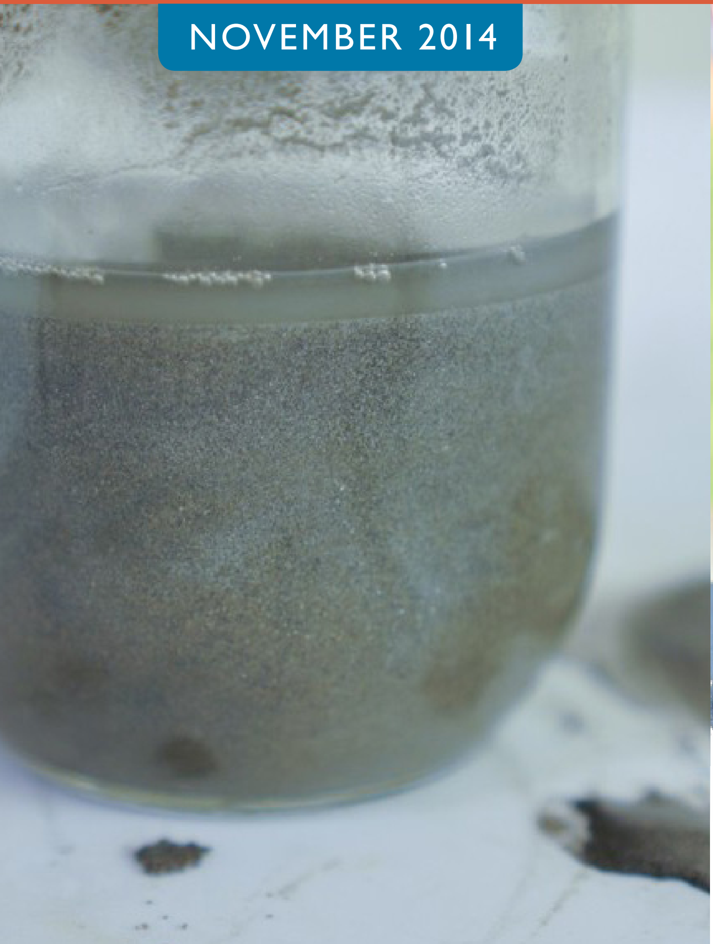
DON'T DRINK THE WATER

GROUNDWATER CONTAMINATION AND THE **"BENEFICIAL REUSE"** OF COAL ASH IN SOUTHEAST WISCONSIN

NOVEMBER 2014



cleanwisconsin

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FRONT COVER PHOTOS

top: A bluff collapse near the Oak Creek Power Plant in Wisconsin that sent coal ash and debris into Lake Michigan. Photo credit: MARK HOFFMAN/Milwaukee Journal Sentinel

bottom left: Coal ash contaminated sludge from North Carolina's Dan River. Photo courtesy of the Waterkeeper Alliance.

bottom right: Girl drinking water from a fountain. Photo credit–dhammonds

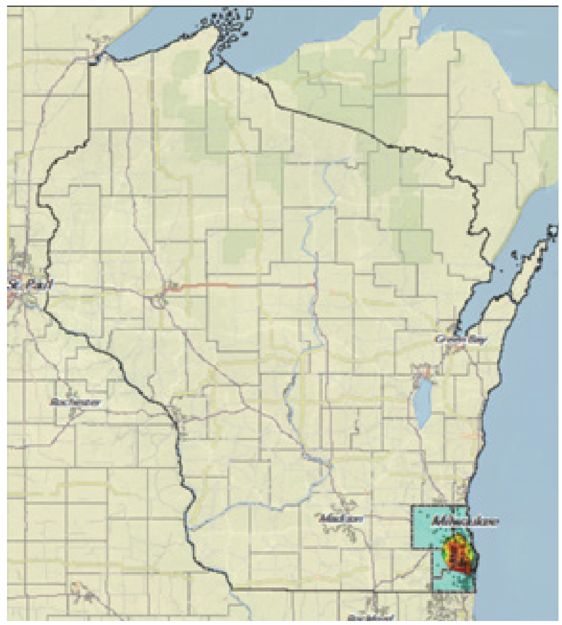
Executive Summary

Hundreds of children at the Yorkville Elementary School in rural southeastern Wisconsin cannot drink the water at their school because it is contaminated. Homeowners in the four surrounding counties have had to drink bottled water or install expensive water filters to protect their families. Their wells, and much of the groundwater in the area, contain unsafe levels of molybdenum, a metal found in coal ash.

With the discovery of those harmful chemicals in the drinking water, at schools and in scores of Wisconsin homes, Clean Wisconsin decided to look further. In addition to widespread water contamination, our investigation revealed that southeast Wisconsin is blanketed with at least 1 million tons of coal combustion waste (coal ash), and probably much more. We also found that homes nearer to those coal ash reuse sites have significantly higher levels of molybdenum in their drinking water on average than homes farther from coal ash sites.

This report describes Clean Wisconsin's research on the groundwater contamination in Waukesha, Milwaukee, Racine and Kenosha counties, the widespread disposal of coal ash in the area, and the potential connection between them. We make recommendations for changes in state and federal regulation of coal ash to prevent drinking water contamination in the future, and for actions that need to be taken to protect children and families in southeastern Wisconsin.

Coal ash contains toxic materials like arsenic, boron, lead, mercury, molybdenum, and hexavalent chromium. These toxic chemicals can leach out of the ash into water, polluting our drinking water supplies. Yet the Wisconsin Department of Natural Resources (DNR) allows the utilities that generate millions of tons of this waste each year to market large volumes for use in a wide variety of projects—from spreading the waste on fields and recreational trails to structural fill under roadways and schools.[1]

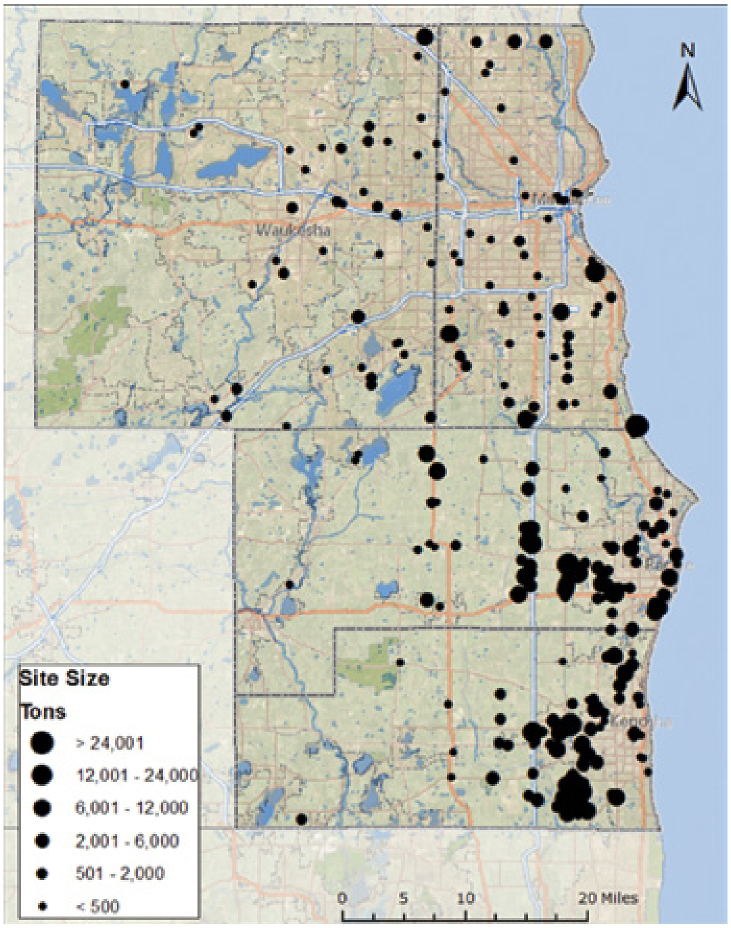


MAP OF STUDY AREA: Waukesha, Milwaukee, Racine, and Kenosha counties.

One in every five wells tested in the area exceeded Wisconsin's "health advisory level" of 90 parts per billion of molybdenum.

Wisconsin's regulation of coal ash disposal and that "reuse" is often held up as an example of how the toxic material can be safely managed. However, despite the potential of those projects to put families in harm's way, the DNR does not require the utilities to disclose how and where much of the coal ash is being used. Not only does that mean Wisconsin's regulations are leaving the public in the dark, this study calls into question whether the drinking water and health of Wisconsin citizens are being adequately protected.

This report focuses on the extensive "beneficial use" of coal ash in unencapsulated applications (where ash is not bound up in a product, but left loose with the potential to contaminate water). Based on extensive groundwater monitoring data collected by the DNR, we found a disturbing correlation between where coal ash is dumped and contaminated drinking water wells in southeastern Wisconsin. We discovered that the closer drinking water wells were to large



COAL ASH IN STUDY AREA: Map of 399 documented "reuse" project sites, totaling over 1 million tons, in Waukesha, Milwaukee, Racine, and Kenosha counties.

coal ash "reuse" sites, the higher the levels of molybdenum contamination in those wells was likely to be.

The significance of those trends suggests that coal ash is likely to be at least contributing to groundwater contamination in southeast Wisconsin. Indeed, the fact that concentrations are much higher than typical groundwater levels and the lack of evidence pointing to any other anthropogenic (man-made) or natural source in the region, suggests that coal ash is the most likely source of the molybdenum contamination. Furthermore, this is not likely to be the only area where such problems exist; it is likely that there is much more coal ash spread throughout southeast Wisconsin than the 1 million tons we found records for, and reuse practices are not likely confined to just that part of the state.

The data also clearly show the severity of the drinking water contamination: the average molybdenum level value from almost 1,000 wells sampled in the region is nearly 50 ppb of molybdenum—much higher than natural levels and above the DNR Enforcement Standard of 40 parts per billion (ppb). Furthermore, one in every five wells exceeded Wisconsin's new "health advisory level" of 90 ppb, set by the Wisconsin Department of Health Services (DHS). Above that level,

> *"DHS recommends that you not use your water for drinking or in foods where water is a main ingredient, (like soup, coffee, tea, Jell-O, etc.) and that you find a different source of safe water to drink."*[2]

New sampling done by Clean Wisconsin as part of this study also confirms the water contamination in Yorkville Elementary School, where coal ash was used in a construction project. The same contamination extends into the surrounding neighborhood: all wells sampled nearby had molybdenum concentrations above the state enforcement standard, and all boron levels and over 90% of arsenic levels (pollutants commonly associated with coal ash) were above the state preventive action limits.

The toxic chemicals in coal ash waste can pose a significant threat to human health. Despite this, in Wisconsin coal ash is spread near our favorite parks and trails, under the buildings we visit and the schools where we send our children, and on the roads we travel. Often we don't even know it's there, and because of this and the lack of protective state regulations, we cannot protect ourselves and our families.

