit	Unit Cost	Cost
1	Mobilization / Demobilization	1	LS	\$ 164,278	\$ 164,278
2	Site Preparation / Access Matting to Nearest Road at Distal Locations	2800	LF	\$ 91	\$ 253,400
3	Extraction Well Installation - 6" Dia., 90 ft Depth, Mud Rotary	5	Ea	\$ 26,067	\$ 130,333
4	Piezometer Installation - 2" Dia., 90 ft Depth, Sonic	5	Ea	\$ 15,000	\$ 75,000
5	Forcemain - Heat Traced and Insulated (to distal wells)	5500	LF	\$ 41.98	\$ 230,868
6	Trench Excavation and Backfill	1000	LF	\$ 20.00	\$ 20,000
7	Utility Bedding Soil	1000	LF	\$ 3.50	\$ 3,500
8	HDPE Forcemain - 2" Dia., SDR11 (each well)	1000	LF	\$ 3.50	\$ 3,500
9	Directional Drilling - 4" Dia. Line 8' Deep	7700	LF	\$ 10.00	\$ 77,000
10	HDPE Forcemain - 4" Dia. SDR11 (pipe around LF to east infilt. basin)	7700	LF	\$ 6.00	\$ 46,200
11	Pressure Testing and Quality Control	1	LS	\$ 33,200	\$ 33,200
12	Insulation - 4" Thickness, 4' wide	1000	LF	\$ 12.50	\$ 12,500
13	Well Power Supply and Conduit	11000	LF	\$ 11.00	\$ 121,000
14	Water Treatment Structure	1	LS	\$ 96,280	\$ 96,280
15	Water Treatment Units	1	LS	\$ 232,400	\$ 232,400
16	Water Treatment Plumbing	1	LS	\$ 33,200	\$ 33,200
17	Equalization Tank, Controls, and Transfer Pumps	1	LS	\$ 50,300	\$ 50,300
18	Extraction Well, Controls, Well Pumps, and Instrumentation	1	LS	\$ 166,000	\$ 166,000
19	Rapid Infiltration Basin	1	LS	\$ 24,900	\$ 24,900
20	Startup / Commissioning	1	LS	\$ 33,200	\$ 33,200
21	Construction Contingency			25%	\$ 451,765
Construction Cost Subtotal					\$ 2,258,824
22	Discharge Permitting	1	LS	\$ 20,000	\$ 20,000
23	Model Application	1	LS	\$ 20,000	\$ 20,000
24	Treatment Pilot Test	1	LS	\$ 100,000	\$ 100,000
25	Design Investigation	1	LS	\$ 50,000	\$ 50,000
26	Engineering and Construction Administration			19%	\$ 430,000
Engineering Cost Subtotal					\$ 620,000
Estimated Capital Cost					\$ 2,900,000

Alt 4
Groundwater Extraction (on off-site) and Treatment
Corrective Action Evaluation Report

		30 YR NPV, 5% interest rate	
Operation and Maintenance	1 ANNUAL	\$ 281,366	\$ 6,200,000
		ESTIMATED TOTAL	\$ 9,100,000
		High Range (+50%)	\$ 14,000,000
		Low Range (-30%)	\$ 6,400,000

Primary Assumptions:

- Engineering and construction administration based on A Guide to Developing and Documenting Cost Estimates During the Feasibility Study (EPA 540-R-00-002)
- Five extraction wells will operate to achieve remedial goals.
- Lump sum construction unit costs scaled up from Alt 2 by 66% to account for extra wells, flow, and infrastructure.
- Total depth of extraction wells and piezometers will average 90 feet below ground surface.

Appendix F

Monitoring Well Network Considerations

Appendix F

Monitoring Well Network Considerations

The ERL monitoring network includes 39 monitoring wells, of which 25 are sampled three times per year. Monitoring network considerations are provided below based on the corrective action evaluation and feedback from MPCA and others:

- P-301L area – vinyl chloride concentrations were above the IL in sample from monitoring well P-301L during the three triannual sampling events in 2019 and not detected (<0.050 µg/L) in the April 2020 sample (Appendix A). This suggests well P-301L remains on the northern fringe of the vinyl chloride plume. Vinyl chloride concentrations at P-301L will be watched, and if necessary, an additional lower outwash monitoring well will be considered.
- P-694477 area - vinyl chloride was detected and confirmed in monitoring well P-694477 in October and December 2019 and was not detected (at an elevated reporting limit) in the April 2020 sample (Appendix A). As part of the corrective action implementation, unique well #626780 (which is sidegradient to the organics) is a candidate for replacement and conversion of the existing supply well to a lower outwash monitoring well that will provide monitoring data southeast of well P-694477.
- Northern Rice Lake/Tibbits Brook (RL/TB) - the County has suggested the installation of a monitoring well north of well P-325L in RL/TB. The installation of a well(s) in this area is a significant undertaking during installation and raises safety concerns for the individuals responsible for preparing the area for drilling, drilling and installing the well, and samplers who monitor the wells. ERL will provide access to the County to install the well (at the County's risk) if requested. Please contact Mr. Terry Johnson if you would like to schedule a site visit to conduct a site walk in RL/TB for reconnaissance purposes or to discuss our experience with creating access, drilling in RL/TB and a similar wetlands in Minnesota, and safety concerns.

ERL will consider incorporating monitoring wells P-327L and P-328L to the monitoring network for sampling on an annual basis.

- Upgradient Lower Outwash Well – ERL will provide a plan to establish additional upgradient monitoring under separate cover.

EXHIBIT 16

Natural Wild Rice In Minnesota

**A Wild Rice Study document submitted to
the Minnesota Legislature by the Minnesota
Department of Natural Resources
February 15, 2008**



Fiscal Disclosure

Pursuant to Minnesota Statutes, Section 3.197, we estimate that it cost approximately \$72,614 to produce this report. This includes Minnesota Department of Natural Resources (MNDNR) staff time for conducting the inventory, attending meetings, drafting and reviewing the report and compiling comments and recommendations (\$45,159) and meeting expenses, including travel, for consultation with the Technical and Partnership Teams (\$1,772). In addition, costs accrued to other agencies and individuals participating on the Technical Team are \$22,618 for time and \$3,065 for travel. These costs do not include the costs of preceding research and public participation efforts conducted by the MNDNR or Team members prior to the requirement that this report be prepared.

Table of Contents

Executive Summary	1
Introduction.....	6
Importance of Natural Wild Rice in Minnesota.....	7
Cultural Importance	7
Ecological Importance	8
Economic Importance	10
Wild Rice Background.....	12
Taxonomy	12
Distribution and Abundance	12
Life History	14
Legal Considerations	16
Threats to Natural Wild Rice in Minnesota	21
Stand Level Threats	21
Hydrological Changes.....	21
Recreational Water Use and Shoreland Development.....	22
Wildlife Activity	23
Plant Competition	24
Mining and Other Industrial Activity	25
Statewide Threats.....	25
Loss of Natural Genetic Characteristics	25
Non-native Invasive Species.....	27
Climate Change.....	29
Lack of Recruitment and Retention of Harvesters.....	31
Management Challenges.....	33
Multiple Jurisdictions.....	33
Annual Crop Variability	34
Information Needs	35
Recommendations.....	36
Literature Cited	39
Appendix	
A. Natural Wild Rice Study Development Process	48
B. Natural Wild Rice Distribution and Abundance in Minnesota	51
C. Natural Wild Rice Harvest Survey	84
D. The Life History of Natural Wild Rice.....	87
E. Wild Rice Bibliography.....	91
F. Stakeholder Comments.....	105

Executive Summary

Introduction

This report fulfills the requirements of Session Law 2007, Chapter 57, Article 1, Section 163 requiring the Commissioner of Natural Resources to prepare a study for natural wild rice that includes: (1) the current location and estimated acreage and area of natural stands; (2) potential threats to natural stands, including, but not limited to, development pressure, water levels, pollution, invasive species, and genetically engineered strains; and (3) recommendations to the house and senate committees with jurisdiction over natural resources on protecting and increasing natural wild rice stands in the state.

In fulfilling these requirements, the Minnesota Department of Natural Resources (MNDNR) established a Technical Team of wild rice experts from State, Tribal, and Federal governments, as well as academia and the private sector. The MNDNR also established a Partnership Team representing major stakeholders.

Importance of Natural Wild Rice

Nowhere has natural wild rice been more important, nor had a richer history, than in Minnesota. No other native Minnesota plant approaches the level of cultural, ecological, and economic values embodied by this species. Natural wild rice has been hand harvested as a source of food in the Great Lakes region for thousands of years.

The Ojibwe people have a special cultural and spiritual tie to natural wild rice. Known to their people as Manoomin, it is revered as a special gift from the Creator. In addition many immigrants to Minnesota adopted hand harvesting of natural wild rice as an annual ritual. Annual sales of state licenses for wild rice harvesting peaked in 1968 at over 16,000. In recent years, annual sales have averaged fewer than 1500. In many instances, though, tribal harvesters are not required to buy state licenses. It is thought that more than 3000 tribal members participate in wild rice harvesting, providing a statewide total (tribal and nontribal) of 4000-5000 individuals annually.

The value of natural wild rice to wildlife has been long appreciated by American Indians and was marveled at by early European explorers. Research since then has documented that wild rice provides food and shelter for many fish and wildlife species. It is one of the most important foods for waterfowl in North America. More than 17 species of wildlife listed in the MNDNR's Comprehensive Wildlife Conservation Strategy as "species of greatest conservation need" use wild rice lakes as habitat for reproduction or foraging.

Wild rice harvest has provided important economic benefits to local economies. As with other commodities, the price paid for unprocessed natural wild rice can vary considerably. Although pricing is mainly determined by supply, marketing also plays a role. During the past 70 years, the price of one pound of unprocessed wild rice has ranged from \$0.10 in 1940 to \$2.17 in 1966. Adjusted for inflation these prices in today's dollars are equivalent to \$0.75 and \$13 per pound, respectively. As an example, the 1966 harvest of 924,000 lbs would have been worth over \$12 million today.

Prior to 1970, Minnesota provided half of the global market supply of wild rice. Most of this rice was from hand harvested natural stands. By 1990, the large-scale production of cultivated wild rice had expanded, and natural wild rice accounted for less than 10% of the global market supply. The total annual yield of cultivated and hand harvested wild rice in Minnesota today ranges from four to eight million pounds. A recent MNDNR survey found the average annual hand harvest of natural stands to be 430 pounds per individual.

Background

Although stands of natural wild rice occur most commonly in central and north-central Minnesota, the historic range of wild rice included all of the state. Based on the inventory conducted for this report, the range of natural wild rice today includes 55 counties in Minnesota. Stands of natural wild rice were present or occurred in recent history on approximately 1286 lakes and river/stream segments. These areas support a minimum of 64,328 acres of natural wild rice when growing conditions are favorable.

The greatest concentration of lakes supporting natural wild rice is in Aitkin (4,859 acres), Cass (8,323 acres), Crow Wing (3,751 acres), Itasca (8,448 acres), and St. Louis (8,939 acres) counties. These counties contain over 60% of the inventoried natural wild rice acreage in Minnesota. These counties also account for over 70% of the harvesting trips for natural wild rice.

Natural wild rice generally requires some moving water, with rivers, flowages, and lakes with inlets and outlets being optimal areas for growth. Wild rice grows well at depths of 0.5 to 3 feet of water, although some plants may be found in deeper waters. As an annual plant, natural wild rice develops each spring from seeds that fell into the water during a previous fall. Germination requires a dormancy period of three to four months of cold, nearly freezing water (35° F or colder). Seeds are unlikely to survive prolonged dry conditions.

The entire process, from germination of a new plant to dropping of mature seeds, requires about 110 to 130 days, depending on temperature and other environmental factors. Seeds begin ripening at the top of the stem and then ripen over several days on an individual plant. Plants within a stand ripen at different times because of genetic, developmental, and environmental variation. This staggered maturation process means that ripe seeds may be available within individual stands for several weeks, and across the entire range of natural wild rice in Minnesota for a month or longer.

The earliest laws and regulations concerning wild rice in Minnesota focused on wild rice harvest and date back more than 75 years. Today, there is a complex mix of tribal, federal, state, and local laws and regulations. These are associated with the formal recognition of the significance of natural wild rice and its protection, management, and harvest. The application of regulations varies by jurisdiction (i.e., tribal versus state) and geography (i.e., on-reservation versus off-reservation, or within various ceded territories). Regulatory authority governing different aspects of wild rice management occurs within several state agencies yet within state statutes there is no unifying policy to provide overall guidance in implementation.

Threats

Despite its rich history and abundance in Minnesota, natural wild rice faces many current and potential threats in this region. In general, any factor that can affect water quality, seasonal water levels, lakebed conditions, regional climate, aquatic vegetation, or the natural genetic diversity of wild rice could potentially threaten natural stands. These threats may work in concert or individually to damage wild rice stands.

Important threats that impact local stands of natural wild rice include changes in local hydrology due to dams and channelization, water-based recreation and shoreland development, and mining and other industrial activities. Although the impacts are to local stands, the cumulative effect of these threats can have statewide implications. Hydrological impacts and shoreland development are particularly important.

On a statewide and regional scale, the most important threats are the potential loss of genetic integrity, invasive species, and climate change. Nearly all of the concern expressed about wild rice genetics focuses on the potential of genetic engineering. Invasive species are an ongoing statewide issue impacting aquatic systems in general. Climate change has the potential for the greatest long-term impacts on natural wild rice.

As citizens become more distant from positive experiences with natural wild rice through harvesting, hunting, trapping, or wildlife watching, they are less likely to recognize the very real impacts that the previously noted threats could have on natural wild rice in Minnesota. This loss of appreciation, while not a direct threat to the wild rice resource, nevertheless increases the risks because the level of resource protection and management is often based on the perceived value of a resource.

Unfortunately wild rice harvesters are relatively few in number and have experienced a long-term decline, although the number of tribal harvesters has rebounded in recent years. Only about 4000-5000 people participate in hand harvesting natural stands of wild rice annually.

The future of natural wild rice in Minnesota will depend in large part on its protection and management by state and tribal natural resource agencies. The role of the agencies is complicated by the limitations of their authority and the challenges posed by multiple jurisdictions, annual variability of wild rice crops due to weather and other factors, and lack of information concerning the natural ecology of wild rice, historical losses, trends in abundance and distribution, threats to its future, and a better understanding of wild rice harvesters.

Recommendations

The following recommendations were developed with valuable input and discussion from the members of the Wild Rice Study Technical Team and Partnership Team. However, the MNDNR assumes sole responsibility for these recommendations as written and presented here.

MNDNR recognizes the importance of protecting natural wild rice beds from genetic modification and agrees with wild rice stakeholders that this protection is critical to the future of this resource. We strongly support the Minnesota Environmental Quality Board in adopting rules

that require an Environmental Impact Statement for a proposed release of genetically engineered wild rice (MS 116C.94 Subd.1b).

Recommendation 1

Recodify current wild rice harvest statutes and rules to remove duplication and inconsistencies.

Rationale: The state's wild rice statutes and rules have been developed and modified piecemeal over a long period of time. As a result they contain a number of inconsistencies and duplication.

Recommendation 2

Establish statutory policy guidance on wild rice and its management.

Rationale: Within state statutes there is no unifying policy that provides direction to agencies responsible for some aspect of wild rice management.

Recommendation 3

The MNDNR will convene an interagency workgroup in 2008 to identify desired statutory updates in harvest regulations.

Rationale: Harvest regulations and license fee structure should be reviewed by an interagency work group for suggested changes.

Recommendation 4

The MNDNR will designate and publish a list of important natural wild rice areas.

Rationale: Recognizing important wild rice areas and publishing the list would call attention to the importance of these areas, indicate management priorities, and provide a formal list that may prove useful for local units of government that are considering zoning and surface use restrictions.

Recommendation 5

The MNDNR will convene a standing interagency wild rice workgroup to share information and develop recommendations for inventory methodology and trend assessments, education and information outreach, lake planning and management, harvester recruitment and retention, and other management issues as they arise.

Rationale: Comprehensive protection and management of wild rice involves multiple agencies. Management needs include better inventory information including consistent methodology for trend analysis, documenting natural genetic diversity, and establishing long-term case studies on identified lakes.

Recommendation 6

Increase intensive natural wild rice lake management efforts and accelerate the restoration of wild rice stands within its historic range.

Rationale: Protecting and managing natural wild rice resources on many lakes requires active annual management activities to maintain free flowing outlets. Active management is also required to restore wild rice to wildlife habitat areas within its historic range. These efforts should be accelerated as funding, time, and opportunity permit.

Sacred Food and Medicine

Wild rice, or manoomin, is a sacred food and medicine integral to the religion, culture, livelihood, and identity of the Anishinaabeg. According to our sacred migration story, in the long ago a prophet at the third of seven fires beheld a vision from the Creator calling the Anishinaabe to move west (to a land previously occupied long ago) until they found the place “where food grows on the water.” The Anishinaabeg of the upper Mississippi and western Great Lakes have for generations understood their connection to anishinaabe akiing (the land of the people) in terms of the presence of this plant as a gift from the Creator. In the words of White Earth’s Tribal Historian, Andy Favorite, “Wild rice is part of our prophecy, our process of being human, our process of being Anishinaabe ... we are here because of the wild rice. We are living a prophecy fulfilled.”

In our Ojibwe language, manoomin is animate, grammatically referred to as “him/her” not “it,” a non-human being, not just an inanimate “resource.” It is both difficult and of utmost importance to adequately translate and appreciate this worldview in the language of mainstream culture and society with its scientific advisory boards for the study of humans and animals but not plants. According to Anishinaabe author, Basil Johnson, “...in essence each plant ... was a composite being, possessing an incorporeal substance, its own unique soul-spirit. It was the vitalizing substance that gave to its physical form growth, and self-healing.” The Anishinaabeg believe that wild rice will always grow where they live. Menominee chief Chieg Nio’pet said his people did not need to sow rice because it would follow them wherever they went. He told of how Shawano Lake never had manoomin until the Menominee moved there. Similarly when they were banned from Lake Winnebago, the rice that had been plentiful there all but disappeared. Whatever happens to the land and to manoomin happens to the Anishinaabe.

Our ceremonies and aadizookanag -sacred stories- also tell of our people’s relations with this plant. White Earth Anishinaabe, Joe LaGarde, notes that wild rice and water are the only two things required at every ceremony. Manoomin accompanies our celebrations, mourning, initiations, and feasts, as both a food and a spiritual presence. It holds special significance in traditional stories, which are only told during ricing time or when the ground is frozen. “In these stories, wild rice is a crucial element in the realm of the supernaturals and in their interactions with animals and humans; these legends explain the origin of wild rice and recount its discovery...” by Wenabozhoo, or Nanabozho, the principal manidoo or spirit in our sacred aadizookanag.

Manoomin is just as central to our future survival as our past. While we try to overcome tremendous obstacles to our collective health, the sacred food of manoomin is both food and medicine. “Wild rice is consequently a very special gift, with medicinal as well as nutritional values—belief reflected in the Ojibwe use of wild rice as a food to promote recovery from sickness as well as for ceremonial purposes.” (Vennum 62). Manoomin is inextricably bound to the religion and identity of the Anishinaabeg. This is why these threats are potentially so devastating and why it is essential that the sanctity and integrity of this plant be preserved. If artificially produced or engineered varieties of wild rice were to compromise the wild manoomin that has existed in the lakes for thousands of years, it will compromise the Anishinaabe people and our way of life. Joe LaGarde puts it plainly, “If we lose our rice, we won’t exist as a people for long. We’ll be done too.”

*Erma Vizenor, Tribal Chairwoman, White Earth Nation
With the participation of Carlton College Students.*

Introduction

This report fulfills the requirements of Session Law 2007, Chapter 57, Article 1, Section 163:

By February 15, 2008, the commissioner of natural resources must prepare a study for natural wild rice that includes: (1) the current location and estimated acreage and area of natural stands; (2) potential threats to natural stands, including, but not limited to, development pressure, water levels, pollution, invasive species, and genetically engineered strains; and (3) recommendations to the house and senate committees with jurisdiction over natural resources on protecting and increasing natural wild rice stands in the state.

In developing the study, the commissioner must contact and ask for comments from the state's wild rice industry, the commissioner of agriculture, local officials with significant areas of wild rice within their jurisdictions, tribal leaders within affected federally recognized tribes, and interested citizens.

In fulfilling these requirements, the Minnesota Department of Natural Resources (MNDNR) established a Technical Team of wild rice experts from State, Tribal, and Federal governments; the Minnesota cultivated wild rice industry; Ducks Unlimited; Save Our Rice Alliance (SORA), an organization of interested citizens who hand harvest natural wild rice; White Earth Land Recovery Project; the University of Minnesota; and the University of Wisconsin (Appendix A). The MNDNR also established a Partnership Team representing the Minnesota wild rice industry, the state commissioner of agriculture, the Association of Minnesota Counties, tribal leaders within affected federally recognized tribes, the United States Fish and Wildlife Service, Ducks Unlimited, Minnesota Waterfowl Association, and SORA (Appendix A).

The Technical Team, working with MNDNR staff, developed drafts of the wild rice study document for review by the Partnership Team. The collaboration of these two teams was instrumental in producing this document for MNDNR review and approval. The MNDNR is indebted to team members for their contributions of time, expertise, and hard work. It should be clear, however, that the MNDNR assumes sole responsibility for the content and recommendations of this document.

The wild rice study document and its appendices are intended to provide the reader with a thorough background on the importance of natural wild rice to Minnesota, its natural ecology and distribution, threats to its future, challenges in managing the resource, and recommendations to insure its abundance for future generations.

Importance of Natural Wild Rice in Minnesota

As directed by the legislature, the wild rice study document focuses on natural wild rice. For this study, we define natural wild rice as native species of wild rice (*Zizania*) that are growing in public waters and are not subject to cultivation. The simplest description of natural wild rice in Minnesota is that it is an annual aquatic grass that produces an edible grain.

This simple description, of course, does not do justice to this unique and valuable plant. History is replete with examples of its importance to wildlife and value to humans both nutritionally and culturally. Wild rice (manoomin to the Ojibwe) is a spiritually significant resource for Native Americans in the Great Lakes region, and it has been for centuries. Nowhere has this grain been more important, nor had a richer history, than in Minnesota. No state harbors more acres of natural wild rice than Minnesota (Moyle and Krueger 1964). No other native Minnesota plant approaches the level of cultural, ecological, and economic values embodied by natural wild rice.

Cultural Importance

Natural wild rice has been hand harvested as a source of food in the Great Lakes region for thousands of years. Evidence of its human use dates back to the Late Archaic and Early Woodland periods, more than 2000 years ago (Valppu 2000). Archeological evidence indicates that from the 1600s to the 1800s wild rice was a staple food for the Algonquian and Dakota peoples throughout the area now known as Minnesota. It has been important historically for gifting and trading, as well. For example, when Dakota Chief Wabasha hosted Zebulon Pike in 1805 he offered gifts of wild rice to the explorer (Vennum 1988).

The Ojibwe people have a special cultural and spiritual tie to natural wild rice. Their Migration Story describes how they undertook a westward migration from the eastern coast of North America. Tribal prophets had foretold that this migration would continue until the Ojibwe people found “the food that grows on water” (Benton-Banai 1988). That food was wild rice, known as manoomin, and is revered to this day by the Ojibwe as a special gift from the Creator (Ackley 2000; Schlender 2000).

Early European explorers and fur traders were impressed with the availability and nutritional quality of wild rice, and attempts were made to import it to Europe as early as 1790 (Oelke 2007). Many immigrants to Minnesota adopted hand harvesting of natural wild rice as an annual ritual. The importance of this harvest to European settlers lessened only when cultivated non-native grains became more readily available.

The tradition of hand harvesting natural wild rice continues to this day among both tribal and nontribal cultures. This tradition has been preserved through tribal code and state regulations that reflect traditional methods of harvesting. State statutes in Minnesota include regulations that restrict the maximum length (18 feet) and width (36 inches) of the harvesting boat, as well as the maximum weight (1 pound) and length (30 inches) of hand flails. The regulations also require that push poles have forks 12 inches or less in length. The use of any machine or mechanical device to harvest natural wild rice is generally prohibited.

Annual sales of state licenses for wild rice harvesting peaked in 1968 at over 16,000. In recent years, annual sales have averaged fewer than 1500. However, because in many instances tribal harvesters are not required to buy state licenses, state numbers do not adequately reflect the numbers of individuals participating in wild rice harvesting. It is thought that more than 3000 tribal members participate in wild rice harvesting providing the statewide total (tribal and nontribal) of 4,000 to 5,000 individuals.

Annual harvests can vary greatly. Rice productivity, weather, and harvester participation are all important factors. The MNDNR survey of state licensees from 2004 to 2006 found the average annual harvest to be 430 pounds per individual (MNDNR 2007). Aitkin, Cass, Crow Wing, Itasca, and St. Louis counties accounted for over 70% of the harvesting trips for natural wild rice. Estimates of annual harvest of natural stands in Minnesota between 1940 and 1972 ranged from 20 thousand to nearly 4 million pounds of unprocessed grain (Oelke et al. 1973).

Another aspect of the cultural importance of wild rice is its nutritional value. Noted for its importance as a whole grain, wild rice is an excellent source of complex carbohydrates, vitamins, minerals, fiber and protein. It is a particularly good source of potassium, zinc and riboflavin (Oelke 2007). Access to traditional foods is felt to be an important element of restoring individual and community health of the Ojibwe people (W. LaDuke, personal communication). Natural wild rice is one of the mainstays of traditional foods for the Ojibwe community.

Concerns for the preservation of hand harvesting traditions and related issues led to the formation in 2007 of a tribal and nontribal partnership called Save Our Rice Alliance (SORA). The stated mission of SORA is “To preserve and enhance the culture, economy, and sustainability of native wild rice” (A. Drewes, personal communication).

Ecological Importance

The value of natural wild rice to wildlife has been long appreciated by American Indians and was marveled at by early European explorers (Jenks 1900). Jonathan Carver traveled through eastern portions of North America in the 1760s and observed of wild rice that “the sweetness and nutritious quality of it attracts an infinite number of wild fowl of every kind which flock from distant climes to enjoy this rare repast, and by it become inexpressively fat and delicious” (Stoddard 1957).

Both migrating and resident wildlife rely on the nutritious and abundant seeds of natural wild rice. One acre of natural wild rice can produce more than 500 pounds of seed. These seeds have long been recognized as an important source of food during fall migrations (McAtee 1917). Martin and Uhler (1939) listed wild rice as the ninth most important source of food for ducks throughout the United States and Canada, and the third most important source of food for ducks in the eastern portions of the continent. Research conducted on the Chippewa National Forest found that natural wild rice was the most important food for mallards during the fall (Stoudt 1944). Although the value of wild rice to mallards, wood ducks, and ring-necked ducks is most commonly recognized, other ducks such as black ducks, pintail, teal, wigeon, redheads, and lesser scaup also use stands of wild rice (Rossman et al. 1982, Huseby 1997).

The stems of wild rice provide nesting material for such species as common loons, red-necked grebes, and muskrats; and critical brood cover for waterfowl. The entire wild rice plant provides food during the summer for herbivores such as Canada geese, trumpeter swans, muskrats, beaver, white-tailed deer, and moose (Martin et al.1951, Tester 1995). In addition, rice worms and other insect larvae feed heavily on natural wild rice. These, in turn, provide a rich source of food for blackbirds, bobolinks, rails, and wrens. In the spring, decaying rice straw supports a diverse community of invertebrates and thus provides an important source of food for a variety of wetland wildlife including birds, small fish, and amphibians. Indeed, every stage of growth of natural wild rice provides food for wildlife (McAtee 1917, Stoudt 1944).

As a result, wild rice lakes and streams are breeding and nesting areas for many species. More than 17 species of wildlife listed in the MNDNR's Comprehensive Wildlife Conservation Strategy (2006) as "species of greatest conservation need" use wild rice lakes as habitat for reproduction or foraging (Henderson 1980, Martin et al.1951). Listed bird species can be found in Table 1.

Table 1. Minnesota birds that utilize wild rice habitat and are listed in *Tomorrow's Habitat for the Wild and Rare* as species of special concern.

Birds of Special Concern	Life Cycle Stage
American Black Duck	Breeding and migration
Lesser Scaup	Migrant
Northern Pintail	Migration, Rare Breeder
Trumpeter Swan	Breeding and migration
American Bittern	Breeding and migration
Least Bittern	Breeding and migration
Red-necked Grebe	Breeding and migration
Common Loon	Breeding and migration
Sora Rail	Breeding and migration
King Rail	Casual migrant
Virginia Rail	Breeding and migration
Yellow Rail	Breeding and migration
Black Tern	Breeding and migration
Bobolink	Foraging and migration
Rusty Blackbird	Foraging and migration
Sedge Wren	Breeding and migration
Bald Eagle	Foraging and migration

Natural wild rice has other ecological values as well. Emergent aquatic plants such as wild rice, bulrush, and cattails protect shorelines and provide habitat for fish (Radomski and Goeman 2001). Dense stands of wild rice stabilize loose soils and form natural windbreaks that can limit the mixing of soil nutrients into the water column (Meeker 2000). In addition, natural wild rice has relatively high requirements for nutrients such as phosphorus and nitrogen (Oelke et al. 2000). During periods of rapid growth, which occurs in spring and summer, the plants sequester

these nutrients. Thus stands of natural wild rice counter the effects of nutrient loading and the potential increases in algal growth and lake turbidity.

Economic Importance

Prior to European settlement of Minnesota, natural wild rice was the most important grain available to native peoples, early explorers, and fur traders (Vennum1988). Properly dried, and stored in clean, dry conditions, uncooked wild rice has an estimated shelf life of up to 10 years. One pound yields up to ten and a half cups of cooked wild rice (Oelke 2007). As a dietary staple that was so easily stored and used, wild rice had considerable economic value. With the influx of immigrant settlers and the agricultural production of non-native grains, the overall economic value of wild rice waned. Nevertheless, harvest of natural wild rice continued to be popular in Minnesota. During the 1960s, sales of state licenses averaged over 10,000 per year.

The economic value of wild rice is reflected in the efforts of many to expand its occurrence into new waters. Native peoples have long sown wild rice to create additional sources of grain (Vennum 1988). Waterfowl hunters have commonly planted wild rice to attract ducks. The demand for seed of wild rice and other aquatic wildlife foods presumably fostered the establishment of Wildlife Nurseries, Inc. in Oshkosh, Wisconsin in 1898 (Oelke 2007). This firm continues selling wild rice for planting today. Conservation agencies have long participated in planting efforts as well, working to establish new stands of wild rice and perpetuate traditional areas (Moyle 1944b).

David Owens noted the potential benefits of cultivating wild rice as early as 1852 (Vennum 1988). In 1853, Oliver H. Kelley published an article discussing the merits of wild rice cultivation. Albert E. Jenks discussed wild rice cultivation as part of “agricultural development” in 1901. Yet not until 50 years later did James and Gerald Godward pioneer the first real efforts. They began production of cultivated wild rice in central Minnesota, near Merrifield, in 1950 (Oelke 2007).

The 1950s and 1960s may well have been the peak of modern hand harvesting of wild rice. From 1957 to 1963 the state of Minnesota sold an average of 10,012 wild rice harvest licenses (Table 2). The average annual harvest of unprocessed wild rice exceeded 2 million pounds or about 227 pounds per picker per year (Moyle and Krueger 1964).

As with other commodities, the price paid for unprocessed natural wild rice can vary considerably. Although pricing is mainly determined by supply, marketing also plays a role. During the past 70 years, the price of one pound of unprocessed wild rice has ranged from \$0.10 in 1940 to \$2.17 in 1966 (Oelke 2007). Adjusted for inflation these prices in today’s dollars are equivalent to \$0.75 and \$13 per pound, respectively. The 1966 harvest of 924,000 lbs would have been worth over \$12 million today. Since 1990, the price paid for unprocessed rice from the Leech Lake Reservation has varied between \$1.00 and \$1.50 per pound (R. Robinson,

Table 2. Hand harvesting of natural wild rice 1957-1963.

Year	Licenses sold	Harvest *
1957	7,535	1,057,000
1958	9,702	3,224,000
1959	9,332	2,067,000
1960	9,664	2,301,000
1961	14,660	2,772,000
1962	6,709	1,292,000
1963	12,482	3,212,000

*Harvest is in unprocessed pounds

Jr., personal communication). Sales during this period ranged from approximately 7,400 to 280,000 pounds.

Prior to 1970, Minnesota provided half of the global market supply of wild rice. Most of this rice was from hand harvested natural stands. By 1990, the large-scale production of cultivated wild rice had expanded, and natural wild rice accounted for less than 10% of the global market supply. Cultivated wild rice from Minnesota provided 40% of the market and California provided 50% (Lee 2000). California still leads the cultivated wild rice industry. The total annual yield of cultivated and hand harvested wild rice in Minnesota today ranges from four to eight million pounds.

Although cultivated rice dominates these production numbers, hand harvested natural wild rice remains a vital component of tribal and local economies in Minnesota. The MNDNR survey of 2004 – 2006 state license buyers found an average annual individual harvest of 430 pounds. In 2007, nearly 300,000 pounds of unprocessed rice were purchased from LLBO-licensed harvesters. At \$1.50 per pound, this harvest generated more than \$400,000 of income for tribal members (R. Robinson, Jr., personal communication).

Wild Rice Background

Taxonomy

Native North American wild rice is classified as a grass in the family *Poaceae* and the genus *Zizania*. The most common species throughout Minnesota is northern wild rice, or *Zizania palustris* L. (Ownbey and Morley, 1991). Two varieties of natural wild rice occur in this region and in other parts of the Upper Midwest: *Z. palustris* var. *palustris* and *Z. palustris* var. *interior* (Gleason and Cronquist, 1991; Flora of North America, 1993+).

A more southern and eastern species, *Zizania aquatica* L., is uncommon but thought by many to occur in Minnesota as well. The precise distribution of *Z. aquatica* is unclear because of differences in taxonomic interpretations and potentially overlapping ranges. *Z. aquatica* is physically larger than *Z. palustris* but its grain is more slender and difficult to harvest. Both of these species are native only to North America.

Distribution and Abundance

Minnesota historically harbored more acres of natural wild rice than any other state (Moyle and Krueger 1964). Despite losses of wild rice habitat, the importance of Minnesota as a center of natural wild rice abundance has actually increased as wild rice acreage has declined elsewhere in the United States. For thousands of years, wild rice thrived in shallow lakes, rivers, and streams left behind by melting glaciers. Although stands of natural wild rice occur most commonly in areas of glacial moraines, such as in central and north-central Minnesota, the historic range of wild rice included all of Minnesota (Moyle 1944b).

Its range also extended westward into the present-day Dakotas and eastward to the Atlantic coast. While not distributed evenly, wild rice likely occurred in many places where its ecological requirements were met. Because wild rice also was planted in areas where it did not occur naturally, it is sometimes difficult today to distinguish between historically natural stands and successfully seeded stands (Vennum 1988).

An updated inventory of the distribution and abundance of natural wild rice was compiled for this study by selected members of the Technical Team and the MNDNR (Appendix B). Data are from lake-habitat surveys, reported observations, and interviews with field personnel of state, federal, and tribal agencies. Although this inventory provides a marked improvement in our understanding of natural wild rice distribution in Minnesota, it should be considered a minimum estimate. The data for many wild rice lakes, streams and rivers is incomplete or totally lacking.

Based on this inventory, the range of natural wild rice today includes 55 counties in Minnesota (Figure 1). The only Minnesota counties without significant populations of natural wild rice are along the western and southwestern boundaries of the state. It should be noted, however, that historical records of wild rice include herbarium specimens that were collected in several western counties not documented by the current inventory. These counties include Pipestone, Cottonwood, Chippewa, Swift, Clay, and western Polk (Moyle 1939, Ownbey and Morley, 1991).

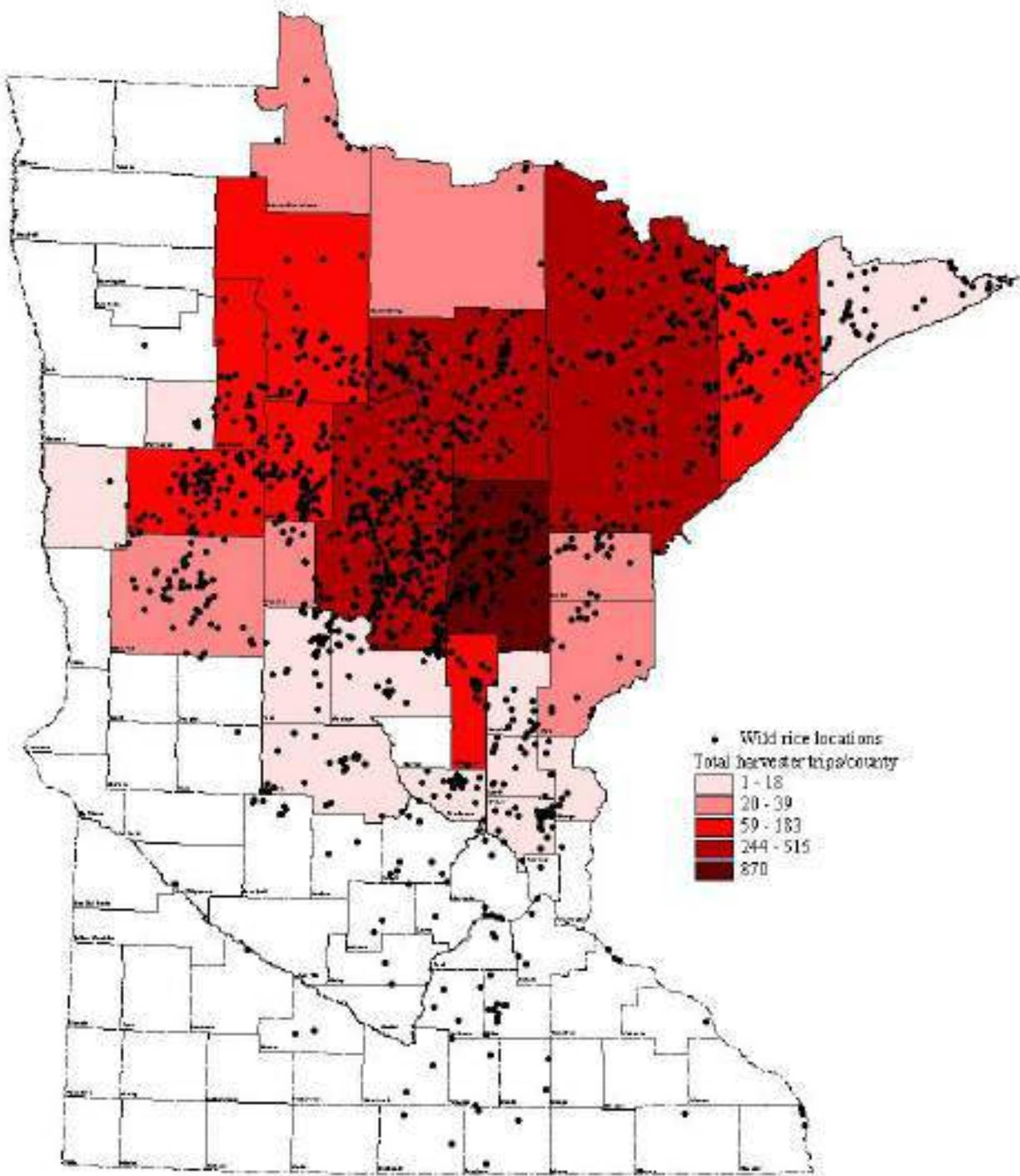


Figure 1. Distribution of wild rice lakes and wild rice harvesting pressure in Minnesota.

Stands of natural wild rice were present or occurred in recent history on approximately 1,286 lakes and river/stream segments (Figure 1). These areas support a minimum of 64,328 acres of natural wild rice when growing conditions are favorable. These areas vary from large, shallow lakes dominated by natural wild rice stands (i.e. Nature's Lake in Cass County) to significant bays within large fish lakes (i.e. Leech Lake) to a narrow fringe along lake/river shorelines. The greatest concentrations of lakes that support natural wild rice are in Aitkin (4,859 acres), Cass (8,323 acres), Crow Wing (3,751 acres), Itasca (8,448 acres), and St. Louis (8,939 acres) counties. These counties contain over 60% of the inventoried natural wild rice acreage in Minnesota. These counties also account for over 70% of the harvesting trips for natural wild rice (MNDNR 2006 harvest survey, Appendix C).

The abundance of natural wild rice in Minnesota today is largely due to abundant suitable habitat, favorable climate, and natural genetic variability that allows for environmental selection of traits that perform well under varying conditions. Studies in Wisconsin found sufficient genetic diversity between geographically separated stands of wild rice to potentially identify regional populations. Within-stand diversity also varied greatly, with larger and denser stands having greater genetic diversity (Waller et al. 2000).

Life History

While the historical range of natural wild rice illustrates its broad distribution, its specific occurrence and abundance is in large part dependent on local environmental conditions. For example, clear to moderately colored (stained) water is preferred, as darkly stained water can limit sunlight and may hinder early plant development.

Wild rice grows within a wide range of chemical parameters (i.e. alkalinity, salinity, pH, and iron; Meeker 2000). However, productivity is highest in water with a pH of 6.0 to 8.0 and alkalinity greater than 40 ppm. While researchers have observed that natural wild rice stands are relatively nutrient rich, excess levels of some nutrients, especially phosphorus, can have significant adverse effects on productivity (Persell and Swan 1986).

Natural wild rice generally requires some moving water, with rivers, flowages, and lakes with inlets and outlets being optimal areas for growth. Seasonal water depth is critical, however. Water levels that are relatively stable or decline gradually during the growing season are preferred. In particular, abrupt increases during the early growing season can uproot plants. Wild rice grows well at depths of 0.5 to 3 feet of water, although some plants may be found in deeper waters (M. McDowell, J. Persell personal communication).

Shallower sites can allow strong competition from perennial emergent plant species, while deeper sites can stress wild rice plants and limit seed production. Although wild rice may occur in a variety of lake bottoms, the most consistently productive stands are those with soft, organic sediment (Lee 1986). Nitrogen and phosphorus are limiting nutrients for wild rice (Carson 2002).

As an annual plant, natural wild rice develops each spring from seeds that fell into the water and settled into the sediment during a previous fall. Germination requires a dormancy period of three

to four months of cold, nearly freezing water (35° F or colder). Seeds are unlikely to survive prolonged dry conditions.

Seed germination typically occurs when the substrate and surrounding water temperatures reach about 40° F. Depending on water depth, latitude, and the progression of spring weather, wild rice germinates in Minnesota sometime in April, well ahead of most but not all perennial plants. Within three weeks, the seedlings develop roots and submerged leaves.