This report highlights the imminent need to:

- Conduct systematic testing of groundwater in areas where coal ash has been placed in the ground, including throughout Kenosha, Milwaukee, Racine, and Waukesha counties.
- Investigate historical coal ash use and dumping, make all records publicly available, and identify potentially dangerous placement.
- Establish complete reporting requirements for uses of coal ash.
- Require coal ash to be tested for all chemicals with the potential to contaminate drinking water supplies.

- Establish groundwater monitoring requirements for uses of coal ash.
- Conduct research and testing to determine the role of coal ash in groundwater contamination.
- Stop spreading coal ash into the environment until better safeguards to prevent groundwater contamination are in place.
- Require liners, leachate collection systems, caps, and additional groundwater monitoring for large structural fills, as well as place limitations on where structural fill can be used.
- Require a more accurate leach test to assess the toxicity of coal ash.
- Regulate hazardous coal ash as a hazardous waste.

Wisconsin has the highest "beneficial reuse" rate of coal ash in the nation. Congress, in fact, has looked to Wisconsin as the "gold standard" of coal ash regulatory programs. Yet we have found that coal ash reuse is not always beneficial. It may, in fact, be threatening public health and the environment in our state. Wisconsin must immediately address the threat posed to citizens near coal ash reuse sites. And because every citizen deserves safe drinking water, the U.S. EPA must establish strong federal rules controlling coal ash disposal and reuse, applicable in every state, to protect the health of all Americans.

HARMFUL LEVELS OF MOLYBDENUM IN 45 PERCENT OF PRIVATE WELLS TESTED IN SOUTHEAST WISCONSIN

(Data from 967 unique wells, 2010–2014)

	PERCENTAGE OF WELLS	
Very High Levels of Molybdenum (>90 *ppb; Above Wisconsin Health Advisory Level*)	22%	**45%**
High Levels of Molybdenum (40-90 *ppb; Above DNR Enforcement Standard*)	23%	
Moderate Levels of Molybdenum (20-40 *ppb; Below DNR Enforcement Standard*)	15%	**32%**
Low Levels of Molybdenum (10-20 *ppb; Slightly Elevated Concentrations*)	17%	
Natural Background Range (0-10 *ppb*)	16%	**23%**
No Molybdenum Detected (0 *ppb*)	7%	

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Background

What Is Coal Ash and Where Does it Come From?

Each year, utility companies in the United States burn nearly one billion tons of coal. This coal burning produces exhaust, wastewater, and about 130 million tons of leftover solid waste known as "coal ash."[3]

That "coal ash" waste takes four general forms: fly ash, bottom ash, boiler slag, and flue gas desulfurization ("FGD") sludge, which each come from a slightly different place in a coal burning furnace. It is made up of the materials in the original coal that do not burn. As a result, it has concentrated levels of many contaminants, like heavy metals, that occur naturally in the coal.[4] This means that coal ash can contain high levels of hazardous materials like arsenic, chromium, lead, mercury, and molybdenum.

Those concentrated levels of hazardous materials can then leach out of the coal ash into the environment. This is especially true when coal ash used in unencapsulated applications (where the ash is not bound up in a product) comes into contact with water, where it can release the contaminants in dangerous quantities.

Water Pollution and the Failure to Regulate the Disposal of Coal Ash

Largely unregulated by the U.S. Environmental Protection Agency (EPA) for decades, coal ash contains toxic chemicals that can harm health and the environment. For most types of waste, that potential for harm would require careful treatment under the Resource Conservation and Recovery Act (RCRA)—the federal law that governs waste disposal. However, lobbying by the coal and electric utility industries resulted in a loophole excluding coal ash from any specific federal requirements.[6]

Consequently, each state has been free to regulate coal ash as it sees fit. Some states have absolutely no regulations, while others like Wisconsin have established coal ash regulatory programs. This has led to an inconsistent patchwork system of controls that have failed to protect Americans nationwide from pollution.

In fact, toxic coal ash has contaminated water at more than 200 sites[7] in 37 states, including at 13 sites in Wisconsin.[8] This underestimates the actual damage though, because most coal ash dumps are not monitored—meaning coal ash pollution goes largely undetected.

The lack of federal safety standards has also led to three huge spills in the last six years. This includes the largest toxic waste spill in the nation's history at the TVA Kingston Plant in Tennessee in 2008, where 5.4 million cubic yards (more than 1 billion gallons) of toxic waste covered 300 acres of river and shore,[9] the We Energies Oak Creek landslide in 2011 where 25,000 tons of ash collapsed from a bluff on the shore of Lake Michigan;[10] and the Duke Energy Dan River coal ash spill in February 2014, where 140,000 tons of coal ash and wastewater fouled 70 miles of the Dan River in North Carolina.[11]

Unfortunately, the lack of specific limitations or safeguards on coal ash disposal also means that much of it is discarded in ways that are even less controlled than dumping it in landfills. Often termed "coal ash reuse," these types of disposal have been increasing in recent years—to the point where they account for tens of millions of tons of coal ash disposed of each year. In 2012 for example, over 26 million tons of coal ash was used in "unencapsulated" ways (where the ash is not bound up or contained in a product)[12] that have not been evaluated and endorsed by the EPA.[13]

Reuse dumping of coal ash can range from disposal under buildings, roadways, or highway

TABLE 1. TYPES OF COAL ASH WASTE

NAME	ORIGIN
Fly Ash	Fine particles small and light enough to rise with the exhaust gases
Bottom Ash	Leftover materials that collect either at the bottom or on the sides of the furnace
Boiler Slag	Specific type of bottom ash, created in "wet-bottom" boilers, when molten bottom ash is removed and quenched with water to form a crystalline material
FGD Sludge	From a type of control ("scrubbers") used to remove sulfur dioxide from the exhaust gases. Sulfur dioxide gas in the exhaust is combined with chemical reagents to form a solid material that falls down to the bottom of the scrubber.

TABLE 2. TOXIC ELEMENTS IN COAL ASH AND POTENTIAL HEALTH IMPACTS.[5]

HAZARDOUS SUBSTANCE	NEGATIVE HEALTH IMPACTS
Arsenic	Cancer of the bladder, kidneys, liver, lungs, prostate, and skin
Boron	Harm to male reproductive organs, birth defects
Cadmium	Kidney damage
Chromium	Hexavalent chromium can cause stomach ulcers, convulsions, kidney and liver damage, and cancer
Lead	Nervous system, brain and kidney damage; miscarriage.
Mercury	Nervous system damage; developmental and cognitive deficits in children
Molybdenum	Gout-like pain and inflammation of the joints; reproduction and developmental impacts (degenerative changes in brain and nervous system, fetal mortality shown in animal studies)
Selenium	Nausea, vomiting, diarrhea, neurological problems

berms, to spreading it on roadways, paths, fields, and even in parks. In addition to doing nothing to prevent toxic materials from leaching into groundwater, lack of regulation on those projects means that there is little information available to the homeowners whose faucets may be affected. It also means that very little research has been done on what cumulative impacts decades of that dumping may be having on our water resources.

A lawsuit, brought by Earthjustice in 2012, requires EPA to finalize national coal ash regulations in December 2014.[14] It remains to be seen whether EPA's first-ever coal ash rule will be sufficient to prevent further contamination of air and water.

The Wisconsin Story

In a typical year, Wisconsin's large coal plants (those 100 megawatts and larger) alone generate nearly 1.8 million tons of coal ash.[16] That coal ash is considered an "industrial byproduct" under state regulations, which allow utilities to handle the waste in a variety of ways including: disposing of it in landfills, storing it onsite, and selling or giving it away for "reuse" projects[1] (for more information on Wisconsin's "beneficial use" regulations, Wis. Admin. ch. NR 538., see Appendix F.)

When "beneficially used," Wisconsin state law exempts the generation, use, transportation, or storage of coal ash from waste disposal standards. As a result, while only about half of all coal ash goes to "reuse" projects nationwide, around 85% of all coal ash is typically "reused" in Wisconsin.[17] This makes Wisconsin's reuse rate the highest in the nation.

At first glance, this coal ash reuse would appear to be a win-win situation. All landfills can leak harmful chemicals, and Wisconsin has documented more sites than any other state where the EPA confirms that coal ash has adversely impacted groundwater.[8] Reuse projects simultaneously keep coal ash out of those landfills, while saving utilities money in disposal expenses.[16]

All the coal ash kept out of landfills doesn't disappear, however. And despite having been held up as the "gold standard" of coal ash programs,[18] Wisconsin's regulation of coal ash reuse is failing to protect drinking water.

For example, Wisconsin has no requirements for coal-burning utilities to disclose where and how they beneficially reuse much of their waste. That lack of reporting requirements means that there is little information available on potentially dangerous reuse practices in the state, and leaves families in the dark about coal ash dumping in their neighborhoods.

It is clear, however, that utilities have been dumping coal ash into the environment in Wisconsin for decades, and that some of this reuse has been done unsafely. For example, when a highway bridge in Green Bay nearly collapsed, it was determined that coal ash in the ground had corroded the bridge's footings.[19] Similarly, a bluff in Oak Creek that collapsed into Lake Michigan in October 2011 resulted in 25,000 tons of coal ash fouling the lakeshore. That bluff, next to the Oak Creek Power Plant, was found to be made of coal ash that, according to We Energies, "was used to fill the ravine area in that site during the 1950s."[20]

Photograph of bridge footing corrosion resulting from fly ash. *Wisconsin Dept of Trans I-43 Leo Frigo Memorial Bridge Investigation Report ID 1220-15-01. August 27, 2014.*

Photograph of Oak Creek coal ash bluff collapse. *Mark Hoffman/Milwaukee Journal Sentinel.*

FAULTY COAL ASH CLASSIFICATION

In Wisconsin, coal ash is classified into one of five different categories, based on the testing results on a sample of the waste. However, the leach test required by the WI regulations does not reliably determine the level of chemicals that will leach from coal ash in a real-world environment. In fact, both the US EPA's Science Advisory Board and the National Research Council reject the use of the test, stating that it will not reliably characterize the leaching potential of coal ashes.[15]

Yet the results of this scientifically unreliable test determine what the coal ash can be used for in Wisconsin, ranging from a "category 1" waste, which can be used for almost any application, to a "category 5" waste that can only be used in certain ways.[1]

Additionally, Wisconsin only requires coal ash to be tested for leaching of at most 14 chemicals for any "beneficial use" listed under NR 538. Notably absent from those requirements is testing coal ash for molybdenum leaching. There is also no testing required of arsenic, lead, mercury, or molybdenum, for category 4 coal ash uses including covered structural fill—and therefore no limit to the amount of leaching allowed under roads, or non-residential parking lots or buildings like schools and churches.

Because the WI leach test may grossly underestimate the level of toxic chemicals like arsenic and molybdenum that can leach from the ash, the system of characterization is fatally flawed.

What is Molybdenum?

Molybdenum (muh-LIB-duh-num) is a potentially toxic metallic element found in the Earth's crust. While it is an essential nutrient at very low levels, a typical American diet provides around 100 micrograms per day through food alone,[2] well more than the recommended dietary allowance of 45 micrograms for adults (only 2 micrograms for infants).[21]

Too much molybdenum has been shown to have toxic effects. In particular, it causes reproductive and developmental problems in animals, including fetal mortality and degenerative changes in the brain and nervous system.[22] At high levels, molybdenum can also cause gout-like disease in people "characterized by joint pains of the legs and hands, enlargement of the liver, disorders of the gastrointestinal tract, liver and kidney..."[23]

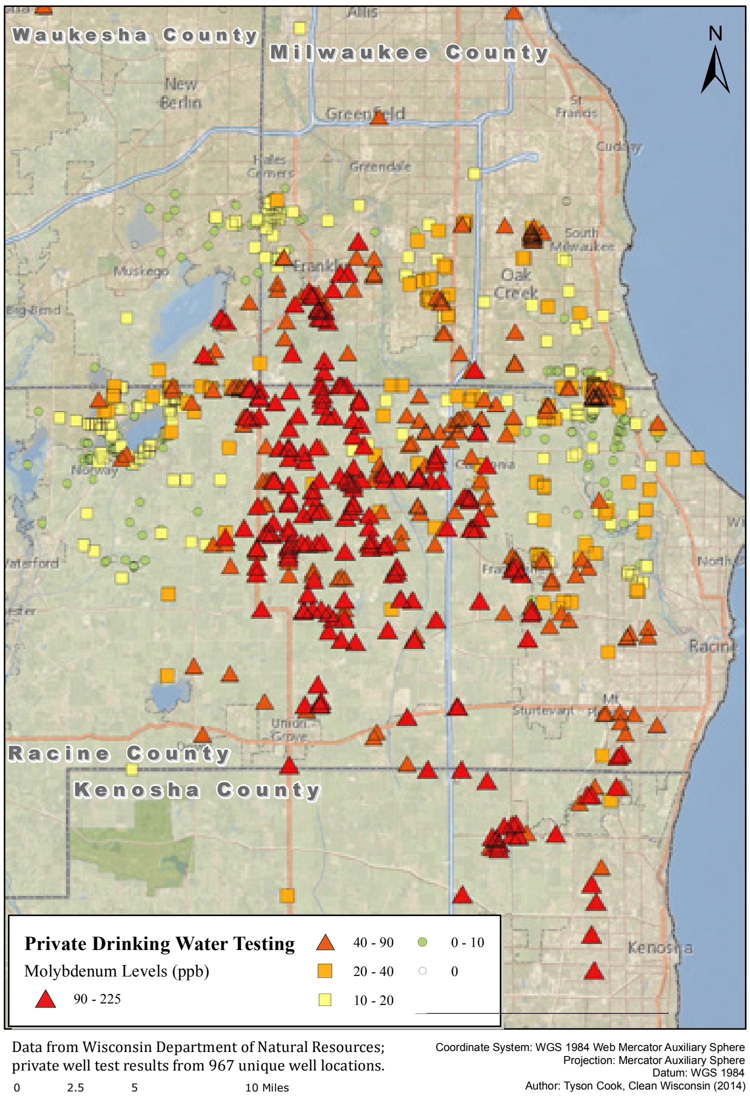
As a result, the EPA set a "lifetime Health Advisory" level for molybdenum in drinking water, indicating that adults should not consistently drink water with concentrations higher than 40 parts per billion (ppb).[24] Since kids are at even greater risk, the EPA also set a Health Advisory level for children indicating that they should avoid drinking water with more than 80 ppb of molybdenum for even a single day.

In Wisconsin, the DNR has an Enforcement Standard for drinking water at 40 ppb, and the Wisconsin DHS has a Health Advisory Level at 90 ppb. Above that level, the DHS recommends that, "you not use your water for drinking or in foods where water is a main ingredient (like soup, coffee, tea, Jell-O, etc.), and that you find a different source of safe water to drink."[2]

Fortunately, molybdenum is relatively uncommon in surface and groundwater, with naturally occurring levels below 20 parts per billion.[2] Where it is elevated however, molybdenum removal requires advanced water treatment processes like distillers or reverse-osmosis systems, which can be expensive, inefficient, and aren't commonly used by homeowners.

Clean Wisconsin's Research

FIGURE 1. MAP OF MOLYBDENUM CONCENTRATIONS IN DRINKING WATER IN SOUTHEAST WISCONSIN. (Private well test results from 967 unique well locations.)



Drinking Water Contamination in Southeastern Wisconsin

Over the past five years, it has become clear that there is a significant drinking water contamination in southeastern Wisconsin. Reports out of the Caledonia area, for example, have pointed to a number of private wells over the DNR Enforcement Standard for molybdenum (see "Contamination in Caledonia," below).

In order to protect families in the area, the Wisconsin Department of Health Services (DHS) offered free well testing to residents in the area starting in 2010, and later suggested that residents throughout the region have their water tested. While this testing provided data that allowed us to conduct this study, the full extent of the groundwater contamination problem in the region and the rest of the state is still not known.

To assess the range of the contamination, we gathered testing data from nearly 1,000 private drinking water wells in southeast Wisconsin. By mapping that data, we found that the contamination is not isolated to the small zone around Caledonia studied by the DNR.[26] Instead, while there were some areas with consistently safer water, the contamination spans across southeastern Wisconsin, including parts of Racine, Waukesha, Kenosha and Milwaukee Counties (Figure 1).

The currently available data also point to the severity of the drinking water contamination in the region; the average value from all wells sampled is nearly 50 ppb of molybdenum (much higher than typical natural levels below 10 ppb, and above the DNR Enforcement Standard of 40 ppb). One in every five wells exceeded the new "health advisory level" of 90 ppb (Table 3).

While these data clearly show widespread and significant groundwater contamination in the region, we still don't know the full extent of the problem. The wells for which there was molybdenum data come solely from private homeowners who choose to have their water tested. As a result, there are geographically clustered well samples, as well as large unsampled areas. There were also areas outside of the study region (where molybdenum data were available) where spatial trends indicate the potential for signifi-

DOUBLE STANDARD

There are currently two standards in place in Wisconsin for molybdenum levels: an "Enforcement Standard" and a "Health Advisory Level."

The groundwater quality Enforcement Standard (ES) of 40 parts per billion (ppb) is a legally enforceable limit set by the Wisconsin Department of Natural Resource (DNR). It is designed to protect public health and welfare in the state and matches the EPA "lifetime Health Advisory" level for molybdenum in drinking water.[24] Until 2013, it was the only standard in place.

The Wisconsin Health Advisory Level (HAL) of 90 ppb molybdenum was created in 2013, and is the level used for individual drinking water advisories. It was established when the DNR, two months after publishing their study of groundwater contamination in the Caledonia area, asked the state Department of Health Services (DHS) to review the molybdenum Enforcement Standard. When that review did not reveal any new information that hadn't already been considered by the EPA in setting their health advisory level, the DHS had no reason to change the Enforcement Standard, so it was left unchanged. Instead, the new, Wisconsin-specific HAL for molybdenum was set.[25]

In addition to being more than double the federal advisory level and WI Enforcement Standard, the new 90 ppb level used for Wisconsin health advisories allows more molybdenum in drinking water than the EPA recommends children be exposed to for even a single day (80 ppb).[24] While not all states have a molybdenum standard, Vermont, Maine and New Jersey use the EPA standard of 40 ppb as a health-based guideline. The World Health Organization in 2011 recommended a health-based level of 70 ppb.[23]

cant contamination—particularly southward into Kenosha County. Systematic sampling and testing throughout the region and state, including analysis of well construction information that was not available for this study, would provide further information on where drinking water contaminant concentrations may exceed the state water and health standards.

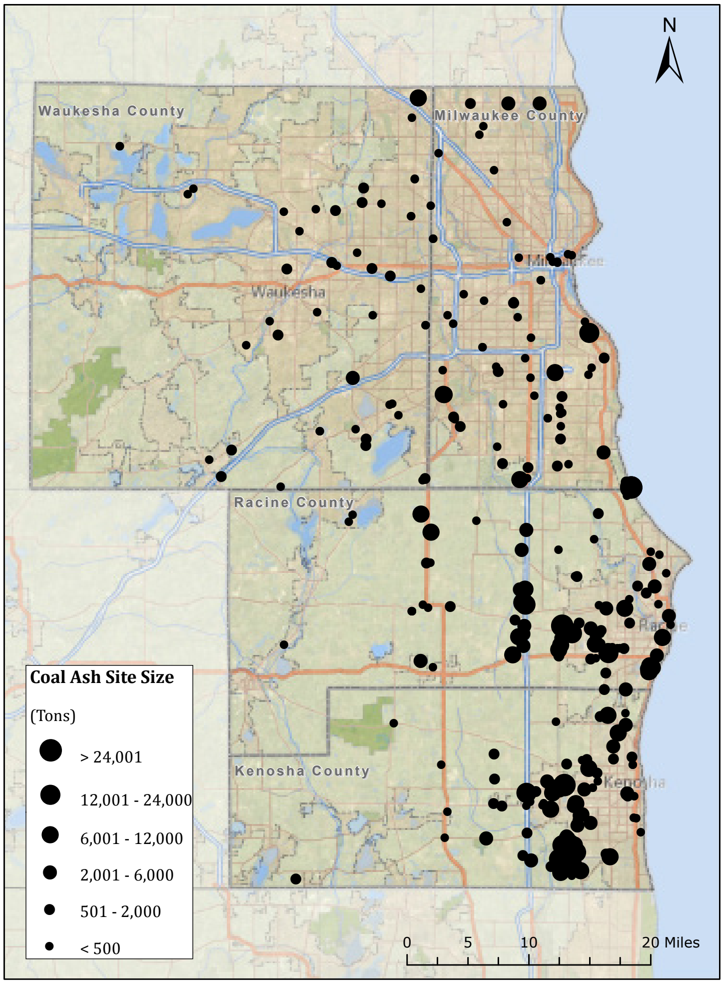
TABLE 3. SUMMARY OF HIGH MOLYBDENUM TEST RESULTS FROM 967 UNIQUE WELL LOCATIONS IN SE WISCONSIN.