The emergent stage begins with the development of one or two floating leaves and continues with the development of several aerial leaves two to three weeks later. The floating leaves appear in late May to mid June in Minnesota, again dependent on water depth, latitude, and weather. Because of the natural buoyancy of the plant, it is at this stage of growth that wild rice is most susceptible to uprooting by rapidly rising water levels. Plants can be significantly stressed even when they remain rooted.

Natural wild rice begins to flower in mid to late July in Minnesota. Flowering times are dependent on both day length and temperature. Flowers are produced in a branching panicle. Female flowers (pistillate or seed-producing) occur at the top of the panicle on appressed branches. Male flowers (staminate or pollen-producing) occur on the lower portion of the panicle on nearly horizontal branches. Natural wild rice is primarily pollinated by wind. High temperatures and low humidity can negatively affect fertilization rates.

Cross-pollination is typical in natural wild rice stands because female flowers develop, become receptive, and are pollinated before male flowers on the same plant shed pollen. Cross-pollination is further enhanced by plant-to-plant variation in flowering times within stands. This cross-pollination within and among wild rice populations helps to preserve the genetic variability and thus biologic potential for wild rice to adapt to changing conditions such as the highly variable climate of the Great Lakes region.

The genetic variability that exists today in natural wild rice may be a critical determinant of whether stands of wild rice can adapt to long-term changes in regional climate. Studies in northern Wisconsin found sufficient genetic diversity among geographically distinct stands of natural wild rice to identify four regional populations. The degree of diversity within stands varied widely as well, with larger and denser stands having greater diversity (Waller et al. 2000).

Wild rice seeds are visible two weeks after fertilization, and they mature in four to five weeks. Immature seeds have a green outer layer that typically turns purplish black as the seed reaches maturity. Seeds begin ripening at the top of the stem and then ripen over several days on an individual plant. Plants within a stand ripen at different times because of genetic and developmental variation. In general, natural wild rice in rivers ripens earlier than that in lakes, rice in shallow waters earlier than that in deeper waters, and rice in northern Minnesota earlier than that in more southerly stands.

This staggered maturation process means that ripe seeds may be available within individual stands for several weeks, and across the entire range of natural wild rice in Minnesota for a month or longer. This extended period of “shattering”, or dropping of ripened seed, is an

important mechanism to ensure that some seeds will survive environmental conditions and perpetuate the natural stand. The entire process, from germination of a new plant to dropping of mature seeds, requires about 110 to 130 days, depending on water and air temperatures and other environmental factors.

Not all wild rice seeds germinate the following year. Seeds may remain dormant in the bottom sediment for many years to several decades if conditions are not suitable for germination. This mechanism allows wild rice populations to survive through years of high water levels or storms that reduce or eliminate productivity. Moreover, natural wild rice can germinate and re-colonize sites after other species have been reduced or eliminated by environmental disturbance (Meeker 2000).

Even under ideal growing conditions, populations of natural wild rice undergo approximately three to five year cycles in which productivity can vary greatly (Jenks 1900, Moyle 1944b, Pastor and Durkee Walker 2006, Durkee Walker et al. 2006). Highly productive years are frequently followed by a year of low productivity, that is then followed by a gradual recovery in wild rice yield (Moyle 1944b, Grava and Raisanen 1978, Atkins 1986, Lee 1986, Aiken et al. 1988, Archibold et al. 1989).

Recent studies suggest that oscillations in wild rice productivity may be caused in part by the accumulation of old straw from previous growth that inhibits plant growth and seed production (Pastor and Durkee Walker 2006, Durkee Walker et al. 2006). In particular, the amount of wild rice straw, its stage of decay, and its tissue chemistry likely affect nutrient availability, influence wild rice productivity, and thus drive cycling of wild rice populations (Durkee Walker, Ph.D. thesis 2008).

Legal Considerations

The earliest laws and regulations concerning wild rice in Minnesota date back more than 75 years. While some harvesting regulations existed through earlier session laws and statutes, comprehensive state regulation of the wild rice harvest was apparently first codified in 1939. These regulations controlled methods and locations of harvest to reduce damage to natural beds and to distribute the harvest.

Today, there is a complex mix of tribal, federal, state, and local laws and regulations. These are associated with the formal recognition of the significance of natural wild rice and its protection, management, and harvest. It is difficult to capture all the important details that exist within these myriad regulations in a summary overview. The application of regulations varies by jurisdiction (i.e., tribal versus state) and geography (i.e., on-reservation versus off-reservation, or within various ceded territories). In addition, some regulations may be changed over time.

The following discussion is not intended to provide a complete legal brief of the law as it relates to natural wild rice. Rather the intent is to indicate the complexity of this law and to make clear the multiple jurisdictions that have recognized legal interests in Minnesota wild rice.

Treaties and Tribal Regulations

Tribal regulations of the harvest and protection of wild rice within reservation boundaries vary from tribe to tribe. Therefore individual tribal governments or their natural resource departments should be contacted for details.

In addition to tribal regulations, treaties and other agreements with the U.S. government reserved off-reservation harvesting rights for some tribes. For example, the Ojibwe tribes that co-signed the Treaty of 1837 reserved the right to gather wild rice from the lands ceded in that treaty. These include an area that eventually became part of east-central Minnesota. The standing of these off-reservation rights was upheld by the U.S. Supreme Court in 1999.^{1,2,3}

Similar off-reservation rights are reserved for other Ojibwe tribes in the 1854 ceded territory, in northeastern Minnesota. Rights of traditional tribal harvesting have also been preserved through other agreements between tribes and the U.S. government. For example, in the early 1900s the U.S. began buying lands adjacent to wild rice stands on Minnesota lakes. These were stands that had traditionally been harvested or lands that were to be used as rice camps by the Minnesota Chippewa Tribe (MCT). Lands were purchased and placed into trust status on Swamp, Mallard and Minnewawa Lakes in Aitkin County; on Basswood Lake in Becker County; on Leech, Mud, and Laura Lakes in Cass County; on Lower Dean Lake in Crow Wing County; on Sugar and Bowstring Lakes in Itasca County; on Onamia and Ogechie Lakes in Mille Lacs County; and on Star Lake in Ottertail County.

MCT members can harvest wild rice on these lakes with a tribal identification card issued under the sovereign authority of their respective tribal governments and current Minnesota statute (MS 84.10). Similarly, local tribal members can harvest wild rice on Rice Lake National Wildlife Refuge and on Tamarack National Wildlife Refuge under the 1936 Collier agreement between the U.S. Bureau of Indian Affairs and Bureau of Biological Survey (predecessor to the U.S. Fish and Wildlife Service).

This Wild Rice Study document is not intended to provide an indepth analysis of treaties and subsequent agreements affecting tribal harvest of wild rice in Minnesota. Tribal governments have sovereignty over the harvest of wild rice within the boundaries of their reservations. Some tribal governments also have the authority to regulate harvest by tribal members within certain ceded lands, while other tribal rights exist for specific off-reservation waters. The state of Minnesota has jurisdiction over the wild rice harvest by nontribal harvesters within ceded territories and over all off-reservation wild rice harvest outside of the ceded lands.

^{1,2,3}[Minnesota, et al., Petitioners v. Mille Lacs Band of Chippewa Indians et al. [No. 97-1337].

² See McClurken et al., 2003: 30 for a map of ceded lands in Minnesota under this and subsequent treaties.

³ See McClurken et al., 2003: 486 for exact treaty language pertaining to cession of land and gathering wild rice.

State and Local Regulations

State laws addressing issues of wild rice in Minnesota date back to 1929 or perhaps earlier. These statutes state that wild rice and other aquatic vegetation is owned by the state and that a person may not acquire a property interest in or destroy wild rice except as allowed by law (MS 84.091). State statutes also regulate the harvest of natural wild rice with the exceptions of tribal jurisdictions and regulations, as noted above (MS 84.10, 84.15, 84.027, 84.28). State regulations address the methods and timing of natural wild rice harvest (MS 84.105, 84.111, and 84.152). In addition, several Agency rules also govern the harvest of wild rice in Minnesota (Minnesota Rules 6284.0300 to 6284.0700).

Because State statutes and rules affecting wild rice in Minnesota have been developed and modified over many years, they contain inconsistencies and duplications. These laws could be clarified and made more concise through recodification.

A long-standing tradition of tribal governments and the state of Minnesota involved posting of “closed” signage on selected individual lakes until the wild rice was deemed ripe for harvest. In 1996, after years of criticism from harvesters about particular decisions to open or close wild rice stands, a state law was passed that would open the ricing season on July 15 each year (MS 84.105). The new law also made it illegal to pick wild rice that is not ripe. Wild rice usually ripens in Minnesota between the third week of August and the second week of September, thus the new law was intended to employ a “pick when ripe” philosophy. The opening date was set early enough so that it would always precede the ripening of the rice, and it would also help avoid opening day rushes that can potentially damage rice stands.

One of the rationales behind the new state law was that most other plant products harvested from the wild are picked when the harvester judges them as ready for food, decorative, or medicinal use. Harvesting wild rice before it is ripe produces a product that has no value as a food or cash crop. The new law reduced the need for extensive MNDNR staff time and subjective judgments. It also helps avoid the opening day “stampede” that seems to be associated with all “opening days”, which are often perceived as the best day based on “first-come, first-served”.

Most of the treaties, agreements, and statutes discussed above are concerned with the harvest of the wild rice grain rather than with protection or enhancement of natural wild rice ecosystems. Harvest issues are moot if the wild rice resource is lost due to damage of natural stands. The viability of these stands often depends on active management.

For example, more than 200 wild rice lakes benefit annually from removal of beaver dams. These dams block the outlets of significant wild rice lakes, and their removal allows the outlets to flow freely; reducing the threat of excessive flooding of wild rice stands. The authority to remove beaver, beaver dams, and beaver lodges is found in MS 97A.045 Subd.1; 97A.401 Subd. 5; and 97B.655, Subd. 2. Without these statutes the current management efforts of the DNR and its partners (i.e., Ducks Unlimited) would be significantly restricted.

Wild rice and other aquatic plants are protected from unauthorized removal under the MNDNR Aquatic Plant Management Program (MS 103G.615). Guidelines prohibit the removal of

emergent aquatic plants, including wild rice, without an approved permit. Notable exceptions involve the building of duck hunting blinds and gaining access to open water from shorelines. Removal of aquatic plants is allowed for such access though removal is limited to an area 15 feet or less in width.

Less direct, although important, protection is also provided through shoreland protection laws and regulations (MS 103F.201 through 103F.221). This protection is based on a system of classification for lakes and rivers that applies different zoning regulations depending on classification. Classifications include three for lakes and six for rivers. These regulations are implemented by local units of government within a statewide statutory framework that dictates minimum standards. These standards address issues of shoreland development and uses such as sewage treatment, storm water management, minimum lot size and water frontage, building and septic system setbacks, building heights, subdivisions, and alterations of land and vegetation close to the shore.

The stakeholders group for a pilot project in the five-county north-central lakes area surrounding Brainerd raised concerns about increased shoreline development potentially threatening water quality and the traditional use of individual lakes. One result was the development of alternative shoreland management standards through an advisory committee. The alternative standards provide options for local governments to address specific shoreland issues identified in the five-county area. Subsequently, local governments outside the pilot area began considering elements of these alternative standards for use in their own shoreland ordinances.

In 2005, for example, Beltrami County initiated a review of all of their Natural Environment Lakes in cooperation with the MNDNR and Minnesota Pollution Control Agency (PCA). The MNDNR Section of Wildlife and Division of Ecological Resources procured funding to hire two 2-person crews to conduct site visits to inventory these lakes. Surveys were completed with additional funding from the MNDNR Section of Wildlife in 2006. As a result of this work and the input from a Citizen Advisory Committee, Beltrami County rewrote their shoreland ordinance and reclassified their Natural Environment Lakes. They created one additional lake class, Sensitive Area, with protection criteria intermediate between Natural Environment and the more protective Special Protection. The new Beltrami County Shoreland Ordinance was voted on and approved by the Beltrami County Board in December 2006 (R. Gorham personal communication).

Alternative shoreland management standards may include the promotion of conservation subdivisions over conventional subdivisions (i.e., lot and block); multiple classifications on a single lake (i.e. Natural Environment bay within a General Development lake); districts designated as Sensitive Areas for lakeshore segments so that development standards follow Natural Environment Lake class standards; and a new classification of Special Protection for lakes that have considerable wetland fringe, shallow depth, or unique fish and wildlife habitat.

While these alternative standards can provide protection for natural wild rice habitat, local governments too often lack information on the locations of significant stands of natural wild rice. An updated inventory of wild rice stands in Minnesota would help provide this information.

Further regulation of wild rice occurs through the Minnesota Department of Agriculture (MDA). The MDA has approval authority over the permit-regulated release of genetically modified organisms (GMO), which would include genetically engineered wild rice, under MS Chapter 18. MS Chapter 18 also provides for the issuance of export certificates for the international sale of wild rice. In addition, the MDA inspects and certifies that wild rice seed is free of weed contamination and meets germination standards, and that the labeling of packaged wild rice is truthful and accurate (MS Chapter 21).

The 2006 Minnesota Legislature provided the state Environmental Quality Board (EQB) additional authority over issues related to natural wild rice. The EQB is now required to notify interested parties if a permit to release genetically engineered wild rice is issued anywhere in the United States (MS 116C.92, Subd. 2). The 2006 legislation also requires that EQB adopt rules requiring an Environmental Impact Statement (EIS) for any proposed release and a permit for an actual release of genetically engineered wild rice (MS 116C.94 Subd.1b).

While two other State statutes further signify the importance of natural wild rice in Minnesota, they do not provide additional protection for the resource. One statute, adopted in 1977, recognizes wild rice as the State Grain of Minnesota (MS 1.148). This law needs to be amended, however, to accommodate revised scientific nomenclature.

Another important State statute is the labeling law for packaged wild rice (MS 30.49). This was adopted in 1989 following a joint effort between tribal governments and the Minnesota Cultivated Wild Rice Council. Consumers of wild rice benefit from this law in that it distinguishes among natural lake or river wild rice that is hand-harvested, wild rice that is machine-harvested, and wild rice that is cultivated. This legislation further distinguishes between wild rice that is grown in Minnesota and that which is grown outside of the state.

Threats to Natural Wild Rice in Minnesota

Despite its rich history and abundance in Minnesota, natural wild rice faces many current and potential threats in this region. In general, any factor that can affect water quality, seasonal water levels, lakebed conditions, regional climate, aquatic vegetation, or wild rice's natural genetic makeup could potentially threaten stands of natural wild rice. These threats may work in concert or individually to damage wild rice stands. The order in which the threats are presented in this report is not intended to portray or imply the significance of the threat. Instead these threats are divided into stand level or statewide level categories.

Stand-Level Threats

Hydrologic Changes

Wild rice is by its very nature a shallow water plant and sensitive to changes in water levels. The status of natural wild rice in Minnesota was particularly threatened in the late 1800s and 1900s by installations of dams to increase water levels for navigation, logging, flood control and power production. Although wild rice may persist at depths greater than three feet, these plants typically have poor or no seed production. Over time the plants will decline in numbers and density (Engel 1994). Although some aquatic plants will readily migrate to newly created shallow waters, wild rice apparently does so much less frequently. This may be due to limitations on its rate of seed dispersal.

Even when the normal runout elevation of a lake remains steady, heavy precipitation can cause an abrupt though temporary change in water level that can uproot aquatic plants. Natural wild rice is particularly susceptible to uprooting during its floating-leaf stage, which occurs in early summer. At this stage, any rapid increase in water level can cause damage to natural stands. Changes in lake outlets that reduce flow capacity can also significantly impact wild rice by increasing the frequency and severity of these temporary flood events. For example, permanent dams, beaver dams, culverts, and debris such as mats of vegetation can reduce outlet flow capacity and impact wild rice habitat (Ustipak 1983).

These factors can work in concert to produce cumulative effects. For example, culverts can attract beaver because the culvert is a much more restricted area than the creek or riverbed which channels through it. The roadbed often associated with culverts acts as a ready made dike that further contributes to the ease of blockage. As another example, dams and other outlets can be plugged by vegetation such as floating bogs that break loose in high winds. The effect of the dam in reducing outflows is compounded by the blockage raising water levels and increasing the probability of additional bog breaking off.

Changes in upstream watersheds can also reduce the productivity of natural wild rice stands. Drainage ditches and tiles, pumps, and channelization can increase the quantity and speed of waters moving downstream. The resulting peaks in water levels can produce the same effects as reduced outlet capacity by creating abrupt "bounces" or rapid increases in water depth. Increased sedimentation caused by drainage and channelization can also bury seeds and reduce germination.

Increased sedimentation can also increase the height of runout elevations and reduce outlet capacity. These changes can cause long-term damage to natural wild rice stands. The situation is exacerbated by the installation of artificial dams. Removing the natural flushing action at outlets causes sediment to accumulate more readily (R. Ustipak, personal communication).

Dams that maintain stable water levels can have long-term deleterious effects on natural wild rice, as well. Water levels that are held stable year after year can create conditions that favor perennial vegetation and shoreline encroachments that impair wild rice habitat.

Recreational Water Use and Shoreland Development

Natural wild rice represents different things to different people. While some consider this native aquatic grass to be a nuisance, others value it greatly as a spiritual entity or as prime habitat for fish and wildlife.

Minnesota is a national leader in numbers of recreational boaters and anglers, with approximately 862,937 registrations for recreational watercraft. Although wild rice provides habitat for spawning fish and their offspring, stands of wild rice can be very frustrating for anglers to fish. Recreational boaters often consider wild rice to be a nuisance because it can be difficult to motor through. The strong stems of erect plants are easily tangled in propellers and may require removal by hand, often by forcibly cutting the tightly wrapped stems.

As a result, wild rice plants are often removed by boaters near docks, in navigational channels, and in other high-use areas. Removal can be direct or incidental due to cutting by propellers or dislodging by excessive wave action (Asplund 2000, Tynan 2000).

As the human population increases, so will the number of boaters. Predictions of demographic changes in Minnesota suggest that the areas of greatest population increases over the next 20

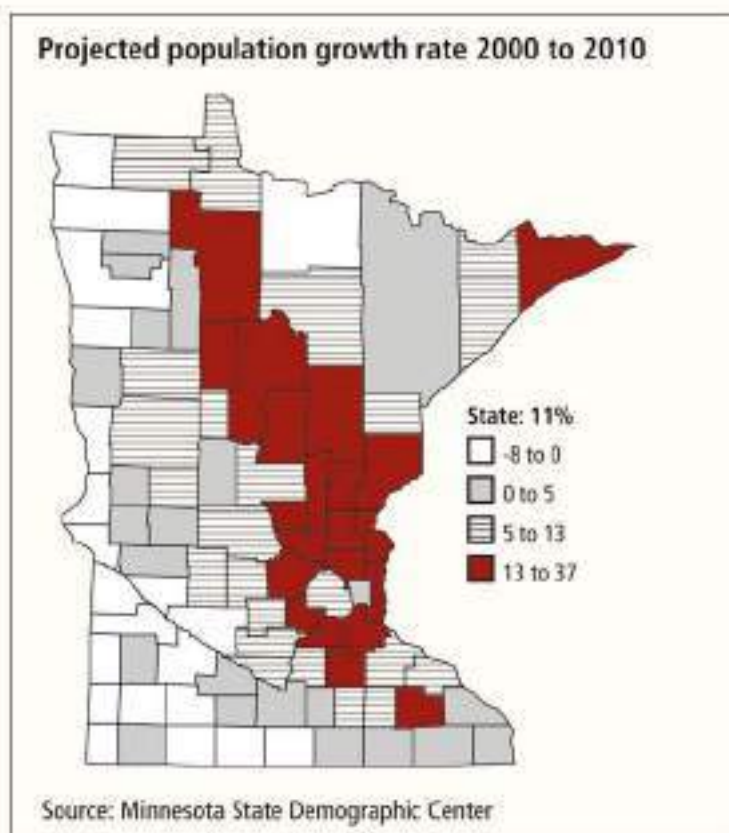


Figure 2. Greatest predicted population growth will occur within the primary range of wild rice in Minnesota.

years will include those counties that currently have the highest occurrence of natural wild rice (Figure 2, Minnesota Department of Administration 2007).

The damming of lakes to enhance recreational water use often corresponds with the increased development of shorelands. Shoreland development has increased dramatically in Minnesota, especially in those counties that include the greatest amount of habitat for natural wild rice. This development is often associated with installations of docks, removal of aquatic vegetation, and increases in nutrient-rich runoff.

Seasonal housing across the lake country of the upper Midwest jumped 500% during the past twenty years (United States Forest Service 2007). As lands bordering deeper lakes become more fully developed, prospective lakeshore buyers are increasingly considering lakes that are shallower, often well-vegetated, and more likely to support wild rice habitat.

The changing pattern of forestland ownership in Minnesota is adding to development pressure. Internationally-owned timber corporations are increasingly divesting of their land holdings as part of their fiscal management strategy. These lands have previously been managed somewhat as public lands and have been protected from development. However, as market values increase for shorelands and riparian areas, corporate stockholders are increasingly interested in selling these parcels. About seven million acres of forestland in Minnesota is privately owned, and predictions are that about one million of these acres may be sold for development (Myers 2006).

Such development often accompanies major changes in shorelines and near-shore vegetation (Radomski and Goeman 2001). Natural wild rice is often viewed only as a nuisance to boaters and other lakeshore users. Few shoreland owners consider the cumulative impacts of docks, vegetation removal, dredging, and runoff.

Although known violations of MNDNR Aquatic Plant Management permits do not always indicate which vegetative species were removed, wild rice is a common target where it occurs. A recent permit violation included the removal of 600 feet of natural wild rice from the shoreline of Upper Whitefish Lake in Crow Wing County. The violator was a new landowner who explained that the plants were an “eyesore”.

Wildlife Activity

Natural stands of wild rice provide excellent habitat for wildlife such as waterfowl and aquatic furbearers. The activities of these animals generally have minimal impact on wild rice stands. Although animals use plant stems for building overwater bird nests and muskrat houses, this activity usually affects only small areas. Moreover, wildlife activity often enhances overall aquatic habitat by creating stand diversity.

An exception to this is when beaver use wild rice stems and other vegetation to plug outlets. The resulting dam increases overall water levels and the probability of damage to natural stands by uprooting wild rice plants.

Birds generally have little impact on natural wild rice. For example, blackbirds, waterfowl and other birds can consume most of the ripening wild rice grain yet still leave more than 200 seeds per square foot (Haramis and Kearns 2004). Canada geese, though, can seriously damage stands of wild rice by grazing on emerging stems. For example, researchers monitored tidal marshes along the Patuxent River in Maryland and documented the loss of existing stands of wild rice due to season-long grazing by the geese (Haramis and Kearns 2004).

Although currently not common in Minnesota, some damage to rice stands has been attributed to Canada geese. High concentrations of geese on small lakes or impoundments have eliminated wild rice crops in some years through overgrazing of the emerging stems (R. Naplin and D. Rhode, personal communication). However, ongoing management of resident populations of Canada geese in Minnesota can limit this type of depredation through increased harvest levels. By contrast, shoreline development that converts communities of native vegetation to managed lawns can result in locally concentrated populations of geese that then may overgraze adjacent wild rice stands.

The effect of trumpeter swans on natural stands of wild rice is less clear. Populations of these native birds are slowly recovering after extirpation in the 1800s from most of their range. Anecdotal reports suggest that swans can damage natural stands of wild rice in particular areas (P. David and R. Naplin, personal communication). Nevertheless, low numbers of trumpeter swans combined with a preference for submergent vegetation suggest that these birds pose a minimal threat to natural wild rice (LaMontagne 2000, Norrgard 2006).

Some non-native species of wildlife do threaten stands of wild rice. These will be discussed below (Non-native Invasive Species section).

Plant Competition

Natural wild rice must compete for space, light, and nutrients with other aquatic plants, particularly perennial species (Rogosin 1951). Competitive species include submerged pondweeds (primarily *Potamogeton* L. spp.), floating leaved plants such as waterlilies (*Nuphar* J.E. Smith and *Nymphaea* L. spp.), and emergents such as cattail (*Typha* L. spp.) and pickerelweed (*Pontederia cordata* L.). Seasonal water levels play an important role in this competition (Meeker 2000). Natural wild rice may be favored at depths of one to two feet.

Pickerelweed may be an exception in at least three locations in Minnesota where ongoing management to benefit wild rice also found pickerelweed increasing significantly (N. Hansel-Welch, personal communication). Promising management responses have included lowering water levels in winter to freeze and desiccate pickerelweed roots, and cutting competitive species during spring and summer using airboats (McDowell, 2006) or harvesting machines (T. Howes, personal communication). However, maintaining stable water levels over many years may favor other species (D. Vogt, personal communication). Perennial species such as pickerelweed can establish footholds and thus gain the advantage in lakes that are maintained at constant levels.

The seeds of natural wild rice can remain dormant for years until conditions are more favorable for germination. This trait allows rice to maintain long-term viability through years of low

productivity. Natural wild rice is well-adapted to annual fluctuations in water levels, while other species may be less suited to such changes.

Strong competition among native aquatic plants appears to be localized and specific to individual stands. It does not appear to be a significant factor limiting the distribution or abundance of natural wild rice in Minnesota (Meeker 2000, Norrgard 2006).

Mining and Other Industrial Activity

Mining and industrial activities can potentially adversely affect stands of natural wild rice. For example, this can occur when hydrology is altered in watersheds that support natural wild rice. Alterations can result from the pumping and dewatering of sites. This increases downstream flows (discussed earlier in Hydrologic Changes section) and subsequent depressions in groundwater in surrounding areas. The potential effects of groundwater depression are not well understood. Water levels in basins with higher gradients could be sufficiently lowered to cause shallow areas inhabited by wild rice to dry out.

Other adverse effects can result from the release of chemicals such as sulfate from mine pits and tailings. These chemicals can negatively affect wild rice as well as other plant and animal species in the area. Seepages from tailings can exceed the state established water quality criteria of 10 mg/L for wild rice waters. For example, sulfate has been measured at 1,000 mg/L in these seepages (Udd 2007). State agencies are working with mining companies to decrease sulfate concentrations in discharge waters. Tribal governments express strong concern over the cumulative impacts of the many historic, currently operational, and planned mines in northeastern Minnesota.

Statewide Threats

Loss of Natural Genetic Characteristics

The cultural, ecological, and economic value of natural wild rice distinguishes it as a unique natural resource in Minnesota. There is strong agreement among stakeholders that it is critically important to maintain the natural genetic diversity of natural stands of wild rice (Porter et al. 2000, LaDuke and Carlson 2003). This importance reflects an understanding of spiritual and cultural values, biological and ecological principles, and agricultural and economic realities.

Natural population diversity provides wild rice the ability to adapt to changing environmental conditions such as annual variations in temperature and precipitation. Maintaining natural genetic diversity provides the best chance for any species to survive variations related to global warming, for example (BSU-CRI 2007). Ongoing analyses continue to support the position that managing for high biodiversity will best insure the survival of plant and animal communities that have characterized the Great Lakes region for thousands of years.

The flower structure and timing of maturation of wild rice promotes cross-pollination within and among stands. Wind pollination further insures genetic diversity. Genetic variability allows for the natural selection of traits that perform best under different environmental conditions. Studies

in Wisconsin found sufficient genetic diversity between distinct stands of natural wild rice to identify potentially distinct regional populations. The degree of diversity within the stands also varied widely, with larger and denser stands being most diverse (Lu et al. 2005, Waller et al., 2000). The degree of genetic variability within and among natural stands of wild rice in Minnesota is not known. Thus our ability to recognize changes in the genetics of natural wild rice in this region is limited.

Although some studies of wild rice pollen travel have been conducted (Cregan 2004), more research is needed to understand the potential for genetic transfer among natural and cultivated stands. Drift of wild rice pollen may exceed that of other cultivated crops due to the small size of the pollen and its relatively slow settling rate (P. Bloom, personal communication). In addition, a study in Canada has provided evidence that wild geese, and perhaps ducks, can be important transporters of pollen to lake sediments (McAndrews et al. 2007). This raises the possibility that waterfowl may also serve as transporters of viable pollen.

Another means of introducing new genotypes into local populations is the intentional seeding of wild rice to restore historical sites or to develop new stands. Such plantings have a long history in Minnesota. For example, the demand for seeds of wild rice and other native plants helped to establish businesses such as Wildlife Nurseries, Inc. in 1898, in Oshkosh, Wisconsin (Oelke 2007). However, the risks associated with introducing nonlocal genes into local native gene pools are of increasing concern to many scientists (Maki and Galatowitsch 2004).

Plant breeding programs have developed strains of wild rice suitable for commercial production (Oelke 2007). Consistency in plant morphology, control of shattering, and disease resistance have been important objectives of these programs. Because wild rice pollen is airborne, some have expressed concerns about unplanned cross-pollination between cultivated stands and natural stands. At this point in time, however, traditional wild rice breeding programs are not thought to pose a threat to natural stands since the cultivated varieties reflect the selection of genes from within the naturally occurring gene pool (R. Porter, personal communication).

There have been concerns expressed about the potential impact of transgenic engineering. The dramatic increase in use of this technique to alter food crops has been followed by questions concerning its safety, economic losses, potential impact on the natural environment, regulatory framework and compliance, and the ability to mediate unplanned releases. One of the driving forces behind these concerns is evidence that current gene containment practices cannot achieve absolute protection from unwanted pollination (Thai 2005). The unplanned cross-pollination between cultivated crops such as creeping bentgrass and wild relatives has fueled the concerns of both environmentalists and agricultural producers (Haygood et al. 2003, Weiss 2006).

These concerns are evident in the international guidelines for sustainable forest management developed by the Forest Stewardship Council (FSC). The state of Minnesota has actively sought certification of its public forestlands under the Regional Forest Stewardship Standards published by the council. These standards specifically prohibit the use of genetically modified organisms within certified forests (Minnesota Forest Resource Council 2004).

While there are no known research programs in any country to produce transgenic varieties of wild rice (R. Phillips, personal communication), DNA of wild rice has been transferred to white rice (Abedinia et al., 2000). The very possibility of transgenic engineering wild rice generates deep cultural, economic, and ecologic concerns. These include issues surrounding Native American rights, food safety and nutritional value, protection of economic markets, patenting of species, and protection of natural resources that already face significant threats (LaDuke and Carlson 2003).

This controversy ultimately relates to differing worldviews and the valuation of risk and consequences. For some stakeholders, there is no level of acceptable risk. For others, the potential benefits of genetically engineered wild rice may be worth the possible consequences of escaped transgenic traits. A thorough analysis of the cultural, economic, and ecological consequences of genetic contamination of natural wild rice in Minnesota is required to assess potential impacts.

Transgenic alterations of some U.S. crops will likely continue for the foreseeable future. Traditional plant breeding will also continue. A better understanding of the natural genetic variability of wild rice in Minnesota would increase our understanding of the potential impacts of these activities. Efforts to restore native wild rice to its historical range should be encouraged. Studies of the natural variability and ecological requirements of natural wild rice in this region would enhance these efforts.

Non-native Invasive Species

Non-native invasive species impact every aspect of natural resource management in Minnesota. Protecting and managing natural stands of wild rice is no exception. The movement of watercraft from one wild rice lake to another creates the potential for transfer of invasive animals and plants.

The common carp (*Cyprinus carpio*) leads the way in historical presence and impact. Common carp feed primarily on invertebrates in bottom soils. Their feeding action dislodges plants and suspends fine particles into the water column. The increased turbidity, caused both by disturbed sediments and by algae stimulated by the phosphorus released from disturbed sediments, shades out aquatic plants. Turbidity then increases as non-vegetated lake bottoms are disturbed by wind. The reduction in aquatic vegetation also allows for increased boat traffic and wave action that can further dislodge plants such as wild rice (Pillsbury and Bergey 2000).

Natural stands of wild rice are negatively impacted by turbid conditions during early stages of growth and by disturbances to bottom soils and boat traffic in later stages. The common carp is primarily a problem today in southern Minnesota, where the species occurs in high densities. Carp likely contributed to the loss of natural wild rice from its historic range in this region (Norrgard, 2006). If the predicted changes in climate in northern Minnesota result in warmer waters, carp could achieve higher densities in that region and cause significant damage within the core of prime habitat for natural wild rice.

The non-native rusty crayfish (*Orconectes rusticus*) can directly impact wild rice by cutting stems of the plant. Although the extent of this depredation in Minnesota is not known, significant impacts of native crayfish on cultivated wild rice have been documented (Richards et al. 1995). Native to parts of some states in the Great Lakes region, rusty crayfish have invaded portions of Minnesota, Wisconsin, and Ontario, including areas that are important for wild rice. Rusty crayfish frequently displace the native crayfish, reduce the diversity and abundance of aquatic plants and invertebrates, and reduce some fish populations (MNDNR 2007).

Rusty crayfish were first documented in Minnesota in 1967, at Otter Creek in southern Minnesota. Twenty years later, a statewide survey documented their presence in many areas (Helgen 1990). To date, rusty crayfish have been found in 31 lakes and streams in 11 counties. They prefer areas where rocks, logs, or other debris provide cover. Preferred sediment types include clay, silt, sand, gravel, and rock. The soft organic sediments usually favored by wild rice do not seem to be favored by rusty crayfish and may help minimize their impact.

The non-native mute swan (*Cygnus olor*) can seriously threaten the sustainability of natural wild rice stands (P. Wilson, personal communication). To date, Minnesota has limited the number of these birds to only a few that are held in captivity. With continued efforts to identify free-ranging non-native swans and to respond rapidly with control measures, their impact on natural wild rice in Minnesota could be minimal.

Invasive plants such as purple loosestrife (*Lythrum salicaria* L.), curlyleaf pondweed (*Potamogeton crispus* L.), and Eurasian water milfoil (*Myriophyllum spicatum* L.) occur throughout much of the range of natural wild rice. Although these species may prefer water depths that do not favor wild rice, more research is needed to better understand the potential for competition. It is known that these invasive species can disrupt local aquatic ecosystems and lower habitat quality overall. However, it is also important to monitor the mechanisms of control to insure that these do not have unintended effects on natural wild rice.

Hybrid cattail (*Typha x glauca*), a cross of native and non-native cattail (*Typha latifolia* L. and *Typha angustifolia* L., respectively), competes directly with natural wild rice for shallow-water habitat. These plants aggressively form thick mats of roots that can float as water levels fluctuate. The bog-like mats expand across areas of shallow water and can plug lake outlets when broken off and blown by high winds.

Native sedge bogs often border wild rice lakes in northern regions. These bogs are increasingly being invaded and eventually dominated by hybrid cattails. High infestations of hybrid or non-native cattails near lake outlets can increase rates of sedimentation. This, in turn, can combine with the additional plant material to further decrease outlet capacity (R. Ustipak, personal communication).

A relatively new threat to natural stands of wild rice is the non-native flowering rush (*Butomus umbellatus* L.). Found in similar habitats as native bulrush (*Scirpus* L. spp.), which it resembles, flowering rush can persist in either emergent or submergent forms. Though its distribution in Minnesota is limited, its range is expanding. Flowering rush spreads primarily through

rootstalks. At a site in Idaho, flowering rush was documented to be out-competing other plants such as willow (*Salix* L. spp.) and cattail (MNDNR 2007).

Another potential threat to natural wild rice in Minnesota is the non-native form of phragmites, or common reed [*Phragmites australis* (Cav.) Trin.]. While phragmites appears in fossil records for North America as early as 40,000 years ago, the non-native form was likely introduced in the late 1700s in ship ballast from Europe. Common reed has since dominated Atlantic coastal marshes and migrated landward, particularly during the 1900s. To date, the non-native form of common reed has invaded natural areas in 18 states including Wisconsin and other Great Lakes states. Although it is still rare in Minnesota, this exotic has been observed in a few disturbed sites in the Minneapolis-St. Paul area and in Duluth harbor (L. Skinner, personal communication).

Although phragmites can spread by seed, the most aggressive growth occurs through rhizomes. Non-native phragmites forms a dense network of roots that can reach several feet in depth. It spreads horizontally by sending out rhizome runners that can grow ten or more feet in a single season if conditions are favorable. Very dense stands are formed, that include live stems as well as standing dead stems from the previous year. The stems of non-native phragmites often reach 15 feet in height along the Atlantic coast.

In a recent study of phragmites in wetlands at Long Point, Lake Erie, researchers found that the occurrence of phragmites increased exponentially in the late 1990s. Of the 31 stands analyzed, 28 (90%) were dominated by the non-native strain (Wilcox et al. 2003). Part of the rapid expansion of the non-native form may be related to its ability to weaken the root structure of adjacent plants through the secretion of gallic acid, which attacks a structural protein (tubulin) in the roots of competing plants (Murray 2007).

Climate Change

The warming of the earth is now evident from measurements and observations. These include increases in average global air and ocean temperatures, widespread melting of snow and ice, and rising global sea levels. The average surface temperature of Earth has risen by about 1.3° F since 1850. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), published in 2007, projects that the average global surface temperature is likely to further increase by 3 to 7° F by the year 2100. This projection assumes a moderate level of action to reduce anthropogenic emissions of greenhouse gases.

According to the IPCC, the lower end of this range (i.e., a further warming of 3° F) represents a threshold for the earth beyond which irreversible and possibly catastrophic changes are likely. If the projections of global warming this century are met, most living things on Earth will likely face severe consequences.

What will predicted changes in climate mean for natural stands of wild rice in Minnesota?

Although climatologists agree that temperatures in this region will increase, predictions of precipitation vary (Figure 3, Kling et al. 2003). Some climate models predict that increasing temperatures will lead to increasing frequency and duration of droughts in the Dakotas and

western Minnesota. Hot, dry conditions can negatively impact the pollination of wild rice and thereby reduce its seed production.

Warmer temperatures will also reduce the severity of winters. The required cold temperature (35° F or less) dormancy of three to four months for wild rice seeds could be reduced, particularly in the southern portions of its range. In addition, warmer conditions often favor non-native species. In particular, warmer waters may increase the survival and spread of carp across Minnesota. Because wild rice lakes, rivers, and wetlands are interconnected, protection of wild rice habitat from carp could become very difficult.

Invasive species such as the non-native phragmites may also benefit from warmer temperatures. Many exotics, such as hydrilla [*Hydrilla verticillata* (L. f.) Royle] and water hyacinth [*Eichhornia crassipes* (Martius) Solms-Laub.] are limited by cold climates (Holm et al. 1977; Langeland 1996). Increased average temperatures may enable these extremely invasive non-native species to migrate and gain footholds in Minnesota. Species such as these could have severe impacts on wild rice waters.



Figure 3. Predicted climate change will effectively alter Minnesota to reflect the climate of states to the south.

The frequency of dewpoints above 70° F is already trending upward in Minnesota (Seeley 2007a). Warm, humid conditions support diseases of wild rice such as brown spot (*Bipolaris oryzae* Luttrell and *Bipolaris sorokiniana* Luttrell) and other pathogens. For example, high humidity and sustained warm overnight temperatures in early August 2007 promoted the development of brown spot in many natural wild rice stands in Minnesota. Estimated crop losses in some stands were 70 to 90% (R. Ustipak, personal communication).

There is strong agreement that global warming will result in increased severity of individual weather events (Seeley 2006). According to Dr. Mark Seeley, University of Minnesota climatologist, 2007 may be representative of the future conditions in Minnesota. In August 2007, the U.S. Department of Agriculture declared 24 Minnesota counties to be in severe drought and eligible for federal assistance. Also in August 2007, the Federal Emergency Management Agency declared seven counties in southeastern Minnesota to be flood disasters, also eligible for federal assistance (Seeley 2007b).

In nearly two hundred years of weather history, there are no records of such extremes occurring in the same month of the same year in Minnesota. Increasing severity of storm events will cause more flooding and hence more abrupt changes in lake levels during the growing seasons of wild rice and other aquatic vegetation. Natural wild rice will be particularly susceptible to damage while in the floating-leaf stage.

The southern edge of the range for natural wild rice may already be receding northward. While many factors have likely contributed to a decline in range of natural wild rice, climate may well be involved.

Lack of Recruitment and Retention of Harvesters

As Minnesotans have fewer positive experiences with natural wild rice through harvesting, hunting, trapping, or wildlife watching, they are less likely to recognize or have concerns about its potential loss. They are also less likely to appreciate the severe impacts that the previously noted threats could have on wild rice, and thus on the historic and culturally rich quality of life in Minnesota. This loss of appreciation, while not a direct threat to rice in itself, nevertheless increases the risks for wild rice because the level of resource protection and management is often based on its perceived value.

The protection and management of natural wild rice relies not only on tribes and agencies, but on the users of the resource, as well. Harvesters support management activities through the purchase of annual licenses. Because they have a personal stake in the future of natural wild rice in Minnesota, they are the ones most likely to report activities that are damaging the resource. Harvesters are also great advocates for natural wild rice. They promote its value within the ricing community and to the state as a whole.

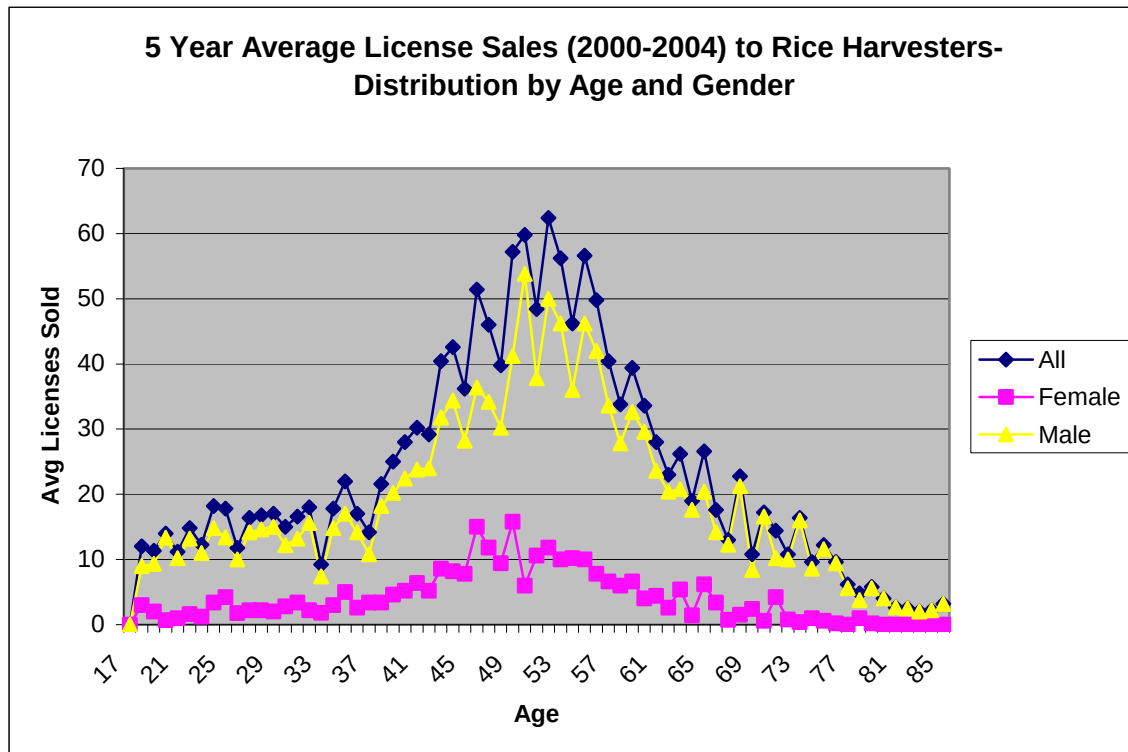


Figure 4. Age distribution of state licensed wild rice harvesters.