	PERCENTAGE OF WELLS	
Very High Levels of Molybdenum *(>90 ppb; Above Wisconsin Health Advisory Level)*	22%	45%
High Levels of Molybdenum *(40-90 ppb; Above DNR Enforcement Standard)*	23%	
Moderate Levels of Molybdenum *(20-40 ppb; Below DNR Enforcement Standard)*	15%	32%
Low Levels of Molybdenum *(10-20 ppb; Slightly Elevated Concentrations)*	17%	
Natural Background Range *(0-10 ppb)*	16%	23%
No Molybdenum Detected *(0 ppb)*	7%	

Coal Ash Placement In Southeast Wisconsin

When the DNR conducted its investigation into the cause of water contamination in Caledonia, they focused on three coal ash landfills in the area, because they were deemed to be the most significant potential sources (see "Contamination in Caledonia," below). While the DNR was unable to find evidence definitively pointing to those landfills as the cause of contamination, the DNR did not examine the other coal ash disposed or "reused" in the region. Yet reports to the Energy Information Administration showed that over 800,000 tons of coal ash from Wisconsin coal plants operated by the local utility (We Energies) were "used offsite" in 2011 alone.[16]

The lack of reporting requirements means that complete information on where coal ash has



Data from We Energies, as reported to Wisconsin Department of Natural Resources. A total of 399 projects, using 1,065,364 tons of coal ash, were able to be geocoded to the region.

Years range 1988-2012; no records were found for the years 1990, 1991, 1993, 1995, or 1998.

Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
Projection: Mercator Auxiliary Sphere
Datum: WGS 1984
Author: Tyson Cook, Clean Wisconsin (2014)

FIGURE 2: COAL ASH IN STUDY AREA Map of 399 documented "reuse" project sites, totaling over 1 million tons, in Waukesha, Milwaukee, Racine, and Kenosha counties.

been placed is not available. Of the 833,000 tons of coal ash that We Energies reported as being used offsite in 2011, the records obtained from DNR contain documentation for only 26,000 tons for that year.

However, the information that we were able to access in public records reveals that coal ash placement is indeed widespread, and isn't limited to the Caledonia area. We found records from 1988 through 2012 of 1.6 million tons of We Energies' coal ash being "reused" in over 575 projects throughout the region (Table 4). These records are likely only a small subset of the total amount; coal ash has been spread in the area for over 50 years.[20]

TABLE 4. SUMMARY OF ALL AVAILABLE COAL ASH REUSE DATA AS REPORTED BY WE ENERGIES, 1988-2012.

YEAR	# PROJECTS	TOTAL TONS USED
1988	6	4,572
1989	5	10,400
1990	DATA MISSING	
1991	DATA MISSING	
1992	2	20,000
1993	DATA MISSING	
1994	32	4,696
1995	DATA MISSING	
1996	12	31,317
1997	26	92,562
1998	DATA MISSING	
1999	66	149,793
2000	28	73,192
2001	14	65,565
2002	31	142,124
2003	27	106,541
2004	52	68,821
2005	64	83,940
2006	59	195,855
2007	25	8,062
2008	48	104,959
2009	37	147,284
2010	24	208,243
2011	7	26,331
2012	13	72,769
TOTAL	**578**	**1,617,026**

No records were found for the years 1990, 1991, 1993, 1995, or 1998. A total of 399 projects, using 1,065,364 tons of coal ash, were able to be mapped in Kenosha, Milwaukee, Racine, and Waukesha counties.

Of those records we were able to find, we were able to locate 399 projects in southeast Wisconsin in Kenosha, Milwaukee, Racine, and

Waukesha counties. Those amounted to over one million tons of coal ash we were able to map (Figure 2).

Connection between Coal Ash Reuse and Drinking Water Contamination

Since there are limited natural sources of molybdenum,[27, 28] any high concentrations (i.e., greater than 20 ppb) are very likely to be the result of human activity.[29, 30] In southeastern Wisconsin in particular, research has shown that groundwater contamination with molybdenum is not likely to come from natural sources (see Appendix A for more information). In contrast, molybdenum is one of the signature elements of coal ash contamination, because burning coal concentrates and magnifies molybdenum levels in the ash.[4]

Based on this, we conducted an analysis to see if there was a relationship between the widespread "reuse" of coal ash in southeastern Wisconsin and the widespread molybdenum contamination in the area. The methods used for this analysis are discussed in detail in Appendix B, and in-depth results are presented in Appendix C.

We found a strong correlation between the widespread molybdenum contamination in southeastern Wisconsin and the "reuse" of coal ash in the region: the closer a well was to a large coal ash reuse site, the higher the molybdenum values were likely to be (Figure 3).

For example, for all the wells that were tested within 1 mile of where large amounts of coal ash (more than 500 tons) had been disposed of into the environment, the median level of molybdenum in drinking water wells was 47 ppb, and the average was 55 ppm—above the enforcement standard of 40 ppb. For wells more than 3 miles from large reuse sites, on the other hand, the median concentration was 10 ppb, with an average of 11.7 ppb.

Standard distance measurements aren't ideal for such analysis, however, because groundwater contamination does not flow uniformly in all directions. Instead, contaminants leach down through the ground and then generally follow the path of groundwater flow. To account for

FIGURE 3. TRENDS IN MOLYBDENUM CONCENTRATIONS MEASURED AT PRIVATE DRINKING WATER WELLS IN SE WISCONSIN, NEAR COAL ASH "REUSE" SITES LARGER THAN 500 TONS (BY LINEAR DISTANCE).

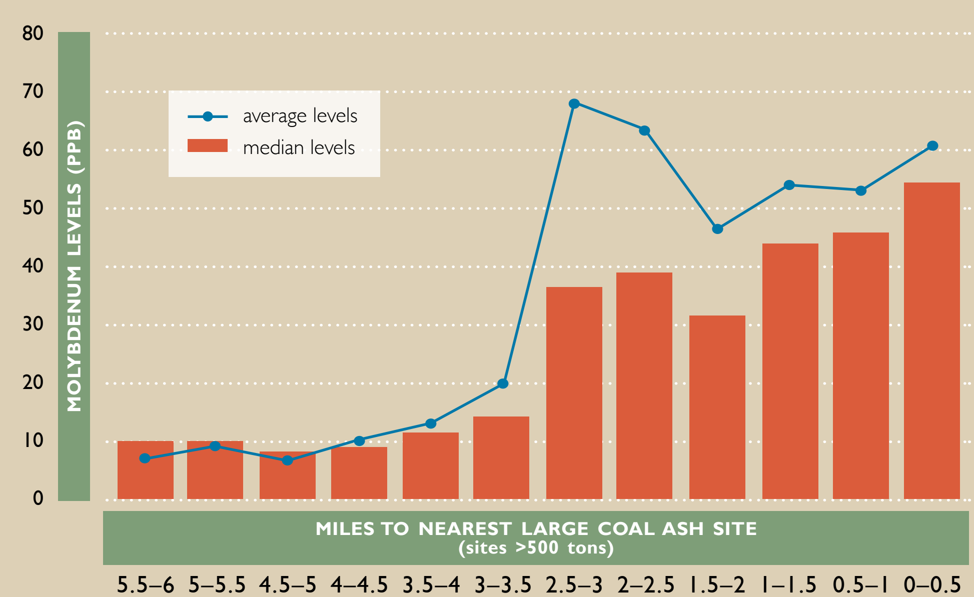
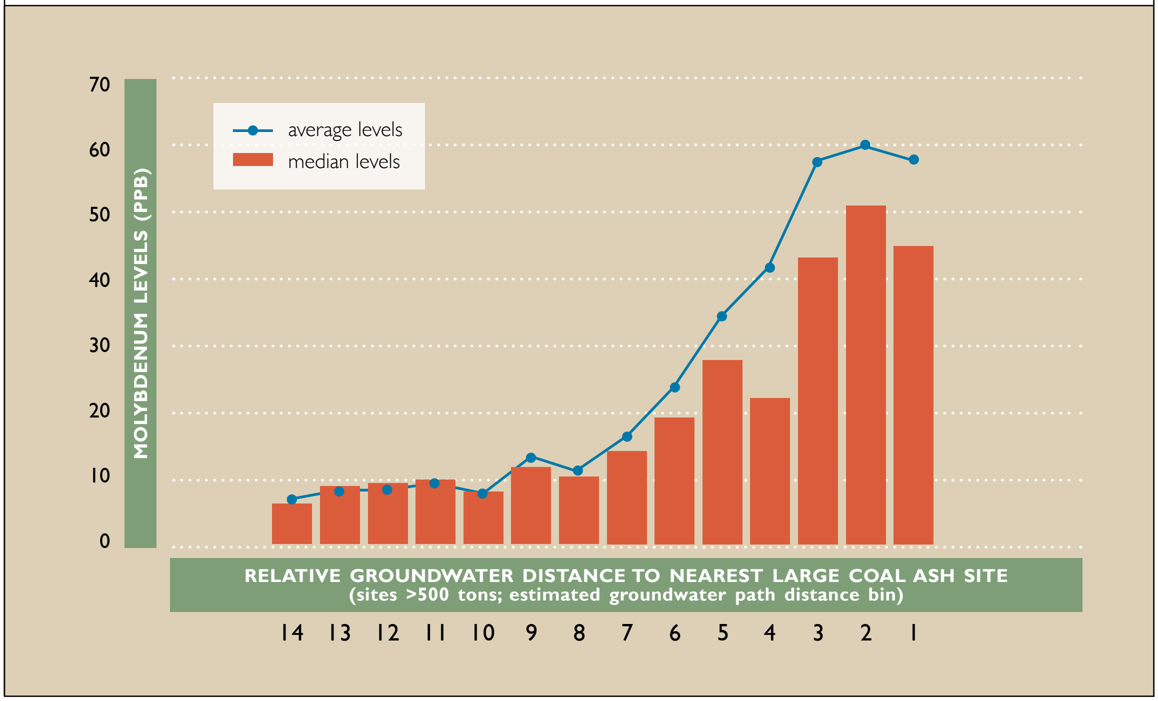


FIGURE 4. TRENDS IN MOLYBDENUM CONCENTRATIONS MEASURED AT PRIVATE DRINKING WATER WELLS IN SE WISCONSIN, NEAR COAL ASH "REUSE" SITES LARGER THAN 500 TONS (BY ESTIMATED GROUNDWATER PATH DISTANCE).



this, we conducted a similar analysis based on a model that accounts for general groundwater flow. Using this analysis, we found that the trend was even more striking: wells "downflow" of large coal reuse sites tended to have much higher levels of molybdenum (Figure 4).

It should be noted that due to a lack of detailed well information, we were forced to group together the test results from all wells, which could be drawing water from different sources of groundwater. However, in this area in particular, water moves freely between the primary sources of private drinking water (the sand and gravel aquifer and the Silurian dolomite aquifer).[31]

To rule out other manmade sources of molybdenum, we also looked at the other potential sources of facilities with permits for water discharge,[32] hazardous waste storage facilities, solid waste transfer facilities, closed and active landfills,[33] and EPA Superfund sites.[34] When taken together, these non-coal sources did not show trends consistent with being causes of contamination (with either standard or groundwater path distance analyses; for more information, see Appendix E).

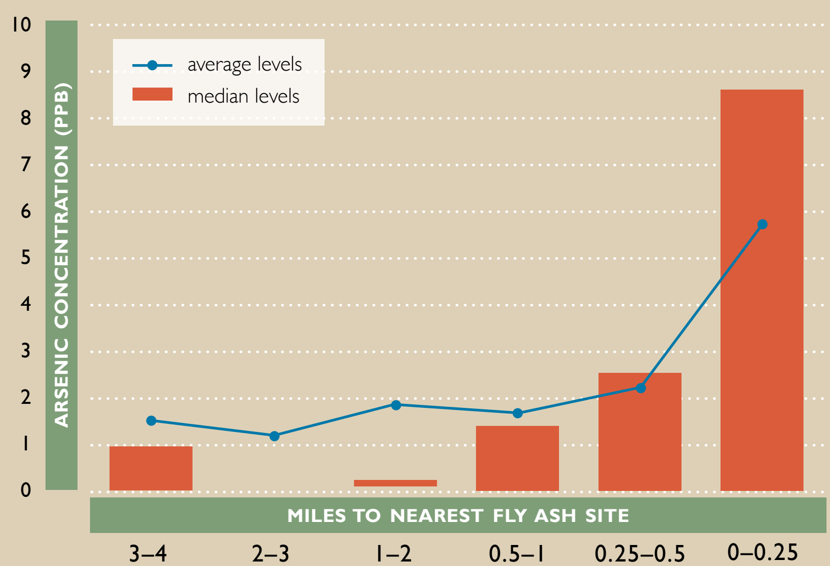
In addition to showing the overall correlations between coal ash reuse and groundwater contamination, our research clearly demonstrates the need for more information to be collected and made public. For example, there is a cluster of wells with high levels of molybdenum around Raymond, Wisconsin, with no identified potential source (it is this cluster that causes the secondary peaks in Figure 3 and Figure 4). It is very possible that the contamination in this area is the result of coal ash reuse sites for which we had no data due to the gaps in available information.

ARSENIC

Molybdenum is only one of many toxic pollutants that leach into water from coal ash. This report focuses on molybdenum, because the unique history of residential well sampling in southeastern Wisconsin provided more widespread data on molybdenum than are normally available for toxic groundwater contaminants. Molybdenum is not only an element of concern on its own though. Indeed, if molybdenum contamination is caused by industrial sources such as coal ash, it is likely to be accompanied by other toxic coal ash pollutants like arsenic.

To investigate whether the molybdenum contamination is indicative of even larger problems from coal ash leaching, we analyzed arsenic levels in the groundwater. Arsenic analysis is less straightforward than analysis of molybdenum for a number of reasons. However, despite the limitations, we found similar correlations: there was higher contamination near fly ash reuse sites. These correlations were statistically significant with both linear distance (Figure 5) and groundwater flow path from fly ash sites to nearby wells. This indicates that arsenic leaching and contamination from coal ash could also be a problem in the region. For more information on arsenic analyses, see Appendix D.

FIGURE 5. TRENDS IN ARSENIC CONCENTRATIONS MEASURED AT SHALLOW TO MODERATE GROUNDWATER WELLS (depths 25–250 feet) IN SE WISCONSIN, NEAR FLY ASH "REUSE" SITES (by linear distance).



How Molybdenum Contamination is Harming Wisconsin Communities

Yorkville Elementary School: The high cost of contamination

In early 2013, the DNR released information showing molybdenum contamination in southeast Wisconsin was more widespread than initially believed and extended at least to the Yorkville area of Racine County. When the Yorkville Elementary School had its well tested in 2013, the community learned that the school's drinking water was contaminated with extremely high molybdenum levels (up to 138 ppb, or over 70% higher than the one-day exposure level deemed safe for children by US EPA[24]). Since that time, the school district has been buying bottled water to protect their students and staff.[15]

Through our research, we found beneficial reuse records submitted to WDNR by We Energies showing that 856 tons of bottom ash was placed at the school site as part of a construction project in 2000. Based on this information and other records of high molybdenum levels nearby, we collected water samples from the school and 10 nearby homes to get more details on the groundwater contamination in the area.

This sampling, done between September 29 and October 21, 2014 confirmed the contamination of the local drinking water (Figure 6). We found that the school and all wells in the area had molybdenum above the state enforcement standard (Table 5). Additionally, all boron levels and and over 90% of arsenic levels were above the state preventive action limit. All three of these elements have been identified as indicators of coal ash contamination.[39]

In this testing, the lowest molybdenum levels were at the sites farthest away from Yorkville Elementary School. Similarly, when looking at the combined results of our testing and previous tests nearby (1.5 miles was chosen to reduce the potential for impacts from other nearby coal ash sites), there is a significant trend of higher levels of contamination closer to the school (Figure 7). Also in that area, there was an even stronger trend of higher molybdenum levels closer to the school based on estimated path distance (Figure 8).

As discussed elsewhere in this report, molybdenum levels above 20 ppb, let alone 100 ppb, are very likely the result of anthropogenic (man-made) contamination.[29, 30] While this analysis doesn't rule out contributions from other sources near Yorkville Elementary (unknown coal ash reuse and dumping sites, for example, or sewage

TABLE 5. RESULTS OF PRIVATE WELL TESTING NEAR YORKVILLE ELEMENTARY SCHOOL. (11 WELLS, 2014. ALL VALUES IN PPB).

Chemical	Average Concentration	Range	Groundwater Preventive Action Limit (WI)	Groundwater Enforcement Standard (Wi)
Arsenic	2.45	0 – 6	1	10
Boron	595	420 – 760	200	1,000
Molybdenum	108	76 – 140	8	40

FIGURE 6. MOLYBDENUM CONCENTRATIONS (WELL TESTING RESULTS) NEAR YORKVILLE ELEMENTARY SCHOOL, 2014. CONTOURS SHOW LINES OF EQUAL ESTIMATED GROUNDWATER PATH DISTANCE.

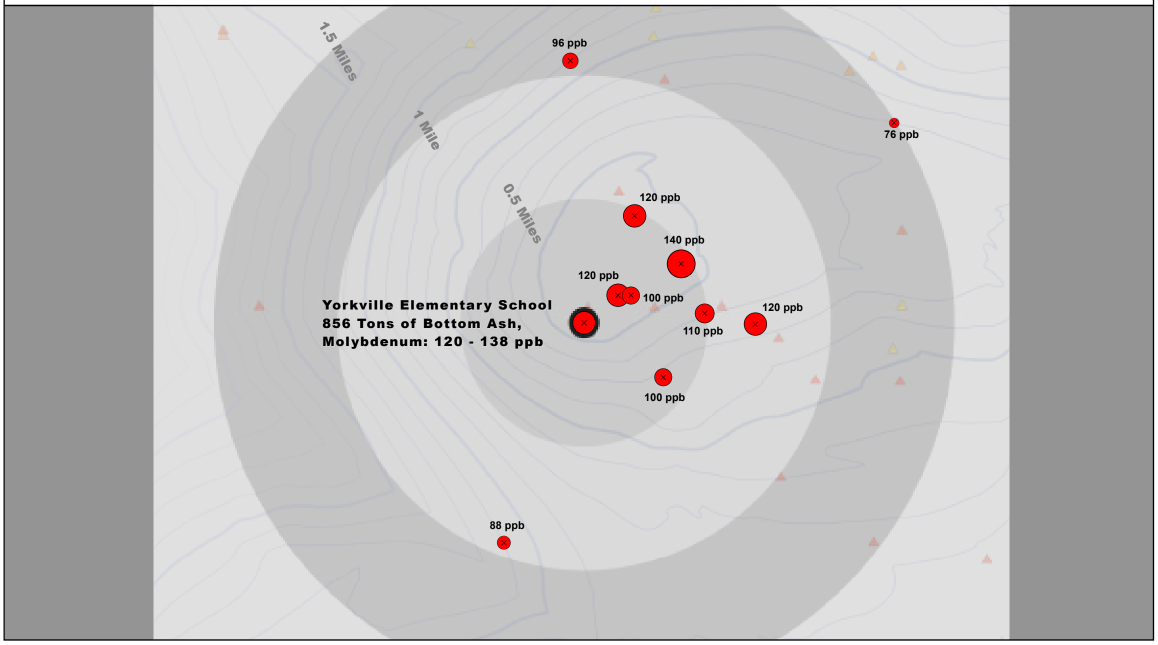


FIGURE 7. TRENDS IN MOLYBDENUM CONCENTRATIONS MEASURED AT PRIVATE DRINKING WATER WELLS NEAR YORKVILLE ELEMENTARY SCHOOL (by estimated linear distance).