Wild rice harvesters are relatively few in numbers, though, and these numbers have declined over the last fifty years. During the 1960s, sales of state licenses in Minnesota averaged over 10,000 per year. Since 2000, these sales have averaged fewer than 1,500 annually. Harvesters under tribal regulations are not required to purchase a state license. Their numbers are estimated to exceed 3000 (R. Norrgard personal communication) and have likely experienced moderate increases in recent years (J. Persell, personal communication).

The MNDNR surveyed wild rice harvesters who purchased licenses from 2004 to 2006 to gather information on harvester characteristics and potential barriers to participation. This survey found that the majority of harvesters were male and at least 40 years old (82% and 81%, respectively). Figure 5 illustrates a similar age distribution from 2000 to 2004. Nearly all of the harvesters who responded had been introduced to wild rice harvesting by a friend or family member (87%).

Although most were satisfied with their harvest experience (82.3%), those surveyed identified several barriers to continuing this tradition. The most important barriers were time, knowing when to harvest, knowing where to harvest, and finding a wild rice processor. Other barriers included finding a ricing partner, physical challenges, financial expenses, finding a buyer, and having proper equipment.

Even for experienced harvesters, the difficulty of finding information on where and when to harvest can limit participation. For those living outside of natural wild rice areas, finding this information can be particularly difficult. For new harvesters, even finding a processor to finish the rice is a significant challenge.

Difficulty in acquiring harvest-related information may influence the distribution of harvesters and harvesting pressure on individual stands. The MNDNR 2006 survey revealed that only 25 lakes accounted for half of all harvesting trips. By contrast, the inventory of wild rice stands compiled for this document indicates that 119 lakes (100+ acres in size) account for more than half of the acreage of natural wild rice in Minnesota.

Addressing the educational or informational needs of Minnesotans interested in natural wild rice has been largely ignored. As with other natural resources in Minnesota, the lack of recruitment and retention of harvesters threatens the sustainability of natural wild rice in the state. Without readily available information and inspiring programs of education, public support of protection and management of the very resources that define Minnesota will likely decline.

Management Challenges

The future of natural wild rice in Minnesota will depend in large part on its protection and management by state and tribal natural resource agencies. The most important management issues relate to those threats identified in the previous section. The challenges that managers of natural wild rice face are further complicated because of limitations to their authority, inherent variability of wild rice production, and the need for additional information concerning wild rice in Minnesota.

Multiple Jurisdictions

Minnesota state statutes provide that ownership of wild rice and other aquatic vegetation is vested in the state (MS 84.091). State statutes also establish regulatory control over wild rice removal and harvest (MS 84.10, 84.15, 84.027, 84.28). Exceptions to state harvest regulations apply in geographic locations that are described by treaties and subsequent agreements, statutes, and rules (MS 84.10, MR 6284.0600 and 6284.0700). State and tribal enforcement officers often operate under temporary agreements until formal agreements are finalized.

The enforcement of harvest regulations in Minnesota is mainly stable and without major controversy. One issue still being discussed, however, is the posting of lakes as “closed” to wild rice harvest until it is determined that the grain is ripe. Both state and tribal governments have done this in the past on lakes that are popular with harvesters. In 1996, a new state law was passed that opened the ricing season on July 15 each year and made it illegal to pick rice that is not ripe (MS 84.105). Because wild rice usually ripens in Minnesota between the third week of August and the second week of September, the new law was intended to encourage a “pick when ripe” philosophy.

Most tribal governments have continued to post popular wild rice lakes within their jurisdictions. For many tribes, this practice is part of a long-standing tradition that relies on counsel provided by tribal committees. Tribes have urged the state to work cooperatively to post additional lakes. The position of the state, however, is that posting is unnecessary for the long-term health of the wild rice resource and the MNDNR currently has statutory authority only to post lakes as “closed” to “protect against undue depletion of the crop so as to retard reseeding or restocking of such area or so as to endanger its effective use as a natural food for waterfowl” (MS 84.15). In some cases, productive wild rice lakes are within both tribal and state jurisdictions. For these lakes, the differences in management philosophy have created conflicts between tribal and state agencies and with some harvesters.

Jurisdictional issues also arise over management of lake resources in general. Although the state of Minnesota has the responsibility of ownership of natural wild rice, the state includes many agencies, and each has its own mission and interest groups. No single agency or governmental entity in Minnesota assumes all of the responsibility for protecting natural wild rice. In public waters, the MNDNR takes the lead to regulate harvest and damage or removal of wild rice plants. Counties take the lead, within state statutory guidelines, to regulate shoreline development and most local recreational surface-water use. The Minnesota Pollution Control Agency regulates discharges to waters throughout the state; the Minnesota Department of

Agriculture assumes the lead for issues involving cultivated wild rice; and the state Environmental Quality Board has the lead responsibility to coordinate, notify, and evaluate any potential release of genetically engineered wild rice.

Within the MNDNR, the Division of Waters assumes the lead on shoreline regulations; the Division of Ecological Resources leads on aquatic plant management and invasive species; and the Division of Fish and Wildlife leads on habitat management for fisheries and wildlife values. The MNDNR Division of Enforcement is responsible for enforcement of natural resource regulations including the harvest of natural wild rice except when tribal regulations apply.

A formal, interdisciplinary planning process for Minnesota lakes does not exist. Lake management plans typically reflect the specific goals of the sponsoring entity. The plans often focus on aspects of either fisheries, wildlife, water quality, or vegetation without considering a comprehensive approach that addresses all of these components of a lake ecosystem.

Within Minnesota state statutes, there is no unifying policy of wild rice management that provides integration of these various agencies. By contrast, a unifying policy is clear regarding wetlands. Under public water laws, state statutes declare that it is in the public interest to increase the quantity, quality, and biological diversity of Minnesota's wetlands (MS 103A.201 subd. 2). A similar policy statement would help insure the sustainability of the natural wild rice resource in Minnesota.

Annual Crop Variability

Management by MNDNR and its conservation partners to maintain water levels beneficial to natural wild rice stands has never been greater. Water level monitoring, beaver control, debris removal, and invasive species management has annually taken place on more than 200 lakes and impoundments with significant wild rice stands. This management is based on the combined efforts of the Minnesota Department of Natural Resources, U. S. Fish and Wildlife Service, Ducks Unlimited, Tribal governments, and at least three lake associations. Much of the funding for these management efforts comes from the revenue generated by wild rice license sales.

Nevertheless, the expectations of those who value natural wild rice often exceed the capabilities of those responsible for protecting and managing this resource in Minnesota. A particularly difficult challenge for managers is the critical role that weather plays in wild rice development. Even when growing conditions have been exceptionally favorable, a single storm can reduce or even devastate the local harvest. At best, wild rice managers can “set the table” by maintaining free-flowing outlets or by setting appropriate runout elevations on water control structures. These management actions improve the harvest potential in good years and lessen the impact of poor conditions in less favorable years.

It can be easy for both user groups and managers to overlook the reality that natural wild rice has adapted to changing weather patterns through strategies that promote long-term survival rather than consistent annual abundance. The boom and bust cycle of natural wild rice has been recognized for centuries. This variation in annual productivity may be driven as much by seed dormancy and nutrient cycling as it is by variable weather. Resource managers, wild rice

harvesters, and other stakeholders must remember that productivity of natural wild rice is highly variable, both by stand and by year. Responsible management of this unique resource should strive to maximize its long-term sustainability in the Great Lakes region.

Information Needs

To effectively manage natural wild rice for future generations, resource managers need a better understanding of its natural ecology; its historical losses and patterns of abundance and distribution; threats to its sustainability; and the needs of harvesters.

While much has been learned about the ecology of wild rice over the last several decades, adequate information is still lacking on environmental tolerances and limiting factors such as water and sediment chemistry, seasonal water levels, and disturbance. This information will help create a better understanding of the historical reductions in wild rice distribution and provide much needed guidance for restoration of wild rice habitat.

In addition, a better understanding of ecological relationships in wild rice waters could guide strategies to counter threats such as mining and climate change. Improved ecological understanding would also provide much needed insight into the issues of invasive species. Of particular concern is the potential spread of carp, flowering rush, and exotic phragmites. Better assessments of the damage caused by rusty crayfish are needed as well.

Another concern is that basic information concerning the natural genetic makeup of native stands of wild rice is lacking. An understanding of the natural genetic variability of natural wild rice in the Great Lakes region and genetic drift between stands is critical. This information is needed to guide restoration efforts, particularly in the face of changing climate, and to help detect changes in diversity. We also need to better understand reproduction and its role in population genetics of natural wild rice.

More thorough information is needed on the distribution and overall acreage of natural wild rice in Minnesota. For this study, the MNDNR and the Wild Rice Study Technical Team revised and updated an earlier database of this information (Appendix B). While the recent revision is the most complete and detailed information of its kind for Minnesota, it still represents a gross estimate because information for many lakes, wetlands, rivers, and streams is incomplete or totally lacking. Further refinements and updates to this database are needed. In addition, refined methods are needed to improve the monitoring of annual productivity and the effects of management actions. This information would also help identify new opportunities for harvesters and better distribute harvesting pressure. With improved methods of monitoring and more complete databases, the overall health of the wild rice resource will be better managed.

Managers also need to better understand the harvesters of natural wild rice. What are annual trends? How can agencies and the wild rice community encourage retention of existing harvesters and recruit new people to continue this tradition? Who are the potential harvesters and what do they need in terms of ricing information, education, and support to be successful? The future of the wild rice resource in Minnesota may very well depend on the level of interest in its harvest and traditions.

Department of Natural Resources Recommendations

Introduction

This section is in response to the legislative request to include recommendations “on protecting and increasing natural wild rice stands in the state”. The following recommendations were developed with valuable input and discussion from the members of the Wild Rice Study Technical Team and Partnership Team. However, the Minnesota Department of Natural Resources assumes sole responsibility for these recommendations as written and presented here.

MNDNR recognizes the importance of protecting natural wild rice beds from genetic modification and agrees with wild rice stakeholders that this protection is critical to the future of this resource. We strongly support the Environmental Quality Board in adopting rules that require an environmental impact statement for a proposed release of genetically engineered wild rice (MS 116C.94 Subd.1b).

Recommendation 1

Recodify current wild rice harvest statutes and rules to remove duplication and inconsistencies.

Rationale: The state’s wild rice statutes and rules have been developed and modified piecemeal over a long period of time. As a result they contain a number of inconsistencies and duplication. Most of these changes relate to the harvest regulations (MS 84.27 – 84.91) although statutory recognition of wild rice as the state grain (MS 1.148) is also out of date in its nomenclature.

Recommendation 2

Establish statutory policy guidance on wild rice and its management.

Rationale: Within state statutes there is no unifying policy that provides direction to agencies responsible for some aspect of wild rice management. In contrast, the policy of the state is clear when it comes to wetlands. State statutes declare that it is in the public interest to increase the quantity, quality, and biological diversity of Minnesota's wetlands (MS 103A.201 subd. 2). A similar policy statement concerning natural wild rice would be useful guidance for state and local agencies. Suggested language includes “The legislature finds that natural wild rice in Minnesota provides public value by its contributions to fish and wildlife habitat, ecological diversity, environmental quality, recreational opportunities, cultural traditions, human sustenance, and economic well-being, and that it is in the public interest to protect existing natural wild rice stands, including their inherent genetic diversity, and restore wild rice to its historic range and abundance for its ecological, economic, and cultural values.”

Recommendation 3

The DNR will convene an interagency workgroup in 2008 to identify desired statutory updates in harvest regulations.

Rationale: Harvest regulations and license fee structure should be reviewed by an interagency work group for suggested changes that would work towards resolution of posting lakes closed to harvest and regulating reservation border lakes, as well as encouraging recruitment and retention of wild rice harvesters. Possible changes include broadening the use of funds deposited in the wild rice account to allow for information and education, removal of the season framework, adding a combination (spouse) license, extending special one-day license, providing special one-day mentored license for resident and nonresident participants in formal education programs, and establishing a special youth day when mentors are not required to have a license.

Recommendation 4

The DNR will designate and publish a list of important natural wild rice areas.

Rationale: Recognizing important wild rice areas and publishing the list would call attention to the importance of these areas, indicate management priorities, and provide a formal list that may prove useful for local units of government that are considering zoning and surface use restrictions.

Recommendation 5

The DNR will convene a standing interagency wild rice workgroup to share information and develop recommendations for inventory methodology and trend assessments, education and information outreach, lake planning and management, harvester recruitment and retention, and other management issues as they arise.

Rationale: Comprehensive protection and management of wild rice involves multiple agencies. Management needs include better inventory information including consistent methodology for trend analysis, documenting natural genetic diversity, and establishing long-term case studies on identified lakes. This information will encourage sound restoration strategies and help foster the development of interdisciplinary lake management plans. In addition, the workgroup should focus on developing outreach information for harvesters, shoreline owners, realtors, boaters, and outdoor educators.

Recommendation 6

Increase intensive natural wild rice lake management efforts and accelerate the restoration of wild rice stands within its historic range.

Rationale: Protecting and managing natural wild rice resources on many lakes requires active annual management activities to maintain free flowing outlets. The MNDNR works cooperatively with other agencies and nonprofit organizations such as Ducks Unlimited to accomplish this management. Tribal agencies also conduct independent management efforts on specific lakes. In recent years these efforts have improved wild

rice habitat on approximately 200 lakes and impoundments annually. Additional funding could expand accomplishments beyond current efforts.

The MNDNR has also been involved to a lesser extent in restoring wild rice to wildlife habitat areas within the historic range of natural wild rice. These efforts should be accelerated as funding, time, and opportunity permit.

Literature Cited

- Abedinia, M., R. J. Henry, A. B. Blakeney, and L. G. Lewin. 2000. Accessing genes in the tertiary gene pool of rice by direct introduction of total DNA from *Zizania palustris* (Wild Rice). *Plant Molecular Biology Reporter* 18:133-138.
- Ackley, F. 2000. Manoomin – A gift from the creator. Pages 8-10 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA
- Aiken, S. G., P. F. Lee, D. Punter, and J. M. Stewart. 1988. Wild rice in Canada. Agriculture Canada Publication 1830, NC Press Limited, Toronto, Ontario, Canada.
- Archibold, O. W., A. G. Good, and J. M. Sutherland. 1989. Annual variation in wild rice growth. *Canadian Journal Plant Science* 69:653-655.
- Asplund, T. R. 2000. The effects of motorized watercraft on aquatic ecosystems. Wisconsin Department of Natural Resources and University of Wisconsin, Publication PUBL-SS-948-00, Madison, USA.
- Atkins, T. 1986. The life history and ecology of wild rice. In *Wild Rice, The Natural Crop Conference*, 13-15 May 1986, Lakehead University, Minaki, Ontario, Canada.
- Benton-Banai, E. 1988. *The Mishomis book: the voice of the Ojibwe*. Indian Country Communications, Inc., St. Paul, Minnesota, USA.
- Carson, T. L. 2002. The effects of sediment nutrient variation, water depth, and emergent aquatic perennials on wild rice (*Zizania palustris*) production at the Rice Lake National Wildlife Refuge. Thesis, University of Minnesota, Minneapolis, USA.
- Cregan, J. 2004. Aspects of seed storage, pollen travel and population dynamics of wild rice (*Zizania palustris*). Thesis, University of Minnesota, Minneapolis, USA.
- Durkee W. R., J. Pastor, and B. W. Dewey. 2006. Effects of wild rice (*Zizania palustris*) straw on biomass and seed production in northern Minnesota. *Canadian Journal of Botany* 84:1019-1024.
- Durkee W. R. 2008. Thesis pending. University of Minnesota, Minneapolis, USA.
- Engel, S., and S. A. Nichols. 1994. Aquatic macrophyte growth in a turbid windswept lake. *Journal of Freshwater Ecology* 9(2): 97-109.
- Flora of North America Editorial Committee, editors. 1993+. *Flora of North America north of Mexico*. 12+ volumes. New York, USA and Oxford, UK.
- Forest Stewardship Council. 2004. *Regional Forest Stewardship Standard for the Lake States – Central Hardwoods Region*.

- Gleason, H.A., and A. Cronquist. 1991. Manual of vascular plants of northeastern United States and adjacent Canada, second edition. The New York Botanical Garden, Bronx, New York, USA.
- Grava, J., and K. A. Raisanen. 1978. Growth and nutrient accumulation and distribution in wild rice. *Agronomy Journal* 70:1077-1081.
- Haramis, G. M., and G. D. Kearns. 2004. Invasive Herbivory: resident Canada geese and the decline of wild rice along the tidal Patuxent River. Pages 37-38 in M. C. Perry, editor. *Proceedings of a Symposium: Mute Swans and Their Chesapeake Bay Habitats*. U. S. Geological Survey, Biological Resources Discipline Information and Technology Report USGS/BRD/ITR-2004-0005.
- Haygood, R., A. R. Ives, and D. A. Andow. 2003. Consequences of recurrent gene flow from crops to wild relatives. *Proceedings of The Royal Society London B* 270:1879-1886.
- Helgen, J. C. 1990. The distribution of crayfish in Minnesota. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report Number 405.
- Henderson, C. 1980. A Preliminary Atlas of Breeding Birds in Minnesota. Minnesota Department of Natural Resources, St. Paul, Minnesota
- Holm, L.G., D.L. Plucknett, J.V. Pancho, and J.P. Herberger. 1977. The world's worst weeds: distribution and biology. University Press, Hawaii, Honolulu. 609 pp.
- Huseby, J. T. 1997. Use of cultivated wild rice paddies and associated habitats by migrating and breeding waterfowl in northwest Minnesota. Dissertation, University of North Dakota, Grand Forks, USA.
- Jenks, A. E. 1900. The wild rice gatherers of the Upper Lakes: a study in American primitive economics. Pages 1013-1137 in *Nineteenth Annual Report of the Bureau of American Ethnology, 1897-1898*. Government Printing Office, Washington, D.C., USA.
- Kling, G., L. Johnson and S. Polasky. 2003. Confronting Climate Change in the Great Lakes Region. Impacts on Minnesota Communities. Union of Concerned Scientists and the Ecological Society of America. <http://www.ucsusa.org/greatlakes/glchallengereport.html>
- LaDuke, W., and B. Carlson. 2003. Our manoomin, our life: The Anishinaabeg struggle to protect wild rice. White Earth Land Recovery Project, Ponsford, Minnesota.
- LaMontagne, J. 2000. Use of migratory stopover areas by trumpeter swans in southern Alberta. Thesis. University of Calgary, Calgary, Alberta.
- Langeland, K.A. 1996. *Hydrilla verticillata*: "The perfect aquatic weed." *Castanea* 61:293-304.

- Lee, P. F. 1986. Ecological relationships of wild rice, *Zizania aquatica*. 4. Environmental regions within a wild rice lake. *Canadian Journal Botany* 64:2037-2044.
- Lee, P. F. 2000. Research and the conservation of wild rice. Pages 11-14 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Lee, P. F., and J. M. Stewart. 1983. Ecological relationships of wild rice, *Zizania aquatica*. 2. Sediment plant tissue concentrations. *Canadian Journal of Botany* 61:1775-1784.
- Lu, Y., D. Waller, and P. David. 2005. Genetic variability is correlated with population size and reproduction in American wild rice (*Zizania palustris* var. *paustris*, *Poaceae*) populations. *American Journal of Botany* 92:990-997.
- Maki, K., and S. Galatowitsch. 2004. Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. *Biological Conservation* 118(3):389-396.
- Martin, A. C., and F. M. Uhler. 1939. Foods of game ducks in the United States and Canada. U. S. Department of Agriculture Technical Bulletin 634. Wash., D.C.
- Martin, A. C., H. S. Zim, and A. L. Nelson. 1951. *American wildlife and plants*. Dover Publications. New York, New York.
- McAndrews, J. H. and C. L. Turton. 2007. Canada geese dispersed cultigen pollen grains from prehistoric Iroquoian fields to Crawford Lake, Ontario, Canada. *Palynology* 31: 9-18.
- McAtee, W. L. 1917. Propagation of wild duck foods. U. S. Department of Agriculture Bulletin 465. Government Printing Office, Washington, D.C.
- McDowell, M. 2006. Adaptive management of wild rice and pickerelweed at Rice Lake National Wildlife Refuge. Manoomin Niikaanisag Wild Rice Coalition Building and Conference, 8-11 August 2006, Watersmeet, Michigan, USA.
- Meeker, J. 2000. The ecology of "Wild" wild rice (*Zizania palustris* var. *palustris*) in the Kakagon Sloughs, a riverine wetland on Lake Superior. Pages 68-83 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Minnesota Department of Administration, State Demographic Center. 2007. Extrapolated population for Minnesota cities and townships outside the Twin Cities region, 2006 – 2035. <http://www.demography.state.mn.us> Accessed 25 Oct 2007.

- Minnesota Department of Natural Resources. 2006. Tomorrow's habitat for the wild and rare: an action plan for Minnesota wildlife, comprehensive wildlife conservation strategy. Minnesota Department of Natural Resources, Division of Ecological Services, St. Paul, USA.
- Minnesota Department of Natural Resources. 2007. Invasive species website. <http://www.dnr.state.mn.us/invasives/index.html>, St. Paul, Minnesota.
- Mississippi Flyway Council. 2005. Meeting Minutes, July 23-24, Robinsonville, MS.
- Moyle, J. B. 1939. The larger aquatic plants of Minnesota and the factors determining their distribution. Dissertation, University of Minnesota, Minneapolis, USA.
- Moyle, J. B. 1944a. Some chemical factors influencing the distribution of aquatic plants in Minnesota. *American Midland Naturalist* 34:402-420.
- Moyle, J. B. 1944b. Wild Rice in Minnesota. *The Journal of Wildlife Management* 8(3):177-184.
- Moyle, J. B. and P. Kueger. 1964. Wild Rice in Minnesota. *The Conservation Volunteer*. Nov. – Dec. pp. 30-37.
- Murray, M. 2007. Killer reed's lethal weapon discovered. *The News Journal*. 18 October 2007. www.delawareonline.com.
- Myers, J. 2006. Breaking up the forest. *Minnesota Conservation Volunteer*. January-February, http://www.dnr.state.mn.us/volunteer/janfeb06/breaking_up.html.
- Norrsgaard, R. 2006. An overview of threats to the future of wild rice conservation and management. Manoomin Niikaanisag Wild Rice Coalition Building and Conference, 8-11 August 2006, Watersmeet, Michigan, USA.
- Oelke, E. A. 2007. *Saga of the grain: a tribute to Minnesota cultivated wild rice growers*. Hobar Publications. Lakeville, MN.
- Oelke, E. A., P. R. Bloom, R. A. Porter, and Q. Liu. 2000. Wild rice plant development and seed physiology. Pages 54-67 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Oelke, E. A., W. A. Elliot, M. F. Kern Camp, and D. N. Noetzel. 1973. *Commercial production of wild rice*. University of Minnesota Agricultural Extension Service, Extension Folder 284. St. Paul, USA.
- Ownby, G. B., and T. Morley. 1991. *Vascular plants of Minnesota: a checklist and atlas*. University of Minnesota Press, Minneapolis, USA.

- Pastor, J., and R. W. Durkee Walker. 2006. Delays in nutrient cycling and plant population oscillations. *Oikos* 112(3):698-705.
- Peden, D. G. 1982. Factors associated with growth of wild rice in northern Saskatchewan. *Arctic* 35(2):307-311.
- Persell, J., and M. Swan. 1986. Wild rice ecosystems, a general description. Minnesota Chippewa Tribe Water Research Lab, Cass Lake, USA.
- Pillsbury, R. W., and E. A. Bergey. 2000. The effects of root mass and disturbance on wild rice (*Palustris aquatica*) survivorship. Pages 206-214 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Porter, R. A., R. L. Phillips, R. F. Nyvall, and E. A. Oelke. 2000. A genetic overview of wild rice from three decades of breeding. Pages 109-121 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Radomski, P., and T. J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. *North American Journal of Fisheries Management* 21:46-61.
- Richards, C., J. Gunderson, P. Tucker, and M. McDonald. 1995. Crayfish and baitfish culture in wild rice paddies. Natural Resources Research Institute, Technical Report NRRI/TR-95/39, University of Minnesota, Duluth, USA.
- Rogosin, A. 1951. An ecological history of wild rice. Minnesota Commission on Wild Rice. Minnesota Department of Conservation, St. Paul, USA.
- Rossman, G., A. Rossman, and R. Rossman. 1982. Recollections of 50 years: duck hunting in northern Minnesota. Northprint Company, Grand Rapids, Minnesota, USA.
- Schlender, J. H. 2000. Forward. *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Seeley, M. 2006. Minnesota weather almanac. Minnesota Historical Society Press, St. Paul, USA.
- Seeley, M. 2007. Climate change implications for Minnesota's tourism and recreation. Sustainable Tourism Conference presentation, 25 April, 2007, Chanhassen, USA.
- Stoddard, C. H. 1957. Utilization of waste swamplands for wild rice production. *Land Economics* 33(1):77-80.

- Stoudt, J. M. 1944. The food preferences of mallards in the Chippewa National Forest, Minnesota. *Journal of Wildlife Management* 8:110-112.
- Tester, J. R. 1995. Minnesota's natural heritage. University of Minnesota Press, Minneapolis, USA.
- Thai, W. 2005. Transgenic crops: the good, the bad, and the laws. *Minnesota Journal of Law, Science and Technology* 6(2):873-891.
- Tynan, T. 2000. Testing the effects of motorboats on wild rice (*Zizania palustris* var. *interior*). Pages 192-205 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Udd, Jeff. 2007. Correspondence from Jeff Udd, MN Pollution Control Agency, to Anne Jagunich, Minnesota Department of Natural Resources, Lands and Minerals Division, Hibbing, Minnesota, USA
- U. S. Forest Service. North Central Research Station - The changing Midwest assessment: percent change in density of seasonal housing units, 1980-2000. <http://www.ncrs.fs.fed.us/4153/deltawest/humandemo/seasonal001.asp>. Accessed 22 Oct 2007.
- Ustipak, R. 1983. Wild rice initiative. *Minnesota Waterfowl Assn. News*, Jan/Feb, Page 7.
- Valppu, S. H. 2000. Paleoethnobotanical investigations at the Big Rice Site: Laurel culture use of wild rice (*Zizania aquatica* L.) and associated radiocarbon dates. Pages 27-39 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Vennum, T. Jr. 1988. Wild rice and the Ojibway people. Minnesota Historical Society Press, St. Paul, USA.
- Walker, R.D., Pastor, J., Dewey, B.W. (2006) Effects of wild rice (*Zizania palustris* L.) straw on biomass and seed production in northern Minnesota. *Canadian Journal of Botany*, 84 (6): 1019-1024.
- Waller, D. M., Y. Lu, and P. David. 2000. Genetic variation among populations of wild rice (*Zizania palustris*). Pages 122-135 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Weiss, R. 2006. Gene-altered profit-killer: a slight taint of biotech rice puts farmers' overseas sales in peril. *Washington Post*. 21 September 2006.

Wilcox, K. L., S. A. Petrie, L. A. Maynard, and S. W. Meyer. 2003. Historical distribution and abundance of *Phragmites australis* at Long Point, Lake Erie, Ontario. *Journal of Great Lakes Research* 29(4): 664-680

Personal Communication Cited

- Bloom, P. R. 2007. Personal Communication. Department of Soil, Water and Climate. University of Minnesota. St. Paul, Minnesota, USA
- David, P. 2007. Personal communication. Wildlife Biologist. Great Lakes Indian Fish and Wildlife Commission. Ojibwe, Wisconsin, USA. USA
- Drewes, A. 2007. Personal communication. University of Wisconsin, Institute for Environmental Studies, Madison, Wisconsin, USA
- Gorham, R. 2007. Personal communication. Minnesota Department of Natural Resources, Wildlife Management Section, Area Wildlife Supervisor, Bemidji, Minnesota, USA
- Hansel-Welch, N. 2007. Personal communication. Minnesota Department of Natural Resources, Wildlife Management Section, Shallow Lakes Program Supervisor, Brainerd, Minnesota, USA
- Howes, t. 2007. Personal communication. Fond du Lac Reservation, Department of Resource Management, Natural Resources Manager, Cloquet, Minnesota, USA
- LaDuke, W. 2007. Personal communication. White Earth Land Recovery Project, Callaway, Minnesota, USA
- McDowell, M. 2007. Personal communication. Rice Lake National Wildlife Refuge, U. S. Fish and Wildlife Service, McGregor, Minnesota, USA.
- Naplin, R. 2005. Personal communication. Minnesota Department of Natural Resources, Wildlife Management Section, Area Wildlife Supervisor, Park Rapids, Minnesota, USA
- Norrgard, R. 2007. Personal communication. Minnesota Department of Natural Resources Wildlife Management Section, Wetland Wildlife Program, St. Paul, Minnesota. USA
- Persell, J. 2007. Leech Lake Band of Ojibwe, Division of Resource Management, Cass Lake, Minnesota, USA.
- Phillips, R. L. 2007. Personal communication. University of Minnesota, Department of Agronomy and Plant Genetics, Regents' Professor, St. Paul, Minnesota, USA
- Porter, R. A. 2007. Personal Communication. North Central Research and Outreach Center, University of Minnesota. Grand Rapids, Minnesota, USA
- Rhode, D. 2007. Personal communication. Minnesota Department of Natural Resources Wildlife Management Section, Carlos Avery Wildlife Management Area, Area Wildlife Supervisor, Anoka, USA.

- Robinson, R. 2007. Personal communication. Leech Lake Band of Ojibwe, Division of Resource Management, Director, Cass Lake, Minnesota, USA.
- Skinner, L. 2007. Personal Communication. Minnesota Department of Natural Resources, Division of Ecological resources, Invasive Species Unit Supervisor, St. Paul, Minnesota, USA
- Ustipak, R. 2007. Personal communication. Private Consultant, Brainerd, Minnesota, USA
- Vogt, D. 2007. Personal communication. 1854 Treaty Authority, Environmental Management Division, Environmental Biologist, Duluth, Minnesota, USA.
- Wilson, P. 2006. Personal communication. Little River Band of Ottawa Indians – Tribal Ogema, Manistee, Michigan, USA.

Appendix A

Natural Wild Rice Study Development Process

Scope: This study provided an information document on natural wild rice developed with conservation partner input, review, and possible endorsement. The document included the current location and estimated acreage and area of natural stands; potential threats to natural stands, including, but not limited to, development pressure, water levels, pollution, invasive species, and genetically engineered strains; and recommendations to the house and senate committees with jurisdiction over natural resources on protecting and increasing natural wild rice stands in the state.

Format: The final document was formatted to include an Executive Summary, Introduction, Background, Threats, Management Challenges, Recommendations, and Appendices.

Process: A Partnership Team was organized to review, comment, and consider endorsement of the planning process, interim draft of the document, and the final draft to be released for public review. DNR Assistant Commissioner Bob Meier chaired the Partnership Team. Invited members of the Partnership Team included representatives from other agencies and organizations including DNR Tribal Liaison Paul Swenson, the DNR Divisions of Ecological Services, Enforcement and Waters, MN Department of Agriculture, Board of Water and Soil Resources, Minnesota legislature (Representatives Frank Moe and Sondra Erickson), U. S. Bureau of Indian Affairs, U. S. Fish and Wildlife Service, U. S. Natural Resources and Conservation Service, Minnesota Chippewa Tribe, Tribal representatives, Ducks Unlimited, MN Wild Rice Council, Minnesota Waterfowl Association, Save Our Rice Alliance, Minnesota Waters, and the Association of Minnesota Counties. The Partnership Team was offered the opportunity to submit dissenting reports to be included in the appendices.

A Technical Team was organized to propose the document development process, develop the draft document and incorporate revisions as the process proceeded. DNR Wetland Wildlife Program Leader Ray Norrgard chaired the team and assumed the role of lead writer. Invited members of the Technical Team will include DNR wildlife field staff Gary Drotts, Ann Geisen, Shelley Gorham, Beau Liddell, Rob Naplin and Regional Enforcement Supervisor Ken Soring, along with Michelle McDowell (Fish and Wildlife Service), Becky Knowles (Leech Lake Department of Resource Management), Rod Ustipak (Consultant), Jon Schneider (Ducks Unlimited), MN Wild Rice Council (Beth Nelson and Jon Dokter), Rachel Walker (University of Minnesota – St. Paul), Dr. Ron Phillips (University of Minnesota – St. Paul), Dr. Raymie Porter (University of Minnesota- Grand Rapids), Annette Drewes (University of Wisconsin), Thomas Howes (Fond du Lac Reservation), Darren Vogt (1854 Authority), Steve Smith and John Persell (Minnesota Chippewa Tribe), Mike Swan (White Earth Reservation), Andrea Hanks (White Earth Land Recovery Project), and Peter David (Great Lakes Indian Fish and Wildlife Commission).

Timelines: The process began with the passage of the 2007 legislative request and will end with a completed report to the legislature by February 15, 2008. The Technical Team met on August 14, 2007 to develop the final draft of the proposed document development process, and a draft outline of the final document. The Technical Team communicated by email and followed up with meetings on November 13, 2007 and January 7, 2008. The draft study document underwent 10 revisions in all. The Partnership Team met on September 19 and December 3, 2007 to review

the Technical Team's proposals. Review of the final working draft of the study document was conducted by mail. The final document will be presented to the legislature by February 15, 2008. Copies of the final document will be posted on the MNDNR website and available upon request through DNR regions and central office.

Partnership Team Roster

Organization	Name	Title
Association of Minnesota Counties	Anna Lee Garletz	Policy Analyst
Bois Forte DNR	Cory Strong	Commissioner
Bureau of Indian Affairs	Bob Jackson	
Clearwater County	Tom Anderson	County Commissioner
DNR Commissioner's Office	Bob Meier	Asst Commissioner/Policy
DNR Division of Ecological Resources	Lee Pfannmuller (Donna Perleberg)	Director
DNR Division of Enforcement	Mike, Hamm	Director
DNR Division of Waters	Kent, Lokkesmoe	Director
DNR Northwest Region Office	Paul Swenson	Tribal Liaison
Ducks Unlimited	Ryan Heiniger	Director, Cons Programs
Fond du Lac Resource Management	Reginald Defoe (Tom Howes)	Director
Grand Portage Tribal Council	Norman Deschampe	Chairman
Leech Lake DRM	Rich Robinson	Director
Mille Lacs Natural Resources	Curt Kalk	Commissioner
Minnesota Chippewa Tribe	Gary Frazer	Executive Director
Minnesota Legislature	Sondra Erickson	State Representative
Minnesota Legislature	Frank Moe	State Representative
Minnesota Waters	Bruce Johnson	Executive Director
Minnesota Wild Rice Council	Beth Nelson (Peter Imle, Ken Gunvalson)	President
MN Board of Water & Soil Resources	John Jaschke (Greg Larson)	Executive Director
MN Department of Agriculture	Gene, Hugoson (Chuck Dale, Chuck Dryke, Geir Friisoe)	Commissioner
MN Valley National Wildlife Refuge	Jim Leach (Barb Boyle)	Director
MN Waterfowl Association	Brad Nylin	Executive Director
Natural Resources Conservation Service	Bill Hunt	State Conservationist
Red Lake DNR	Al Pemberton	Director
Save Our Rice Alliance	Richard Draper	
White Earth DNR	Mike Swan (Doug McArthur)	Director
White Earth Land Recovery Project	Winona LaDuke	Founding Director

Technical Team Roster

First Name	Title	Organization
Peter David	Wildlife Biologist	Great Lakes Indian Fish and Wildlife Commission
Jon Dokter	Associate Director	Wild Rice Council
Annette Drewes	Ph.D Candidate Environmental Studies	University of Wisconsin-Madison Save Our Rice Alliance
Gary Drotts	Area Wildlife Supervisor	MN Department of Natural Resources
Ann Geisen	Wildlife Shallow Lakes Specialist	MN Department of Natural Resources
Shelley Gorham	Area Wildlife Supervisor	MN Department of Natural Resources
Andrea Hanks	Wild Rice Campaign Coordinator	White Earth Land Recovery Project (WELRP)
Tom Howes	Natural resources Manager	Fond du Lac Department of Resource Management
Becky Knowles	Plant Ecologist	LLBO DRM-Fish, Wildlife, and Plants
Beau Liddell	Area Wildlife Supervisor	MN Department of Natural Resources
Doug McArthur	Biologist	White Earth Dept. of Natural Resources
Michelle McDowell	Wildlife Biologist	Rice Lake National Wildlife Refuge
Rob Naplin	Area Wildlife Supervisor	MN Department of Natural Resources
Beth Nelson	President	Wild Rice Council
Ray Norrgard	Wetland Wildlife Program Leader	MN Department of Natural Resources
John Persell	Biologist	LLBO DRM-Fish, Wildlife, and Plants
Ron Phillips	Regents Professor	University of Minnesota
Raymie Porter	Research	University of Minnesota
Jon Schneider	Manager MN Conservation Programs	Ducks Unlimited
Steve Smith	Acting Director - Water Quality	Minnesota Chippewa Tribe
Ken Soring	NE Regional Enforcement Supervisor	MN Department of Natural Resources
Mike Swan	Director	White Earth Dept. of Natural Resources
Rod Ustipak	Consultant	
Darren Vogt	Wildlife Biologist	1854 Treaty Authority
Rachel Walker	Ph.D Candidate Water Resources	University of Minnesota

Appendix B

Wild Rice Distribution and Abundance in Minnesota

EXECUTIVE SUMMARY

Project Leader

Gary Drotts

Minnesota Department of Natural Resources

Area Wildlife Supervisor - Brainerd

Purpose

To further the understanding of natural wild rice distribution and abundance in Minnesota, Minnesota Department of Natural Resources (MNDNR) staff and other Technical Team members of the Natural Wild Rice in Minnesota Legislative Study undertook an effort to consolidate and update existing natural wild rice inventory information. The following objectives guided inventory design and development.

1. Consolidate various data/information on the location (i.e. lake, wetland, or river segment) of natural wild rice stands in Minnesota.
2. Determine size and natural wild coverage for each location.
3. Determine type of water level management structure (if present) on each location and primary management authority.
4. Document Tribal, Treaty and/or State authority for each location.
5. Determine natural wild rice harvest potential, harvest pressure, and access for each location.
6. Provide a starting point for a useable data framework/information system for the long-term protection, management and monitoring of natural wild rice in Minnesota.

Methods

An existing dataset (Microsoft Access) maintained by the MNDNR Shallow Lake Program provided the starting point for this effort. This dataset originated in the late 1980's based on a review and consolidation of the best existing data sources at that time (i.e. MNDNR Enforcement wild rice lists, tribal rice camps, etc.) followed up with field interviews to MNDNR Area Wildlife and Tribal offices in the primary natural wild rice range. This initial assessment found over 700 lakes in 31 counties totaling 1.5 million basin acres contained approximately 61,000 acres of natural wild rice.

Since this initial dataset was formed, various MNDNR, federal, treaty and tribal authorities have accomplished a significant amount of additional inventory work. This information was reviewed, consolidated and added to the initial dataset and sent out for review to MNDNR Area Wildlife and Treaty/Tribal authorities for their comments and input. Return information was entered into a finalized dataset.

Primary information collected consisted of a location (i.e county, basin name), basin area and estimated natural wild rice coverage. For basins having a significant stand of natural wild rice, additional information was requested as to: water level management restrictions (i.e. dam at outlet); general wild rice location within the basin; treaty/tribal authority; and harvest potential, pressure and access.

Information sources

Information sources included the following:

- Minnesota DNR – initial survey data, 2006 Wild Rice Harvesters Survey, Fisheries lake surveys, Wildlife/shallow lake surveys, aquatic plant management permits, and aquatic plant survey data from Ecological Resources.
- Treaty/Tribal - 1854 Treaty Authority, Great Lakes Indian Fish and Wildlife Commission, Fond Du Lac Indian Reservation, Mille Lacs Indian Reservation, Leech Lake Indian Reservation, and, White Earth Indian Reservation.
- U.S. Fish and Wildlife Service, National Wildlife Refuge System

Results

Inventory results note that stands of natural wild rice were present or occurred in recent history on 1,292 lakes or river/stream segments in Minnesota. Of these 1,286 locations, 777 have information on natural wild rice coverage, which totals approximately 64,328 acres. The remaining 509 locations that currently do not have coverage information are primarily small lakes/wetlands on the edge of the current natural wild rice range (southern and western Minnesota) or river/stream segments.

On a county basis, the greatest concentration of natural wild rice locations is in St. Louis (8,939 acres), Itasca (8,448 acres), Cass (8,323 acres), Aitkin (4,859 acres), and Crow Wing (3,751 acres). These five counties contain over 60% of the inventoried natural wild rice acreage in Minnesota.

Recommendations

- This inventory should be considered a work in progress. Further edits and review are needed, especially for small lakes/wetlands on the edge of current natural wild rice range and the numerous river/stream segments that may have been missed in this inventory.
- A procedure to review and update this inventory on a regular basis (every 5-10 years) should be undertaken.
- Information gathered on harvest potential, pressure and access to these natural wild rice locations should be listed/posted on appropriate web sites (i.e. MNDNR web site).