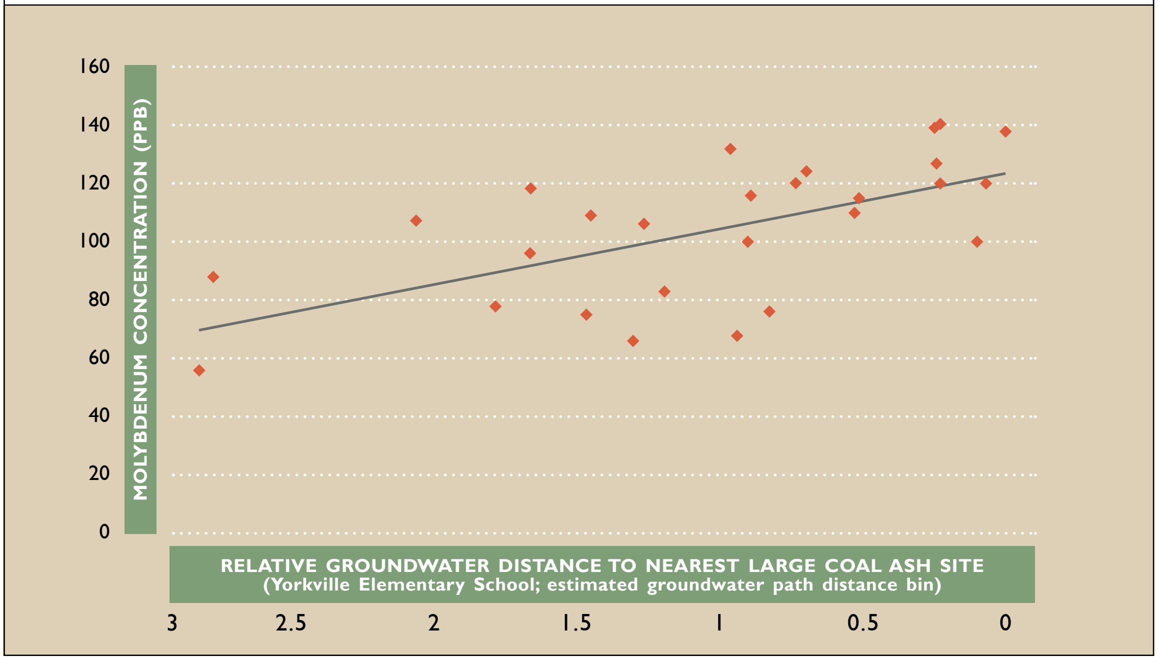
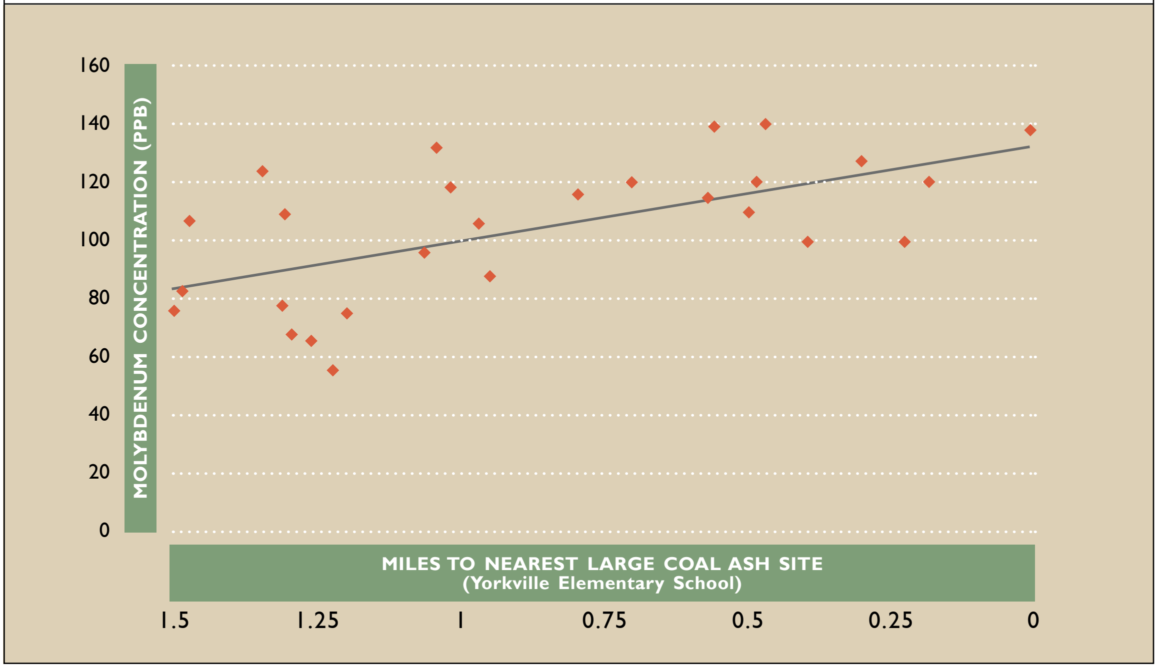


FIGURE 8. TRENDS IN MOLYBDENUM CONCENTRATIONS MEASURED AT PRIVATE DRINKING WATER WELLS NEAR YORKVILLE ELEMENTARY SCHOOL (by path distance).



sludge spread on farmland in the area[36]), these results point strongly to the coal ash project at the school being a likely source of molybdenum in the area.

Unfortunately, Yorkville Elementary is not the only school in the area to find high levels of molybdenum in its drinking water. North Cape Elementary School had elevated molybdenum levels and is also suppling bottled drinking water to their children.[35] We found similar records of coal ash use near that school: a 2007 construction project used 191 tons of fly ash as soil stabilization and a nearby project less than 1/2 mile away used 654 tons of bottom ash in 2005.

Contamination in Caledonia: A long history of problems

There is evidence that drinking water contamination from coal ash has been occurring since the 1980s in Caledonia and nearby Oak Creek. As part of a land use agreement that allowed them to use land in the Village of Caledonia, We Energies was required to sample private drinking wells located near the power plant starting in 1989. While it wasn't until 1993 that molybdenum was added to the list of tested elements, at that point it was found in 14 of the 20 private wells sampled.

There wasn't clarity about the degree of concern that contamination raised though, until the DNR set an Enforcement Standard (ES) of 40 ppb (parts per billion) for molybdenum levels in drinking water to protect public health. That benchmark showed the severity of the problem: molybdenum levels in 14 of the 27 wells tested by 2007 were above the DNR Enforcement Standard.

It took two years, however, for We Energies to inform the DNR and local residents of this contamination. In 2009, We Energies began distributing bottled water to local residents to replace the unsafe water in their wells.

Also in 2009, We Energies began buying properties in the area; to date, 20 homes have been purchased and bulldozed to the ground[37]—a practice sometimes referred to as "buy-up and plug-up" of contaminated wells.

In 2010, the Department of Health Services encouraged residents in the area to test their wells and offered free sample kits. The Wisconsin State Laboratory of Hygiene conducted the testing, and 20 of 124 participants had wells with molybdenum levels above the enforcement standard. Later that year, a report by Environmental Integrity Project, Earthjustice, and Sierra Club ("In Harm's Way") made the case that coal ash at the Oak Creek Power Plant is the source of contamination for molybdenum for wells adjacent to the facility, and that additional deposits of coal ash are the likely source for contaminated wells farther away from the plant.[38]

Following that report, in 2011, the DNR started an investigation to examine whether coal ash landfills in the area were the cause of the local drinking water contamination. They collected samples from private wells and groundwater monitoring wells and did an analysis comparing the boron found in those wells to boron found at the landfills.

The DNR released their report in January 2013. While the report detailed the areas and level of contamination in Caledonia, the DNR concluded that their analysis did not provide enough evidence to show that the landfills were the source of all the contamination in the area.

In June of 2013, however, the EPA released documentation accepting the findings of the "In Harm's Way" report. Along with the Oak Creek bluff collapse, the EPA determined that Caledonia was an area where damage resulting from coal ash had been proven.[8]

A key flaw in the DNR's study that kept them from identifying coal ash as the source of contamination is the fact that they didn't investigate the potential for additional contamination coming from coal ash disposed outside of the landfills in the area. The DNR acknowledged as much when it concluded that "... (1) either there is one or more unknown manmade source(s) in the region contaminating a large area, or (2) there is a more widespread naturally occurring source."[15]

Indeed, instead of being confined to a few landfills, the four-county area surrounding Caledonia is carpeted with over one million tons of coal ash waste, tucked beneath roadways, schools, hospitals, and many other buildings. It has even been used to cover public recreational trails, parking lots, and city streets.

Highway 59 Coal Ash Landfill: An Unsolved Problem

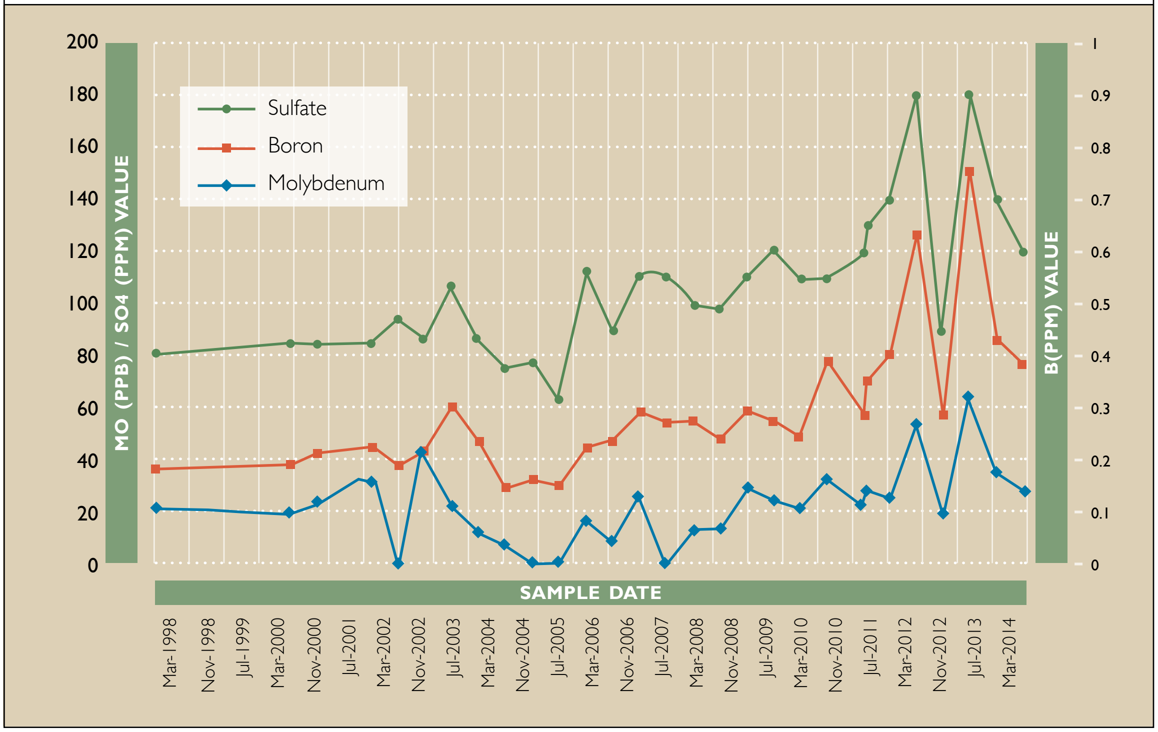
Between 1969 and 1978, We Energies dumped approximately 600,000 tons of coal ash in the unlined Highway 59 Landfill in Waukesha, WI.[39] This landfill was identified as a "proven damage case" by the EPA for contaminating nearby private drinking wells with arsenic, boron, chloride, iron, manganese, and sulfate.[40] Residents near the landfill were paid by We Energies to abandon their drinking water wells and were supplied with municipal water.[39] As part of the cleanup agreement, most of the landfill was recapped with a synthetic geomembrane, and saturated ash that was originally placed below the water table was removed.[39] Following the cleanup, most of the monitoring wells showed improvement.

Photograph of house demolition near the Oak Creek Power Plant. *Calendonia Wisconsin.* January 2014.

Recent test results, however, suggest that contamination at some active private wells near the landfill is still continuing 15 years after the cleanup was completed.

Four private drinking wells show molybdenum levels recently above Wisconsin's health standards. In those wells, the test results show that since 2002, molybdenum, boron, and sulfate levels are increasing and decreasing more or less in tandem with each other. This suggests that the elements are all coming from the same source, and these three elements have been identified as indicators of coal ash contamination. These pollutants have exceeded health levels at times, and

FIGURE 9. EXAMPLE OF TEMPORAL TRENDS IN MOLYBDENUM, SULFATE AND BORON; SAMPLE VALUES IN WELL NI174. STATE PREVENTATIVE ACTION LIMIT/ENFORCEMENT STANDARDS FOR MOLYBDENUM, SULFATE, AND BORON ARE 8/40 PPB, 125/250 PPM, AND 0.2/1.0 PPM, RESPECTIVELY.



for some wells the levels appear to be increasing (Figure 9).

Over 45 years ago, coal ash was disposed at the Highway 59 Landfill. The continuing contamination in the area illustrates the persistence of coal ash pollutants and the difficulty of effecting successful cleanups. It also illustrates the need for long term monitoring of coal ash dumps to ensure that continued leaking does not threaten human health.

Recommendations For Public Safety

Wisconsin DNR Must Take Actions to Protect Public Health

As the case of southeastern Wisconsin demonstrates, there is an urgent need to rethink how coal ash is handled to ensure the health and safety of our water, our land and our families. To do this, we offer ten practical solutions to improve the management and regulation of coal ash reuse in Wisconsin.

1. Wisconsin should conduct systematic testing of groundwater in areas where coal ash has been placed in the ground, including throughout Kenosha, Milwaukee, Racine, and Waukesha counties.

The available information on groundwater quality shows a widespread pattern of groundwater contamination in southeast Wisconsin. With limited information, however, it is impossible to determine the extent of the contamination, or to predict which wells will be most affected. A systematic sampling and testing plan throughout the region is needed to assess the full extent of the problem in Kenosha, Milwaukee, Racine, and Waukesha counties, as well as other areas in the state where coal ash has been placed in the ground, or where groundwater contaminant concentrations may exceed the state water and health standards, including those in Wis. Admin. Code ch. NR 140. Additionally, residents in areas that have been shown to be at risk for exceedances of those limits should be advised of the risks associated with the contamination.

2. Wisconsin should investigate historical coal ash use and dumping, make all records publicly available, and identify potentially dangerous placement.

Our work brought to light 1.6 million tons of coal ash spread through southeast Wisconsin. However, it is clear that considerably more coal ash has been spread in the region over a long period of time. The records we obtained only date back to 1988, and the records we have are incomplete for the period 1988-2014. Given the reports of coal ash placement dating back to at least the 1950's, our records likely represent only a very small fraction of the coal ash "beneficially" used. Of particular importance are sites where coal ash was placed below the water table such as wetland filling. It is also important to identify potentially unstable coal ash fills, like the ravine fill that collapsed in Oak Creek in 2011.

A first step would be to publicly release all historical records of coal ash "reuse," or any other sort of dumping into the environment. This includes any records at the DNR as well as utility records throughout the state. Wisconsin families have a right to know where coal ash has been placed in their neighborhoods. Thereafter, additional investigation by DNR is needed to provide a more complete picture of coal ash placement and its associated risks for the public.

3. Wisconsin should establish complete reporting requirements for uses of coal ash.

Wisconsin state law does not currently require coal ash generators or users to report many coal ash reuse sites through the state regulations of "beneficial use" (Wis. Admin. Code ch. NR 538). For example, We Energies power plants in SE Wisconsin used over 833,000 tons of coal ash offsite in 2011.[16] However, the records obtained from DNR contain documentation for only 26,000 tons, or 3% of the total offsite use. The lack of reporting makes it difficult to identify problem areas where coal ash may be contaminating groundwater and to identify locations of coal ash when groundwater contamination is found. It also leaves families in the dark about coal ash dumping in their neighborhoods. Generators and users of coal ash should be required to report at a minimum where, when, how much, and in what manner coal ash is being used, as well as the characteristics of the coal ash in that particular project, regardless of the project type or size.

4. Wisconsin should require coal ash to be tested for all chemicals with the potential to contaminate drinking water supplies, in accordance with Wis. Admin. Code ch. NR 538.04.

Wisconsin's rules on the use of industrial byproducts (NR 538) require that no coal ash storage, handling, or use be allowed that will have a "detrimental effect on any surface water," or that will cause a "detrimental effect on groundwater quality or will cause or exacerbate an attainment or exceedance of any preventive action limit or enforcement standard [...] as defined in ch. NR 140."[1] Wis. Admin. Code ch. NR 140 in turn, establishes public-health-related groundwater standards for 138 chemicals and public welfare related groundwater standards for an additional 8 chemicals.

However, testing of coal ash leaching is only required for at most 14 chemicals for any beneficial uses listed under NR 538. Notably absent from those required tests is any testing of coal ash for the leaching of molybdenum for any listed use. Yet molybdenum is known to be associated with coal ash contamination and there are widespread exceedances of both the preventive action limit and the enforcement standard for molybdenum in southeast Wisconsin. Similarly there is no testing required of arsenic, lead, or mercury, for the category of coal ash uses which include covered structural fill—and therefore no limit to the amount of leaching allowed under roads, or non-residential parking lots or buildings like schools and churches.

In order to prevent drinking water contamination and protect public health, as well as to comply with existing rules at NR 538.04, Wisconsin needs to revise NR 538 to require that all coal ash to be "beneficially used" is tested for any chemicals where that use could contribute to exceedance of groundwater standards listed in NR 140.

5. Wisconsin should establish groundwater monitoring requirements for beneficial uses of coal ash.

It is imperative to require environmental monitoring wherever coal ash is disposed or "reused." While Wisconsin requires coal ash generators to monitor transportation facility embankments, the state does not currently require any monitoring for other beneficial uses. Wisconsin should follow the lead of other states like North Carolina that better monitor coal ash use. Wisconsin should require coal ash disposal and uses to comply with water monitoring regulations and require the development and implementation of a water quality monitoring plan. Such monitoring must include all potential coal ash contaminants to ensure that toxic chemicals in coal ash are not leaching from the ash into drinking water.

6. Wisconsin should conduct research and testing to determine the role of coal ash in groundwater contamination.

This study shows that along with exceptionally high molybdenum levels in southeast Wisconsin groundwater, there is a potential source of contamination from the widespread "reuse" of coal ash in the area. Moreover, in spite of limitations such as gaps in available information, this study shows that molybdenum levels are generally higher closer to known coal ash reuse sites. Based on this information, there is a clear need to fully assess the contribution of coal ash reuse sites to groundwater contamination. Higher priority should be given to sites most likely to cause significant contamination, such as those where large quantities of coal ash have been placed below the water table. At those sites, detailed and targeted investigations are needed to determine the extent of contaminant leaching.

Such targeted research and testing are urgently needed given the toxicity of coal ash leachate, the extent of the potential contamination, and the fact that "reuse" projects are becoming an increasingly popular way to dispose of coal ash. If the widespread elevated levels of molybdenum in southeastern Wisconsin are due even in part to coal ash disposal, residents may also be exposed to more acutely dangerous toxins such as arsenic.

7. Stop spreading coal ash into the environment until better safeguards to prevent groundwater contamination are in place.

The additional research and testing that must be urgently conducted will provide more clarity on exactly how damaging current coal ash practices are and what new rules need to be put in place to protect our water supply. Until the results of such a study are known, Wisconsin should place a moratorium on spreading coal ash into the environment, as North Carolina has recently done.[41] In particular, the unencapsulated reuse that is currently allowed under NR 538 and examined in this report should be prohibited unless it can be proven that it is not causing or contributing to groundwater contamination in the state. Additionally, Wisconsin should start immediately by following the lead of other states that prohibit or conditionally prohibit the most harmful uses of coal ash. The rules in place now are clearly limited in effect and not sufficient to protect our drinking water.

8. Wisconsin should require liners, leachate collection systems, caps, and additional groundwater monitoring for large structural fills, as well as limitations on where structural fill can be used.

Wisconsin state law generally does not currently require protections be put in place for much of the coal ash dumping that is deemed a "beneficial reuse," even when those uses involve large quantities of coal ash in close proximity to private drinking water wells. Wisconsin should protect the health of its citizens by enacting regulations like those enacted in North Carolina that require large structural fill projects to protect groundwater and surface water by using liners, leachate collection systems, caps, and groundwater monitoring systems.[41] Wisconsin should also require safeguards to protect groundwater from small fill projects and follow the lead of other states that prohibit the placement of coal ash as structural fill near streams, floodplains, wetlands, private dwellings or wells, near property boundaries, or near the seasonal high groundwater table. Pennsylvania, for example, requires that coal ash not be used in a manner that causes water pollution and not be placed within 8 feet of the water table.[42]

9. Wisconsin should require a more accurate leach test to access the toxicity of coal ash.

There are many toxic chemicals present in coal ash that can be released into water supplies. Depending on the characteristics of the coal ash, how it is disposed, and the characteristics of the water it comes into contact with, these chemicals can leach out at different rates and quantities. When pollutants leach, they can seep into wetlands, creeks, underground aquifers, and drinking water supplies.

Unfortunately, the way the DNR evaluates the risk of heavy metal leaching out of coal ash is wholly inadequate. Currently, the DNR utilizes a "shake extraction test" where water is added to a sample of coal ash, the mixture is shaken, and the results are based on the amount of chemicals that leach out within 24 hours.[1] However, this testing does not simulate natural processes and environments. In reality, coal ash comes in contact with differing levels of acidity and different temperatures that affect how chemicals are released. The current test used by DNR also doesn't account for changes in leach rates over time, which can peak long after initial environmental exposure. As a result, the EPA's Science Advisory Board and the National Research Council of the National Academies of Science have rejected its use, stating that this test will not reliably characterize the leaching potential of coal ashes.[15]

In order to protect residents from toxic chemicals contaminating the groundwater from coal ash, Wisconsin should implement a test method for the leaching potential of coal ash that better reflects the complex conditions that are present in the real world. EPA recently approved a test method that more accurately assesses the leaching potential of coal ash, the Leaching Environmental Assessment Framework (LEAF).[43] Wisconsin should require coal ash to be tested using the LEAF prior to approval for unencapsulated reuse. Coal ash currently being used for beneficial use should also be required to be recharacterized using the more accurate leach test.

10. Wisconsin should regulate hazardous coal ash as a hazardous waste.

Coal ash is known to contain toxic chemicals that are hazardous to human health and the environment. Currently, however, Wisconsin exempts any and all coal ash from being considered a "hazardous waste" under state regulations, even when the current testing shows that it is highly toxic and corrosive.

Wisconsin needs to revise its rules so that when coal ash is truly hazardous, as shown by an up-to-date and accurate leach test, it is regulated as hazardous. Coal ash should only be exempted from a "hazardous waste" classification when tests determine that the ash will not leach toxic chemicals at levels sufficient to harm health and the environment.

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Due to the history of widespread disposal of coal ash throughout the environment, dangerous pollution from coal ash will continue to be a problem well into the future in Wisconsin and across the nation. In light of the significant impact such pollution can have on drinking water, and the loopholes coal ash producers currently enjoy that keep the public uninformed about where and how coal ash is used, Wisconsin and the EPA need to take action to ensure that rules governing coal ash reuse and disposal genuinely protect Americans and their environment.