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Aitkin	Aitkin	01004000	850	298
Aitkin	Anderson	01003100	97	30
Aitkin	Bear	01006400	127	1
Aitkin	Big Sandy	01006200	9,380	94
Aitkin	Birch	01020600	449	5
Aitkin	Blind	01018800	323	39
Aitkin	Brown	01007800	97	34
Aitkin	Camp	01009800	127	30
Aitkin	Clear	01010600	123	20
Aitkin	Cornish Pool	01042700	600	30
Aitkin	Davis	01007101	76	30
Aitkin	Deer	01008600	47	3
Aitkin	Elm Island	01012300	656	30
Aitkin	Farm Island	01015900	2,025	20
Aitkin	Fleming	01010500	326	1
Aitkin	Flowage	01006100	720	432
Aitkin	Gun	01009900	735	60
Aitkin	Hammal	01016100	376	1
Aitkin	Hay	01005900	133	1
Aitkin	Hickory	01017900	183	10
Aitkin	Jenkins	01010000	127	1
Aitkin	Jewett State WMA - Impoundment	01038300	180	30
Aitkin	Johnson	01013100	27	6
Aitkin	Killroy	01023800	23	4
Aitkin	Kimberly State WMA - Lower Pool	01043300	300	30
Aitkin	Kimberly State WMA - Upper Pool	01041100	900	76
Aitkin	Krilwitz	01IMP002	30	6
Aitkin	Lily	01008800	50	2
Aitkin	Little Hill River State WMA - Pool 1	01043300	135	18
Aitkin	Little McKinney	01019700	26	6
Aitkin	Little Pine	01017600	126	1
Aitkin	Little Prairie	01001600	78	1
Aitkin	Little Red Horse Lake	01005200	32	3
Aitkin	Little Willow River State WMA - Upper Pool	W0642001	50	20
Aitkin	Little Willow State WMA - Lower Pool	01033200	140	50
Aitkin	Mallard	01014900	354	320
Aitkin	Mandy	01006800	107	27
Aitkin	Minnewawa	01003300	2,451	130
Aitkin	Monson	01012600	48	25
Aitkin	Moose	01014000	148	117
Aitkin	Moose River	01r4		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Aitkin	Moose Willow State WMA - Moose Pool	01035800	900	89
Aitkin	Moose Willow State WMA - Willow Pool	01043100	300	50
Aitkin	Moulton	01021200	282	1
Aitkin	Mud (Grayling Marsh WMA, pool 1)	01002900	400	1
Aitkin	Mud (Little White Elk)	01019400	135	68
Aitkin	Nelson	01001000	71	1
Aitkin	Newstrom	01009700	97	76
Aitkin	Pine	01000100	391	4
Aitkin	Portage	01006900	387	5
Aitkin	Prairie River	01r6		
Aitkin	Rat	01007700	442	45
Aitkin	Rat House	01005300	122	100
Aitkin	Red	01010700	97	4
Aitkin	Rice	01000500	83	50
Aitkin	Rice (Big)	01006700	3,635	1,700
Aitkin	Rice River	01r1	190	25
Aitkin	Ripple	01014600	676	50
Aitkin	Ripple River	01r3		
Aitkin	Rock	01007200	366	50
Aitkin	Round	01013700	634	1
Aitkin	Salo Marsh State WMA - Pool	01041500	690	76
Aitkin	Sanders	01007600	55	36
Aitkin	Sandy River	01006000	368	200
Aitkin	Sandy River	01r2		
Aitkin	Savanna	01001400	86	1
Aitkin	Savanna River	01r5		
Aitkin	Section Ten	01011500	440	52
Aitkin	Section Twelve	01012000	167	1
Aitkin	Shovel	01020000	230	207
Aitkin	Sissabagamah	01012900	386	39
Aitkin	Sitas	01013200	59	5
Aitkin	Sixteen	01012400	18	1
Aitkin	Sjodin	01031600	43	28
Aitkin	Spectacle	01015600	107	1
Aitkin	Spirit	01017800	523	26
Aitkin	Split Rock	01000200	27	1
Aitkin	Spruce	01015100	80	80
Aitkin	Steamboat	01007102	59	15
Aitkin	Stony	01001700	52	5
Aitkin	Sugar	01008400	23	1
Aitkin	Sugar	01008700	416	1
Aitkin	Swamp	01009200	270	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Aitkin	Tamarack River	01r7		
Aitkin	Twenty	01008500	153	119
Aitkin	Unnamed (L. Wolf)	01002000	19	1
Aitkin	Unnamed (Rice)	01041900	16	1
Aitkin	Unnamed (Round Lake Pothole)	01028500	15	12
Aitkin	Unnamed (Upper Blind)	01033100	14	3
Aitkin	Unnamed (W. Washburn)	01026200	14	1
Aitkin	Washburn	01011100	73	4
Aitkin	Waukenabo	01013600	819	49
Aitkin	West	01028700	51	20
Aitkin	White Elk	01014800	780	350
Anoka	Carlos Avery WMA - Pool 1	W9001001	180	15
Anoka	Carlos Avery WMA - Pool 13	W9001013	586	2
Anoka	Carlos Avery WMA - Pool 14	W9001014	749	15
Anoka	Carlos Avery WMA - Pool 15	W9001015	365	1
Anoka	Carlos Avery WMA - Pool 16	W9001016	67	
Anoka	Carlos Avery WMA - Pool 17	W9001017	185	
Anoka	Carlos Avery WMA - Pool 2	W9001002	683	20
Anoka	Carlos Avery WMA - Pool 22	W9001022	141	10
Anoka	Carlos Avery WMA - Pool 23	W9001023	1,600	
Anoka	Carlos Avery WMA - Pool 24	W9001024	35	2
Anoka	Carlos Avery WMA - Pool 26	W9001026	200	5
Anoka	Carlos Avery WMA - Pool 3	W9001003	186	120
Anoka	Carlos Avery WMA - Pool 5	W9001005	52	25
Anoka	Carlos Avery WMA - Pool 6	W9001006	200	1
Anoka	Carlos Avery WMA - Pool 7	W9001007	240	3
Anoka	Carlos Avery WMA - Pool 9	W9001009	269	120
Anoka	Carlos Avery WMA - Pool 9(2)	W9001011	71	30
Anoka	East Twin	02002000	171	1
Anoka	Grass	02011300		
Anoka	Grass	02009200		
Anoka	Hickey	02009600	41	
Anoka	Little Coon	02003200	486	10
Anoka	Pickerel	02013000	303	25
Anoka	Rice	02000800		
Anoka	Rice	02004300		
Anoka	Rice Creek	02r1		
Anoka	Rondeau	02001500	552	
Anoka	Rum River	02r2		
Anoka	Swan	02009800	273	33
Anoka	West Twin	02003300	18	
Becker	Abners	03003900	100	80

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Becker	Albertson	03026600	73	
Becker	Aspinwall	03010400	178	18
Becker	Axberg	03066000	47	
Becker	Balsam	03029200	148	10
Becker	Bass	03048000	28	
Becker	Bass	03008800	208	10
Becker	Bean	03041100	19	
Becker	Big Basswood	03009600	586	304
Becker	Big Rat	03024600	1,102	110
Becker	Big Rush	03010300	1,128	20
Becker	Blackbird	03019700	284	42
Becker	Blueberry	03000700	160	2
Becker	Booth	03019800	48	43
Becker	Buffalo	03035000	444	89
Becker	Bullhead	03031200	39	6
Becker	Bush	03021200	110	40
Becker	Cabin	03034600	38	
Becker	Camp Seven	03015100	78	8
Becker	Carman	03020900	217	30
Becker	Chippewa	03019600	960	288
Becker	Dahlberg	03057700	77	
Becker	Dead	03016000	296	
Becker	Dinner	03004400	53	11
Becker	Eagen	03031800	85	
Becker	Equay	03021900	73	7
Becker	Flat	03024200	1,970	197
Becker	Gull Creek	03r2		
Becker	Gyles	03006600	42	16
Becker	Halverson	03041200	18	
Becker	Height of Land	03019500	3,943	197
Becker	Hubbel Pond	03024000	561	168
Becker	Indian Creek Imp.	03r4		
Becker	Johnson	03019900	181	40
Becker	Kneebone	03009000	149	15
Becker	Little Basswood	03009200	105	31
Becker	Little Dinner	03004500	12	5
Becker	Little Flat	03021700	235	211
Becker	Little Mud	03002200	25	6
Becker	Little Rice	03023900	110	21
Becker	Little Round	03030200	565	
Becker	Lower Egg	03021000	171	75
Becker	Lyman WPA	03IMP003		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Becker	Manomin Creek	03r5		
Becker	Mary Yellowhead	03024300	68	7
Becker	Mud	03012000	170	
Becker	Mud	03002300	85	42
Becker	Mud	03006700	88	83
Becker	Mud	03001600	86	
Becker	Ottertail River	03r1		
Becker	Pearl	03048600	268	
Becker	Rice	03028500	51	
Becker	Rice	03017300	37	
Becker	Rice	03029100	245	196
Becker	Rice	03020100	245	245
Becker	Rock	03029300	1,198	240
Becker	Round	03015500	1,094	
Becker	Schultz	03027800	103	82
Becker	Shell	03010200	3,147	169
Becker	Shipman	03000500	71	1
Becker	Spindler	03021400	185	125
Becker	Tamarack	03024100	2,227	245
Becker	Tamarack NWR - Ogemash Pool	03IMP002	71	20
Becker	Tea Cracker	03015700	122	30
Becker	Town	03026400	117	35
Becker	Trieglaff	03026300	111	56
Becker	Twin Island	03003300	71	5
Becker	Two Inlets	03001700	643	40
Becker	Unnamed	03008700	23	
Becker	Unnamed	03060000	59	
Becker	Unnamed	03059800	36	
Becker	Unnamed	03059900	34	
Becker	Unnamed	03014000	43	
Becker	Unnamed	03109300	72	7
Becker	Unnamed	03077600	20	10
Becker	Unnamed	03071600	25	12
Becker	Unnamed	03043400	21	17
Becker	Upper Egg	03020600	493	24
Becker	Wild Rice River	03r3		
Becker	Winter	03021600	117	43
Becker	Wolf	03010100	1,453	10
Beltrami	Big	04004900	3,565	250
Beltrami	Big Rice	04003100	642	96
Beltrami	Bootleg	04021100	308	185
Beltrami	Burns	04000100	131	105

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Beltrami	Campbell	04019600	462	23
Beltrami	Carr	04014100	51	8
Beltrami	Cass	04003000	15,958	10
Beltrami	Clearwater	04034300	1,039	
Beltrami	Cranberry	04012300	77	46
Beltrami	Dutchman	04006700	171	
Beltrami	Erickson	04006800	111	50
Beltrami	George	04017500	89	18
Beltrami	Grant Creek	04r1		
Beltrami	Grass	04021600	233	
Beltrami	Gull	04006400	170	34
Beltrami	Heart	04027100	10	
Beltrami	Irving	04014000	644	97
Beltrami	Kitchi	04000700	1,850	185
Beltrami	Little Puposky	04019700	158	95
Beltrami	Little Rice	04017000	72	
Beltrami	Little Rice	04001500	123	60
Beltrami	Little Rice Pond	04002300		
Beltrami	Little Turtle	04015500	464	23
Beltrami	Manomin	04028600	288	144
Beltrami	Marquette	04014200	578	
Beltrami	Medicine	04012200	458	69
Beltrami	Mississippi	04r2		
Beltrami	Moose	04001100	617	96
Beltrami	Moose	04034200	133	
Beltrami	Norman	04002900	61	8
Beltrami	Pimushe	04003200	1,350	135
Beltrami	Puposky	04019800	2,120	236
Beltrami	Rabideau	04003400	723	217
Beltrami	Rice	04017400	55	
Beltrami	Rice	04012100	36	
Beltrami	Rice	04025000	124	
Beltrami	Rice Pond	04005900	247	123
Beltrami	Three Island	04013400	836	125
Beltrami	Turtle River	04011100	1,664	
Beltrami	Upper Red	04003501	119,271	
Beltrami	Whitefish	04030900	126	
Blue Earth	Rice	07005900		
Blue Earth	Rice Creek	07r1		
Brown	Altematt	08005400		
Brown	Rice Lake	08003500		
Carlton	Bang	09004600	58	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Carlton	Bob	09002600	78	1
Carlton	Cedar	09003100	62	10
Carlton	Cross	09006200	110	6
Carlton	Dead Fish	09005100	153	115
Carlton	Flower	09006400	14	10
Carlton	Hardwood	09003000	100	25
Carlton	Hay	09001000	103	1
Carlton	Island	09006000	456	46
Carlton	Jaskari	09005000	74	74
Carlton	Kettle	09004900	611	415
Carlton	Long	09006600	17	4
Carlton	Miller	09005300	156	156
Carlton	Moose	09004300		
Carlton	Moosehead	09004100		
Carlton	Perch	09003600	796	597
Carlton	Rice Portage	09003700	832	120
Carlton	Sterle Pool	W0854002	29	2
Carlton	Tamarack	09006700	228	11
Carlton	Tamarack River	09r1		
Carlton	Wild Rice	09002300	54	36
Carlton	Woodbury	09006300	59	10
Cass	Baby	11028300	736	7
Cass	Bergkeller	11044700	120	5
Cass	Beuber	11035300	135	15
Cass	Big Birch	11001700	255	45
Cass	Big Portage	11030800	956	30
Cass	Big Rice (Remer)	11007300	2,717	1,411
Cass	Big Sand	11007700	752	10
Cass	Birch	11041200	1,262	1
Cass	Bluebill	11039700	51	1
Cass	Bowen	11035000	182	
Cass	Boy (& Boy River)	11014300	5,544	340
Cass	Brockway	11036600	182	55
Cass	Bullhead	11018400	88	
Cass	Cat	11050900	108	5
Cass	Cedar	11048100	34	3
Cass	Cedar	11044400	17	4
Cass	Child	11026300	295	12
Cass	Chub	11051700	57	51
Cass	Ding Pot	11056500	29	29
Cass	Donkey	11028000	54	
Cass	Drumbeater	11014500	376	5

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cass	East Twin	11012300	297	50
Cass	Esterday	11051100	43	3
Cass	Farnham	11051300	142	71
Cass	Five Point	11035100	265	13
Cass	George	11010100	720	262
Cass	Gijik	11018500	118	1
Cass	Goose	11009600	844	844
Cass	Grass	11031500	113	
Cass	Grass	11009000		
Cass	Gull	11030500	9,541	15
Cass	Gull River	11r1	219	110
Cass	Hand (Lower)	11025100	122	50
Cass	Hand (Upper)	11024200	316	20
Cass	Hardy	11033200	89	2
Cass	Hattie	11023200	592	40
Cass	Hay	11019900	364	36
Cass	Hole-In-Bog	11019700	76	
Cass	Hunter	11017000	189	2
Cass	Inguadona	11012000	935	19
Cass	Island	11010200	390	10
Cass	Island	11036000	117	30
Cass	Kelly	11042800	50	10
Cass	Kerr	11026800	81	1
Cass	Kid	11026200	167	3
Cass	Laura	11010400	1,424	854
Cass	Leech	11020300	109,415	4,000
Cass	Lind	11036700	462	95
Cass	Little Birch	11001800	25	25
Cass	Little Boy	11036900	71	1
Cass	Little Boy	11016700	1,396	10
Cass	Little Swift	11013100	62	16
Cass	Little Vermillion	11003000	138	15
Cass	Little Woman	11026500	50	8
Cass	Lizotte	11023100	75	50
Cass	Lomish	11013600	282	197
Cass	Lower Milton	11008000	80	5
Cass	Lower Trelipe	11012900	618	20
Cass	Mad Dog	11019300	27	
Cass	Margaret	11022200	230	3
Cass	McCarthy	11016800	194	78
Cass	McKeown	11026100	171	3
Cass	Moon	11007800	58	5

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cass	Moose	11042400	92	1
Cass	Mud	11030900	18	18
Cass	Mud	11010000	1,440	1,300
Cass	Norway	11030700	498	10
Cass	Nushka	11013700	78	
Cass	Ododikossi	11007400	20	10
Cass	Oxbow	11007500	172	4
Cass	Peterson	11015400	139	3
Cass	Pick	11026700	36	1
Cass	Pickerel	11035200	66	
Cass	Pillager	11032000	213	10
Cass	Pine Mountain	11041100	1,657	40
Cass	Portage	11047600	277	
Cass	Potshot	11014900	28	14
Cass	Rat	11028500	104	
Cass	Ray	11022000	183	37
Cass	Rice	11040200	188	5
Cass	Rice	11016200	342	137
Cass	Rice	11013800	55	1
Cass	Rice (Carrol's)	11022700	46	46
Cass	Rice (Pillager)	11032100	232	100
Cass	Rice Pad	11072000	14	4
Cass	Rock	11032400	249	10
Cass	Sailor	11001900	42	10
Cass	Schafer	11000400	44	2
Cass	Scribner	11044100	93	5
Cass	Six Mile	11014600	1,288	70
Cass	Skunk	11002700	145	30
Cass	Spring	11002200	86	12
Cass	Stephens	11021300	104	1
Cass	Swift	11013300	359	51
Cass	Tamarack	11034700	46	4
Cass	Tamarack	11018900	63	6
Cass	Thiebault	11002000	37	5
Cass	Third Guide	11000100	44	14
Cass	Thirty-Six	11017300	49	1
Cass	Thunder	11006200	1,316	2
Cass	Twin	11048400	168	
Cass	Unnamed	11077700	40	
Cass	Unnamed	11078000	10	4
Cass	Unnamed (Pistol Lake Rice Bed)	11073800	22	20
Cass	Unnamed (Rice Swamp)	11069800	11	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cass	Unnamed (Rice)	11061500	11	
Cass	Upper Gull	11021800	345	2
Cass	Upper Loon	11022500	114	
Cass	Wabedo	11017100	1,272	5
Cass	Wabegon	11040300	42	4
Cass	Washburn	11005900	1,768	60
Cass	Wax	11012400	95	10
Cass	West Twin	11012500	200	11
Cass	White Oak	11001600	68	1
Cass	Widow	11027300	197	
Cass	Winnibigoshish	11014700	69,821	1,000
Cass	Woman	11020100	5,360	54
Chippewa	Chippewa River	12r1		
Chisago	Goose	13008300	710	
Chisago	Rush	13006900	3,170	
Clay	Cromwell	14010300	27	
Clearwater	Anderson	15007400	53	3
Clearwater	Bagley	15004000	106	
Clearwater	Berg	15002500	50	
Clearwater	Clearwater River	15r1		
Clearwater	Duncan	15002400	18	
Clearwater	Elk	15001000	305	
Clearwater	First	15013900	60	3
Clearwater	Gill	15001900	380	38
Clearwater	Itasca	15001600	1,065	
Clearwater	Lomond	15008100	108	5
Clearwater	Lower Red	15020200		
Clearwater	Lower Rice	15013000	2,375	1,568
Clearwater	Mallard	15001800	123	25
Clearwater	Minerva	15007900	239	36
Clearwater	Mississippi	15r3		
Clearwater	Mud	15006100	294	103
Clearwater	Pine	15014900	1,465	220
Clearwater	Second	15014000	68	7
Clearwater	Sucker	15002000	90	14
Clearwater	Tamarack	15005600	21	
Clearwater	Tamarack	15013600	115	
Clearwater	Third	15014100	38	2
Clearwater	Unnamed (Rice Bed)	15002100	150	45
Clearwater	Upper Rice	15005900	1,860	1,116
Clearwater	Wild Rice River	15r2		
Cook	Bigsby	16034400	89	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cook	Caribou	16036000	714	7
Cook	Christine	16037300	192	19
Cook	Elbow	16009600	415	124
Cook	Fente	16074100	35	
Cook	Four Mile	16063900	593	42
Cook	Grassy	16039000	22	
Cook	Gust	16038000	159	1
Cook	Iron	16032800	125	
Cook	Jack	16052100	127	12
Cook	Kelly	16047600	188	56
Cook	Luffs	16000600		
Cook	Mark	16025000	126	
Cook	Marsh	16048800	62	31
Cook	Moore	16048900	64	48
Cook	Mt. Maud	16wtld2		
Cook	North Fowl	16003600	297	
Cook	Northern Light	16008900	443	133
Cook	Peterson	16047800	104	1
Cook	Phoebe	16080800	758	1
Cook	Prout	16001300	18	
Cook	Rib	16054400	89	
Cook	Rice	16045300	230	92
Cook	Richey	16064300	114	
Cook	Royal River	16r1		
Cook	South Fowl	16003400	508	
Cook	Swamp	16000900		
Cook	Swamp River	16r2		
Cook	Swamp River Reservoir	16090100	165	153
Cook	Teal	16000300	73	1
Cook	Temperance River	16r3		
Cook	Toohey	16064500	369	
Cook	Turtle	16025100	61	
Cook	Unnamed	16wtld1		
Cook	Unnamed	16041600	14	14
Cook	White Pine	16036900	374	
Crow Wing	Arrowhead	18036600	285	40
Crow Wing	Bass	18001100	65	13
Crow Wing	Bass	18022900	114	1
Crow Wing	Bay	18003400	2,435	1
Crow Wing	Big Bird	18028500	205	10
Crow Wing	Birchdale	18017500	80	40
Crow Wing	Borden	18002000	1,038	31

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Crow Wing	Buffalo	18015200	36	18
Crow Wing	Bulldog	18001400	151	5
Crow Wing	Butterfield	18023100	225	1
Crow Wing	Camp	18001800	537	22
Crow Wing	Caraway	18017900	40	32
Crow Wing	Carlson	18039500	45	1
Crow Wing	Clark	18037400	309	3
Crow Wing	Cole	18012700	114	1
Crow Wing	Crow Wing	18015500	378	
Crow Wing	Dahler	18020400	277	28
Crow Wing	Deadman's	18018800	28	5
Crow Wing	Deer	18018200	78	30
Crow Wing	Dog	18010700	71	71
Crow Wing	Duck	18017800	310	175
Crow Wing	Duck	18031400	160	3
Crow Wing	Eagle	18029600	356	1
Crow Wing	Emily	18020300	675	2
Crow Wing	Erskine	18000900	186	7
Crow Wing	Faupel	18023700	42	25
Crow Wing	Flanders	18024700	181	20
Crow Wing	Garden	18032900	262	100
Crow Wing	Gilbert	18032000	391	7
Crow Wing	Goggle	18022300	107	11
Crow Wing	Goodrich	18022600	382	5
Crow Wing	Grass	18036200	45	1
Crow Wing	Grass	18023000	78	4
Crow Wing	Green	18023300	14	1
Crow Wing	Greer	18028700	384	20
Crow Wing	Half Moon	18023800	70	14
Crow Wing	Happy	18010100	51	36
Crow Wing	Hay	18044400	46	29
Crow Wing	Hole-in-the-Day	18040100	217	90
Crow Wing	Holt	18002900	164	10
Crow Wing	Horseshoe	18031700	33	13
Crow Wing	Island	18005200	37	18
Crow Wing	Island	18038300	85	2
Crow Wing	Jail	18041500	190	2
Crow Wing	Johnson	18032800	129	25
Crow Wing	Lily Pad	18027500	47	30
Crow Wing	Little Pine	18026600	384	20
Crow Wing	Little Pine	18017600	135	30
Crow Wing	Lizzie	18041600	384	100

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Crow Wing	Long	18003100	80	4
Crow Wing	Love	18038800	88	18
Crow Wing	Lower Dean	18018100	372	360
Crow Wing	Lower Mission	18024300	739	50
Crow Wing	Lows	18018000	320	45
Crow Wing	Mahnomen	18012600	238	1
Crow Wing	Mallard	18033400	73	4
Crow Wing	Maple	18004500	68	20
Crow Wing	Middle Cullen	18037700	405	2
Crow Wing	Mississippi River	18r1		1
Crow Wing	Mitchell	18029400	460	3
Crow Wing	Mollie	18033500	421	17
Crow Wing	Mud	18009400	78	6
Crow Wing	Mud	18013700	132	40
Crow Wing	Mud	18032600	82	60
Crow Wing	Mud	18019800	103	10
Crow Wing	Nelson	18016400	323	100
Crow Wing	Nisswa	18039900	213	25
Crow Wing	North Long	18037200	6,178	10
Crow Wing	Olson	18017100	28	3
Crow Wing	Ossawinnamakee	18035200	739	1
Crow Wing	Perch	18030400	181	8
Crow Wing	Pine	18026100	391	60
Crow Wing	Platte	18008800	1,768	350
Crow Wing	Pointon	18010500	193	14
Crow Wing	Rat	18041000	100	2
Crow Wing	Red Sand	18038600	569	28
Crow Wing	Rice (Blomberg's)	18012100	78	60
Crow Wing	Rice (Clark Lake rice bed)	18032700	181	124
Crow Wing	Rice (Deerwood)	18006800	185	170
Crow Wing	Rice (Hesitation State WMA)	18005300	168	138
Crow Wing	Rice (Lowell State WMA)	18040500	85	33
Crow Wing	Rice (Pratt's)	18031600	100	90
Crow Wing	Rice Bed	18018700	50	47
Crow Wing	Rock	18001600	210	10
Crow Wing	Rogers	18018400	249	4
Crow Wing	Round	18014700	144	5
Crow Wing	Round (Round-Rice Bed State WMA)	18003200	82	5
Crow Wing	Roy	18039800	310	5
Crow Wing	Sebie	18016100	180	2
Crow Wing	Sewells Pond	18044600	20	16
Crow Wing	Sibley	18040400	412	10

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Crow Wing	Smith	18002800	486	49
Crow Wing	South Long	18013600	1,380	4
Crow Wing	Stewart	18036700	254	5
Crow Wing	Tamarack	18031800	34	30
Crow Wing	Terry	18016200	102	55
Crow Wing	Twenty Two	18000800	169	42
Crow Wing	Twin Island	18010600	85	42
Crow Wing	Unnamed	18020100	16	1
Crow Wing	Unnamed	18041300	103	27
Crow Wing	Unnamed	18055000	30	30
Crow Wing	Unnamed	18005500	70	1
Crow Wing	Unnamed (Blackies Slough)	18054400	33	20
Crow Wing	Unnamed (Lost Rice)	18022800	157	80
Crow Wing	Unnamed (Nokasippi R. Rice Bed)	18048500	166	40
Crow Wing	Unnamed (Total's Pothole)	18054300	28	16
Crow Wing	Upper Cullen	18037600	459	23
Crow Wing	Upper Dean	18017000	263	10
Crow Wing	Upper Hay	18041200	640	2
Crow Wing	Upper Mission	18024200	895	5
Crow Wing	Upper Whitefish	18031000	7,969	50
Crow Wing	Velvet	18028400	167	2
Crow Wing	Whipple	18038700	345	40
Crow Wing	Whitefish	18000100	709	30
Crow Wing	Williams	18002400	47	3
Crow Wing	Wilson	18004900	63	4
Crow Wing	Wolf	18011200	218	25
Dakota	Blackhawk	19005900		
Dakota	Chub	19002000	301	1
Douglas	Mud	21023600	50	
Faribault	Minnesota	22003300	1,915	
Faribault	Rice	22000700		
Faribault	Rice	22007500		
Fillmore	Rice Creek	23r1		
Freeborn	Bear	24002800	1,560	
Freeborn	Geneva	24001500	1,875	18
Freeborn	Spicer	24004500	125	100
Freeborn	Trenton	24004900	184	18
Goodhue	Cannon River	25r2		
Goodhue	Rice Bottoms	25r1		
Goodhue	Sturgeon	25001701		
Hennepin	Grass	27008000	326	
Hennepin	Rice	27013200	294	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Hennepin	Rice	27011600		
Houston	Blue	28000503	362	
Houston	Lawrence	28000501	142	
Houston	Target	28000502	424	
Hubbard	Alice	29028600	150	15
Hubbard	Birch Creek	29r1		
Hubbard	Clausens	29009700	222	
Hubbard	Crow Wing	29011600		
Hubbard	Crow Wing River	29river		
Hubbard	Deer	29009000	193	
Hubbard	Eagle	29025600	440	4
Hubbard	Eighth Crow Wing	29007200	493	1
Hubbard	Eleventh Crow Wing	29003600	752	1
Hubbard	Fifth Crow Wing	29009200	406	10
Hubbard	First Crow Wing	29008600	564	50
Hubbard	Fishhook River	29r4		
Hubbard	Fourth Crow Wing	29007800	523	130
Hubbard	Garfield	29006100	984	90
Hubbard	George	29021600	882	18
Hubbard	Hart	29006300	236	118
Hubbard	Hattie	29030000	359	
Hubbard	Holland-Lucy	29009500	44	
Hubbard	Horseshoe	29005900	264	
Hubbard	Island	29025400	522	60
Hubbard	Kabekona River	29r6		
Hubbard	Kabekona River	290075T2		
Hubbard	Kabekona	29007500		
Hubbard	Little Rice	29018300	27	1
Hubbard	Little Stony	29008000	55	
Hubbard	Loon	29002000	112	
Hubbard	Lower Bottle	29018000	712	10
Hubbard	Lower Mud	29026700	30	30
Hubbard	Mantrap	29015100	1,770	200
Hubbard	Mud	29011900	146	30
Hubbard	Mud Creek	29r3		
Hubbard	Necktie River	29r2		
Hubbard	Ninth Crow Wing	29002500	235	
Hubbard	Oak	29006000	58	1
Hubbard	Oelschlager Slough	29000600	328	
Hubbard	Paine	29021700	258	
Hubbard	Plantagenet	29015600	2,620	
Hubbard	Portage	29025000	429	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Hubbard	Potato	29024300	2,239	30
Hubbard	Rice	29017700	230	58
Hubbard	Schoolcraft	29021500	176	35
Hubbard	Second Crow Wing	29008500	228	5
Hubbard	Seventh Crow Wing	29009100	251	10
Hubbard	Shallow	29008900	295	9
Hubbard	Shell River	29r5		
Hubbard	Sixth Crow Wing	29009300	358	5
Hubbard	Spider	29011700	593	
Hubbard	Spring	29005400	43	
Hubbard	Sunday	29014400	62	
Hubbard	Tamarack	29009400	36	
Hubbard	Tenth Crow Wing	29004500	185	9
Hubbard	Third Crow Wing	29007700	636	40
Hubbard	Tripp	29000500	155	1
Hubbard	Twin	29029300		
Hubbard	Unnamed	29011500	16	
Hubbard	Unnamed	29011800	21	
Hubbard	Unnamed	29011400	24	
Hubbard	Unnamed	29008400	87	
Hubbard	Unnamed	29007900	38	
Hubbard	Unnamed	29017900	16	
Hubbard	Unnamed	29009900	26	
Hubbard	Unnamed	29015800	60	
Hubbard	Unnamed	29002100		
Hubbard	Unnamed	29026300	20	
Hubbard	Unnamed	29001900	15	
Hubbard	Unnamed (Boudora)	29008200	48	1
Hubbard	Unnamed (Hay Creek)	29055400	38	20
Hubbard	Upper Bass	29003400	30	
Hubbard	Upper Bottle	29014800	505	30
Hubbard	Upper Mud	29028400	50	50
Hubbard	Upper Twin	29015700	212	1
Isanti	Elizabeth	30008300	323	
Isanti	German	30010000	340	
Isanti	Grass	30014200	33	
Isanti	Krone	30014000	142	
Isanti	Lindgren	30014400	75	
Isanti	Little Stanchfield	30004400	155	
Isanti	Mud	30006500	300	
Isanti	Mud	30010600	81	
Isanti	Mud	30011700		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Isanti	North Stanchfield	30014300	153	
Isanti	Rice	30001800		
Isanti	Section	30006000	130	
Isanti	South Stanchfield	30013800	433	
Isanti	Typo	30000900	273	
Isanti	Upper Rice	30005700	208	208
Itasca	Ann	31030500	94	5
Itasca	Aspen	31069000	86	5
Itasca	Bass	31057600	2,844	427
Itasca	Big Fork River	31r3		
Itasca	Birdseye	31083400	73	11
Itasca	Blackberry	31021000	240	50
Itasca	Blackwater	31056100	674	300
Itasca	Bluebill	31026500	144	14
Itasca	Bosley	31040300	41	10
Itasca	Bowstring (& Bowstring River)	31081300	8,900	1,335
Itasca	Bowstring River	31r4		
Itasca	Buckman	31027200	222	33
Itasca	Clearwater	31040200	67	10
Itasca	Clubhouse	3105400		
Itasca	Coddington	31088300	70	18
Itasca	Copenhagen	31053900		
Itasca	Cresent	31029400	42	2
Itasca	Crooked	31020300	80	12
Itasca	Cut Foot Sioux	31085700	3,222	322
Itasca	Damon	31094400	53	20
Itasca	Decker	31093400	292	58
Itasca	Deer	31034400	1,854	
Itasca	Dishpan	31099200	15	15
Itasca	Dixon	31092100	666	67
Itasca	Dora	31088200	477	89
Itasca	Egg	31081700	118	11
Itasca	Farley	31090200	33	5
Itasca	First River	31081800	228	160
Itasca	Grass	31072700		
Itasca	Grass	31052700		
Itasca	Gunny Sack	31026700	81	8
Itasca	Hamrey	31091100	61	15
Itasca	Harrigan	31017400	27	3
Itasca	Hay	31003700		
Itasca	Helen	31084000	109	76
Itasca	Hunters	31045000	162	16

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Itasca	Ima	31063400		
Itasca	Irene	31087800	10	1
Itasca	Island	31075400	291	10
Itasca	Kelly	31029100	31	19
Itasca	Lawrence	31023100	382	19
Itasca	Leighton	31003200	242	12
Itasca	Lillian	31075000	90	14
Itasca	Little Ball Club	31082200	181	10
Itasca	Little Cut Foot	31085200	1,357	136
Itasca	Little Drum	31074100	89	22
Itasca	Little Island	31017900	26	3
Itasca	Little Moose	31061000	234	12
Itasca	Little Rice	31071600		
Itasca	Little Spring	31079700	121	3
Itasca	Little White Oak	31074000	493	25
Itasca	Lost	31028900		
Itasca	Lost	31090000	26	5
Itasca	Lower Pigeon	31089300	53	20
Itasca	Marble	31027100	155	20
Itasca	Marie	31093700	45	10
Itasca	Middle Pigeon	31089200	182	15
Itasca	Mississippi River	31r6		
Itasca	Morph	31092900	67	3
Itasca	Mosomo	31086100	47	5
Itasca	Mud	31020600	271	203
Itasca	Munzer	31036000	108	3
Itasca	Nagel	31037700	90	50
Itasca	Natures	31087700	2,885	2,499
Itasca	O'Donnell	31030300	47	10
Itasca	Otter	31030100		
Itasca	Pigeon Dam	31089400	511	500
Itasca	Pokegama	31053200	15,600	100
Itasca	Pothole	31099100		
Itasca	Prairie	31038400	1,167	45
Itasca	Prairie (& Prairie River)	31005300	29	1
Itasca	Rabbits	31092300	209	157
Itasca	Raven	31092500	97	70
Itasca	Rice	31031500	37	15
Itasca	Rice	31071700		
Itasca	Rice	31077700		
Itasca	Rice	31087600	911	729
Itasca	Rice	31020100	115	6

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Itasca	Rice	31070700		
Itasca	Rice	31094200	39	
Itasca	Rice Creek	31r5		
Itasca	Rice Creek	31r1		
Itasca	Rice River	31r2		
Itasca	Ruby	31042200	243	5
Itasca	Sand	31082600	3,391	50
Itasca	Shallow Pond	31091000	281	11
Itasca	Simpson	31086700	35	5
Itasca	Sioux	31090700	69	27
Itasca	Skimmerhorn	31093900	30	6
Itasca	Soneman	31027600	40	16
Itasca	Spruce	31034700	58	58
Itasca	Stevens	31071800	224	11
Itasca	Stone Axe	31082800	37	4
Itasca	Swan	31006700	2,472	50
Itasca	Tuttle	31082100	56	16
Itasca	Unnamed	31081500	109	5
Itasca	Unnamed	31096100	10	2
Itasca	Unnamed	31020400	28	3
Itasca	Unnamed	31032200	28	2
Itasca	Unnamed	31006600	23	3
Itasca	Unnamed	31086000	24	5
Itasca	Upper Pigeon	31090800	86	10
Itasca	Walters	31029800	120	18
Itasca	Wart	31085900	14	5
Itasca	White Fish	31014200	31	2
Itasca	White Oak	31077600	905	271
Itasca	Whitefish	31084300	493	10
Itasca	Wilderness	31090100	26	4
Kanabec	Ann	33004000	363	18
Kanabec	Grass	33001300		
Kanabec	Kent	33003500	34	
Kanabec	Knife	33002800		
Kanabec	Mud	33001500		
Kanabec	Pomroy	33000900	267	
Kanabec	Rice	33001100	172	
Kanabec	Rice	33003100		
Kanabec	Sells	33001800	64	
Kanabec	Twin or East	33001900	27	
Kanabec	Unnamed	33002900	21	
Kanabec	Unnamed	33011100	33	27

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Kanabec	Unnamed	33001400	30	
Kanabec	Unnamed	33007200	31	1
Kanabec	Unnamed	33001200	11	
Kandiyohi	Bear	34014800	128	
Kandiyohi	Blaamylhre	34034500	121	
Kandiyohi	Eight	34014600	89	
Kandiyohi	Glesne	34035200	205	
Kandiyohi	Monongalia	34IMP001	1,500	
Kandiyohi	Mud	34015800	2,516	
Kandiyohi	Ole	34034200	66	
Kandiyohi	Unnamed	34023600	117	
Koochiching	Nett	36000100	7,369	
Koochiching	Rainy Lake	36000100	7,301	2,000
Koochiching	Rat Root	36000600	734	
Koochiching	Tilson Creek	36r1		
Lake	Bald Eagle	38063700	1,243	
Lake	Basswood	38064500	14,610	485
Lake	Bluebill	38026100	44	11
Lake	Bonga	38076200	138	138
Lake	Cabin	38026000	71	55
Lake	Campers	38067900	56	56
Lake	Charity	38005500	26	
Lake	Christianson	38075000	158	
Lake	Clark	38067400		
Lake	Clark	38064700	49	
Lake	Cloquet	38053900	176	
Lake	Cloquet River	38r1		
Lake	Comfort	38029000	42	
Lake	Cougar	38076700	71	1
Lake	Cramer	38001400	69	55
Lake	Crooked	38002400		
Lake	Crooked	38081700		
Lake	Crown	38041900	69	
Lake	Driller	38065200	24	
Lake	Dumbbell	38039300	476	48
Lake	Ella Hall	38072700	372	1
Lake	Fall	38081100	2,322	23
Lake	Farm	38077900	1,292	
Lake	Flat Horn	38056800	52	
Lake	Fools	38076100	14	14
Lake	Gabbro	38070100	927	
Lake	Garden	38078200	4,236	212

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Lake	Gegoka	38057300	174	14
Lake	Greenwood	38065600	1,469	15
Lake	Harris	38073600	121	18
Lake	Hjalmer	38075800	109	2
Lake	Hoist	38025100	117	
Lake	Horse River	38r5		
Lake	Hula	38072800	121	121
Lake	Isabella	38039600	1,318	
Lake	Isabella River	38r4		
Lake	Island River	38084200	49	49
Lake	Kawishiwi	38008000	468	
Lake	Kawishiwi River	38r2		
Lake	Little Gabbro	38070300	151	
Lake	Little Wampus	38068400		
Lake	Lobo	38076600	132	99
Lake	Manomin	38061600	455	23
Lake	Middle McDougal	38065800	104	
Lake	Moose	38003600	201	
Lake	Mud	38074200	164	
Lake	Muskeg	38078800	178	71
Lake	Newton	38078400		
Lake	Nine A.M.	38044500	27	14
Lake	North McDougal	38068600	273	
Lake	Papoose	38081800	54	3
Lake	Phantom	38065300	70	
Lake	Railroad	38065500	11	1
Lake	Rice	38046500	206	206
Lake	Roe	38013900	76	
Lake	Round Island	38041700	58	58
Lake	Sand	38073500	506	51
Lake	Sand River	38r3		
Lake	Scott	38027100	52	
Lake	Silver Island	38021900	1,239	
Lake	Slate	38066600	293	
Lake	Snowbank	38052900	4,819	50
Lake	Source	38065400	35	1
Lake	Sourdough	38070800	17	17
Lake	South McDougal	38065900	277	3
Lake	Stony	38066000	409	245
Lake	Stony River	38r6		
Lake	Upland	38075600	74	1
Lake	Vera	38049100	262	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Lake	Wampus	38068500	146	
Lake	Wind	38064200	952	10
Lake	Wood	38072900	587	125
Lake of the Woods	Baudette River	39r2		
Lake of the Woods	Bostick Creek	39r1		
Lake of the Woods	Lake of the Woods	39000200	950,400	225
Lake of the Woods	Rainy River	39r5		
Lake of the Woods	Roseau Flowage	39IMP001	200	100
Lake of the Woods	Silver Creek	39r3		
Lake of the Woods	Winter Road River	39r4		
Le Sueur	Rice	40wtld1		
Le Sueur	Rice	40011400		
Le Sueur	Rice	40003700		
Le Sueur	Rice	40001600		
Mahnomen	Grass	44004700	22	
Mahnomen	Long	44000200	117	
Mahnomen	Peabody	44-wetld		
Mahnomen	Rice	44002400	120	
Mahnomen	Roy	44000100	689	
Mahnomen	Sargent (Little Rice)	44010800	174	
McLeod	Grass	43001300		
McLeod	Rice	43004200		
McLeod	Schaefer Prairie	43r1		
Mille Lacs	Dewitt Marsh	48002000	110	131
Mille Lacs	Dewitt Pool	48IMP004	146	131
Mille Lacs	Ernst Pool	48003600	300	200
Mille Lacs	Korsness Pool 1	48003500	130	90
Mille Lacs	Mille Lacs WMA - Headquarters 2 Pool	W9004009	500	13
Mille Lacs	Mille Lacs WMA - Jones 1 Dk Pool	W9004008	520	3
Mille Lacs	Mille Lacs WMA - Korsness Pool 2	W9004002	33	30
Mille Lacs	Mille Lacs WMA - Korsness Pool 3	W9004003	18	5
Mille Lacs	Mille Lacs WMA - Olson Pool	W9004007	85	2
Mille Lacs	Mille Lacs WMA - Townhall Pool	W9004010	110	3
Mille Lacs	Ogechie	48001400	732	
Mille Lacs	Onamia	48000900	2,250	1,350
Mille Lacs	Rice	48001000	512	
Mille Lacs	Shakopee	48001200	771	
Mille Lacs	Unnamed	48004300	60	10
Mille Lacs	Unnamed	48004400	500	
Mille Lacs	Unnamed	48005400	32	25
Mille Lacs	W. brnch Groundhouse Riv	48IMP002	50	1
Morrison	Bernhart	49013500	39	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Morrison	Coon	49002000	75	75
Morrison	Crookneck	49013300	200	
Morrison	Hannah	49001400	109	27
Morrison	Long	49001500	128	32
Morrison	Longs	49010400	60	
Morrison	Madaline	49010100	50	
Morrison	Miller	49005100	39	9
Morrison	Mud	49009500	105	
Morrison	Mud	49007200	83	5
Morrison	Mud	49002700	23	9
Morrison	Mud	49001800		
Morrison	Peavy	49000500	140	
Morrison	Pelkey	49003000	113	10
Morrison	Placid	49008000	537	
Morrison	Platte River	49r2		
Morrison	Popple	49003300	153	
Morrison	Rice	49002500	323	250
Morrison	Rice Creek	49r1		
Morrison	Round	49001900	134	14
Morrison	Skunk	49002600	320	256
Morrison	Skunk	49000700		
Morrison	Sullivan	49001600	1,199	20
Morrison	Twelve	49000600	159	80
Nicollet	Rice	52003300		
Otter Tail	Armor	56038100		
Otter Tail	Beauty Shore	56019500	233	
Otter Tail	Berger	56114900	190	
Otter Tail	Davies	56031100	69	
Otter Tail	Dead	56038300	7,827	
Otter Tail	Duck	56092500	41	
Otter Tail	East Red River	56057300	292	
Otter Tail	Emma	56019400	473	
Otter Tail	Gourd	56013900		
Otter Tail	Grass	56011500		
Otter Tail	Grass	56072300		
Otter Tail	Grass	56071700		
Otter Tail	Head	56021300	499	
Otter Tail	Little McDonald	56032800	1,506	
Otter Tail	Long	56021000		
Otter Tail	Mud	56021500	138	
Otter Tail	Mud	56022200	437	
Otter Tail	Mud	56013200	155	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Otter Tail	Mud	56114800	134	
Otter Tail	North Maple	56001300	161	
Otter Tail	North Rice	56034900	103	
Otter Tail	Otter Tail River	56r1		
Otter Tail	Peterson	56047100	141	
Otter Tail	Rankle	56093500	57	
Otter Tail	Reed	56087600	155	
Otter Tail	Rice	56000600		
Otter Tail	Rice	56035200		
Otter Tail	Rice	56070200		
Otter Tail	Rice	56021100	263	
Otter Tail	Rice	56036300	350	
Otter Tail	Rush	56014100	5,340	
Otter Tail	Sharp	56048200	160	
Otter Tail	Sixteen	56010000	107	
Otter Tail	South Maple	56000400	160	
Otter Tail	Star	56038500	4,809	
Otter Tail	Tamarack	56019200	440	
Otter Tail	Tamarack	56043300	470	
Otter Tail	Unnamed	56127300	126	
Otter Tail	Unnamed	56151700	23	
Otter Tail	Unnamed	56155000	14	
Otter Tail	Unnamed	56157800	29	
Otter Tail	Unnamed	56019800	69	
Otter Tail	Unnamed	56028400	83	
Otter Tail	Unnamed	56108300	198	
Otter Tail	Unnamed	56092700	35	
Otter Tail	Unnamed	56125900	12	
Otter Tail	West Battle	56023900		
Otter Tail	West Lost	56048100	915	
Otter Tail	Wing River	56004300	138	
Pine	Big Pine	58013800		
Pine	Cedar	58008900	71	
Pine	Crooked	58002600	94	85
Pine	Fox	58010200		
Pine	Grass	58012500		
Pine	Hay Creek Flowage	58000500	66	40
Pine	Kettle River	58r2		
Pine	Little North Sturgeon	58006600	20	
Pine	McCormick	58005800		
Pine	Passenger	58007600	75	
Pine	Pokegama (& River)	58014200	1,621	16

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Pine	Rush	58007800	88	
Pine	Stanton	58011100	84	34
Pine	Willow River	58r1		
Polk	Unnamed (Round)	60072100	9	2
Pope	Rice	61006900		
Ramsey	Grass	62007400		
Redwood	Rice Creek	64r1		
Rice	Cedar	66005200	927	93
Rice	Dudley	66001400	83	
Rice	Hatch	66006300	102	10
Rice	Hunt	66004700	190	19
Rice	Kelly	66001500	62	
Rice	Mud	66005400	269	54
Rice	Pooles	66004600	182	
Rice	Rice	66004800		
Rice	Unnamed	66010300	26	
Rice	Weinberger	66004100	53	8
Rice	Willing	66005100	53	5
Roseau	Bednar Impoundment	68IMP002	240	40
Scott	Artic	70008500		
Scott	Blue	70008800	316	120
Scott	Fisher	70008700	396	190
Scott	Rice	70006000		
Scott	Rice	70002500	328	160
Scott	Rice	70000100		
Sherburne	Big Mud	71008500	263	100
Sherburne	Buck Lake	71IMP007	30	26
Sherburne	Clitty	71011600	56	
Sherburne	Fremont	71001600	466	
Sherburne	Jim	71011100	20	20
Sherburne	Johnson Slough	71IMP004	65	10
Sherburne	Johnson Slought	71008400		
Sherburne	Josephine	71006800	132	
Sherburne	Josephine Pool	71IMP008	143	72
Sherburne	Kliever Marsh	71000300	37	
Sherburne	Long Pond	71003600	82	
Sherburne	Lower Roadside	71IMP006	8	7
Sherburne	Lundberg Slough	71010900	50	
Sherburne	Muskrat Pool	71IMP003	299	15
Sherburne	Orrock Lake	71IMP010	215	162
Sherburne	Rice	71001500	11	
Sherburne	Rice	71007800	505	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Sherburne	Rice	71014200	187	2
Sherburne	Schoolhouse Pool	71IMP009	225	90
Sherburne	Sherburne NWR - Pool 1	71IMP001	2	2
Sherburne	Sherburne NWR - Pool 2	71IMP002	30	15
Sherburne	Sherburne NWR - Pool 31	71IMP011		
Sherburne	Unnamed	71002500	31	
Sherburne	Upper Roadside	71IMP005		
Sibley	Titlow	72004200	924	
St. Louis	???	69IMP002		15
St. Louis	Alden	69013100	190	
St. Louis	Anchor	69064100	316	32
St. Louis	Angell Pool	W0889001	500	80
St. Louis	Artichoke	69062300	306	
St. Louis	Balkan	69086000	36	2
St. Louis	Bear	69011200	125	125
St. Louis	Bear Island River	69r8		
St. Louis	Bear Trap	69008900	131	
St. Louis	Big	69019000	2,049	20
St. Louis	Big Rice	69017800	416	416
St. Louis	Big Rice	69066900	2,072	1,700
St. Louis	Birch	69000300	7,628	381
St. Louis	Black	69074000	118	
St. Louis	Blueberry	69005400	130	13
St. Louis	Bootleg	69045200	352	
St. Louis	Breda	69003700	137	135
St. Louis	Burntside	69011800	7,314	
St. Louis	Canary	69005500	22	1
St. Louis	Caribou	69048900	569	3
St. Louis	Cloquet River	69r5		
St. Louis	Comet	69026700	28	
St. Louis	Cranberry	69014700	69	
St. Louis	Crane	69061600	3,396	600
St. Louis	Deadmans	69IMP001	5	
St. Louis	Dollar	69053400	51	51
St. Louis	Duck	69019100	126	
St. Louis	Eagles Nest #3	69028500	1,028	
St. Louis	East Stone	69063800	92	24
St. Louis	East Twin	69016300		
St. Louis	Echo	69061500		
St. Louis	Ed Shave	69019900	90	
St. Louis	Elliot	69064200	393	20
St. Louis	Embarrass River	69r3		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
St. Louis	Five Mile	69028800	106	10
St. Louis	Four Mile	69028100	86	1
St. Louis	Gafvert	69028000	33	1
St. Louis	George	69004000	42	
St. Louis	Gill	69066700	18	
St. Louis	Grand	69051100	1,742	10
St. Louis	Grass	69077600	49	1
St. Louis	Grassey	69091300		
St. Louis	Grassy	69008200		
St. Louis	Grassy	69021600		
St. Louis	Gull	69009200	196	20
St. Louis	Hay	69044100	47	
St. Louis	Hay	69043500	78	78
St. Louis	Hay	69015000	32	1
St. Louis	Hay	69057900	114	114
St. Louis	Hay	69043900	42	1
St. Louis	Hay	69041700	82	45
St. Louis	Hockey	69084900	139	70
St. Louis	Hoodoo	69080200	252	252
St. Louis	Horseshoe	69025500	39	10
St. Louis	Indian	69002300	57	
St. Louis	Jeanette	69045600		
St. Louis	Johnson	69011700	473	24
St. Louis	Joker	69001500	46	5
St. Louis	King	69000800	320	39
St. Louis	Kylen	69003400	16	2
St. Louis	La Pond	69017700	176	176
St. Louis	Leeman	69087500	284	90
St. Louis	Lieung	69012300	476	10
St. Louis	Little Birch	69027100	58	
St. Louis	Little Cloquet River	69r6		
St. Louis	Little Indian Sioux River	69r7		
St. Louis	Little Mesaba	69043600		
St. Louis	Little Rice	69061200	266	266
St. Louis	Little Sandy	69072900	89	89
St. Louis	Little Stone	69002800	163	
St. Louis	Little Vermillion	69060800	558	
St. Louis	Long (Butterball)	69004400	442	400
St. Louis	Low	69007000	353	71
St. Louis	Lower Pauness	69046400	162	1
St. Louis	Martin	69076800	71	
St. Louis	Moose	69079800	82	62

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
St. Louis	Mud	69015100	51	
St. Louis	Mud	69080000	71	18
St. Louis	Mud	69004700		
St. Louis	Mud Hen	69049400	165	
St. Louis	Myrtle	69074900	876	
St. Louis	Nels	69008000	200	2
St. Louis	Nichols	69062700	444	22
St. Louis	One Pine	69006100	369	37
St. Louis	Oriniack	69058700	748	
St. Louis	Papoose	69002400	16	16
St. Louis	Pelican (& River)	69084100	11,944	119
St. Louis	Perch	69068800	79	32
St. Louis	Petrel Creek	69r4		
St. Louis	Picket	69007900	78	7
St. Louis	Pike River	69r1		
St. Louis	Prairie	69084800	807	16
St. Louis	Rainy	69069400	220,800	
St. Louis	Rainy (Grassy Narrows)	69064000		
St. Louis	Rat	69092200		
St. Louis	Rat	69073700		
St. Louis	Rice	69057800	41	41
St. Louis	Rice	69080300		
St. Louis	Round	69004800	336	
St. Louis	Ruth	69001400	47	9
St. Louis	Sandpoint	69061700		
St. Louis	Sandy	69073000	121	121
St. Louis	Seven Beaver	69000200	1,508	1,282
St. Louis	Shannon (& River)	69092500	135	108
St. Louis	Side	69069900	25	15
St. Louis	Simian Lake	69061900	81	5
St. Louis	Sioux River	69r9		
St. Louis	Six Mile	69028300	103	1
St. Louis	St. Louis River	69r2		
St. Louis	Stone	69004600	230	173
St. Louis	Stone	69068600	160	24
St. Louis	Sturgeon	69093900	2,050	243
St. Louis	Sunset	69076400	309	6
St. Louis	Susan	69074100	305	
St. Louis	Tommila	69003500	87	85
St. Louis	Trettel Pool	W0889002	30	3
St. Louis	Turpela	69042700	76	61
St. Louis	Twin	69050400	18	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
St. Louis	Twin	69069500		
St. Louis	Unnamed	69063400	101	20
St. Louis	Unnamed (Camp 97)	69059400	25	
St. Louis	Upper Bug	69040600	23	
St. Louis	Upper Pauness	69046500	215	1
St. Louis	Vang	69087600	126	3
St. Louis	Vermilion	69037800	49,110	250
St. Louis	Vermilion River	69061300	1,125	562
St. Louis	Wabuse	69040800	64	51
St. Louis	Washusk #1	69040900	51	40
St. Louis	Watercress	69079700	43	43
St. Louis	Watercress (Mud)	69079700	30	
St. Louis	Wheel	69073500	11	6
St. Louis	Whitchel	69053100	71	53
St. Louis	White Iron	69000400		
St. Louis	Wild Rice	69037100	2,133	1
St. Louis	Wolf	69014300	456	
Stearns	Anna	73012600	133	
Stearns	Big Rice	73016800	282	
Stearns	Cedar	73022600	152	
Stearns	Crow	73027900	461	
Stearns	Fifth	73018000	76	
Stearns	Fish	73028100	204	
Stearns	Grass	73029400	157	
Stearns	Gravel	73020400	55	
Stearns	Henry	73016000	62	
Stearns	Henry	73023700	191	
Stearns	Linneman	73012700	108	
Stearns	Little Rice	73016700	56	
Stearns	Lower Spunk	73012300	269	
Stearns	McCormic	73027300	211	
Stearns	Middle Spunk	73012800	242	
Stearns	Mud	73016100	55	
Stearns	Raymond	73028500	126	
Stearns	Rice	73019600	1,568	
Stearns	Sagatagan	73009200	170	
Stearns	Schultz Slough	73020100	29	
Stearns	Tamarack	73027800	470	235
Steele	Oak Glen	74000400	350	4
Steele	Rice	74000100	697	467
Todd	Beck	77005600	57	25
Todd	Cass County	77000400	25	18

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Todd	Hayden	77008000	253	1
Todd	Jacobson	77014300	40	
Todd	Jaeger	77007500	46	28
Todd	Lawrence	77008300	172	
Todd	Little Fishtrap	77007400		
Todd	Little Pine	77013400		
Todd	Long	77006900	356	338
Todd	Mud	77008700	398	318
Todd	Pine Island	77007700	156	
Todd	Rice	77006100	675	60
Todd	Robbinson Pond	77IMP001	60	30
Todd	Rogers	77007300	185	130
Todd	Sheets	77012200	100	
Todd	Stones	77008100	63	
Todd	Thunder	77006600		
Todd	Tucker	77013900	43	
Todd	Twin	77002100	317	159
Todd	Unnamed	77020200	70	
Todd	Unnamed	77017600	40	2
Todd	Unnamed	77019700	53	
Todd	Unnamed	77017800	42	23
Todd	Unnamed	77014000	61	
Todd	West Nelson	77000500	84	70
Wabasha	Pool 5	79IMP001	600	35
Wabasha	Unnamed	W0580001	160	25
Wadena	Blueberry	80003400	555	30
Wadena	Burgen	80001800	92	86
Wadena	Finn	80002800	148	30
Wadena	Granning	80001200	50	50
Wadena	Jim Cook	80002700	238	
Wadena	Lower Twin	80003000	267	5
Wadena	Rice	80002400	8	1
Wadena	Round	80001900	58	58
Wadena	Strike	80001300	76	76
Wadena	Unnamed	80000700	16	16
Wadena	Yaeger	80002200	384	346
Wright	Albion	86021200	238	
Wright	Beaver Dam	86029600	253	
Wright	Butler	86019800	131	
Wright	Butternut	86025300	203	
Wright	Carrigan	86009700	162	
Wright	Cedar	86003400	191	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Wright	Gilchrist	86006400	388	
Wright	Gonz	86001900	152	
Wright	Henshaw	86021300	277	
Wright	Long	86019400	255	
Wright	Louisa	86028200	183	
Wright	Malardi	86011200	149	
Wright	Mallard Pass	86018500	51	
Wright	Maple	86019700	82	
Wright	Maple Unit	86015700	177	
Wright	Mary	86004900	331	
Wright	Millstone	86015200	221	
Wright	Mink	86022900	304	
Wright	Mud	86002600	128	
Wright	Mud	86021900	66	
Wright	Pelican	86003100	2,793	
Wright	Pooles	86010200	166	
Wright	Rice	86003200	246	
Wright	Rice	86000200	57	
Wright	Sandy	86022400	118	150
Wright	School	86002500	76	
Wright	School Section	86018000	266	
Wright	Shakopee	86025500	206	
Wright	Smith	86025000	330	
Wright	Spring	86020000	63	
Wright	Taylor	86020400	78	
Wright	White	86021400	145	
Wright	Willima	86020900	246	
1,286 total locations				
For the 777 locations that have coverage data			1,569,889	64,328

Appendix C

Wild Rice Harvest Survey

The full report will be posted on the MNDNR website www.dnr.state.mn.us prior to March 1, 2008

Executive Summary

Introduction

The following objectives guided the study design, survey instrument and final report for this effort.

- To determine the characteristics of wild rice harvesters in Minnesota.
- To assess current harvest levels and harvester satisfaction.
- To assess current natural wild rice harvest use of Minnesota lakes and rivers.
- To obtain wild rice harvester opinions of current state regulations and proposed revisions.
- To determine factors that limit wild rice harvesting.
- Identify information needs of wild rice harvesters, and the best means to deliver information to harvesters.
- To determine support for natural wild rice management priorities.

In November of 2006 the Minnesota Department of Natural Resources initiated a self-administered, mail questionnaire of all 2006 wild rice license holders (n=1,625) to gather information on the objectives listed above, and all 2004 and 2005 license holders who did not purchase a license in 2006 (n=945) to gather information on why they did not harvest wild rice in 2006. Completed questionnaires were returned by 53 percent (n=1,365) of the 2,574-license holder sample.

Characteristics

The 2004 to 2006 wild rice license holder respondents were predominately male (82%), Minnesota residents (98%), and averaged 51 years of age. A large majority (81%) are 40 years of age or older. A majority harvested wild rice under only a state license (86%). The average age that harvesters began gathering wild rice was 31. Friends and parents were the primary means of introduction to the activity, and 69 percent of harvesters reported introducing others to gathering wild rice. The average harvester has 13 seasons of experience.

Harvest Levels

Based on responses, an estimated average of 430 pounds of unprocessed natural wild rice was gathered per harvester in 2006. Based on state issued license sales of 1,625 in 2006, this creates a total harvest estimate of approximately 700,000 pounds of natural wild rice. Approximately two percent of 2006 respondents harvested more than 2,000 pounds of rice, while 79 percent harvested less than 500 pounds. When comparing these groups (those harvesting > 500 lbs and those harvesting < 500 lbs) there is a difference in both the average age they began harvesting (20 and 33 years old, respectively) and the average number of seasons participated (25 and 12 years, respectively). A large majority (85%) of harvesters harvest for personal use.

Harvester Satisfaction

A large majority (82%) of 2006 harvesters were satisfied with their overall wild rice harvesting experience, with only one in ten expressing dissatisfaction. Harvesters were neutral on the existing wild rice season opening date (July 15th) and slightly in favor of the current wild rice season hours (9 a.m. to 3 p.m.). Other comment topics included: high licensing fees, less than ideal water levels, lack of processor information, lack of enforcement, weather, shoreline degradation, motor boats in wild rice stands, beaver control, and a need for more regulation of genetically modified wild rice.

Use of Minnesota Lake and Rivers to Harvest Wild Rice

A total of 3,151 trips were reported by 845 harvesters, resulting in an average of 4 trips per person to gather wild rice. Sixty percent (60%) of 2006 harvesters took three or fewer trips, while 12 harvesters (1%) managed 20 or more trips. One half (50%) of the respondents reported harvesting on only one lake, indicating that multiple trips were made to the same lakes. An additional 28 percent reported harvesting on two lakes. The average number of lakes visited for harvesting wild rice was 1.8 across all harvesters. The maximum number of lakes visited was six.

During 2006, over two-thirds (70%) of all wild rice harvesting trips were in Aitkin, St. Louis, Itasca, Crow Wing or Cass counties. The next five counties with the highest number of trips were Becker, Clearwater, Beltrami, Lake and Hubbard counties. The above ten counties had 91 percent of all wild rice harvesting trips. A total of 28 counties were identified as being visited for wild rice gathering.

While 407 locations were identified from the survey results to at least the county level, only 313 noted a specific name (i.e. lake name or river segment). Of these 313 locations, the top ten harvest locations based on harvest pressure (number of trips) account for 27.4 percent of the statewide total. Further review notes that 50 percent of total trips are represented by the top 32 locations and that the top 68 locations represent 66.6 percent of total trips.

State Regulations

About half (53%) of the respondents supported a change in harvesting hours from 9 a.m. - 3 p.m. to 10 a.m. - sunset, and three-fourths (77%) supported changing the wild rice season opening from July 15 to August 14. More than half (62% and 66% respectively) of the respondents opposed use of watercraft up to 38 inches wide or establishing a 7-day nonresident license.

Participation, Information Needs

The most important factors identified by respondents that limit participation in harvesting were personal time, and knowing when and where to harvest wild rice. For respondents that did not harvest in 2006, finding a rice processor ranked highest after personal time. Where and when to harvest are again ranked high for information helpful to 2006 ricers. In order of preference, the preferred method for delivery of information is through web sites, pamphlets or as a section of the DNR Hunting Regulation Handbook. Other limiting factors identified in comments include the cost of the license, fuel and transportation costs, and access (to private and reservation lakes).

Management Priorities

A large majority of respondents ranked water level management as the highest management priority, followed by availability of information. Seeding ranked third, while enforcement of regulations, access site improvement, and wild rice research were ranked fourth, fifth and sixth,

respectively. Other comments included protection from genetically modified rice, increased habitat protection, and excessive license fees. Specific habitat protection comments included more restrictions on shoreline development, protection from motorized watercraft, prevention of the removal of wild rice through aquatic plant management permits, and more management of specific lakes that are historical wild rice lakes.

Appendix D

The Life History of Natural Wild Rice

Growth and Development

The following description of the growth of wild rice plants is adapted primarily from the work of Dr. Ervin Oelke and others at the University of Minnesota unless noted otherwise (Oelke et al. 2000, Oelke 2007).

As an annual plant, wild rice develops each spring from seeds that fell into the water and settled into sediment the previous fall or before. Germination requires three to four months of cold, nearly freezing water (35° F or colder). Seeds exposed to drying die. Seed dormancy is regulated through hormonal growth promoters and inhibitors and by an impermeable, tough, wax-covered pericarp. Low oxygen levels can also inhibit germination.

Seed germination typically occurs when the substrate and surrounding water temperatures reach about 40° F. Depending on water depth, latitude, and the progression of spring weather, wild rice germinates in Minnesota sometime in April, well ahead of most but not all perennial plants. Within three weeks, rooted wild rice seedlings develop three submerged leaves. These leaves usually remain submerged and decay as the plant matures. Adventitious roots arise at the first leaf node and occasionally at the second and third nodes. Most, but not all, roots are shallow, often rust-tinged due to iron deposits, and may spread 8 to 12 inches. Natural mortality can be relatively high during the submerged leaf stage (Meeker 2000).

The emergent stage begins with the development of one or two floating leaves and continues with the development of several aerial leaves two to three weeks later. The floating leaves are apparent in late May to mid June in Minnesota, again dependent on water depth, latitude, and weather. It is at this stage of growth that wild rice is most susceptible to uprooting by rapidly changing water levels due to the natural buoyancy of the plant. Rising water levels can significantly stress the plant even if it remains rooted.

The upper portion of the wild rice stem is hollow, with thin evenly spaced partitions. The number of tillers, or additional flowering stems, can vary with plant density and water depth. In deep water there may only be one stem per plant while in shallow water the number can exceed 30. Tillers typically mature 7 to 14 days later than the main stem (Meeker 2000).

Wild rice begins to flower in mid to late July in Minnesota. Flowering times are dependent on both day length and temperature. Short day lengths trigger earlier flowering but a reduction in kernel number. Longer day lengths delay flowering while increasing kernel number. Warmer temperatures will accelerate development, and cooler temperatures will slow growth. Wild rice flowers are produced in a branching panicle with female flowers (pistillate or seed-producing) at the top of the panicle on appressed branches. Female florets typically number about 130 per plant. Male flowers (staminate or pollen-producing) are produced on nearly horizontal branches on the lower portion of the panicle. Natural wild rice is primarily pollinated by wind. High temperatures and low humidity can negatively affect fertilization rates.

There are several variations of the typical wild rice panicle. One is the bottlebrush variant, often associated with male sterility, in which the male flowering branches remain appressed and give the panicle a compact bottlebrush appearance. Another variant is the crowsfoot panicle, in which the female flowering branches spread in the same manner as the male branches. In another variant, the male florets are replaced by female florets, resulting in a gynoeceious or entirely female panicle.

Cross-pollination is typical for natural wild rice because the female flowers develop, become receptive, and are pollinated before the male flowers on the same plant shed pollen. The female florets are receptive over a period of about ten days (Moyle 1944b). Cross-pollination is enhanced by plant-to-plant variation for flowering within the same stand due to the effects of water depth, non-synchronous tillering, and genetic differences among plants (Moyle 1944b, Meeker 2000).

Cross-pollination within and among wild rice populations helps maintain genetic variability and the biologic potential for wild rice to adapt to changing conditions. Some changes may be seasonal or annual in nature; others, such as changing climate in the Great Lakes region, will likely be long term. The variability in natural wild rice genetics that exists today may be a critical determinant of whether natural wild rice can adapt to changes in regional weather. Studies in northern Wisconsin found sufficient genetic diversity among geographically distinct stands of natural wild rice to identify four regional populations. The degree of diversity within stands varied widely, however, with larger and denser stands having higher levels (Waller et al. 2000).

When viable pollen grains land on the female stigma, they germinate within one hour and reach the embryo sac within two. Seeds are visible two weeks after fertilization, and they mature in four to five weeks. Immature seeds have a green outer layer that turns purplish black as the seed reaches physiologic maturity.

Seeds ripen over several days on an individual stem, starting at the top. Primary stems ripen earlier than secondary tillers, plants in rivers ripen earlier than those in lakes, plants in shallow water earlier than those in deeper water, and plants in northern Minnesota earlier than those in more southerly stands.

This staggered maturation process means that ripe seeds may be available within individual stands for several weeks, and across the entire range of natural wild rice in Minnesota for a month or longer. This extended period of “shattering”, or dropping of ripened seed, is an important mechanism that insures at least some seeds will survive to perpetuate the natural wild rice stand. The entire process, from germination of a new plant to the dropping of mature seeds, takes about 110 to 130 days (or about 2600 growing-degree days) depending on temperature and other environmental factors.

Not all wild rice seed germinates the following year. Under some conditions, natural wild rice seeds can remain dormant in the bottom sediment for many years to several decades if conditions are not suitable for germination. This allows wild rice to survive years when high water levels or

storms reduce or eliminate productivity. Wild rice can germinate and colonize habitats after other plants have been removed by environmental disturbance if a seed bank is present (Meeker, 1999).

Even under ideal growing conditions, wild rice populations follow approximately three to five year cycles (Jenks 1900, Moyle 1944b, Pastor and Durkee Walker 2006, Walker et al. 2006). Highly productive years are followed by unproductive ones followed by a gradual recovery (Moyle 1944b, Grava and Raisanen 1978, Atkins 1986, Lee 1986, Archibold et al. 1989). Recent study suggests that oscillations in wild rice may be caused by delays in nutrient recycling to plant uptake. Wild rice litter accumulation may inhibit plant growth and production (Pastor and Durkee Walker 2006, Walker et al. 2006). In particular, the amount of wild rice straw, stage of decay, and tissue chemistry (root litter) may affect available nutrients, influence production, and result in population cycling (Walker, Ph.D. thesis 2008).

Habitat Requirements

While the historical range of wild rice illustrates its broad distribution, its specific occurrence and abundance is in large part dependent on local environmental conditions. The following descriptions are a capsulation of the historical and current literature (Moyle 1944a, Rogosin 1951, Lee 2000, Meeker 2000, Oelke 2007). For more detailed information be sure to check the original sources.

Hydrology

Wild rice generally requires some moving water, with rivers, flowages, and lakes with inlets and outlets being optimal areas. Water basins with intermittent or seasonal flow may sustain beds, but annual production will fluctuate more widely. Seasonal water depth is critical. Wild rice grows well in about 0.5 - 3 feet of water, although plants may be found deeper. Shallower sites support strong competition from perennial emergent plants and deeper water stresses the plant to the point that seed production is limited or nonexistent. At Rice Lake National Wildlife Refuge from 2002 to 2005, production and growth parameters were highest at water depths of 1- 30 inches (McDowell, personal communication).

Water levels that are relatively stable or decline gradually during the growing season are preferred. Abrupt water level increases during the growing season can uproot plants. Wild rice is particularly sensitive to this disturbance during the floating leaf stage. However, some observers feel that water levels kept stable over the long term (multiple years) tend to favor perennial aquatic vegetation over wild rice (David and Vogt, personal communication).

Water characteristics

Clear to moderately stained water is preferred, as darkly stained water may limit sunlight penetration and hinder early plant development.

Wild rice grows over a wide range of alkalinity, pH, iron, and salinity. It does best in water that has a pH range of 6.0 - 8.0 and alkalinity greater than 40 ppm. Some of the measured chemistry

parameters are alkalinity (5-250 ppm), pH (6.4-10.1 SU), Iron (0.1-3.0 ppm) and True Color (50-300 Pt-Co) (Andryk 1986, Persell and Swan 1986).

The state of Minnesota instituted a water quality criterion for sulfate in wild rice waters of 10 mg/liter. The level was established based on observations by Moyle (1944a), however, other field observations and research show that wild rice can grow in waters with significantly higher sulfate concentrations (Grava 1981, Lee and Stewart 1983, Peden 1982). This research also indicates that factors such as oxygen levels and potential sediment anoxia are involved in the wild rice-sulfate connection.

While researchers have observed that natural wild rice ecosystems are relatively nutrient rich, excess levels of nutrients, especially phosphorus, can have significant adverse effects on natural wild rice productivity (Persell and Swan 1986).

Sediment

Although wild rice may be found growing in a variety of bottom types, the most consistently productive are lakes with soft, organic sediments (Lee 1986). The high organic matter content with a rather low carbon/nitrogen ratio is necessary to meet the rather high nitrogen needs of wild rice (Carson 2002). Nitrogen and phosphorus are major limiting nutrients for wild rice (Carson 2002). Flocculent sediments with nitrogen and phosphorus concentrations less than one gram per square meter are typically incapable of supporting sustained production (Lee 1986).

Competing Vegetation

As an annual plant sprouting each year from seed, wild rice can have difficulty competing with aggressive perennial vegetation, particularly where natural hydrologic variation has been reduced. Cattail (*Typha* spp.), particularly hybrid cattail (*Typha x glauca*), yellow water lily (*Nuphar variegata*), and pickerelweed (*Pontederia cordata*) are examples of plants that have been cited as competing with wild rice (Norrsgard, David, and Vogt, personal communication).

Appendix E

Wild Rice Bibliography

- 1854 Authority. 2000. Wild Rice Resource Guide. Duluth, Minnesota, USA.
- Abedinia, M., R. J. Henry, A. B. Blakeney, and L. G. Lewin. 2000. Accessing genes in the tertiary gene pool of rice by direct introduction of total DNA from *Zizania palustris* (Wild Rice). Plant Molecular Biology Reporter 18:133-138.
- Ackley, F. 2000. Manoomin – A gift from the creator. Pages 8-10 in Proceedings of the Wild Rice Research and Management Conference. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- University of Minnesota, Agricultural Experiment Station. Date unknown. Minnesota Wild Rice Research. St. Paul, USA.
- Aiken, S. G., P. F. Lee, D. Punter, and J. M. Stewart. 1988. Wild rice in Canada. Agriculture Canada Publication 1830, NC Press Limited, Toronto, Ontario, Canada.
- Archibold, O. W., A. G. Good, and J. M. Sutherland. 1989. Annual variation in wild rice growth. Canadian Journal Plant Science 69:653-655.
- Archibold, O. W. and B. J. Weichel. 1986. Variation in wild rice (*Zizania palustris*) stands across northern Saskatchewan. Canadian Journal of Botany 64:1204-1211.
- Arnold, J. B. 1923. A story of Grand Portage and vicinity - compiled from the writings of Warren, Winchell, Neill, and Buck. Harrison and Smith Company, Minneapolis, Minnesota, USA.
- Asplund, T. R. 2000. The effects of motorized watercraft on aquatic ecosystems. Wisconsin Department of Natural Resources and University of Wisconsin, Publication PUBL-SS-948-00, Madison, USA.
- Atkins, T. 1986. The life history and ecology of wild rice. In Wild Rice, The Natural Crop Conference, 13-15 May 1986, Lakehead University, Minaki, Ontario, Canada.
- Atkins, T. A., A. G. Thomas, and J. M. Stewart. 1987. The germination of wild rice in response to diurnally fluctuating temperatures and after-ripening period. Aquatic Botany 29:245-259.
- Backer, C. 2003. Wild Rice Information. Unpublished. Minnesota Department of Natural Resources, St. Paul, USA.

- Ball, I. J., D. S. Gilmer, L. M. Cowardin, and J. M. Riechmann. 1975. Survival of wood duck and mallard broods in north-central Minnesota. *Journal of Wildlife Management* 39:776-780
- Barko, J. W., and R. M. Smart. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. *Ecology* 67:1328-1340.
- Bayly, I. L. 1983. The caryopsis as a support organ for germinating wild-rice, *Zizania aquatica*. *Canadian Field Naturalist* 98(3):369-370.
- Behr, M. 1977. Indian potential in the wild rice industry.
- Benton-Banai, E. 1988. The Mishomis book: the voice of the Ojibwe. Indian Country Communications, Inc., St. Paul, Minnesota, USA.
- Berde, S. 1980. Wild ricing: The transformation of an aboriginal subsistence pattern. Pages 101-126 in Anthony J. Paredes, editor. *Anishinabe: 6 Studies of Modern Chippewa*. University Presses of Florida, Tallahassee, USA.
- BSU-CRI, conference host. 2007. Adapting natural resources management in northern Minnesota to a changing climate. Presentations and notes posted online (<http://www.cri-bsu.org/ClimateChangeFall07.html>). Bemidji, Minnesota, USA.
- Caldwell, V. B., E. A. Oelke, and W. A. Elliott. 1978. Seed dormancy mechanisms in wild rice (*Zizania aquatica*). *Agronomy Journal* 70(6):481-484.
- Carson, T. L. 2002. The effects of sediment nutrient variation, water depth, and emergent aquatic perennials on wild rice (*Zizania palustris*) production at the Rice Lake National Wildlife Refuge. Thesis, University of Minnesota, Minneapolis, USA.
- Chambliss, C. E. 1922. Wild rice. U. S. Department of Agriculture, Circular 229. Wash. DC.
- Chambliss, C. E. 1940. The botany and history of *Zizania aquatica* L. ('wild rice'). Pages 369-382 in Annual Report of the Board of Regents of the Smithsonian Institute, year ending June 30, 1940, Government Printing Office, Washington, D.C., USA.
- Coleman, Sister B. 1953. The Ojibwe and the wild rice problem. *Anthropological Quarterly* 26(2):79-88.
- Cregan, J. 2004. Aspects of seed storage, pollen travel and population dynamics of wild rice (*Zizania palustris*). Thesis, University of Minnesota, Minneapolis, USA.
- Danzinger, E. J., Jr. 1990. The Chippewas of Lake Superior. Second Edition. University of Oklahoma Press, Norman, USA.

- Day, W. R., and P. F. Lee. 1989. Ecological relationships of wild rice, *Zizania aquatica*. 8. classification of sediments. Canadian Journal of Botany 67:1381-1386.
- Day, W. R., and P. F. Lee. 1990. Ecological relationships of wild rice *Zizania aquatica*. 9. production in organic-flocculent sediments. Canadian Journal of Botany 68:1542-1548
- Densmore, F. 1928. Uses of plants by the Chippewa Indians. Pages 275-397 in 44th Annual Report of the Bureau of American Ethnology, Government Printing Office, Washington, D.C.
- Dore, W. G. 1969. Wild rice. Canada Department of Agriculture Research Branch Resource Publication 1393, Ottawa, Canada.
- Durkee W. R., J. Pastor, and B. W. Dewey. 2006. Effects of wild rice (*Zizania palustris*) straw on biomass and seed production in northern Minnesota. Canadian Journal of Botany 84:1019-1024.
- Duvall, M. R., and D. D. Biesboer. 1989. Comparisons of electrophoretic seed protein profiles among North American populations of *Zizania*. Biochemical Systematic Ecology 17(1):39-43.
- Dzubin, A., and J. B. Gollop. 1972. Aspects of mallard breeding ecology in Canadian parkland and grassland. Pages 113-152 in Population Ecology of Migratory Birds-A Symposium. Migratory Bird Populations Station, 9-10 October 1969, Laurel, Maryland, USA. Bureau of Sport Fisheries and Wildlife Research Report No. 2.
- Ebbott, E. 1985. Indians in Minnesota. League of Women Voters of Minnesota. Judith Rosenblatt, editor. University of Minneapolis Press, Minneapolis, USA.
- Edman, R. F. 1969. A study of wild rice in Minnesota. Minnesota Resources Commission, St. Paul, USA.
- Elliott, W. A. 1980. Wild Rice (*Zizania aquatica*). Pages 721-731 in W. A. Fehr and H. H. Hadley, editors. Hybridization of Crop Plants. Society of Agronomy and Crop Science Society of America, Madison, USA.
- Engel, S., and S. A. Nichols. 1994. Aquatic macrophyte growth in a turbid windswept lake. Journal of Freshwater Ecology 9(2):97-109.
- Fannucchi, G. T., W. M. Fannucchi, and S. Craven. 1986. The ecology of wild-rice. University of Wisconsin Agricultural Extension Service, Madison, USA.
- Fassett, N. C. 1924. A study of the genus *Zizania*. Rhodora 26:153-160.

- Ferren, R. R., and R. E. Good. 1977. Habitat, morphology and phenology of southern wild rice (*Zizania aquatica*) from the Wading River in New Jersey. *Bulletin of the Torrey Botany Club* 104:392-396.
- Flora of North America Editorial Committee, editors. 1993+. *Flora of North America north of Mexico*. 12+ volumes. New York, USA and Oxford, UK.
- Forest Stewardship Council. 2004. *Regional Forest Stewardship Standard for the Lake States – Central Hardwoods Region*.
- Fruth, J. A. 1980. *Harvesting wild rice*.
- Gilman, C. 1992. *The Grand Portage story*. Minnesota Historical Society Press, St. Paul, USA.
- Gleason, H.A., and A. Cronquist. 1991. *Manual of vascular plants of northeastern United States and adjacent Canada*, second edition. The New York Botanical Garden, Bronx, New York, USA.
- Gould, F. W., and R. B. Shaw. 1983. *Grass systematics*. Texas A&M University Press, College Station, USA.
- Grava, J. 1981. *Minnesota Wild Rice Research 1980*. Agricultural Experiment Station, University of Minnesota. St. Paul MN.
- Grava, J. 1982. Wild rice production in Minnesota. *University of Minnesota Extension Bulletin* 484:18-21
- Grava, J., and K. A. Raisanen. 1978. Growth and nutrient accumulation and distribution in wild rice. *Agronomy Journal* 70:1077-1081.
- Hansel-Welch, N. 2007. Personal communication. Minnesota Department of Natural Resources, Wildlife Management Section, Shallow Lakes Program, Brainerd, USA.
- Haramis, G. M., and G. D. Kearns. 2004. Invasive Herbivory: resident Canada geese and the decline of wild rice along the tidal Patuxent River. Pages 37-38 in M. C. Perry, editor. *Proceedings of a Symposium: Mute Swans and Their Chesapeake Bay Habitats*. U. S. Geological Survey, Biological Resources Discipline Information and Technology Report USGS/BRD/ITR-2004-0005.
- Hass, B. L., J. C. Pires, R. Porter, R. L. Phillips, and S. A. Jackson. 2003. Comparative genetics at the gene and chromosome levels between rice (*Oryza sativa*) and wild rice (*Zizania palustris*). *Theoretical and Applied Genetics* 107:773-786.

- Haygood, R., A. R. Ives, and D. A. Andow. 2003. Consequences of recurrent gene flow from crops to wild relatives. *Proceedings of The Royal Society London B* 270:1879-1886
- Helgen, J. C. 1990. The distribution of crayfish in Minnesota. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report Number 405.
- Henderson, M. 1993. A geographical assessment of wild rice in the Upper St. Louis and Vermilion watersheds. Project proposal to the 1854 Authority, Duluth, Minnesota, and Fond du Lac Band of Lake Superior Chippewa, Cloquet, Minnesota.
- Henderson, M. 1994. A predictive model of potential wild rice habitat in the Vermilion, St. Louis, Rainy River and Lake Superior watersheds. Project proposal to the 1854 Authority, Duluth, Minnesota, and Fond du Lac Band of Lake Superior Chippewa, Cloquet, Minnesota.
- Henry, M., and G. Norenberg. 1994. Invertebrate study of cultivated wild rice paddies in northwest Minnesota. Pages 80-83 in *Minnesota Wild Rice Research – 1993*, Minnesota Agricultural Experiment Station Miscellaneous Publication 82.
- Hilger, I. M. 1939. A social study of one hundred fifty Chippewa Indian families of the White Earth Reservation of Minnesota. 1980, Reprint. Thesis Catholic University of America, AMS Press, New York, New York, USA.
- Hitchcock, A. S., and A. Chase. 1951. *Manual of the grasses of the United States*. Second edition. U. S. Department of Agriculture Miscellaneous Publication No. 200.
- Holm, L.G., D.L. Plucknett, J.V. Pancho, and J.P. Herberger. 1977. *The world's worst weeds: distribution and biology*. University Press, Hawaii, Honolulu. 609 pp.
- Hotchkiss, N. 1932. Marsh and aquatic vegetation of Minnesota and its value to waterfowl. U. S. Department of Agriculture, Bureau of Biological Survey, Division of Food Habits Research.
- Huber, A. 1936. Wild rice harvest, Indians at work. Office of Indian Affairs, Washington, D.C., USA.
- Huseby, J. T. 1997. Use of cultivated wild rice paddies and associated habitats by migrating and breeding waterfowl in northwest Minnesota. Dissertation, University of North Dakota, Grand Forks, USA.
- International Joint Commission. 1917. Final Report of Lake of the Woods Reference. Compiled by Whitehead Kluttz and Lawrence J. Burpee for the Secretary of State.
- Jarvenpa, R. 1971. The wild rice gatherers of Rice Lake, Minnesota: a brief note on cultural historical indicators. *Minnesota Archaeologist* 31:71-105.

- Jenks, A. E. 1898. The wild rice gatherers of the Upper Lakes: A study on American primitive economics. 1977, Reprint. Pages 1019-1131 in Reprinted from the Annual Report of the U. S. Bureau of Ethnology, 1897-1898. J & L Reprint Co., Lincoln, Nebraska, USA.
- Jenks, A. E. 1900. The wild rice gatherers of the Upper Lakes: a study in American primitive economics. Pages 1013-1137 in Nineteenth Annual Report of the Bureau of American Ethnology, 1897-1898. Government Printing Office, Washington, D.C., USA.
- Jenness, D. 1931. Wild rice. Canadian Geography Journal 2:477-482.
- Johnson, D. O. 1976. A spring waterfowl population study of the commercial wild rice paddies of Aitkin and Itasca counties. Thesis, Bemidji State University, Bemidji, Minnesota, USA.
- Johnson, E. 1969. Preliminary notes on the prehistoric use of wild rice. The Minnesota Archaeologist 30(2):31-43.
- Keenan, T. J., and P. F. Lee. 1988. Ecological relationships of wild rice, *Zizania aquatica*. 7. Sediment nutrient depletion following introduction of wild rice to a shallow boreal lake. Canadian Journal of Botany 66:236-241.
- Kegg, M. 1993. Portage Lake: Memories of an Ojibwe childhood. John D. Nichols, translator and editor. University of Minnesota Press, Minneapolis, USA.
- Kennard, W. C., R. L. Phillips, and R. A. Porter. 2002. Genetic dissection of seed shattering, agronomic, and color traits in American wildrice (*Zizania palustris* var. *interior* L.) with a comparative map. Theoretical and Applied Genetics 105:1075-1086
- Kennard, W. C., R. L. Phillips, R. A. Porter, and A. W. Grombacher. 2000. A comparative map of wild rice (*Zizania palustris* L. 2n=2x=30). Theoretical and Applied Genetics 101:677-684.
- Kennedy, C. 1924. The nutritive properties of wild rice *Zizania aquatica*. Journal of Agricultural Resources 27:219-224.
- LaDuke, W., and B. Carlson. 2003. Our manoomin, our life: The Anishinaabeg struggle to protect wild rice. White Earth Land Recovery Project, Ponsford, Minnesota.
- LaMontagne, J. 2000. Use of migratory stopover areas by trumpeter swans in southern Alberta. Thesis. University of Calgary, Calgary, Alberta.
- Lee, P. F. 1986. Ecological relationships of wild rice, *Zizania aquatica*. 4. Environmental regions within a wild rice lake. Canadian Journal Botany 64:2037-2044.

- Lee, P. F. 2000. Research and the conservation of wild rice. Pages 11-14 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Lee, P. F., and J. M. Stewart. 1983. Ecological relationships of wild rice, *Zizania aquatica*. 2. Sediment plant tissue concentrations. *Canadian Journal of Botany* 61:1775-1784.
- Lee, P., and J.M. Stewart. 1983. *Ecological Relationships of wild Rice, Zizania aquatica*. 3. *Factors Affecting Seedling Success*. *Canadian Journal of Botany* 62: 1608-1615
- Lee, P. F. 1986. Summary report: the aquaculture of wild rice. *Proceedings from Wild Rice, The Natural Crop Conference*, 13-15 May 1986, Lakehead University, Minaki, Ontario, Canada.
- Levi, Sister M. C. 1956. *Chippewa Indians of yesterday and today*. Pageant Press, Inc., New York, New York, USA.
- Lu, Y., D. Waller, and P. David. 2005. Genetic variability is correlated with population size and reproduction in American wild rice (*Zizania palustris*. Var. *paustris*, *Poaceae*) populations. *American Journal of Botany* 92:990-997.
- Maki, K., and S. Galatowitsch. 2004. Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. *Biological Conservation* 118(3):389-396.
- Martin, A. C., and F. M. Uhler. 1939. *Foods of game ducks in the United States and Canada*. U. S. Department of Agriculture Technical Bulletin 634. Wash., D.C.
- Martin, A. C., H. S. Zim, and A. L. Nelson. 1951. *American wildlife and plants*. Dover Publications. New York, New York.
- Mather, D., and R. G. Thompson. 1999. Archeological perspectives on wild rice. Pages 15-26 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- McAndrews, J. H. and C. L. Turton. 2007. Canada geese dispersed cultigen pollen grains from prehistoric Iroquoian fields to Crawford Lake, Ontario, Canada. *Palynology* 31: 9-18.
- McAtee, W. L. 1917. *Propagation of wild duck foods*. U. S. Department of Agriculture Bulletin 465. Government Printing Office, Washington, D.C.
- McDowell, M. 2006. Adaptive management of wild rice and pickerelweed at Rice Lake National Wildlife Refuge. *Manoomin Niikaanisag Wild Rice Coalition Building and Conference*, 8-11 August 2006, Watersmeet, Michigan, USA.

- Medsger, O. P. 1939. Edible wild plants. MacMillian, Co., New York, New York, USA.
- Meeker, J. E. 1993. The ecology of "wild" wild-rice (*Zizania palustris* var. *palustris*) in the Kakagon Sloughs, a riverine wetland on Lake Superior. Dissertation, University of Wisconsin, Madison, USA.
- Meeker, J. E. 1996. Wild-rice and sedimentation processes in a Lake Superior coastal wetland. *Wetlands* 16(2): 219-231.
- Meeker, J. 2000. The ecology of "Wild" wild rice (*Zizania palustris* var. *palustris*) in the Kakagon Sloughs, a riverine wetland on Lake Superior. Pages 68-83 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Miller, J. R. 1987. Fall and winter foods of northern pintails in the Sacramento Valley, California. *Journal of Wildlife Management* 51:405-414.
- Minnesota Department of Administration, State Demographic Center. 2007. Extrapolated population for Minnesota cities and townships outside the Twin Cities region, 2006 – 2035. <http://www.demography.state.mn.us>. Accessed 25 Oct 2007.
- Minnesota Department of Natural Resources. 2006. Tomorrow's habitat for the wild and rare: an action plan for Minnesota wildlife, comprehensive wildlife conservation strategy. Minnesota Department of Natural Resources, Division of Ecological Services, St. Paul, USA.
- Minnesota Department of Natural Resources. 2007. Invasive species website. <http://www.dnr.state.mn.us/invasives/index.html>, St. Paul, Minnesota.
- Mississippi Flyway Council. 2005. Meeting Minutes, July 23-24, Robinsonville, MS.
- Moyle, J. B. 1939. The larger aquatic plants of Minnesota and the factors determining their distribution. Dissertation, University of Minnesota, Minneapolis, USA.
- Moyle, J. B. 1941a. Minnesota's wild rice crop: a lesser known natural resource. *Conservation Volunteer* 3(15):30-32.
- Moyle, J. B. 1941b. Report on Minnesota wild rice for 1940. Submitted to W. L. Strunk, Minnesota Commissioner of Conservation, St. Paul, USA.
- Moyle, J. B. 1942. The 1941 Minnesota wild rice crop. Fisheries Research Investigational Report No. 40, Bureau of Fisheries Research, Division of Game and Fish, Minnesota Department of Natural Resources, St. Paul, USA.
- Moyle, J. B. 1944a. Some chemical factors influencing the distribution of aquatic plants in Minnesota. *American Midland Naturalist* 34:402-420.

- Moyle, J. B. 1944b. Wild Rice in Minnesota. *The Journal of Wildlife Management* 8(3):177-184.
- Moyle, J. B. 1945. Manomin - Minnesota's native cereal. *Conservation Volunteer*. January-February:29-31.
- Moyle, J. B. and P. Krueger. 1964. Wild Rice in Minnesota. *The Conservation Volunteer*. Nov. – Dec. pp. 30-37.
- Moyle, J. B., editor. 1964. Ducks and land use in Minnesota. Minnesota Department of Natural Resources Technical Bulletin No. 8, St. Paul, USA.
- Moyle, J. B. 1969. Wild rice - some notes, comments and problems. Minnesota Department of Conservation, Division of Game and Fish No. 47. Revised from Seminar on Wild Rice, Department of Agronomy and Plant Genetics, University of Minnesota.
- Murray, M. 2007. Killer reed's lethal weapon discovered. *The News Journal*. 18 October 2007. www.delawareonline.com.
- Myers, J. 2006. Breaking up the forest. *Minnesota Conservation Volunteer*. January-February, http://www.dnr.state.mn.us/volunteer/janfeb06/breaking_up.html.
- Nelson, R. N. 1986. The wild rice industry: economic analysis of rapid growth and implications for Minnesota. Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, USA.
- Norrgard, R. 2006. An overview of threats to the future of wild rice conservation and management. Manoomin Niikaanisag Wild Rice Coalition Building and Conference, 8-11 August 2006, Watersmeet, Michigan, USA.
- Nute, G. 1941. The voyageur's highway, Minnesota's border lake land. The Minnesota Historical Society, St. Paul, USA.
- Nute, G. 1950. Rainy River country: a brief history of the region bordering Minnesota and Ontario. The Minnesota Historical Society, St. Paul, USA.
- Oelke, E. A. 1993. Wild rice: domestication of a native North American genus. Pages 235-243 in J. Janick and J. E. Simon, editors. *New crops*. Wiley, New York, New York, USA.
- Oelke, E. A. 2007. *Saga of the grain: a tribute to Minnesota cultivated wild rice growers*. Hobar Publications. Lakeville, MN.
- Oelke, E. A., P. R. Bloom, R. A. Porter, and Q. Liu. 2000. Wild rice plant development and seed physiology. Pages 54-67 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.

- Oelke, E. A., W. A. Elliot, M. F. Kern Camp, and D. N. Noetzel. 1973. Commercial production of wild rice. University of Minnesota Agricultural Extension Service, Extension Folder 284. St. Paul, USA.
- Oelke, E. A., J. Grava, D. Noetzel, D. Barron, J. Percich, C. Schertz, J. Strait, and R. Stucker. 1982. Wild rice production in Minnesota. Minnesota Agricultural Extension Bulletin 464-1982, St. Paul, Minnesota, USA.
- Oelke, E. A., D. G. LeGare, and H. J. Schumer. 1995. Wild rice production research – 1995. Minnesota Agricultural Extension Station Miscellaneous Bulletin Publication 89-1996, St. Paul, Minnesota, USA.
- Ownby, G. B., and T. Morley. 1991. Vascular plants of Minnesota: a checklist and atlas. University of Minnesota Press, Minneapolis, USA.
- Pastor, J., and R. W. Durkee Walker. 2006. Delays in nutrient cycling and plant population oscillations. *Oikos* 112(3):698-705.
- Pedan, D. G. 1977. Waterfowl use of exotic wild rice habitat in northern Saskatchewan. *Canadian Field Naturalist* 91:286-287.
- Peden, D. G. 1982. Factors associated with growth of wild rice in northern Saskatchewan. *Arctic* 35(2):307-311.
- Persell, J., and M. Swan. 1986. Wild rice ecosystems, a general description. Minnesota Chippewa Tribe Water Research Lab, Cass Lake, USA.
- Pillsbury, R. W., and E. A. Bergey. 2000. The effects of root mass and disturbance on wild rice (*Palustris aquatica*) survivorship. Pages 206-214 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Pip, E., and J. Stepaniuk. 1988. The effect of flooding on wild rice, *Zizania aquatica* L. *Aquatic Botany* 32:283-290.
- Porter, R. A., R. L. Phillips, R. F. Nyvall, and E. A. Oelke. 2000. A genetic overview of wild rice from three decades of breeding. Pages 109-121 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Radomski, P., and T. J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. *North American Journal of Fisheries Management* 21:46-61.
- Reagen, A. B. 1924. The Bois Forte Chippewa. *Wisconsin Archaeologist*, New Series 3 (Sept.):101-132.

- Reagen, A. B. 1928. Plants used by the Bois Forte Chippewa (Ojibwe) Indians of Minnesota. *Wisconsin Archaeologist*, New Series 7 (July):230-248.
- Reagen, A. B. 1933. Some notes on the grand medicine society of the Bois Forte Ojibwe. *Americana* 27:502-519.
- Remecke, K. J., and R. B. Owen, Jr. 1980. Food use and nutrition of black ducks in Maine. *Journal of Wildlife Management* 44:549-558.
- Richards, C., J. Gunderson, P. Tucker, and M. McDonald. 1995. Crayfish and baitfish culture in wild rice paddies. Natural Resources Research Institute, Technical Report NRRI/TR-95/39, University of Minnesota, Duluth, USA.
- Ritzenhaler, R. E. 1970. The woodland Indians of the Western Great Lakes. Natural History Press, Garden City, New York, USA.
- Rogosin, A. 1951. An ecological history of wild rice. Minnesota Commission on Wild Rice. Minnesota Department of Conservation, St. Paul, USA.
- Rossman, L. A. 1939. Wild Rice. Grand Rapids, Minnesota.
- Rossman, G., A. Rossman, and R. Rossman. 1982. Recollections of 50 years: duck hunting in northern Minnesota. Northprint Company, Grand Rapids, Minnesota, USA.
- Roufs, T. G. 1975. The Anishinabe of the Minnesota Chippewa Tribe. Indian Tribal Series, Phoenix, Arizona, USA.
- Sain, P. 1983. Decomposition of wild rice (*Zizania aquatica*) straw in two natural lakes in northwestern Ontario. *Canadian Journal of Botany* 62:1352-1356.
- Saunders, C. F. 1935. Useful wild plants of the United States and Canada. Robert M. McBride and Co, New York, New York, USA.
- Schlender, J. H. 2000. Forward. Proceedings of the Wild Rice Research and Management Conference. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Seeley, M. 2006. Minnesota weather almanac. Minnesota Historical Society Press, St. Paul, USA.
- Seeley, M. 2007a. Climate change implications for Minnesota's tourism and recreation. Sustainable Tourism Conference presentation, 25 April, 2007, Chanhassen, USA.
- Seeley, M. 2007b. Weather Talk. Minnesota Public Radio. December 28.

- Simpson, W. 1941. The wild rice crop on Minnewawa Lake. Letter to the Division of Drainage and Water, Minnesota Department of Conservation, St. Paul, USA.
- Sorenson, D. J. 1973. A spring waterfowl population study of the Red Lake watershed. Thesis, Bemidji State University, Minnesota, USA.
- Stebbins, G. L., and B. Crampton. 1961. A suggested revision of the grass genera of temperate North America. *Recent Advances in Botany* 1:133-145.
- Stephenson, S., and P. Lee. 1987. Ecological relationships of wild rice, *Zizania aquatica*. 6. The effects of increases in water depth on vegetative and reproductive production. *Canadian Journal of Botany* 65:2128-2132.
- Stickney, G. P. 1896. Indian use of wild rice. *Anthropology* 9:115-121.
- Stoddard, C. H. 1957. Utilization of waste swamplands for wild rice production. *Land Economics* 33(1):77-80.
- Stoudt, J. M. 1944. The food preferences of mallards in the Chippewa National Forest, Minnesota. *Journal of Wildlife Management* 8:110-112.
- Stoudt, J. M. 1969. Relationships between waterfowl and water areas on the Redvers waterfowl study area. Pages 123-131 in *Saskatoon Wetlands Seminar*, Canadian Wildlife Service Report Series 6.
- Svedarsky, W. D. 1995. Waterfowl, nongame birds, and invertebrates associated with cultivated wild rice paddies in northwest Minnesota. Northwest Experiment Station, University of Minnesota, Crookston, USA.
- Tanner, H. H., editor. 1987. *Atlas of Great Lakes Indian history. Civilization of the American Indian Series*, University of Oklahoma Press, Norman, USA.
- Terrell E. E., and H. Robinson. 1974. Luziolinae, a new subtribe of Oryzoid grasses. *Bulletin Torrey Botany Club* 101:235-245.
- Tester, J. R. 1995. *Minnesota's natural heritage*. University of Minnesota Press, Minneapolis, USA.
- Thai, W. 2005. Transgenic crops: the good, the bad, and the laws. *Minnesota Journal of Law, Science and Technology* 6(2):873-891.
- Thomas, A.G., and J. M. Stewart. 1969. The effect of different water depths on the growth of wild rice. *Canadian Journal of Botany* 47:1525-1531.

- Tynan, T. 2000. Testing the effects of motorboats on wild rice (*Zizania palustris* var. *interior*). Pages 192-205 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- U. S. Forest Service. North Central Research Station - The changing Midwest assessment: percent change in density of seasonal housing units, 1980-2000. <http://www.ncrs.fs.fed.us/4153/deltawest/humandemo/seasonal001.asp>. Accessed 22 Oct 2007.
- Ustipak, R. 1983. Wild rice initiative. Minnesota Waterfowl Assn. News, Jan/Feb, Page 7.
- Valppu, S. H. 2000. Paleoethnobotanical investigations at the Big Rice Site: Laurel culture use of wild rice (*Zizania aquatica* L.) and associated radiocarbon dates. Pages 27-39 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Vennum, T. Jr. 1988. Wild rice and the Ojibway people. Minnesota Historical Society Press, St. Paul, USA.
- Walker, R.D., Pastor, J., Dewey, B.W. (2006) Effects of wild rice (*Zizania palustris* L.) straw on biomass and seed production in northern Minnesota. *Canadian Journal of Botany*, 84 (6): 1019-1024.
- Walker, S. D. 1939. The wild rice crop on Nett Lake. Memorandum to M. L. Burns, Acting Superintendent of the Consolidated Chippewa Agency, Cass Lake, Minnesota, USA.
- Waller, D. M., Y. Lu, and P. David. 2000. Genetic variation among populations of wild rice (*Zizania palustris*). Pages 122-135 in *Proceedings of the Wild Rice Research and Management Conference*. Great Lakes Indian Fish and Wildlife Commission, 7-8 July 1999, Carlton, Minnesota, USA.
- Walsh, R. 1998. Wild and wilder: is America's native cereal still harvested by Indians in canoes? *Natural History* 107:82-85.
- Warren, W. W. 1984. History of the Ojibwe people. 1984, Reprint. The Minnesota Historical Society, St Paul, USA.
- Warwick, S. I., and S. G. Aiken. 1986. Electrophoretic evidence for the recognition of two species in annual wild rice (*Zizania*, *Poaceae*). *Systematic Botany* 11(3):464-473.
- Weir, C. E., and H. M. Dale. 1960. Developmental study of wild rice, *Zizania aquatica* L. *Canadian Journal of Botany* 38:719-739.
- Weiss, R. 2006. Gene-altered profit-killer: a slight taint of biotech rice puts farmers' overseas sales in peril. *Washington Post*. 21 September 2006.

- Wilcox, D. A., and J. E. Meeker. 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. *Canadian Journal of Botany* 69:1542-1551.
- Wilcox, D. A., J. E. Meeker, and J. E. Elias. 1992. Impacts of water-level regulation on wetlands of the Great Lakes. Phase 2 Report to Working Committee 2, International Joint Commission's Water-Level Reference Study.
- Wilcox, K. L., S. A. Petrie, L. A. Maynard, and S. W. Meyer. 2003. Historical distribution and abundance of *Phragmites australis* at Long Point, Lake Erie, Ontario. *Journal of Great Lakes Research* 29(4):664-680.
- Winchell, E. H. 1984. Wild rice: production, prices and marketing. Agricultural Experiment Station, University of Minnesota, St. Paul, USA.
- Winchell, N. H. 1911. The aborigines of Minnesota: a report based on the collections of Jacob V. Brower and the field surveys and notes of Alfred J. Hill and Theodore H. Lewis. The Minnesota Historical Society, The Pioneer Company, St. Paul, USA.

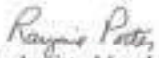
Appendix F

Stakeholder Comments

UNIVERSITY OF MINNESOTA

North Central Research and Outreach Center
College of Food, Agricultural and
Natural Resource Sciences

1861 East Highway 169
Grand Rapids, MN 55744
218-327-4490
Fax: 218-327-4126
<http://ncroc.cfnr.umn.edu>

Date: February 10, 2008
To: Legislators of the State of Minnesota
From: Dr. Raymie Porter, University of Minnesota 
Re: The report "Natural Wild Rice in Minnesota" submitted by the DNR

In this statement I do not speak on behalf of the University of Minnesota, but rather as a scientist who has been engaged in research on cultivated wildrice breeding at the University of Minnesota for almost 20 years.

I would like to commend the Technical Team convened by the DNR to pull together the information that contributed to this report. Although the participants represent diverse interests when it comes to wildrice, our meetings have been characterized by a vigorous interchange of ideas with mutual respect, while focusing on what is actually known about wildrice. I hope that future efforts to deal with the issues identified by this report will be as positive and fruitful as what I have experienced in the meetings of the Technical Team. I would like to add the following comments to the report for emphasis.

The loss of genetic diversity should be viewed *not* as a primary *cause*, but rather as an *effect* resulting from other causes. Granted, addressing the loss of genetic diversity is crucial for the species to flourish in state waters. Loss of genetic diversity means loss of the alleles (or variant forms) of genes across the many natural populations of wildrice, which also means that there are fewer genotypes (genetic types) for a given trait within a given population. Having fewer genotypes may limit a population's ability to respond to seasonal, yearly, or long-term changes in the local environment of that population. This is especially true if the genotypes lost are ones needed for adaptation to conditions that prevail at that site. But, since loss of genetic diversity is usually caused by factors that reduce the number of individuals in populations to low numbers, alleviating the problems that reduce wildrice stands will help maintain the genetic diversity of wildrice. The report does a good job of characterizing the primary threats that limit wildrice stands and that could therefore reduce genetic diversity.

But how will we know whether or how genetic diversity is being affected? Only through knowledge about the genetics of wildrice. Sound scientific knowledge about the genetic make-up of natural stands, coupled with knowledge about how different genes respond to various environmental factors, should prove useful in guiding restoration efforts. If seeds need to be brought in from other natural stands in order to restore a site, knowing the genetics of the potential donor stands could help identify those that might be most similar to the population that remains at, or that once existed at, the site.

What about cultivated wildrice? Is the breeding of wildrice really a threat to natural stands from a genetic perspective? The consensus of the Technical Team is that it is not. I agree with this perspective. In fact, I believe that cultivated wildrice should not be made a scapegoat for problems in natural stands. I have heard speculations that cultivated wildrice causes this or that problem observed in a natural stand—speculations without evidence. What I know about population genetics leads me to the conclusion that such speculations will never find evidence to support them. Some basic facts about population genetics and wildrice should shed light on this.

Cultivated varieties (cultivars) of wildrice in Minnesota are not genetically uniform—they are heterogeneous, or made up of many different genotypes. The wildrice breeding project at the University of Minnesota has endeavored to maintain as much genetic diversity as possible in the cultivars released. Also, since all the genes in cultivars ultimately originated in the natural wildrice gene pool, they are a subset of the total genetic variability of wildrice. No new alleles or genes have been artificially added (i.e., no genetic engineering has been done, nor is it being pursued). Therefore, it seems reasonable to assume that cultivated wildrice has less total genetic diversity than natural wildrice. But this is the norm for any cultivated crop species, since breeders would tend to select only those alleles (variant forms) of genes that make the crop better adapted under the narrower range of cultivated conditions. Conversely, breeding a crop for adaptation to cultivated conditions tends to make it less fit for survival in the wild.

But even if a wildrice cultivar were genetically uniform, that uniformity should not impact the vast diversity of natural wildrice. There are many more acres of natural stands than cultivated stands, and they are rarely in close proximity to each other. That wildrice pollen travels over long distances has *not* been established. But even if pollen should travel between cultivars and natural stands, it could just as easily travel from one natural stand to another. And pollen moving from one natural stand to another natural stand nearby would likely be so few in number compared to the pollen produced locally that it would be diluted to insignificant amounts. Also, the viability of that pollen once it arrives is in doubt, given the short life of wildrice pollen.

"Migration" is the term used by population geneticists to describe gene movement between populations. But what would happen in those cases of successful migration of alleles of genes into a population? If the allele of that gene is *already* present in the population, the migration doesn't add anything new. If the allele is *not* already present, it would *add* to the genetic diversity of the population where it has found its home. This new allele, along with all the other alleles already present in the population, are then subjected to the forces of natural selection. If the allele increases the fitness of the plant to survive under the conditions of that population, natural selection favors it, and it will increase in its frequency in the population according to how much fitness it adds. If it decreases the fitness of the plant, natural selection will not favor it, and other plants with more favorable alleles will out-compete it. In this manner, natural selection will determine the genetic make-up of the population.

The heterogeneous nature of wild populations is the response of those populations to ever-changing local conditions. Any given year, some genotypes will do well, others will do poorly. In a different season, other different genotypes may prevail. In short, those plants with alleles that enable the plant to grow well and produce more seed under the local environmental conditions will contribute those genes to the next generation. Natural selection will enable the best plants to survive. This will be the case as long as there is enough genetic variability to allow adaptation to that environment.

Therefore, those factors that are known to adversely impact natural stands should be the focus of efforts to protect and enhance natural wildrice. This would accomplish the most to prevent loss of genetic diversity. It has been stated in the report that the threat of transgenic wildrice doesn't exist—no one knows of anyone who is pursuing it, and it seems unlikely that they would. Traditional (or conventional) breeding of wildrice is not a threat, by consensus of the Technical Team, for the reasons that I have just given. Other threats have been identified as important. Those threats should be addressed.



4630 Churchill Street, #1, St. Paul, MN 55126 • Phone: 651.638.1955 • Fax: 651.638.0756 • mnwildrice@comcast.net

February 11, 2008

Ray Norrgard
Wetland Wildlife Program Leader
MN DNR
500 Lafayette Rd.
St. Paul, MN 55155-4020

Dear Mr. Norrgard:

As President of the Minnesota Cultivated Wild Rice Council (MCWRC), I appreciate the opportunity to comment on the Natural Wild Rice in Minnesota Study you were required to complete and are submitting to the Minnesota Legislature. The protection of natural stands of wild rice is an extremely important issue and is supported strongly by the MCWRC.

As I'm sure you know, cultivated wild rice plays an important role in Minnesota's rural economy. It is grown on marginal crop lands, providing income to some of the poorest counties in Minnesota. As forestry, mining, and other industries have lost jobs in the region, alternative opportunities for employment have become more important to the region. The cultivated wild rice industry has provided much-needed economic activity in these northern Minnesota counties. More than 500 people derive full or part-time employment directly from the cultivated wild rice industry in Minnesota, many of them on farms that have been in the family for four generations. On a full-time equivalent basis, these jobs equal more than 200 positions.

Additionally, the wild rice industry generates about \$3.1 million in employee compensation annually. It also contributes a total of \$8.7 million in total employee payroll and over \$21 million in revenues to Minnesota's economy. Other industries share in about \$20 million in revenues directly related to the wild rice industry. So you can see how important the cultivated wild rice industry is to northern Minnesota. *(The economic information cited herein is taken from a 1992 study of the economic impact of wild rice in Minnesota. Therefore, these figures understate the contributions of wild rice to Minnesota's economy in today's dollars.)*

With regard to the legislation passed in 2007 which requires an environmental impact statement for any proposed release of genetically modified wild rice and a study of potential threats to natural stands of wild rice, the MCWRC remained neutral. However, we feel it is very important to address a couple of specific issues as they relate to cultivated wild rice in Minnesota.

First, we would like to bring attention to the fact that, as noted in the wild rice study, traditional wild rice breeding programs do not pose a threat to natural stands. Wild rice grown in paddies is the same genus and species as that found in natural stands. Evidence to support this fact can be found by analyzing the 2007 harvest.

In 2007, hand harvesters enjoyed their most productive harvest in more than 40 years - at the same time cultivated wild rice producers recorded their highest production ever, a virtual impossibility if cultivated wild rice truly had a negative impact on natural stands. An article by Rod Ustipak, coordinator of a wild rice management program in Minnesota for Ducks Unlimited (DU) and the Minnesota Department of Natural Resources (DNR), which appeared in the September 16, 2007 edition of the St. Paul Pioneer Press (an article still available online at <http://www.ducks.org/news/1359/DroughtimprovesMinne.html>), explains how drought conditions over the past few years have actually conspired to create an environment in which natural stands thrived and produced a bumper harvest, conditions completely unrelated to cultivated wild rice production.

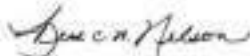
Secondly, although it is mentioned in the Natural Wild Rice in Minnesota Study as a concern, we feel it is extremely important to explicitly state the following: **genetically engineered wild rice does not exist**.

There is a widely held belief, though completely inaccurate, that wild rice is somehow, somewhere being genetically modified or engineered. It is not. The MCWRC is neither developing, nor does it have plans to develop genetically engineered wild rice. We are not aware of any entity that is developing GE wild rice. The federal and state regulatory processes currently in place, coupled with the enormous investment (in the millions of dollars) necessary to develop GE wild rice, renders any effort to do so cost prohibitive. These facts, coupled with the recently passed legislation which requires an environmental impact study prior to the release of any genetically modified varieties of wild rice provide ample safeguards to the environment to ensure food safety and environmental integrity.

Since natural wild rice stands gave birth to the cultivated wild rice industry in Minnesota growers are keenly aware of the importance of protecting them. In fact, the MCWRC board of directors went on record with its support of protecting natural stands when it passed the following resolution at its July 27, 2005, board meeting, *"The MCWRC fully supports the protection of native stands of wild rice in Minnesota. There is no genetic engineering of wild rice occurring. The biosafety requirements in place through the coordinated framework of the USDA, EPA, FDA, the State of Minnesota, and the University of Minnesota are working well to assure a safe environment and food supply."*

Many threats may exist to natural stands of wild rice – shoreline development, climate change, wildlife activity, and recreational water use just to name a few. If we are to be successful in maintaining the vigor and existence of natural stands it is imperative that we analyze and focus our efforts on current threats - those that exist now - rather than perceived threats which are likely never to exist.

Sincerely,



Beth Nelson,
President

**Tribal Statement Regarding MNDNR Wild Rice Study
Submitted To the State Legislature February 15, 2008**

We appreciate the opportunity to provide input into the development of this *Natural Wild Rice in Minnesota* report. Manoomin (wild rice) is a remarkable and valuable component of the Minnesota landscape, and it is commendable that the State is concerned with its future. We concur with most of the wild rice history, ecology and proposed management recommendations contained therein and offer our statements below as points for emphasis and clarity to the Legislature and State DNR.

Manoomin is an inherent part of being Ojibwe. Our lifestyles and cultural identity are intimately bound to manoomin, spiritually, physically and economically. The importance of manoomin to the Ojibwe people cannot be overstated as it holds a central position in the lives and rich history of the Ojibwe people. It is more than just another grain or crop; it is a cultural resource of indescribable importance. It is a sacred gift from the creator to our people and is used for sustenance, ceremonial and commercial purposes.

The right of the Ojibwe to harvest and use manoomin was reserved and guaranteed in treaties signed between the Chippewa Bands of the region and the federal government that predate Minnesota statehood. Recent Supreme Court rulings have upheld the existence of these treaty reserved rights along with the federal trust responsibility to uphold these rights, and resources they are built upon.¹ Today, Tribal members continue to harvest manoomin, as they have for many years, in numbers greater than the rest of the state population. The very existence of the Ojibwe people depends on the vitality of their environment, their resource use and their culture which is intricately connected to natural wild rice.

Science and technology in the world is rapidly changing and challenging the environment of our daily lives. Threats to the existence and integrity of natural stands of wild rice are of immense concern to the Ojibwe. Today, the thought of genetic modification of wild rice poses an alarming threat into the possibility of irreversible genetic contamination of our natural stands of wild rice. This would have a profound negative impact on the Ojibwe people. The connection between Ojibwe culture and wild rice is not a static concept and should not be viewed as such. Rather, our relationship to wild rice should be acknowledged as a respectful, living force that guides the growth and development of our Ojibwe communities, as it has for centuries.

We feel strongly that manoomin must be protected from genetic engineering. From the beginning of the genetic engineering debate in Minnesota, the tribes have wanted GE wild rice banned. For the Ojibwe, no level of contamination is acceptable. Once genetic contamination occurs, there is likely no way to reverse it. There are published documents and reports demonstrating that genetically engineered plants can escape test plots and intermingle with native populations at distances greater than was previously thought. These same studies have shown that the range of impacts on native populations is significantly greater than currently recognized.² Thus, if GE wild rice were to be grown in Minnesota, it is not a question of whether contamination will occur rather, it is a question of how quickly and to what extent contamination will occur.

We recognize and appreciate that the current statute requiring an Environmental Impact Statement prior to any proposed release of GE wild rice represents progress. However, we desire complete and permanent protection for manoomin. There are currently no proven safe guards that could effectively isolate GE strains of wild rice from natural stands. The only way to prevent genetic contamination is to ensure that no GE wild rice is released into the environment. A ban on genetically engineered rice in Minnesota would be the best way to achieve this.

We recommend that the State Legislature require the Environmental Quality Board to specifically include Tribal cultural impacts as part of any GE wild rice Environmental Impact Statement process. Statements should include effects on the cultural practices of the Tribal community and State and address effects on Ojibwe culture, and traditional and customary rights.

We can not afford to hesitate when it comes to protecting natural stands of wild rice. We must conserve the biodiversity of natural wild rice stands. The rapid development of new technology and science combined with corporate exploitation of resources adds to the urgency. We must not allow Minnesota manoomin to be genetically contaminated by genetically engineered varieties that may be developed. This resource is far too precious, far too significant ecologically, economically and culturally, and far too sacred to allow this to occur. The protection and preservation of natural bed wild rice needs to be the concern of all Minnesotans. We desire to work with the State of Minnesota to ensure that wild rice is protected fully and permanently.

Bois Forte Band of Chippewa
Fond du Lac Band of Lake Superior Chippewa
Grand Portage Band of Chippewa
Leech Lake Band of Ojibwe
Mille Lacs Band of Ojibwe
White Earth Band of Ojibwe
The Minnesota Chippewa Tribe
1854 Treaty Authority
Great Lakes Indian Fish and Wildlife Commission
White Earth Land Recovery Project

¹ None of the material in this report can be construed to abrogate, abridge, affect, modify, supersede or alter any treaty-reserved right or other sovereign rights of the regions Chippewa Bands' as recognized by any means, including but not limited to, agreements with the United States, Executive Orders, statutes, judicial decrees, or Federal law.

² The following references represent a small sample of the research on the uncertainty of the impact and fate of genetically engineered organisms on natural ecosystems: Schoen, DJ, Reichman JR, and Ellstrand, NC 2008. Transgene Escape Monitoring, Population Genetics, and the Law. *Bioscience* Vol. 58 No. 1: 71-77; Ponti, Luigi, 2005. Transgenic Crops and Sustainable Agriculture in the European Context, *Bulletin of Science Technology & Society* Vol. 25, No. 4: 289-305; Lundmark, C, 2007, Genetically Modified Maize, *Bioscience* Vol. 57, No. 11: 996.



Ryan P. Heiniger

Director of Conservation Programs – MN/LA

10075 208TH STREET WEST • LAKEVILLE • MINNESOTA • (952) 469-0956 Office • (952) 807-8769 Mobile • www.ducks.org

February 12, 2008

Commissioner Mark Holsten
Department of Natural Resources
500 Lafayette Road
Saint Paul, Minnesota 55155

RE: Wild Rice Study Report

Dear Commissioner Holsten:

I am writing to express Ducks Unlimited's support for the recently completed wild rice report. Thanks to you and your staff for developing such a thorough document and set of recommendations. In particular, we are especially pleased with recommendations in the report that call for increased management, inventory, and stewardship of Minnesota's wild rice lakes and wetlands. Ducks Unlimited looks forward to helping your staff and other partners implement those recommendations in the coming years through our Living Lakes Initiative.

As with many of Minnesota's natural resources, wild rice habitat for waterfowl and other wildlife has been impacted and degraded due to changes to our land and waters. Due to the biological, cultural and economical values of wild rice, it is incumbent upon the state of Minnesota in collaboration with local stakeholders to invest new financial resources to protect and enhance the precious wild rice habitat that remains. Wild rice is one of the most important aquatic plants to migratory waterfowl and it is also critically important to other game and non-game wildlife species.

Since 2001, Ducks Unlimited has worked in partnership with the Minnesota Department of Natural Resources to assess, enhance, manage, and protect over 100 wild rice lakes annually throughout northern Minnesota. Grants from the Minnesota Environment & Natural Resource Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources have also provided important funding to both improve wild rice lakes and protect their shoreline through conservation easements.

DU was pleased provide input during the development of the wild rice study and we support the final report the DNR developed for the legislature. Please advise us of any opportunities to provide further support regarding this important wetland and shallow lake conservation issue.

Sincerely,

Ryan Heiniger
Director of Conservation Programs – MN/LA

Cc: Dave Schad, Dennis Simon, Ray Norrgard, & Nicole Hansel-Welch
Jon Schneider & Rod Ustipak



United States Department of the Interior



FISH AND WILDLIFE SERVICE

Tamarac National Wildlife Refuge
35704 County Highway 26
Rochert, Minnesota 56578-9638
Phone: 218/847-2641 Fax: 218/847-9141

TMC-08-003

February 15, 2008

Ray Norrgard
Wetland Wildlife Program Leader
Minnesota Department of Natural Resources
500 Lafayette Rd.
St. Paul, MN 55155-4020

Subject: **Wild Rice Study document "Natural Wild Rice in Minnesota."**

Dear Mr Norrgard:

This is a letter of endorsement for the above mentioned document and for the document development process. The U.S. Fish and Wildlife Service (Service) has long recognized the ecological importance of natural wild rice stands and associated wetlands. The establishment of National Wildlife Refuges, such as Tamarac and Rice Lake, for the purpose of managing these wetland habitats for the benefit of migrating and resident wildlife is evidence of this appreciation. This study, which provides exceptional background information on the importance of natural wild rice as well as identifies potential threats and management challenges, will be extremely useful in the continued management of this critical resource. Additionally, the process fostered a close working relationship between State, Tribal and Federal governments, university researchers, non-government organizations and well as interested citizens. This collaborative effort is essential to insuring the abundance of natural wild rice for future generations.

Thank you for the opportunity to participate in this process and provide comments.

Sincerely,

Barbara Boyle
Refuge Manager

EXHIBIT 17

RESEARCH ARTICLE

10.1002/2017JG003787

This article is a companion to Myrbo et al. (2017), <https://doi.org/10.1002/2017JG003788> and Pollman et al. (2017), <https://doi.org/10.1002/2017JG003785>.

Key Points:

- Sulfate loading to freshwater ecosystems may alter aquatic plant communities when sulfate is reduced to sulfide in the anoxic rooting zone
- The occurrence of self-sustaining wild rice populations is mainly controlled by pore water sulfide concentrations
- Even if pore water sulfide is low, wild rice is less likely to be found if the surface water is turbid or warm

Supporting Information:

- Table S1
- Table S2
- Table S3
- Data Set S1
- Figure S1

Correspondence to:

A. Myrbo,
amyro@umn.edu

Citation:

Myrbo, A., Swain, E. B., Engstrom, D. R., Coleman Wasik, J., Brenner, J., Dykhuizen Shore, M., ... Blaha, G. (2017). Sulfide generated by sulfate reduction is a primary controller of the occurrence of wild rice (*Zizania palustris*) in shallow aquatic ecosystems. *Journal of Geophysical Research: Biogeosciences*, 122, 2736–2753. <https://doi.org/10.1002/2017JG003787>

Received 25 JAN 2017

Accepted 7 JUN 2017

Accepted article online 22 SEP 2017

Published online 2 NOV 2017

©2017. The Authors.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

Sulfide Generated by Sulfate Reduction is a Primary Controller of the Occurrence of Wild Rice (*Zizania palustris*) in Shallow Aquatic Ecosystems

A. Myrbo¹, E. B. Swain², D. R. Engstrom³, J. Coleman Wasik⁴, J. Brenner⁵, M. Dykhuizen Shore², E. B. Peters^{2,6}, and G. Blaha²

¹LacCore/CSDCO and Department Earth Sciences, University of Minnesota, Minneapolis, MN, USA, ²Biostatistics Division, School of Public Health, University of Minnesota, Minneapolis, MN, USA, ³St. Croix Watershed Research Station, Science Museum of Minnesota, St. Paul, MN, USA, ⁴Plant and Earth Science Department, University of Wisconsin River Falls, River Falls, WI, USA, ⁵Minnesota Department of Health, St. Paul, MN, USA, ⁶Now at Minnesota Department of Natural Resources, St. Paul, MN, USA

Abstract Field observations suggest that surface water sulfate concentrations control the distribution of wild rice, an aquatic grass (*Zizania palustris*). However, hydroponic studies show that sulfate is not toxic to wild rice at even unrealistically high concentrations. To determine how sulfate might directly or indirectly affect wild rice, potential wild rice habitat was characterized for 64 chemical and physical variables in over 100 sites spanning a relatively steep climatic and geological gradient in Minnesota. Habitat suitability was assessed by comparing the occurrence of wild rice with the field variables, through binary logistic regression. This analysis demonstrated that sulfide in sediment pore water, generated by the microbial reduction of sulfate that diffuses or advects into the sediment, is the primary control of wild rice occurrence. Water temperature and water transparency independently control the suitability of habitat for wild rice. In addition to generating phytotoxic sulfide, sulfate reduction also supports anaerobic decomposition of organic matter, releasing nutrients that can compound the harm of direct sulfide toxicity. These results are important because they show that increases in sulfate loading to surface water can have multiple negative consequences for ecosystems, even though sulfate itself is relatively benign.

Plain Language Summary Research in the 1940s and 1950s found that wild rice grew best in low-sulfate Minnesota lakes, but it was not known why. The correlation was a puzzle, since sulfate is not very toxic to plants or animals. This study found that the problem is sulfide, not sulfate. Sulfate can be converted into toxic levels of sulfide in the soil in which wild rice germinates and roots. Wild rice is an annual plant that must sprout each spring from seed that was dropped the previous fall into wet soil. Anaerobic microbes in the soil make sulfide from sulfate in the overlying water. Lakes, streams, and wetlands that have high concentrations of dissolved sulfide in the sediment therefore have a low probability of hosting wild rice. The study also found that wild rice prefers high-transparency water and cold winters.

1. Introduction

Minnesota is unique among U.S. states and Canadian provinces in having a water quality standard that regulates sulfate (SO_4) to protect wild rice, *Zizania palustris* and *Zizania aquatica*. The more common wild rice species in Minnesota, *Z. palustris* (northern wild rice), is an annual emergent aquatic grass that forms monocultures in shallow freshwaters (wetlands, lakes, and rivers) in the area of the Laurentian Great Lakes (Minnesota, Wisconsin, Michigan, Ontario, and Manitoba). Wild rice is culturally important to multiple groups in Minnesota, especially Ojibwe, Dakota, and other Native Americans, and also provides habitat and food for waterfowl and other wildlife (Vennum, 1988). In 1977, the Minnesota legislature voted to make wild rice the Minnesota state grain. Minnesota Rule 7050.0224, promulgated in 1973, seeks to limit the exposure of wild rice to SO_4 concentrations exceeding 10 mg L^{-1} (0.1 mmol L^{-1}). This value was based on empirical research that correlated water chemistry to aquatic plant assemblages and included the observations that no large populations of *Z. palustris* occur in waters exceeding 10 mg L^{-1} SO_4 and that stands are uncommon where SO_4 concentrations exceed 50 mg L^{-1} (Moyle, 1944, 1945). In addition, Moyle (1956) noted that plantings of wild rice seed in high- SO_4 regions generally failed. A larger unpublished Minnesota Department of Natural Resources data set also shows that sites with reported wild rice

presence (DNR, 2008) are generally correlated with surface water SO_4 below 10 mg L^{-1} (Figure S1 in the supporting information).

We report here on a multiyear field survey that was part of a larger study (Myrbo et al., 2017; Pastor et al., 2017; Pollman et al., 2017) designed to reevaluate the 10 mg L^{-1} SO_4 standard by testing potential mechanisms by which SO_4 might be harmful to wild rice. SO_4 is a relatively nontoxic and unreactive compound under aerobic conditions. Pastor et al. (2017) and Fort et al. (2014) have shown that SO_4 is not directly toxic to wild rice at concentrations up to $1,600 \text{ mg L}^{-1}$, which exceeds concentrations in virtually all natural surface waters of the upper Midwest (Gorham, Dean, & Sanger, 1983). The U.S. Environmental Protection Agency's nonmandatory drinking water standard of 250 mg L^{-1} SO_4 (2.6 mmol L^{-1}) is based on taste rather than toxicity (EPA, 2010).

1.1. Potential Effects of Elevated Sulfate and Sulfide in Freshwater Systems

SO_4 concentrations in most freshwaters are less than a few percent of the mean concentration in seawater ($2,800 \text{ mg L}^{-1}$ (29.1 mmol L^{-1})). We surveyed 108 different lakes, streams, and wetlands across Minnesota, where the median SO_4 concentration in lakes is 10 mg L^{-1} (10th and 90th percentiles of 0.2 and 285 mg L^{-1} (MPCA, 2016)). In the much higher SO_4 concentrations of marine waters, it is well established that SO_4 can diffuse into sediment and be converted by microbial sulfate reduction (MSR) to potentially toxic sulfide that influences the presence and absence of rooted macrophytes, such as seagrasses (Borum et al., 2005; Ingold & Havill, 1984; Koch & Erskine, 2001; Lamers et al., 2013).

Despite a long-standing assumption that SO_4 is benign (Pester et al., 2012; Schindler, 1986; Urban et al., 1994) and plays a negligible role in freshwater biogeochemistry (e.g., Capone & Kiene, 1988), there is evidence that SO_4 availability in freshwaters can control the concentration and therefore the toxicity of hydrogen sulfide (H_2S) in sediment pore water to plants and animals (Bagarinao, 1992; Kinsman-Costello, O'Brien, & Hamilton, 2015; Lamers et al., 2013; Wang & Chapman, 1999). The chemical species of H_2S varies with pH; below pH 7, H_2S dominates, and above pH 7, the bisulfide ion (HS^-) dominates. For simplicity in this discussion we refer to the sum of the two species as sulfide.

1.1.1. Sulfide Toxicity to Freshwater Plants

Remarkably little attention has been given to the potential toxicity of sulfide in sediment pore water, even after Bagarinao (1992) concluded in a major review that sulfide had been "largely overlooked as an environmental factor for aquatic organisms." In a discussion of sediment toxicity testing, Wang and Chapman (1999) also observed that the biological implications of sulfide in sediments are poorly understood and "all too often ignored." They suggested that sulfide may be more important than ammonia in determining sediment toxicity to organisms and made a suite of recommendations to fill the knowledge gap, including the measurement of sulfide in undisturbed sediments. Kinsman-Costello et al. (2015) measured sulfide in undisturbed sediments and concluded that the potential toxicity of pore water sulfide is likely shaping the plant and animal communities of freshwater ecosystems. Lamers et al. (2013), in a review of sulfide toxicity to aquatic plants, pointed out that traditional toxicity testing generally neglects the chemistry of the rooting zone. Simkin, Bedford, and Weathers (2013) showed that pore water sulfide in a wetland controlled the distribution of plants more than did nutrients.

The toxicity of elevated sulfide to freshwater plants was first recognized in paddy-grown white rice (*Oryza sativa*) in the 1950s (Lamers et al., 2013; Pearsall, 1950). Rice paddies and other water-saturated soils present a profound challenge for rooted plants because of the chemical changes caused by the absence of oxygen and resulting potential toxicity of the pore water (Ponnamperuma, 1972). Anaerobic decomposition of organic matter results in elevated pore water concentrations of ammonia, organic acids, and variable concentrations of sulfide and ferrous Fe, depending on the availability of SO_4 and Fe. The interaction of Fe and the S cycle is complicated (Hansel et al., 2015), but because under anoxic conditions sulfide forms an insoluble precipitate with Fe, elevated pore water sulfide concentrations occur when Fe availability is relatively low (Ponnamperuma, 1972; van der Welle et al., 2006). It is thought that the iron sulfide precipitates are relatively inert and that only sulfide dissolved in pore water is potentially toxic. The concentration of sulfide in pore water is the balance between production and competing fates of sulfide, including precipitation with metals such as Fe, oxidation by oxygen introduced by bioturbation or by release from the roots of macrophytes (Armstrong & Armstrong, 2005), and by downward advection of surface water due to groundwater movement or transpiration by dense macrophyte stands (Bachand et al., 2014).

1.1.2. Geochemical Consequences of Enhanced Microbial Sulfate Reduction

Increased SO_4 availability can allow increased anaerobic decomposition of organic matter, releasing the inorganic nutrients that generally limit growth of higher plants (N, P, and K) (Lamers, Tomassen, & Roelofs, 1998; Myrbo et al., 2017; Weston et al., 2006, 2011). Enhanced decomposition breaks down particulate and dissolved organic carbon (DOC) in the sediment, which can increase DOC and dissolved inorganic carbon (DIC) in the overlying water (Myrbo et al., 2017).

In addition to supporting organic matter mineralization, MSR production of sulfide causes a cascade of reactions that can alter ecosystem functioning independent of any toxicity to plants and animals. First, sulfide can participate in redox reactions, chemically reducing Fe, which converts Fe from solid phase Fe(III) oxyhydroxides to water-soluble Fe(II) (Hansel et al., 2015). The dissolution of the Fe oxyhydroxides releases sorbed ions into solution, including phosphate and trace metals (Caraco, Cole, & Likens, 1993; Davranche & Bollinger, 2000; Søndergaard, Jensen, & Jeppesen, 2003). Second, sulfide can precipitate dissolved metals, including essential plant nutrients Fe, Cu, and Zn, decreasing their bioavailability and leading to nutrient deficiency (Kirk, 2004; Lamers et al., 1998; Neue & Bloom, 1989; Neue & Lantin, 1994). In systems unpolluted with heavy metals, the sulfide precipitate is overwhelmingly dominated by iron sulfide compounds, consisting of a range of stoichiometries and minerals (Schoonen, 2004), which we here term “FeS compounds.” Third, the conversion of SO_4 to sulfide entails the production of DIC, or alkalinity, an effect not fully appreciated in freshwater systems until the mechanistic consequences of acid rain were investigated in the 1980s (Baker, Brezonik, & Pollman, 1986; Cook et al., 1986; Schindler, 1986). Alkalinity is thought to be a major factor influencing the distribution of aquatic species, including macrophyte species (Moyle, 1945; Vestergaard & Sand-Jensen, 2000). In addition, elevated alkalinity may further enhance decomposition, producing a positive feedback to the effects of SO_4 -driven mineralization (Geurts et al., 2009; Roelofs, 1991).

1.2. Multiple Plausible Negative Effects of Elevated Sulfate and Sulfide Production on Wild Rice

The purpose of this study was to examine the multiple ways that increases in SO_4 concentration and sulfide production can change the biogeochemical functioning of freshwater ecosystems and potentially negatively affect the growth and reproduction of wild rice populations. Before any field data were collected for this study, alternative hypotheses regarding the most likely negative effects were identified (MPCA, 2011), so that appropriate data would be available to test them. The primary hypotheses of how increases in surface water concentrations of SO_4 could harm wild rice populations include direct toxicity by elevated pore water sulfide; reduced bioavailability of Fe, Cu, or Zn; and increased P bioavailability promoting the growth of phytoplankton and macrophytes that compete for light and space. Additional variables were quantified so that exploratory data analysis could be pursued in addition to evaluation of the primary hypotheses. Surface water, pore water, and sediment physical and chemical properties were collected from 108 different sites, both with and without wild rice present, to inform evaluation of these multiple interrelated hypotheses.

2. Methods

2.1. Study Area

2.1.1. Physical Environment

SO_4 concentrations in surface water vary with geology and climate (Gorham et al., 1983) in a northeast-southwest gradient across Minnesota. Bedrock and bedrock-derived glacial deposits of northeastern Minnesota (the “arrowhead”) comprise slowly weathered crystalline materials, generally low in S, and surface waters are dilute (specific conductance of <140 and often $<30 \mu\text{mho cm}^{-1}$; Gorham et al., 1983). Within this area of naturally low SO_4 , iron-mining activities in the “Iron Range” district of northeastern Minnesota have created an “island” of lakes and streams elevated in SO_4 (Figure 1), a result of the weathering of sulfide minerals in waste rock piles and tailing basins. The surficial geology of southwestern Minnesota, in contrast, is derived from marine shales and carbonates that are relatively S-rich and readily weathered: surface waters often exceed $500 \mu\text{mho cm}^{-1}$ and may exceed $7,000 \mu\text{mho cm}^{-1}$ (Gorham et al., 1983). SO_4 concentration is positively correlated with conductivity above about $200 \mu\text{mho cm}^{-1}$ and 10 mg L^{-1} or 0.1 mmol L^{-1} SO_4 (Figure 7B in Gorham et al., 1983). Overprinting this geological pattern is a strong climatic gradient with warmer, drier conditions toward the southwest (toward the northern Great Plains) and colder, more humid conditions to the northeast (toward the Laurentian Great Lakes), which enhances the conductivity gradient: more evaporative conditions in the southwest serve to concentrate surface waters and further increase ionic

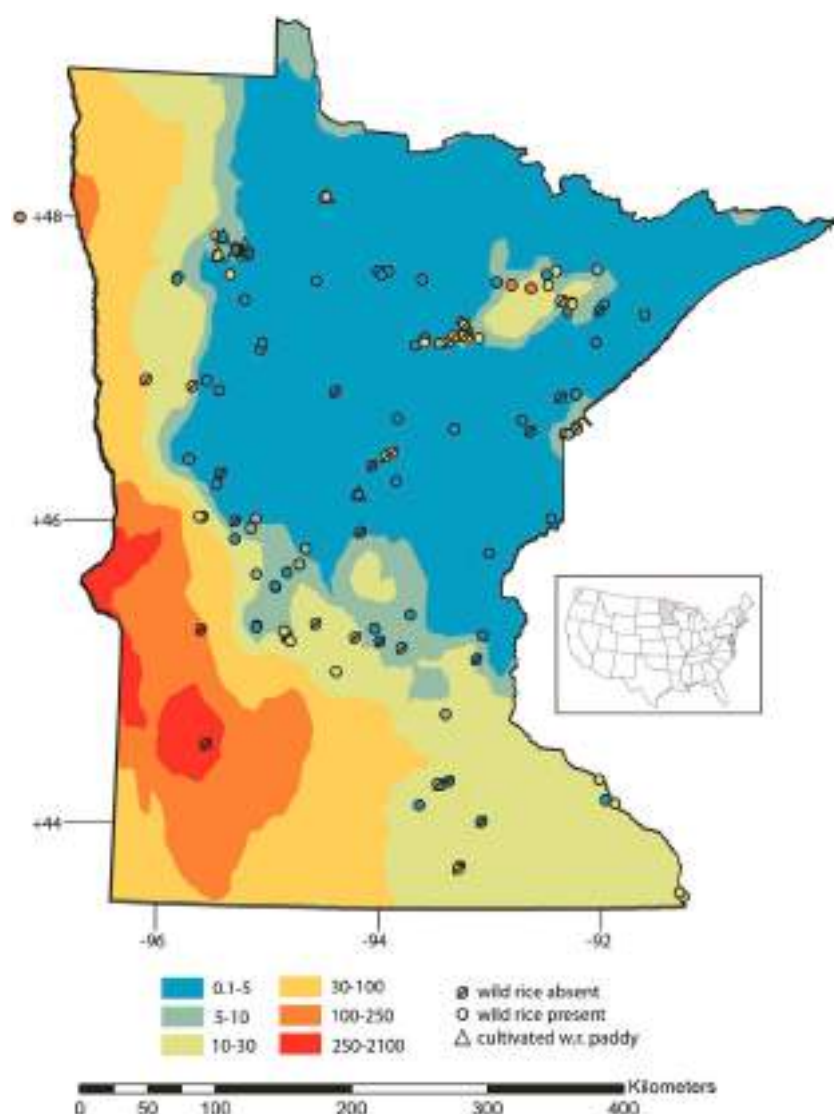


Figure 1. Map of Minnesota showing field sites overlain on kriged contours of average surface water SO_4 concentrations from 4,998 waterbodies (data from MPCA and DNR databases). The symbols are filled with the color corresponding to the site's surface water sulfate concentration. Site to the northwest of the Minnesota map is within the state of North Dakota, 40 km west of the border with Minnesota (see text). Sites where wild rice was not found have a diagonal line through the symbol.

strength, while moister conditions in the northeast maintain low ionic strength in surface waters (Gorham et al., 1983).

2.1.2. Habitat Preferences of Wild Rice

Although the scientific literature contains many assertions concerning the environmental preferences of wild rice regarding water and sediment quality (e.g., DNR, 2008, 2016; Lee, 2002; Moyle, 1944; Moyle & Krueger, 1964; Pillsbury & McGuire, 2009), sometimes little evidence was presented to support the putative preferences. The shallow freshwaters in which wild rice is found are usually relatively transparent because wild rice and other rooted macrophytes do best if they can photosynthesize as they grow each spring from the sediment to the water surface (Scheffer, 1998). Otherwise, any particular habitat preference of wild rice, such as specific chemical ranges of the sediment or surface water, is challenging to identify. Since wild rice is an opportunistic annual plant, a primary habitat requirement is periodic environmental disturbance (Grime, 1977) that keeps perennial plants such as water lilies from controlling the space and light of the shallow waters in which these species cooccur (Pillsbury & McGuire, 2009). Wild rice does not seem to have specific sediment requirements, as it has been observed growing in a variety of substrates (Aiken et al., 1988; Lee,

1986) within its range. Annual plants are adapted to exploit environments intermittently favorable for rapid plant growth and to maximize seed production (Grime, 1977). Wild rice produces between 25 and 150 relatively large seeds per stem (Eule-Nashoba, Biesboer, & Newman, 2012). Seeds buried in the sediment can survive for up to several decades until conditions are again favorable for germination and growth (DNR, 2008). *Zizania palustris* seeds germinate at low rates unless they have been exposed to near-freezing temperatures for at least 3 months (Kovach & Bradford, 1992), although the environmental cues for subsequent germination are poorly understood, aside from elevated temperature.

Because *Z. palustris* does not normally self-pollinate and is wind-pollinated (which implies that the pollen source must be relatively nearby; Friedman & Barrett, 2009), does not reproduce asexually, and has an annual life cycle (Aiken et al., 1988), in this analysis the presence of wild rice plants is taken to mean that the waterbody hosts a successfully reproducing and self-sustaining population. A few of the sites in this study may have experienced recent watershed changes such that steady state has not yet been reached among environmental variables and wild rice reproduction, but the balance of the 108 sites should have been in steady state at the time of sampling. The population of wild rice in a given lake can exhibit large fluctuations from year to year, which has been attributed to disturbances such as abrupt increases in water level (DNR, 2008) and to cyclical changes in N availability (Walker et al., 2010). Wild rice fills a unique ecological niche, in that there are virtually no other annual aquatic macrophytes across the Great Lakes region (Eggers & Reed, 2011).

2.1.3. Site Selection

The goal of the field survey was to identify and sample potential wild rice habitat across a gradient of SO_4 concentrations. Potential wild rice habitat was defined simply as shallow water (30–120 cm deep, though some sampled sites had water as shallow as 5 cm) that was sufficiently transparent to support rooted aquatic macrophytes. Turbidity from dense phytoplankton blooms or suspended solids may effectively exclude rooted macrophytes due to light limitation (Scheffer, 1998).

Most Minnesota lakes that host wild rice populations have low SO_4 concentrations; the median concentration of wild rice lakes is 1.8 mg L^{-1} , and the 75th percentile is 3.6 mg L^{-1} (MPCA, 2014). If only those waters hosting abundant wild rice were sampled, most of those would be low in SO_4 , and little would be learned about how elevated SO_4 concentrations (or other important variables) might affect wild rice. Conservation biologists commonly identify important habitat variables through binary (i.e., is the species present or absent at a given site?) logistic regression, which requires the sampling of sites that do not support the species of interest (e.g., Carroll, Zielinski, & Noss, 1999; Peeters & Gardeniers, 1998; van der Heide et al., 2009). Consequently, potential wild rice habitats with a range in SO_4 concentrations were sampled without regard to whether the waterbody hosted or was known to host wild rice. An effort was made to sample waterbodies that covered the range of SO_4 concentrations across Minnesota and especially to sample sites in high- SO_4 regions that had reports of recent or historical presence of wild rice. This strategy also resulted in the sampling of a high- SO_4 wild rice site in the North Branch of the Turtle River ($198 \text{ mg SO}_4 \text{ L}^{-1}$), 40 km into North Dakota from northwestern Minnesota (Figure 1). A gradient of SO_4 concentrations was sampled by identifying potential wild rice habitat in two areas of elevated SO_4 , the “island” of elevated SO_4 in the Iron Range region of northeastern Minnesota and waters naturally elevated in SO_4 to the west and south of the known range of wild rice (Figures 1 and S1). Nutrient (N and P) availability (reflecting natural soil fertility as well as agricultural runoff) also increases to the west and south, potentially supporting phytoplankton growth sufficient to exclude macrophytes, including wild rice. Consequently, in western and southern Minnesota, DNR lake databases were screened for the presence of water lilies (*Nuphar variegata* or *Nymphaea odorata*), the occurrence of which indicates transparency sufficient to support rooted macrophytes that also often cooccur with wild rice. In an analysis of DNR aquatic plant surveys from 1,753 shallow lakes, we found that the odds of finding wild rice where there are water lilies are 26 times the odds of finding wild rice where there are no water lilies, with a 95% confidence interval of 20–36 times (neither wild rice nor water lilies = 968; wild rice but not water lilies = 60; no wild rice but water lilies = 272; both wild rice and water lilies = 453).

With these considerations, water bodies were selected for sampling based on preliminary data including average water depth, presence of water lilies, conductivity or SO_4 concentration, and geographic distribution (i.e., to sample widely across the state). Both rivers and lakes were sampled, as were seven different cultivated wild rice paddies. Within a given water body, the field team chose a location for sampling based on a decision tree (Table S1 in the supporting information).

2.2. Field Methods

Sampling occurred in August–September 2011 and June–September 2012 and 2013. Sampling efforts were focused in late summer to capture physical and chemical conditions when wild rice plants were maturing and when identification of wild rice is most certain; voucher specimens of wild rice were always taken. Samples were collected from an anchored canoe or small boat, except in the cultivated wild rice paddies when the water was too shallow to float a canoe, and samples were collected on foot. A Hach model HQ40d or Hydrolab Quanta sonde, calibrated daily, was used to measure temperature, specific conductance, dissolved oxygen, and pH in the surface water. Water transparency was determined with a 1 m long Secchi tube (Water Monitoring Equipment & Supply, USA), and apparent color was measured using a Hach model CO-1 color test kit. Surface water samples (later split into separate subsamples; see below) were collected by a technician wearing long nitrile gloves in two 2 L amber Nalgene bottles that had been previously triple rinsed with deionized water and rinsed 3 times with water from the site before filling. Water samples were stored on ice.

Short (~50 cm) sediment cores with ~10–20 cm of overlying water were collected at eight undisturbed locations at least 1 m apart around the boat using an HTH corer (Pylonex, Sweden) with a 7 cm diameter polycarbonate barrel. A piston was inserted in the bottom end of each core as it was retrieved. Cores were kept upright and shaded prior to sample processing.

Aquatic macrophytes were identified and percent cover estimated within a plastic hoop 1 m in diameter placed at 4 locations around the boat. In 2012 and 2013, the number of stems of wild rice inside each hoop was also quantified.

Pore water samples were obtained from cores processed on shore using 10 cm Rhizon™ filters (pore size 0.12–0.18 μm) (Rhizosphere.com, Netherlands; Shotbolt, 2010) inserted vertically into the core tops, following extrusion of overlying water, and connected to evacuated serum bottles with PVC/polyethylene tubing and a stainless steel needle. Three separate cores were sampled, one for nutrients (nitrate + nitrite, TP, and TN) and DOC (70 mL), a second for metals (50 mL), and a third for dissolved silica, Cl, and SO_4 (30 mL). A fourth core was sampled for pore water sulfide, but in this case, the serum bottle was preloaded with 0.2 mL of 2.0 N zinc acetate, 0.5 mL of 15 M sodium hydroxide, and a stir bar, flushed with a nitrogen atmosphere, evacuated, and preweighed. Air was flushed from the Rhizon-tubing assembly with sample pore water using a second evacuated bottle before the needle was inserted into the sulfide sample bottle. In 2011 only pore water samples for sulfide and metals were collected. Pore water pH was measured on a fifth core by inserting the probe of a Hach model HQ40d pH meter into the sediment to a depth of 5 cm and allowing the reading to stabilize.

A composite sediment sample was collected from the uppermost 10 cm of the sixth, seventh, and eighth cores, placed into a stainless steel bowl, and stirred under nitrogen atmosphere to homogenize. A 50-mL subsample was placed in a polypropylene sample bottle along with 1.0 mL of 1.0 N zinc acetate for analysis of acid-volatile sulfide (AVS). The headspace of the AVS sample bottle was flushed with N_2 and the bottle capped; that bottle was placed in a larger glass jar and that jar flushed with N_2 and tightly sealed. The sample was immediately placed in a cooler with dry ice to freeze. The remaining composited sediment was placed into a polycarbonate container and stored on ice for later analysis.

Water subsamples were taken from the large amber Nalgene bottles by a technician wearing nitrile gloves. Sulfuric acid (5 mL of 10%) was immediately added to subsamples for the analysis of P, TKN (total Kjeldahl nitrogen), ammonia, and nitrate + nitrite in 250 mL polyethylene bottles. Nitric acid (2.5 mL of 20%, to acidify to $\text{pH} < 2$) was immediately added to subsamples for the analysis of total metals in 250 mL polyethylene bottles. Samples for dissolved metals were subsampled in 250 polyethylene bottles and subsequently filtered using a 0.45 μm filter and preserved with nitric acid in the laboratory. Samples were stored on ice.

2.3. Laboratory Methods

Surface water, pore water, and most sediment analyses were conducted by the Minnesota Department of Health Environmental Laboratory (MDHEL) in 2012 and 2013, following standard methods. In 2011 other laboratories conducted the analyses (University of Minnesota Soils Laboratory (UMNSL), St. Croix Watershed Research Station (SCWRS), and Gustavus Adolphus College (GAC)); methodological differences are noted, and the laboratory is identified where relevant.

Surface and pore water samples were analyzed for anions (Cl and SO₄) by ion chromatography on a Dionex ICS-3000 (MDHEL), Fe, Ca, Na, Mg, and K by inductively coupled optical emission spectrometry on a Varian 715-ES (MDHEL), Mn, Cu, Zn, Co, Ni, Al, As, and Se by inductively coupled mass spectrometry on a Perkin Elmer Elan DRCE (MDHEL), and DOC by UV-persulfate oxidation on a Tekmar-Dohrmann Phoenix 8000 (SCWRS and MDHEL). N and P were measured by colorimetric methods (on a Lachat Quikchem Flow-Injection Autoanalyzer) at SCWRS and MDHEL following cadmium-reduction (nitrate and ammonia) or dual alkaline-persulfate digestions (TP and TN). Silica was measured colorimetrically at SCWRS on the Lachat Autoanalyzer and at MDHEL on a Beckman Coulter DU 800 UV/VIS spectrophotometer. Pore water sulfide was analyzed colorimetrically on each lab's Lachat Autoanalyzer following in-line acid distillation and NaOH trapping (SM 4500-S2). Alkalinity was measured by potentiometric acid titration (MDHEL) or as DIC by acid digestion and IR detection (SCWRS). DIC was converted to alkalinity using pH, temperature, and specific conductance of the surface water.

Sediment samples from 2011 were analyzed by combustion for total carbon (TC), total nitrogen (TN), and total sulfur (TS) using, respectively, a Tekmar Phoenix 8000 CO₂ analyzer, an Elementar Vario Max N analyzer, and a LECO sulfur analyzer (UMNSL). Samples from 2012 and 2013 were analyzed for CHN on a Costech 4010 Elemental Analyzer (UMN Stable Isotope Laboratory). Total inorganic carbon (carbonate) was analyzed by coulometric titration on a UIC CM5015 CO₂ coulometer, while water and organic matter content were determined by loss-on-ignition methods (Heiri, Lotter, & Lemcke, 2001) in the UMN LacCore facilities. Sediment AVS was analyzed colorimetrically, as above for pore water sulfide, following acid-distillation and in-line alkaline trapping (SM 4500-S2; Hsieh & Shieh, 1997).

Sediment phosphorus was extracted from freeze-dried sediments following methods of Engstrom and Wright (1984) for total-P and Hietjes and Lijklema (1980) for P fractions (NH₄Cl-extractable, NaOH-extractable, HCl-extractable, and residual (organic)-P). The P extracts were measured colorimetrically by flow-injection autoanalyzer (SCWRS). Extractable iron and trace metals were quantified from a 0.25 g homogenized freeze-dried sediment subsample incubated in 0.5 M HCl for 30 min at 80°C. The samples were centrifuged, decanted, and analyzed by ICP-MS at GAC. This extraction releases metal oxyhydroxides, sulfides, and loosely bound phases from the sediment without appreciably attacking the silicate matrix (Balogh et al., 2009).

2.4. Data Subsets and Statistical Analysis

From 2011 to 2013, 260 site visits were conducted in 108 different natural waterbodies, including lakes, small streams, backwaters of the Mississippi River, and wetlands, plus 7 different cultivated wild rice paddies. For a variety of logistical reasons, the full suite of samples could not be collected on some site visits. Three subsets of the field data were identified for the analyses reported here. A subset that consists of all of the samples from natural waterbodies (excluding the cultivated paddies) with virtually complete analyses (surface water, pore water, and bulk sediment; $n = 194$) was termed for internal purposes Class D. Pollman et al. (2017) used Class D to develop a structural equation model to elucidate key variables that govern the concentration of sulfide in sediment pore water. A second subset, Class S, of 51 samples from 7 stream and 8 lake sites was each sampled 3 to 5 times from 27 May to 19 September 2013, to provide a data set to assess seasonality in variables. A third subset, Class B, was used for conducting probabilistic analyses to identify the most likely parameters controlling the presence and absence of wild rice and to examine Spearman nonparametric correlations among field variables. Class B consists of one sample from each site ($n = 108$) and excludes samples collected in 2011, which were analyzed with slightly different lab methods. Although Class B was not created as a random sample of Minnesota waterbodies, the frequency distribution of SO₄ concentrations is intermediate between a probability-based survey conducted by USEPA (MPCA, 2016) and a list of known wild rice water bodies, which are overwhelmingly low-SO₄ lakes (MPCA, 2014). Therefore, the Class B data set is reasonably representative of potential wild rice habitat, and binary logistic regressions can be used to approximate the probability of wild rice occurrence as a function of field variables such as pore water sulfide. The Class B data set is used in all analyses presented here, with two exceptions: (1) Figures 3a–3c present the full Class D data set, plus for comparison, data from the cultivated wild rice paddies; (2) Statistical analysis was performed with the software package R version 3.2.3.

To identify variables associated with the presence and absence of wild rice, we relied on binary logistic regressions (BLR), using the glm function in R. BLR does not require normally distributed data, but

Table 1Field Variable Correlation With the Presence-Absence of Wild Rice, Assessed Through Binary Logistic Regression (BLR), Plus Spearman Correlations Between Variables^a

Field variable	Binary logistic regression (BLR) correlation with field variable			Spearman correlation with field variable (rho)				
	Log transformed?	p value	Correlation direction	Wild rice density (only wild rice sites) n = 67	Pore water sulfide	Sediment AVS	Water transparency	Water temperature
pw K	Y	0.0008***	Negative	−0.27*	0.46***	0.11	−0.10	0.33***
pw sulfide	Y	0.0012***	Negative	−0.31**	1.00	0.29**	−0.07	0.17
Water depth (m)	N	0.0028***	Negative	0.07	0.11	0.08	0.22*	0.19*
Transparency (cm)	N	0.0031***	Positive	0.11	−0.07	−0.13	1.00	−0.08
sw TN	Y	0.0054**	Negative	−0.12	0.22*	0.08	−0.61***	0.23*
sed Se % dry	N	0.0059**	Negative	0.12	0.08	0.27**	−0.21*	0.13
sw Temp	N	0.0077**	Negative	0.08	0.17	0.11	−0.08	1.00
pw Fe	Y	0.0109*	Positive	0.20	−0.58***	0.00	0.04	0.09
sw pH	N	0.0200*	Negative	−0.14	0.28**	0.08	−0.05	0.35***
sw TP	Y	0.0353*	Negative	0.15	0.05	0.29**	−0.58***	0.27**
Latitude	N	0.0376*	Positive	−0.04	−0.06	−0.09	0.13	−0.51***
sed TS % dry	Y	0.0483*	Negative	0.20	0.40***	0.42***	0.03	−0.08
sw K	Y	0.0922		−0.03	0.29**	0.21*	−0.18	−0.08
sed AVS % dry	Y	0.1317		0.02	0.29**	1.00	−0.13	0.11
sw sulfate	Y	0.1475		−0.10	0.44***	0.45***	−0.07	0.04
sed TP % dry	N	0.2697		−0.10	0.07	0.30**	−0.14	0.14
sw alkalinity	Y	0.2786		0.25*	0.22*	0.26**	0.11	0.17
pw TN	Y	0.2963		−0.30	0.31***	0.14	−0.20*	0.34***
pw NH4	Y	0.4505		−0.33**	0.33***	0.22*	−0.17	0.26**
sed Fe % dry	Y	0.4795		0.16	−0.35***	0.38***	−0.10	−0.06
pw DOC	Y	0.4865		0.08	−0.05	−0.1	−0.21*	0.09
pw Si	N	0.5548		0.03	0.33***	0.18	0.07	0.29**
pw TP	Y	0.6341		0.02	0.12	0.30**	−0.26**	0.26**
sed TN % dry	N	0.6807		−0.06	0.14	0.04	0.06	−0.06
sed water content	N	0.7274		−0.07	0.15	0.10	0.10	0.02
sed TOC % dry	N	0.7854		−0.10	0.10	0.02	0.10	−0.06

^aNote. The variables are ordered by the significance of the BLR. The first 12 variables have BLR significance of $p < 0.05$. The additional 14 variables are listed because of their correlation with pore water sulfide, sediment AVS, or surface water transparency or temperature—or their notable lack of correlation with wild rice presence-absence (pw = pore water; sw = surface water; sed = sediment).

* $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

nevertheless, we transformed some variables (Table 1) to achieve approximately normal distributions. BLR also yields the probability of occurrence at a given value of the variable. Spearman nonparametric correlations (rho) between field variables in Class B were examined as part of the effort to identify the major biogeochemical interactions in these shallow-water systems. Seasonality in a variable was assessed using linear mixed effects models, with time (fraction of a year) as a fixed variable and site as a random factor (to account for multiple samples per site). In the model developed for each field variable, we accounted for the seasonal cycle using the following equation (Crawley, 2007), where A , B , and C are fitted model coefficients:

$$y = A + B \sin(2\pi \text{ time}) + C \cos(2\pi \text{ time}) \quad (1)$$

3. Results and Discussion

3.1. Field Variables Associated With Wild Rice Presence and Absence

Of the 64 field quantified variables, BLR identified 12 that are associated with the presence/absence of wild rice at the 0.05 probability level or better (Table 1): pore water sulfide, K, and Fe (Figures 2a, 2b, and 2f); surface water temperature, TP, TN, and pH (Figures 2d, 2m, 2n, and 2o); sediment Se and TS (Figures 2c and 2p); water depth and transparency (not shown; Figure 2e); and latitude of the site (Figure 2g). These variables may be important in controlling the presence or absence of wild rice or may merely be correlated with one or more actual causative factors. Because we are primarily interested in factors that control presence or absence of wild rice, in contrast to the density of wild rice, we place primacy on the BLR results and use the Spearman

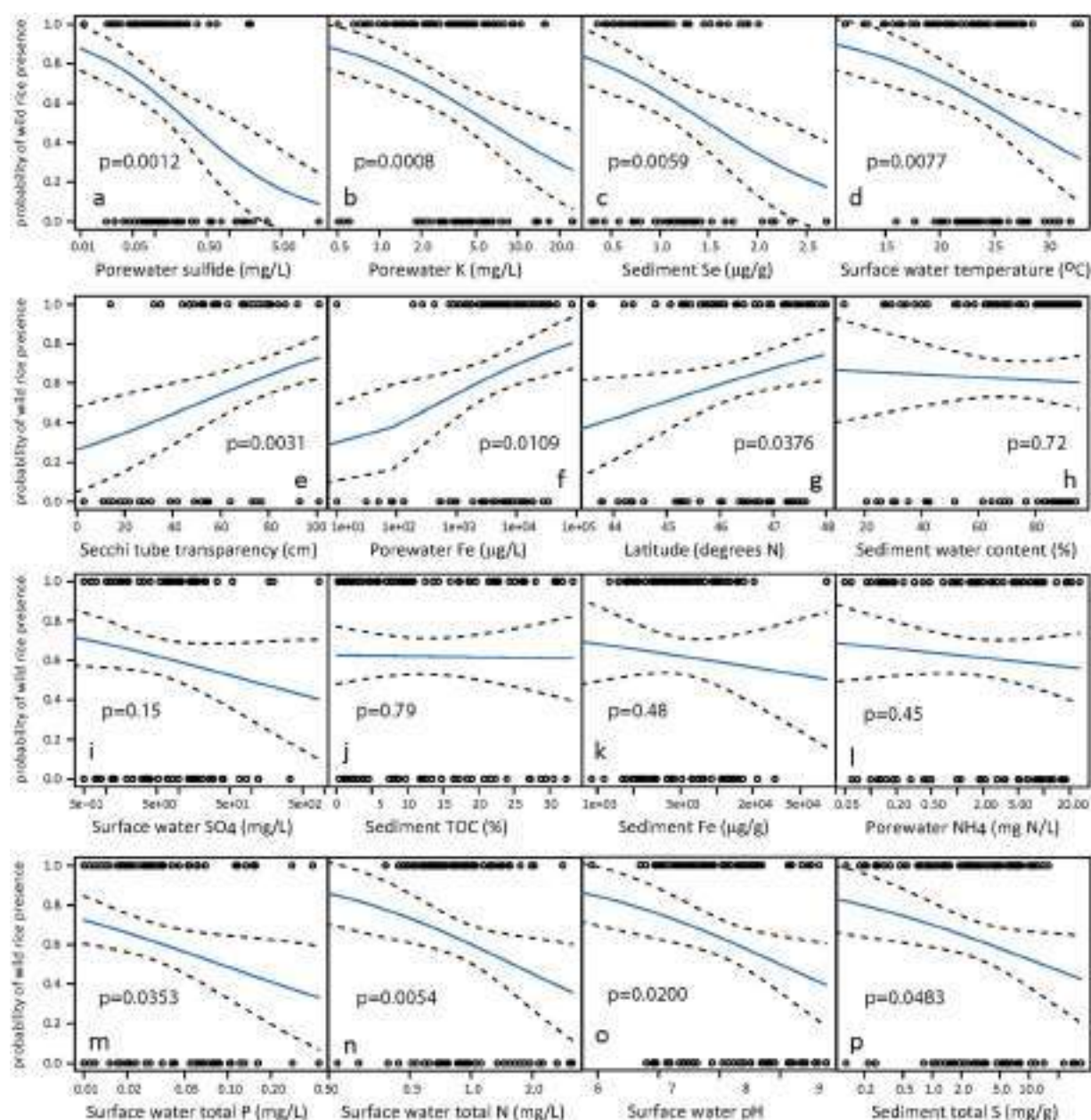


Figure 2. Binary logistic regressions for 16 variables found to be statistically significant in this study or indicated in the literature as important for wild rice habitat. The open circles indicate the value for a given parameter of each site used in the analysis; the circles at the top of a plot indicate sites with wild rice present; the circles at the bottom of a plot indicate sites with wild rice absent. The span of the dashed lines around the solid line indicates the 95% confidence interval.

correlations to help understand the relationships between environmental factors of interest. Wild rice density is negatively correlated with pore water sulfide, potassium (K), and NH_4 and positively correlated with surface water alkalinity (Table 1). There are likely factors controlling the density of wild rice at any particular location in addition to the variables measured, such as herbivory and hydrological disturbances.

One should be cautious in the interpretation of statistically significant associations between wild rice and field variables, in that true cause and effect are not necessarily obvious. For instance, is the toxic quality of pore water sulfide sufficient explanation for its negative associations with both the presence and density of wild rice? Do sites with greater density of wild rice have lower pore water sulfide because low sulfide allows wild rice to grow, or because plants release oxygen from their roots, oxidizing sulfide? The true explanation is likely a combination of the two mechanisms: elevated pore water sulfide can eventually extirpate a wild rice

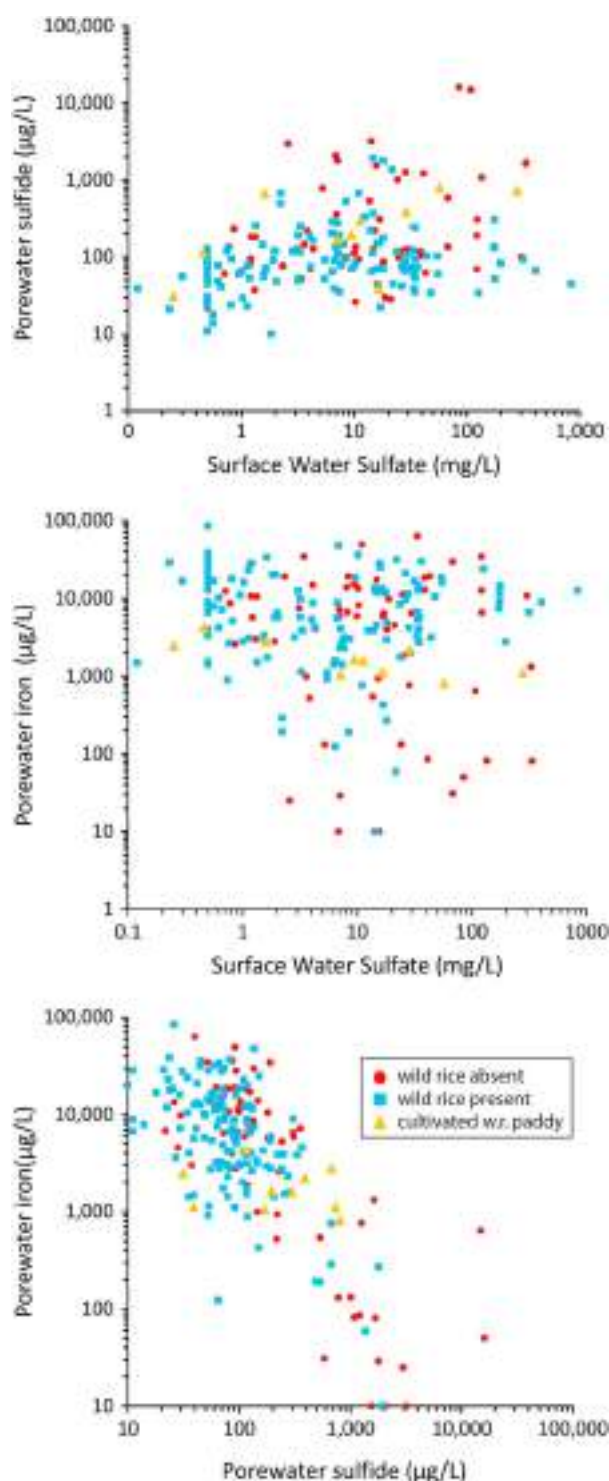


Figure 3. Class D data plus cultivated wild rice paddies (yellow triangles) showing sites with wild rice present (blue squares) and absent (red circles). Note that (a) pore water sulfide is not linearly related to surface water SO_4 , indicating that additional factors besides SO_4 concentration contribute to the sulfide concentration in pore water; (b) wild rice can occur in sites over a wide range of surface water SO_4 values as long as pore water Fe is relatively high; and (c) pore water Fe and sulfide have a strong negative relationship, due to the energetically favorable formation of FeS compounds, and that wild rice mainly occurs where pore water sulfide is $<1,000 \mu\text{g L}^{-1}$.

population by reducing seedling survival and seed production, weight, and viability (Pastor et al., 2017), but oxygen release from roots when sulfide concentrations are low enough to allow wild rice to successfully reproduce drives sulfide to even lower concentrations than would have occurred without the plants (Myrbo et al., 2017). Although the negative correlation between pore water sulfide and wild rice density ($\rho = -0.31, p < 0.01$, Table 1) could be interpreted to mean that lower sulfide allows a larger population to grow, it is also possible the correlation is partly caused by oxygen release from the wild rice roots, decreasing sulfide concentrations. This hypothesis is supported by the observation from a controlled experiment that acid-volatile sulfide (AVS) sediment concentrations were 30% lower when wild rice was present (Myrbo et al., 2017).

Of the 12 variables significantly associated with the occurrence of wild rice, we propose that nine are noncausal and merely related to one or more of three truly causative factors: (1) pore water sulfide, (2) water transparency, and (3) water temperature. These three variables are not significantly correlated with one another (Table 1), and there are plausible mechanisms for each to independently exclude wild rice from otherwise suitable habitat: (1) elevated sulfide reduces the growth of wild rice (Pastor et al., 2017); (2) low water transparency plausibly constrains the ability of a germinated wild rice seed to reach sufficient light before it runs out of endosperm energy (Aiken et al., 1988; DNR, 2008); and (3) warmer winter water temperature at lower latitudes may limit seed germination, as the seeds of *Z. palustris* must experience at least 3 months in cold water to break seed dormancy (Kovach & Bradford, 1992) (although summer temperatures were measured in this study, winter and summer temperatures would be correlated).

3.2. Pore Water Sulfide as a Causal Variable and Associated Correlated Variables

Our primary a priori hypothesis was that elevated surface water SO_4 can produce elevated pore water sulfide concentrations which, in turn, negatively affect potential wild rice habitat. A plot of pore water sulfide against SO_4 , with wild rice presence noted (Figure 3a), suggests that wild rice is generally not found at sites with elevated sulfide. Of the sites with pore water sulfide greater than $1,000 \mu\text{g L}^{-1}$, wild rice was present in 23% (3 of 13, with only a few plants found at 2 of those 3 sites). In contrast, wild rice was present at 74% of the sites where sulfide was less than $1,000 \mu\text{g L}^{-1}$. Despite historical reports of *Zizania aquatica* in Minnesota, inspection of voucher specimens, following the taxonomy of Terrell et al. (1997), found only *Z. palustris* at all sites sampled. *Zizania aquatica* (Southern wild rice) is rare in Minnesota, but its range extends east through Wisconsin and the southern part of the Great Lakes region to New England and occurs in freshwater tidal marshes south to Florida and west to Louisiana (Terrell et al., 1997). The findings of this study, especially those related to temperature, may not apply to *Z. aquatica*.

Despite a strong relationship between sulfide and wild rice, the relationship between SO_4 and pore water sulfide among the 108 field sites was not a simple linear function. High surface water SO_4 did not always result in high pore water sulfide (above $1,000 \mu\text{g L}^{-1}$), and some samples with surface water SO_4 less than 10 mg L^{-1} had pore water sulfide greater

than $1,000 \mu\text{g L}^{-1}$ (Figure 3a). The 33 samples with surface water SO_4 below 1.0 mg L^{-1} all had pore water sulfide less than $200 \mu\text{g L}^{-1}$, suggesting that surface water SO_4 might limit maximum sulfide production.

Wild rice was present at high and low SO_4 concentrations as long as pore water Fe was high and sulfide was low (Figures 3b and 3c): pore water Fe and sulfide each exert antipathetic control over the concentration of the other (Figure 3c; Pollman et al., 2017), and wild rice mainly persists in sites where pore waters are low in sulfide and high in Fe. Pollman et al. (2017) developed a structural equation model showing that variations in three variables (SO_4 , sediment TOC, and sediment extractable Fe) contribute nearly equally to the observed variations in pore water sulfide among the sites in this study. Sulfate-reducing bacteria are simultaneously limited in their production of pore water sulfide by surface water SO_4 and sediment TOC (which are roughly proportional to available SO_4 and labile organic matter, respectively). Concentrations of sulfide in pore water are then constrained by the availability of pore water Fe, which is in turn controlled by the overall supply of Fe in the sediment (Pollman et al., 2017).

If pore water sulfide concentration is a causative factor controlling the presence of wild rice, as hypothesized, then other variables may be statistically significant because they either vary with the process of SO_4 reduction or with the sulfide itself. Pastor et al. (2017) showed that wild rice growth declines in proportion to sulfide concentrations in both hydroponic and outdoor mesocosm experiments. In a study of the Pastor et al. mesocosms, Myrbo et al. (2017) showed that the enhanced mineralization of plant litter associated with SO_4 reduction produced increases in surface water P and N, and increases in pore water sulfide caused decreases in pore water Fe. These effects from the controlled mesocosm experiment are consistent with correlations observed among sites in the field data between pore water sulfide and surface water N and pore water Fe (Table 1). Surface water P is not significantly correlated with pore water sulfide in the field data, despite dual mechanisms of P mobilization from sediment, (1) the interaction between sulfide and Fe (Caraco et al., 1993; Maynard, Dahlgren, & O'Geen, 2011; Smolders & Roelofs, 1993) and (2) mineralization of organic matter. The lack of correlation of surface water P with pore water sulfide in this field study is not surprising because given the wide variety of landscapes sampled, there is no reason that pore water sulfide would be proportional to the mass of Fe that has reacted with sulfide and released sorbed P. In SO_4 addition experiments where the P and Fe content of the sediment is held constant, there is often a significant correlation between pore water sulfide and mobilized P (Myrbo et al., 2017). In contrast to the lack of correlation of pore water sulfide with surface water P in this field study, AVS is significantly correlated with surface water P ($\rho = 0.30$, $p < 0.01$, Table 1), presumably because AVS is proportional to the iron that has reacted with sulfide.

Elevated pore water sulfide is a product of SO_4 reduction-driven mineralization of sediment organic matter, which also releases the constituents of the decaying plant material, N, P, K, silica, and C (either as DIC, which increases alkalinity, or DOC) into sediment pore water and the overlying surface water (Myrbo et al., 2017). Consequently, the occurrence of wild rice is negatively associated not only with pore water sulfide ($p = 0.001$) but also with elevated pore water K ($p = 0.0008$) and surface water TN ($p = 0.005$, Table 1). Median concentrations of these variables are lower in wild rice waters compared to waters with no observed wild rice (88 versus $126 \mu\text{g L}^{-1}$ sulfide, 2.4 versus 4.3 mg L^{-1} pore water K, and 0.74 versus 0.95 mg L^{-1} TN, Table S3). Pore water sulfide is itself positively correlated with pore water K, TN, NH_4 , and silica, surface water K, alkalinity, and pH, and sediment TS and AVS (Tables 1 and S4).

The strong evidence for the association of elevated pore water K with the absence of wild rice (Table 1) is interesting, as K is an essential plant nutrient, and therefore, it is unlikely that the association is based on toxicity to wild rice. Rather, it is likely that the association is a result of the simultaneous mobilization of K with the production of sulfide as plant matter is mineralized. Potassium does not bond covalently with organic compounds and is readily leached out of dead organic matter (Troeh & Thompson, 2005). Silica phytoliths dissolve as plant matter is mineralized, allowing additional K that had been trapped within the phytoliths to be released into sediment pore water (Nguyen et al., 2015). Wild rice and other wetland macrophytes develop abundant phytoliths that release dissolved silica upon decomposition (Struyf & Conley, 2009). Additional dissolved silica is likely released to pore water as epiphytic diatoms are mineralized. Pore water silica, K, and sulfide are all significantly correlated with each other (Tables 1 and S5). The negative correlation of pore water K with wild rice may be magnified by its additional positive correlation with elevated water temperature (Table 1), which plausibly accelerates dissolution of silica in organic matter (Gudas et al., 2010; Kamatani, 1982).

AVS largely consists of solid-phase sulfide, which is not available to plants and therefore is not significantly associated with wild rice presence/absence ($p > 0.10$, Table 1). AVS is a measure of cumulative sulfide production, which is proportional to past mineralization of organic matter, consistent with significant positive correlations between AVS and pore water TP and NH_4 , and surface water TP and alkalinity ($p < 0.01$, 0.05, 0.01, and 0.01, respectively, Table 1).

The negative association of sediment total-S (TS) with wild rice presence (BLR $p = 0.048$, Table 1) is likely the result of both TS and wild rice being controlled by sulfide production; the median TS concentration at sites with wild rice is 2.6 mg g^{-1} , compared to 4.1 mg g^{-1} at sites without wild rice (Table S3). Sediment TS is correlated with both pore water sulfide and AVS. The negative association of sediment Se with wild rice (BLR $p = 0.006$) is surprising, given that median Se concentrations are very low (0.9 and $1.2 \text{ } \mu\text{g g}^{-1}$ in sites with and without wild rice, respectively). The slightly higher Se at sites without wild rice may be caused by the coprecipitation of Se and S by SRB, as shown by Hockin and Gadd (2003). Selenium is correlated with sediment total S ($\rho = 0.35$; $p < 0.001$).

3.3. Water Transparency as a Causal Variable and Associated Correlated Variables

Lower water transparency is associated with a lower probability of wild rice occurrence (BLR $p = 0.003$). Transparency is not related to wild rice density ($\rho = 0.11$, $p > 0.20$, Table 1); however, low transparency can apparently exclude wild rice (11 of the 12 sites with transparency $< 30 \text{ cm}$ had no wild rice), but above that threshold, other variables control wild rice density. Low water transparency decreases photosynthesis of wild rice seedlings while growing to the water surface, which (a) decreases oxygen production that could otherwise be used to detoxify sulfide internally (Krüssel et al., 2014), or externally if released into pore water from the roots (Colmer, 2003); and (b) decreases the energy available for root development, enhancing vulnerability to a sudden increase in water depth, which can uproot an entire year's cohort (DNR, 2008). Wild rice is unusual among grasses in that the stem develops before the root, probably because the seedling may have to grow over 50 cm before reaching the water surface, at which time floating leaves are developed that can supply energy for root development (Aiken, 1986). If transparency is too low, or the water too deep, the energy stored in the seed can be insufficient for the seedling to reach the water surface.

Water transparency can be controlled by the density of phytoplankton, which was not measured in this study. However, transparency is highly correlated with the nutrient concentrations that control phytoplankton growth, total phosphorus ($\rho = -0.58$, $p < 0.001$), and total nitrogen ($\rho = -0.61$, $p < 0.001$). Transparency can also be controlled by colored dissolved organic matter, consistent with the observed significant correlation between transparency and water color ($\rho = -0.68$, $p < 0.001$, Table S4).

3.4. Temperature as a Causal Variable and Associated Correlated Variables

Wild rice germinates at higher rates following longer exposure at temperatures closer to freezing (Kovach & Bradford, 1992), consistent with the significant association of wild rice absence with lower latitudes (BLR $p = 0.04$) and warmer summer water temperature (BLR $p = 0.008$; medians of 21.9° and 23.7°C with and without wild rice, respectively). Sites with warmer summer water temperatures generally also have warmer winter temperatures. Warmer and shorter winters would cause lower germination rates, ultimately reducing the probability that a population could persist over the long term. For this reason, the Minnesota Department of Natural Resources hypothesizes that climate change may push the range of wild rice farther north (DNR, 2008, 2016). However, the temperature control of wild rice germination has not been adequately investigated to rigorously assess this hypothesis. The observed association of wild rice with lower pH surface waters (BLR $p = 0.04$; median pH values of 7.8 and 8.5 at sites with and without wild rice, respectively) may be due simply to the correlation of wild rice with cooler surface waters: the solubility of CO_2 is higher in colder water, leading to lower pH (Spearman correlation between temperature and pH = 0.35 , $p < 0.0001$).

Lower latitude sites are negatively associated with wild rice presence and density (Table 1). Lower latitude sites are correlated with higher water temperature ($\rho = -0.51$, $p < 0.001$). Geological and land use gradients also correlate with latitude, producing correlations with surface water N and P ($\rho = -0.25$ and -0.31 , $p < 0.01$). Despite these correlations with nutrients, latitude is not significantly correlated with water transparency ($\rho = 0.13$), so the general unsuitability of lower latitudes for wild rice may be a combination of warmer winters and some reduced transparency as a result of nutrient enrichment. Latitude is not significantly correlated with pore water sulfide ($\rho = -0.06$).

3.5. Synergy Among the Three Causal Variables of Sulfide, Temperature, and Transparency

While temperature may control wild rice presence/absence through winter temperatures too warm to achieve high rates of seed germination in the spring, higher summer temperatures may act synergistically on variables correlated with pore water sulfide. Elevated summer temperatures likely enhance microbial activity, no matter which electron acceptor is respired by the dominant microbes (Gudasz et al., 2010). Water temperature is indeed correlated with pore water concentrations of the plant nutrients N, P, and K released by decomposition, which are also significantly correlated with either pore water sulfide or AVS (Table 1). Although sulfide production may be enhanced by elevated temperature, the correlation between sulfide and temperature is weak ($\rho = 0.17$; $p > 0.05$).

The production of sulfide plausibly contributes to the significant correlation of six of the nine variables with wild rice occurrence: P and N in surface water, Fe and K in pore water, and S and Se in sediment. Water temperature is significantly correlated with three of these variables (P, N, and K), and therefore, synergistically reinforces their associations with the absence of wild rice. Elevated surface water P and N are further synergistically associated with the absence of wild rice because their release via MSR-driven mineralization also enhances phytoplankton growth, reducing light available to wild rice seedlings; P and N are highly correlated with reduced transparency ($p < 0.001$, Table 1).

In this data set greater water depth is negatively associated with the occurrence of wild rice, not because wild rice grows better in shallower water, which it may, but because of where field crews took samples when wild rice was not present. Following a decision tree (Table S1), when wild rice was not present, field crews usually sampled among water lilies, which, on average, were observed in slightly deeper water than wild rice (67 cm compared to 52 cm).

Finally, *multiple* BLR was employed to investigate the question of whether any of the correlated variables provided additional explanatory power for the occurrence of wild rice beyond the models with sulfide, transparency, or temperature as base predictors. Surface water temperature is predictive of wild rice presence independent of sulfide ($p = 0.03$). Pore water K improves models based on sulfide ($p = 0.02$) or temperature ($p = 0.004$) alone but provides no significant additional explanatory power beyond a model built on both sulfide and temperature ($p = 0.07$). Overall, multiple BLR analysis confirms that other variables provide no additional explanatory power and that the three base predictors are independent of each other.

Multiple BLR was used to model the probability of wild rice occurrence (WR presence) as a function of pore water sulfide (pw sulfide, in mg L^{-1}), water transparency as measured by the Secchi tube (trans, in cm), and water temperature (Temp, in $^{\circ}\text{C}$):

$$\text{Logit (WR presence)} = 0.532 + 0.0183 (\text{trans}) - 1.169 (\log_{10} \text{pw sulfide}) - 0.107 (\text{Temp}) \quad (2)$$

where odds = $\exp(\text{logit})$ and probability = $(\text{odds}/(1 + \text{odds}))$.

Pore water sulfide and water transparency are significant variables in the multiple BLR ($p = 0.012$ and $p = 0.016$, respectively), whereas water temperature is only marginally significant ($p = 0.056$). To visualize the interaction of the variables, a 3-D plot was constructed that predicts the probability of wild rice occurrence as a function of sulfide and transparency, while holding constant the marginally significant variable, temperature, at the median value of the Class B data set (23.2 $^{\circ}\text{C}$; Figure 4). Within the range of variables in Class B, modeled probabilities of wild rice occurrence range from a high of 89.8% (trans = 100 cm, which was the maximum of the measurement device, and pw sulfide = 11 $\mu\text{g L}^{-1}$, which was the reporting limit) to a low of 9.6% (trans = 3 cm, which was the minimum observed, and pw sulfide = 2,000 $\mu\text{g L}^{-1}$). Modeling was cut off at a sulfide concentration of 2,000 $\mu\text{g L}^{-1}$ because only three Class B sites had pore water sulfide greater than 2,000 $\mu\text{g L}^{-1}$ and none of the three hosted wild rice.

3.6. Field Variables not Evidently Associated With Wild Rice Presence and Absence

Some variables included among the initial hypotheses, or in the past cited as important attributes of wild rice habitat, were not found to be significantly associated with wild rice presence and absence. These include sediment TOC ($p = 0.79$, Figure 2j; DNR, 2008; Lee, 1986; Moyle & Krueger, 1964), flocculent sediment (quantified here as the sediment water content; $p = 0.72$, Figure 2h; DNR, 2008; Lee, 1986; Moyle & Krueger, 1964), sediment N ($p = 0.68$, Table 1; Carson, 2002; Walker et al., 2010), sediment P ($p = 0.27$, Table 1; Carson, 2002; DNR, 2008), and surface water alkalinity ($p = 0.28$, Table 1; Moyle, 1944).

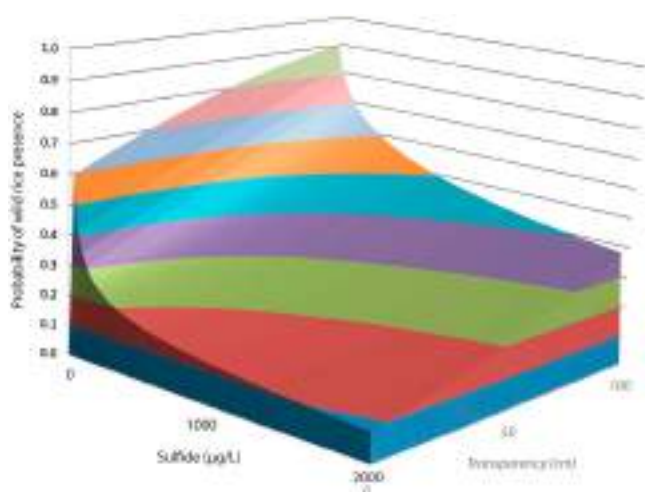


Figure 4. Visualization of the relationship, determined by multiple binary logistic regression, between water transparency and pore water sulfide in controlling the probability of wild rice occurrence at 23.2°C, the median temperature for all sites in the class B data set.

Reduced sediments are generally regarded as producing pore water constituents that are potentially toxic to rooted plants; potentially toxic agents, in addition to sulfide, include ammonia and Fe (Pezeshki & DeLaune, 2012). Analysis of the binary logistic regressions showed no evidence for ammonia toxicity (BLR $p = 0.45$, Figure 2l) or Fe toxicity (wild rice presence is positively correlated with pore water Fe, BLR $p = 0.01$, Figure 2f). As a product of decomposition, ammonia is correlated with pore water sulfide, K, and silica (Spearman correlations $p < 0.001$, Table S4).

The field data provide little evidence that elevated sulfide production excludes wild rice by producing Fe, Cu, or Zn deficiency (Table S3). The possibility that *low* pore water Fe limits wild rice growth is difficult to distinguish from sulfide toxicity because of the strong negative correlation between pore water Fe and pore water sulfide ($\rho = -0.58$, $p < 0.0001$, Table 1). Hydroponic studies using chelated Fe in combination with elevated sulfide (Pastor et al., 2017) show reduced growth, implying that the mechanism is sulfide toxicity, rather than Fe limitation, assuming that the chelated Fe remains bioavailable in the presence of sulfide (Li et al., 2009). The median pore water Fe levels at sites with and without wild rice are similar, 5.7 and 5.9 mg L^{-1} , respectively;

average levels are 11.0 and 7.0 mg L^{-1} , respectively, which produced the significant BLR positive correlation between pore water Fe and wild rice presence. On balance, there is little evidence to support the hypothesis that elevated sulfide reduces wild rice growth through Fe deficiency rather than by direct sulfide toxicity. Pore water Cu concentrations were often below the detection limit in the field sites sampled, precluding analysis of their correlation with wild rice presence and absence. The BLR for pore water Zn concentrations with wild rice presence and absence was not statistically significant (data not shown). Neither Cu nor Zn had a significant Spearman correlation with pore water sulfide (data not shown), unlike Fe.

3.7. Seasonality in Field Variables

Fifteen natural wild rice sites were sampled 3 to 5 times in 2013 to determine which field variables exhibit statistically significant seasonal trends that might be important to consider in the overall analysis, given that different sites were sampled in different months. Some variables conformed to expected seasonal trends, such as water temperature ($p = 0.001$), which increased in early summer, peaked about 1 August, and then declined. Some of the surface water variables exhibited monotonic increased concentrations over the summer (alkalinity, Na, Mg, and SO_4 ; $p = 0.0009$, 0.008, 0.021, and 0.05, respectively). One hypothesis that explains this observation is that waterbodies in Minnesota, after being diluted by spring snowmelt, in general become more concentrated as the summer progresses due to evaporation and, for waterbodies with shorter residence times, greater influence of groundwater flux. Cl and Ca had nonsignificant positive slopes ($p = 0.29$ and 0.37, respectively), whereas K exhibited no trend ($p = 0.48$). As expected, none of the solid-phase variables of the homogenized 10 cm long sediment cores showed any significant seasonal trends (e.g., sediment extractable Fe $p = 0.93$, sediment TOC $p = 0.96$). Among the pore water variables, only K and pH exhibited significant trends. Pore water K values decreased over the summer ($p = 0.006$), likely as a result of diffusion into surface water or uptake by growing rooted macrophytes. Pore water pH generally increased over the summer ($p = 0.003$), which may reflect loss of CO_2 as the sediment warmed over the summer, reducing the solubility of gases. The lack of seasonality in pore water sulfide ($p = 0.62$) indicates that sulfide concentrations were in steady state with the variables that exert primary control over its concentration, surface water SO_4 , extractable Fe, and sediment TOC (Pollman et al., 2017). Of the variables controlling pore water sulfide, only SO_4 exhibited even marginally significant seasonal trends ($p = 0.05$, 0.93, and 0.97, for SO_4 , extractable Fe, and sediment TOC, respectively). Despite the finding of seasonal variation in SO_4 , Pollman et al. (2017) found that SO_4 is one of the primary variables that control pore water sulfide concentrations. Seasonal variation in SO_4 concentrations undoubtedly contributes to noise in the statistical relationship documented by Pollman et al. (2017). Myrbo et al. (2017) found that the microbial production of pore water sulfide in a wild rice sediment is proportional to the long-term average SO_4 surface water concentration.

3.8. Cultivated Wild Rice Paddies

Commercial wild rice paddies have been reported with healthy stands of wild rice growing under surface water SO_4 levels as high as 170 mg L^{-1} (Aiken et al., 1988). Our limited measurements in seven different paddies ranged from 0.3 mg L^{-1} to 279 mg L^{-1} SO_4 , with a median of 8.3 mg L^{-1} ($n = 7$, Table S3). Natural wild rice waters in our study had a median SO_4 concentration of 4.1 mg L^{-1} . Surprisingly, median pore water sulfide in paddies was $182 \mu\text{g L}^{-1}$, greater than the medians of natural wild rice waters ($88 \mu\text{g L}^{-1}$; $n = 67$) and waters without wild rice ($126 \mu\text{g L}^{-1}$; $n = 41$). The median sediment extractable Fe concentration of paddies (4.5 mg g^{-1}) is similar to that of natural wild rice waters (4.8 mg g^{-1}). In contrast, median sediment TOC is much higher in paddies (25.2%) than natural wild rice waters (9.1%). It thus appears that the greater TOC driving enhanced SO_4 reduction (Pollman et al., 2017) and driving median pore water Fe lower than in natural wild rice sediments (1.6 and 5.7 mg L^{-1} , respectively), despite the similar reservoirs of Fe in the sediment. Elevated production of sulfide coupled with the consumption of the available Fe may put some paddies on the brink of sulfide toxicity to wild rice.

However, the physical setting of cultivated wild rice paddies differs from that of natural lakes and streams in a number of important ways. Often paddies and their surface sediments are dewatered during the growing season through use of buried drainage tiles, allowing tillage after harvesting and enhanced aerobic decomposition of rice straw and roots, and possibly reoxidation of sulfide and reduced Fe. Prior to drainage tile installation in the 1980s, failure of wild rice crops was sometimes attributed to elevated sulfide (Grava & Rose, 1975; Gunvalson, personal communication, 2016). Water depth in paddies is also typically shallower (median of 30 cm) than wild rice habitat in natural lakes and rivers (median of 52 cm), allowing seedlings to emerge above water with less energy expended, photosynthesize sooner, and release oxygen from roots to oxidize sulfide. The use of nitrogen fertilizers may further enable seedlings to elongate more quickly through the water and into the air. Fertilized plants have been shown to be more resistant to sulfide toxicity than are control plants (Geurts et al., 2009). The production of sulfide would be inhibited if N fertilizers were applied as nitrate—but N fertilizers are applied as ammonia or urea (Oelke et al., 1997).

3.9. Conclusions and Implications

Analysis of an extensive suite of physical and chemical parameters from 108 different sites with potential wild rice habitat shows that pore water sulfide toxicity is a primary biogeochemical factor controlling the occurrence of wild rice populations in otherwise favorable habitat. High concentrations of pore water sulfide greatly decrease the probability that a wild rice population will be found in a waterbody. When pore water sulfide is low enough to support reproducing wild rice populations, however, it is likely that the relationship between sulfide and wild rice becomes more complicated and analysis of cause and effect more ambiguous. The variation in sulfide concentration is correlated to the density of wild rice, at least partially as a result of oxygen release from roots, and thus, not only does sulfide affect wild rice but wild rice affects sulfide.

Aside from low pore water sulfide, favorable wild rice habitat has long, cold winters and transparent surface water in the ice-free season. *Zizania palustris* seeds germinate at low rates if the winter is too warm or too short. The probability that wild rice seedlings successfully grow to maturity is reduced if photosynthesis is inhibited by low water clarity. Thus, pore water sulfide (itself a function of surface water SO_4 , sediment Fe, and sediment organic matter (Pollman et al., 2017)), water temperature, and water transparency together largely determine wild rice presence and absence. These three factors are independent of one another but may act synergistically on other related processes.

In addition to generating sulfide, SO_4 reduction supports organic matter mineralization that releases nutrients and alkalinity to the surface water, which has the potential to change plant community structure even if Fe is high enough to keep pore water sulfide from reaching phytotoxic levels (Myrbo et al., 2017). Natural and anthropogenic SO_4 loading to freshwaters may thus strongly affect ecosystem composition and function, despite the low direct toxicity of SO_4 under oxic conditions.

References

- Aiken, S. G. (1986). The distinct morphology and germination of the grains of two species of wild rice (*Zizania*, Poaceae). *Canadian Field Naturalist*, 100, 237–240.
- Aiken, S. G., Lee, P. F., Punter, D., & Stewart, J. M. (1988). *Wild Rice in Canada* (pp. 130). Toronto: NC Press.

Acknowledgments

This work was supported by the Clean Water Fund, created by the Clean Water, Land and Legacy Amendment to Minnesota's constitution. LacCore was supported by NSF grant EAR-0949962 to Myrbo and others. LacCore field crew and lab staff: Kristina Brady, Aaron Fish, Cynthia Frickle, Lindsay Hastings, Jessica Heck, Aaron Lingwall, James Marty, Ailsa McCulloch, Emily Mellicant, Mark Neumeyer, Ryan O'Grady, Sean Rogers, June Sayers, Christopher Schodt, Alex Seeling, Valerie Stanley, Michelle Sutherland, Robert Thompson, Emily Whittaker, and Amanda Yourd. A partial data set is available in the EarthChem database: <https://doi.org/10.1594/IEDA/100681>. The full data set is available in the Data Repository for U of M (DRUM): <https://doi.org/10.13020/D6130R>; <http://conservancy.umn.edu/handle/11299/185506>.

- Armstrong, J., & Armstrong, W. (2005). Rice: Sulfide-induced barriers to root radial oxygen loss, Fe^{2+} and water uptake, and lateral root emergence. *Annals of Botany*, 86, 625–638.
- Bachand, P. A. M., Bachand, S., Fleck, J., Anderson, F., & Windham-Myers, L. (2014). Differentiating transpiration from evaporation in seasonal agricultural wetlands and the link to advective fluxes in the root zone. *Science of the Total Environment*, 484, 232–248.
- Bagarinao, T. (1992). Sulfide as an environmental factor and toxicant: Tolerance and adaptations in aquatic organisms. *Aquatic Toxicology*, 24, 21–62.
- Baker, L. A., Brezonik, P. L., & Pollman, C. D. (1986). Model of internal alkalinity generation: Sulfate retention component. *Water, Air, and Soil Pollution*, 31, 89–94.
- Balogh, S. J., Engstrom, D. R., Almendinger, J. E., McDermott, C., Hu, J., Nollet, Y. H., ... Johnson, D. K. (2009). A sediment record of trace metal loadings in the Upper Mississippi River. *Journal of Paleolimnology*, 41, 623–639.
- Borum, J., Pedersen, O., Greve, T. M., Frankovich, T. A., Zieman, J. C., Fourqurean, J. W., & Madden, C. J. (2005). The potential role of plant oxygen and sulphide dynamics in dieoff events of the tropical seagrass, *Thalassia testudinum*. *Journal of Ecology*, 93, 148–158.
- Capone, D. G., & Kiene, R. P. (1988). Comparison of microbial dynamics in marine and freshwater sediments: Contrasts in anaerobic carbon catabolism. *Limnology and Oceanography*, 33, 725–749.
- Caraco, N. F., Cole, J. J., & Likens, G. E. (1993). Sulfate control of phosphorus availability in lakes. *Hydrobiologia*, 253, 275–280.
- Carroll, C., Zielinski, W. J., & Noss, R. F. (1999). Using presence-absence data to build and test spatial habitat models for the fisher in the Klamath region, U.S.A. *Conservation Biology*, 13(6), 1344–1359.
- Carson, T. L. (2002). The effects of sediment nutrient variation, water depth, and emergent aquatic perennials on wild rice (*Zizania palustris*) production at the Rice Lake National Wildlife Refuge. Thesis, University of Minnesota, Minneapolis.
- Colmer, T. D. (2003). Long-distance transport of gases in plants: A perspective on internal aeration and radial oxygen loss from roots. *Plant, Cell and Environment*, 26, 17–36.
- Cook, R. B., Kelly, C. A., Schindler, D. W., & Turner, M. A. (1986). Mechanisms of hydrogen ion neutralization in an experimentally acidified lake. *Limnology and Oceanography*, 31, 134–148.
- Crawley, M. J. (2007). *The R book* (pp. 950). Chichester, UK: Wiley.
- Davranche, M., & Bollinger, J.-C. (2000). Release of metals from iron oxyhydroxides under reductive conditions: Effect of metal/solid interactions. *Journal of Colloid and Interface Science*, 232, 1655–1173.
- DNR (2008). Natural wild rice in Minnesota, Minnesota Department of Natural Resources. 116 pp. St. Paul, Minnesota. Retrieved from http://files.dnr.state.mn.us/fish_wildlife/wildlife/shallowlakes/natural-wild-rice-in-minnesota.pdf (accessed July 22, 2016)
- DNR (2016). *Climate Change and Minnesota Wild Rice* (pp. 7). Minnesota Department of Natural Resources.
- Eggers, S. D., & Reed, D. M. (2011). *Wetland plants and plant communities of Minnesota and Wisconsin* (3rd ed.). (pp. 478). St. Paul: U.S. Army Corps of Engineers.
- Engstrom, D. R., & Wright, H. E., Jr. (1984). Chemical stratigraphy of lake sediments as a record of environmental change. In E. Y. Haworth & J. W. G. Lund (Eds.), *Lake sediments and environmental history* (pp. 11–67). Minneapolis, MN: University Minnesota Press.
- EPA (2010). Secondary drinking water standards: Guidance for nuisance chemicals, U.S. Environmental Protection Agency. Retrieved from <https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance- nuisance-chemicals> (accessed May 12, 2016)
- Eule-Nashoba, A. R., Biesboer, D. D., & Newman, R. M. (2012). Seed size in lacustrine and riverine populations of wild rice in northern Minnesota and Wisconsin. *Botany*, 90, 27–33.
- Fort, D. J., Mathis, M. B., Walker, R., Tuominen, L. K., Hansel, M., Hall, S., ... Anderson, K. (2014). Toxicity of sulfate and chloride to early life stages of wild rice (*Zizania palustris*). *Environmental Toxicology and Chemistry*, 33(12), 2802–2809.
- Friedman, J., & Barrett, S. C. H. (2009). Wind of change: New insights on the ecology and evolution of pollination and mating in wind-pollinated plants. *Annals of Botany*, 103, 1515–1527.
- Geurts, J. J. M., Sarneel, J. M., Willers, B. J. C., Roelofs, J. G. M., Verhoeven, J. T. A., & Lamers, L. P. M. (2009). Interacting effects of sulphate pollution, sulphide toxicity and eutrophication on vegetation development in fens: A mesocosm experiment. *Environmental Pollution*, 157, 2072–2081.
- Gorham, E., Dean, W. E., & Sanger, J. E. (1983). The chemical composition of lakes in the north-central United States. *Limnology and Oceanography*, 28(2), 287–301.
- Grava, J., & Rose, K. F. (1975). Fertility of paddy soils and fertilization of wild rice, Univ. of Minnesota Extension Annual Report, (pp. 214–230).
- Grime, J. P. (1977). Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *American Naturalist*, 111(982), 1169–1194.
- Gudas, C., Bastviken, D., Steger, K., Premke, K., Sobek, S., & Tranvik, L. J. (2010). Temperature-controlled organic carbon mineralization in lake sediments. *Nature*, 466, 478–481.
- Hansel, C. M., Lentini, C. J., Tang, Y., Johnson, D. T., Wankel, S. D., & Jardine, P. M. (2015). Dominance of sulfur-fueled iron oxide reduction in low-sulfate freshwater sediments. *The ISME Journal*, 9, 2400–2412. <https://doi.org/10.1038/ismej.2015.50>
- Heiri, O., Lotter, A. F., & Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: Reproducibility and comparability of results. *Journal of Paleolimnology*, 25, 101–110.
- Hietjes, H. M., & Lijklema, L. (1980). Fractionation of inorganic phosphates in calcareous sediments. *Journal of Environmental Quality*, 9, 405–407.
- Hockin, S. L., & Gadd, G. M. (2003). Linked redox precipitation of sulfur and selenium under anaerobic conditions by sulfate-reducing bacterial biofilms. *Applied and Environmental Microbiology*, 69(12), 7063–7072.
- Hsieh, Y. P., & Shieh, Y. (1997). Analysis of reduced inorganic sulfur by diffusion methods: Improved apparatus and evaluation for sulfur isotopic studies. *Chemical Geology*, 137, 255–261.
- Ingold, A., & Havill, D. C. (1984). The influence of sulphide on the distribution of higher plants in salt marshes. *Journal of Ecology*, 72, 1043–1054. <https://doi.org/10.2307/2259550>
- Kamatani, A. (1982). Dissolution rates of silica from diatoms decomposing at various temperatures. *Marine Biology*, 68, 91–96.
- Kinsman-Costello, L. E., O'Brien, J. M., & Hamilton, S. K. (2015). Natural stressors in uncontaminated sediments of shallow freshwaters: The prevalence of sulfide, ammonia, and reduced iron. *Environmental Toxicology and Chemistry*, 34, 467–479.
- Kirk, G. (2004). *The Biogeochemistry of Submerged Soils* (pp. 291). John Wiley.
- Koch, M. S., & Erskine, J. M. (2001). Sulfide as a phytotoxin to the tropical seagrass *Thalassia testudinum*: Interactions with light, salinity and temperature. *Journal of Experimental Marine Biology and Ecology*, 266, 81–95.

- Kovach, D. A., & Bradford, K. J. (1992). Temperature dependence of viability and dormancy of *Zizania palustris* var. interior seeds stored at high moisture contents. *Annals of Botany*, 69, 297–301.
- Krüssel, L., Junemann, J., Wirtz, M., Birke, H., Thornton, J. D., Browning, L., ... Hildebrandt, T. M. (2014). The mitochondrial sulfur dioxygenase ETHYLMALONIC ENCEPHALOPATHY PROTEIN1 is required for amino acid catabolism during carbohydrate starvation and embryo development in Arabidopsis. *Plant Physiology*, 165, 92–104.
- Lamers, L. P. M., Govers, L. L., Janssen, I. C. J. M., Geurts, J. J. M., van der Welle, M. E. W., van Katwijk, M. M., ... Smolders, A. J. P. (2013). Sulfide as a soil phytotoxin. *Frontiers in Plant Science*, 4, 1–14.
- Lamers, L. P. M., Tomassen, H. B. M., & Roelofs, J. G. M. (1998). Sulfate-induced eutrophication and phytotoxicity in freshwater wetlands. *Environmental Science & Technology*, 32, 199–205.
- Lee, P. F. (1986). Ecological relationships of wild rice, *Zizania aquatica*. 4. Environmental regions within a wild rice lake. *Canadian Journal of Botany*, 64, 2037–2044.
- Lee, P. F. (2002). Ecological relationships of wild rice, *Zizania* spp. 10. Effects of sediment and among-population variations on plant density in *Zizania palustris*. *Canadian Journal of Botany*, 80, 1283–1294.
- Li, S., Mendelssohn, I. A., Chen, H., & Orem, W. H. (2009). Does sulphate enrichment promote the expansion of *Typha domingensis* (cattail) in the Florida Everglades? *Freshwater Biology*, 54, 1909–1923.
- Maynard, J. J., Dahlgren, R. A., & O'Geen, A. T. (2011). Sulfide induced mobilization of wetland phosphorus depends strongly on redox and iron geochemistry. *Soil Science Society of America Journal*, 75, 1986–1999.
- Moyle, J. B. (1944). Wild rice in Minnesota. *Journal of Wildlife Management*, 8(3), 177–184.
- Moyle, J. B. (1945). Some chemical factors influencing the distribution of aquatic plants in Minnesota. *The American Midland Naturalist*, 34, 402–420.
- Moyle, J. B. (1956). Relationships between the chemistry of Minnesota surface waters and wildlife management. *Journal of Wildlife Management*, 20(3), 303–320.
- Moyle, J. B., & Krueger, P. (1964). Wild rice in Minnesota. The Conservation Volunteer, Nov.-Dec., 30–37.
- MPCA (2011). The sulfate standard to protect wild rice: Study protocol. WQ-S6-42a. Minnesota Pollution Control Agency. Retrieved from <https://www.pca.state.mn.us/sites/default/files/wq-s6-42a.pdf> (accessed July 10, 2016).
- MPCA (2014). Analysis of the Wild Rice Sulfate Standard Study: Draft for scientific peer review, Minnesota Pollution Control Agency. Retrieved from <https://www.pca.state.mn.us/sites/default/files/wq-s6-42z.pdf> (accessed July 22, 2016).
- MPCA (2016). National Lakes Assessment 2012: Water chemistry, lake morphometry, and watershed characteristics of Minnesota's 2012 NLA lakes, Minnesota Pollution Control Agency. Retrieved from <https://www.pca.state.mn.us/sites/default/files/wq-nlap1-14.pdf> (accessed Nov 14, 2016).
- Myrbo, A., Swain, E. B., Johnson, N., Pastor, J., Dewey, B., Engstrom, D. R., ... Peters, E. B. (2017). Increase in nutrients, mercury, and methylmercury as a consequence of elevated sulfate reduction to sulfide in experimental wetland mesocosms. *Journal of Geophysical Research: Biogeosciences*, 122. <https://doi.org/10.1002/2017JG003788>
- Neue, H. U., & Bloom, P. R. (1989). Nutrient kinetics and availability in flooded rice soils. In *Progress in Irrigated Rice Research* (pp. 173–190). Manila, International Rice Research Institute.
- Neue, H. U., & Lantin, R. S. (1994). Micronutrient toxicities and deficiencies in rice. In A. R. Yeo & T. J. Flowers (Eds.), *Soil Mineral Stresses: Approaches to Crop Improvement* (pp. 175–200). Berlin: Springer.
- Nguyen, M. N., Dultz, S., Picardal, F., Bui, A. T. K., Pham, Q. V., & Schieber, J. (2015). Release of potassium accompanying the dissolution of rice straw phytolith. *Chemosphere*, 119, 371–376.
- Oelke, E. A., T. M. Teynor, P. R. Carter, J. A. Percich, D. M. Noetzel, P. R. Bloom, R. A. Porter, C. E. Schertz, J. J. Boedecker, and E. I. Fuller (1997). Wild rice. Alternative field crops manual. Retrieved from <http://corn.agronomy.wisc.edu/Crops/WildRice.aspx> (Accessed 23 Nov 2016).
- Pastor, J., Dewey, B., Johnson, N. W., Swain, E. B., Monson, P., Peters, E. B., & Myrbo, A. (2017). Effects of sulfate and sulfide on the life cycle of *Zizania palustris* in hydroponic and mesocosm experiments. *Ecological Applications*, 27, 321–336.
- Pearsall, W. W. (1950). The investigations of wet soils and its agricultural implications. *Empire Journal of Experimental Agriculture*, 18, 289–298.
- Peeters, E. T. H. M., & Gardeniers, J. J. P. (1998). Logistic regression as a tool for defining habitat requirements of two common gammarids. *Freshwater Biology*, 39, 605–615.
- Pester, M., Knorr, K.-H., Friedrich, M. W., Wagner, M., & Loy, A. (2012). Sulfate-reducing microorganisms in wetlands—Fameless actors in carbon cycling and climate change. *Frontiers in Microbiology*, 3, 1–19.
- Pezeshki, S. R., & DeLaune, R. D. (2012). Soil oxidation-reduction in wetlands and its impact on plant functioning. *Biology*, 1, 196–221.
- Pillsbury, R. W., & McGuire, M. A. (2009). Factors affecting the distribution of wild rice (*Zizania palustris*) and the associated macrophyte community. *Wetlands*, 29(2), 724–734.
- Pollman, C. D., Swain, E. B., Bael, D., Myrbo, A., Monson, P., & Dykhuizen Shore, M. (2017). The evolution of sulfide in shallow aquatic ecosystem sediments—An analysis of the roles of sulfate, organic carbon, iron and feedback constraints using structural equation modeling. *Journal of Geophysical Research: Biogeosciences*, 122. <https://doi.org/10.1002/2017JG003785>
- Ponnamperuma, F. N. (1972). The chemistry of submerged soils. *Advances in Agronomy*, 24, 29–88.
- Roelofs, J. G. M. (1991). Inlet of alkaline river water into peaty lowlands: Effects on water quality and *Stratiotes aloides* L. stands. *Aquatic Botany*, 39, 267–293.
- Scheffer, M. (1998). *Ecology of Shallow Lakes*. London: Chapman & Hall.
- Schindler, D. W. (1986). The significance of in-lake production of alkalinity. *Water, Air, and Soil Pollution*, 30, 931–944.
- Schoonen, M. A. A. (2004). Mechanisms of sedimentary pyrite formation. In J. P. Amend, K. J. Edwards, & T. W. Lyons (Eds.), *Sulfur Biogeochemistry—Past and Present, Geological Society of America Special Paper* (Vol. 279, pp. 117–134).
- Shotbolt, L. (2010). Pore water sampling from lake and estuary sediments using Rhizon samplers. *Journal of Paleolimnology*, 44(2), 695–700.
- Simkin, S. M., Bedford, B. L., & Weathers, K. C. (2013). Phytotoxic sulfide more important than nutrients for plants within a groundwater-fed wetland. *Ecosystems*, 16, 1118–1129.
- Smolders, A., & Roelofs, J. G. M. (1993). Sulphate-mediated iron limitation and eutrophication in aquatic ecosystems. *Aquatic Botany*, 46, 247–253.
- Søndergaard, M., Jensen, J. P., & Jeppesen, E. (2003). Role of sediment and internal loading of phosphorus in shallow lakes. *Hydrobiologia*, 506(509), 135–145.
- Struyf, E., & Conley, D. J. (2009). Silica: an essential nutrient in wetland biogeochemistry. *Frontiers in Ecology and the Environment*, 7, 88–94.
- Terrell, E. E., Peterson, P. M., Reveal, J. I., & Duvall, M. R. (1997). Taxonomy of North American species of *Zizania* (Poaceae). *Sida*, 17(3), 533–549.
- Troeh, F. R., & Thompson, L. M. (2005). *Soils and Soil Fertility* (6th ed.). Ames, Iowa: Blackwell Publishing.

- Urban, N. R., Brezonik, P. L., Baker, L. A., & Sherman, L. A. (1994). Sulfate reduction and diffusion in sediments of Little Rock Lake, Wisconsin. *Limnology and Oceanography*, 39(4), 791–815.
- van der Heide, T., Peeters, E. T. H. M., Hermus, D. C. R., van Katwijk, M. M., Roelofs, J. G. M., & Smolders, A. J. P. (2009). Predicting habitat suitability in temperate seagrass ecosystems. *Limnology and Oceanography*, 54(6), 2018–2024.
- van der Welle, M. E. W., Cuppens, M., Lamers, L. P. M., & Roelofs, J. G. M. (2006). Detoxifying toxicants: Interactions between sulfide and iron toxicity in freshwater wetlands. *Environmental Toxicology and Chemistry*, 25(6), 1592–1597.
- Vennum, T. (1988). *Wild Rice and the Ojibway People* (pp. 368). St. Paul: Minnesota Historical Society Press.
- Vestergaard, O., & Sand-Jensen, K. (2000). Alkalinity and trophic state regulate aquatic plant distribution in Danish lakes. *Aquatic Botany*, 67, 85–107.
- Walker, R. E. D., Pastor, J., & Dewey, B. W. (2010). Litter quantity and nitrogen immobilization cause oscillations in productivity of wild rice (*Zizania palustris* L.) in northern Minnesota. *Ecosystems*, 13, 485–498.
- Wang, F. Y., & Chapman, P. M. (1999). Biological implications of sulfide in sediment—A review focusing on sediment toxicity. *Environmental Toxicology and Chemistry*, 18(11), 2526–2532.
- Weston, N. B., Porubsky, W. P., Samarkin, V. A., Erickson, M., Macavoy, S. E., & Joye, S. B. (2006). Porewater stoichiometry of terminal metabolic products, sulfate, and dissolved organic carbon and nitrogen in estuarine intertidal creek-bank sediments. *Biogeochemistry*, 77, 375–408.
- Weston, N. B., Vile, M. A., Neubauer, S. C., & Velinsky, D. J. (2011). Accelerated microbial organic matter mineralization following salt-water intrusion into tidal freshwater marsh soils. *Biogeochemistry*, 102, 135–151.