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APPENDICES

Appendix A: Background Molybdenum Levels

Our analysis focused on coal ash as a cause of molybdenum contamination in groundwater. This is because prior investigations of the region's molybdenum contamination have not identified any other non-natural sources of elevated molybdenum being placed or released into the environment in the area, and because naturally occurring molybdenum levels in groundwater and surface water tend to be much lower than the levels observed in this study (Table 1). Indeed, a number of studies looking at molybdenum levels in water systems all found normal levels to be well below 20 parts per billion (ppb), rarely exceeding 20 ppb.[1, 2, 3]

TABLE 1. SUMMARY OF STUDIES MEASURING MOLYBDENUM CONCENTRATION IN AQUATIC SYSTEMS. ALL CONCENTRATIONS ARE PPB.

GROUNDWATER			
MEAN (RANGE)	**SOURCE**	**REFERENCE**	**NOTES**
0.2 [mdn]	Groundwater samples in UK	Smedley et al. 2014[4]	90% of samples < 1.8; Max level 89
1.0 [mdn]	Groundwater samples from US 1992-2003.	Ayotte et al. 2011[5]	90% of samples < 8.0; 1.5% > 40.
4.1 (.104-304)	Groundwater from wells in the glacial aquifer system of Northern US	Groschen et al. 2009[6]	Median level 1.4; 90% of samples < 7.0; 95% <14.0. Only 5 samples >40 ug/L.
6.5 (1.8-16.6)	Groundwater with high arsenic concentration in Central Illinois	Warner et al. 2001[7]	Mean from 9 wells with the highest As concentration found in the study. Other Mo values not presented.
2.7-6.3	Groundwater Alberta, Canada	Alberta Health & Wellness 2000[8]	
< 4.2	Groundwater in Minnesota	MN PCA 1999[9]	Samples from 954 Groundwater Monitoring Wells across the state
0.2 [mdn]	Groundwater in Central/Northern Wisconsin	Mudray et al. 1992[10]	78% of samples < 4; 98.5% <16; Max level 3500
-	Groundwater in Wisconsin	Siegel 1989[11]	28 of 29 samples were < 13. Highest level = 21.
-	Groundwater in Colorado	Chappell et al. 1979[2]	63% of samples < 1; 6% >10; Max level 28
3	Groundwater in former USSR	Chappell et al. 1979[2]	

TABLE 1. SUMMARY OF STUDIES MEASURING MOLYBDENUM CONCENTRATION IN AQUATIC SYSTEMS. ALL CONCENTRATIONS ARE PPB. (continued)

SURFACE WATER			
MEAN (RANGE)	**SOURCE**	**REFERENCE**	**NOTES**
1.71 (0.1-215)	Surface waters in Ontario	Ontario Ministry of Environment and Energy 2011[12]	Less than 1% of samples >10; Less than 0.2% > 40.
- (0.1-57)	Surface Waters in British Columbia	Canadian Council of Ministers of the Environment 1999[13]	
0.15-2.8	Great Lakes surface water	Rossman & Barres 1988[14]	
<10 (<10-40)	"Generally pristine" lakes in British Columbia	Swain 1986[15]	13% of samples had detectable levels; average of those with detectable levels = 19.
<10	Various surface waters in British Columbia	Swain 1986[15]	High values ranging from 1.1, .5, 30, and 1.5 ug/L
-	Surface Waters in Colorado	Chappell et al. 1979[2]	87% of samples < 10
0.4 [mdn] <0.3-100	170 California Lakes	Friberg et al. 1975[16]	
1.2-4.1	4 Rivers in the American West	Friberg et al. 1975[16]	
68 (2-1500)	Surface waters in US thought to be pollution problem areas	Kopp & Kroner 1967[17]	
1.26 (1.7-6.9)	15 rivers in US and Canada	Durum and Haffty 1961[18]	

Sources of Molybdenum in the Environment

The primary means by which molybdenum reaches surface and groundwater are molybdenum sulfide mining, burning fossil fuels, and the natural weathering of molybdenum-containing rock, particularly shale bedrock.[13,19,20] Although coal combustion is the largest atmospheric source of molybdenum,[1] molybdenum particles combining with rainfall is an insignificant source in the environment.[13,21] Agricultural land use is another anthropogenic source of molybdenum to aquatic systems, through soil disturbance, irrigation and fertilizer use.[6,11] Elevated levels of molybdenum have been found near mines, power plants, and oil shale deposits, as well as in sewage sludges, fertilizers, and agricultural drainwaters.[1,2]

Concentrations in surface or groundwater substantially higher than about 20 ppb are very likely to be the result of human activity.[1,2] In contrast to low naturally occurring levels of molybdenum in water in most areas, certain industrial processes, like burning coal, can result in much higher concentrations. While molybdenum levels in unburned coal are similar to soil levels (1-2 mg/kg), molybdenum and other inorganic elements become enriched in coal combustion products as the organic materials in the raw coal are burned off. With mean molybdenum concentrations of 10-20 mg/kg, coal combustion product leachate contains concentrations of 250 to >3000 ppb.[22] Molybdenum in treated municipal sewage sludge is around 15 mg/kg (range 1-40 mg/kg),[23] putting it at a similar level as found in coal combustion products.

Kopp & Kroner[17] sampled rivers in the vicinity of highly populated areas, industrial areas, recreation use areas, state and national boundaries, and other potential problem areas and found elevated molybdenum levels: 38% of stations had maximum concentrations exceeding 100 ppb and the overall mean for positive detections was 68 ppb. The mean for sampling in the Western Great Lakes Region, which included Wisconsin sample points, was lower than the overall mean at 28 ppb.

Molybdenum in Southeastern Wisconsin

When the DNR study on the Caledonia area did not find any evidence that indicated that the molybdenum contamination in that area was coming from the coal ash landfills they examined, it was suggested that the contamination likely resulted from natural sources or a combination of multiple anthropogenic sources. However, no positive evidence was found to indicate that natural conditions in the area were causing elevated molybdenum levels; the majority of supporting arguments given for a natural molybdenum source revolved around the idea that the We Energies Oak Creek site alone cannot explain all of the elevated molybdenum levels observed in Caledonia.[24] Indeed, later analysis provided further evidence of contamination resulting from the site,[25] which was later accepted by the EPA, along with the 2011 Oak Creek bluff collapse, as a proven case of damage resulting from coal ash.[26] Additionally, the line of reasoning that would indicate natural sources does not consider the widespread use of coal ash waste in the environment, or all of the other potential anthropogenic sources in the area, which were not considered by the DNR.

Indeed, Wisconsin is not in an area generally thought to have high natural levels of molybdenum. Groundwater testing in the central and northern regions of the state found median levels of just 0.2 ppb, with 98.5% of all samples less than 16 ppb[10] Furthermore, in a discussion of the difficulty of separating natural from manmade sources of molybdenum in the environment, Chappell[19] stated that it "seems safe to assume" that the elevated molybdenum levels Kopp & Kroner[17] found in the Midwestern samples were due to industrial sources due to the lack of mineralized areas and the acidic soils in the region. Similarly, Ayotte et al.[5] found that humid regions of the country, including Wisconsin, generally had lower groundwater molybdenum levels than more arid regions.

While areas with shale bedrock, which is found in the southeastern Wisconsin study region, are thought to be associated with elevated molybdenum in the groundwater,[24] two studies that measured molybdenum in areas with shale geology found mean groundwater molybdenum levels below 10 ppb.[7,8] In keeping with this, a drill cutting at the We Energies site in Caledonia showed that the levels of molybdenum in the glacial till and shale bedrock at the site were low, and the levels in both the clay till and the bedrock were less than half the 4.2 ppm average for shale rock.[24] Furthermore, soil molybdenum levels in southeastern Wisconsin are not particularly elevated, suggesting that this area is not a natural molybdenum hotspot.[27]

In sum, the weight of available evidence suggests that southeast Wisconsin is not likely to have particularly high natural levels of molybdenum.

Appendix B: Research Methods

We obtained all private drinking water well tests DNR had on record for molybdenum from 2009 to present (1,222 total records from 967 unique wells). Some wells with multiple tests had notes indicating that reverse osmosis filters had been installed, and subsequent molybdenum levels were much reduced; a number of other wells with multiple tests showed similar reductions in molybdenum levels in later tests suggesting that a filter had also been installed but no note indicating installation of filter was included. Given the uncertainty about which wells had filters installed, we used the highest molybdenum value in our analyses when a well had multiple tests. We also requested all private well test results for boron, sulfate, arsenic, and other signature elements of coal ash contamination.[28]

We also obtained information for 578 coal ash beneficial reuse (NR538) projects reported by We Energies to the Wisconsin Department of Natural Resources Milwaukee office from 1988 through 2012. These projects were geocoded using a combination of online geocoding services (Texas A&M Geocoder, GPS Visualizer) to obtain latitudes and longitudes from street addresses, which were verified and supplemented through the use of individual Google Maps, Bing Maps, and Internet searches. Some projects were located outside of the four-county study region in southeastern Wisconsin (Kenosha, Milwaukee, Racine, and Waukesha counties) while other project descriptions were too vague for those projects to be geocoded.

In order to investigate the possibility of other anthropogenic sources of contamination, we mapped locations of all current Wisconsin Pollutant Discharge Elimination System (WPDES) permittees,[29] all hazardous waste storage facili-

FIGURE 1. Map of estimated near-surface groundwater flow, based on water table in Kenosha, Milwaukee, Racine, and Waukesha counties.

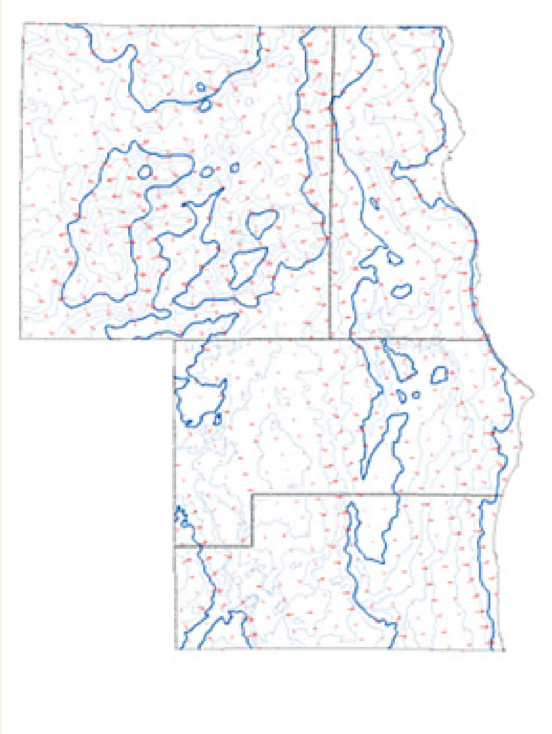
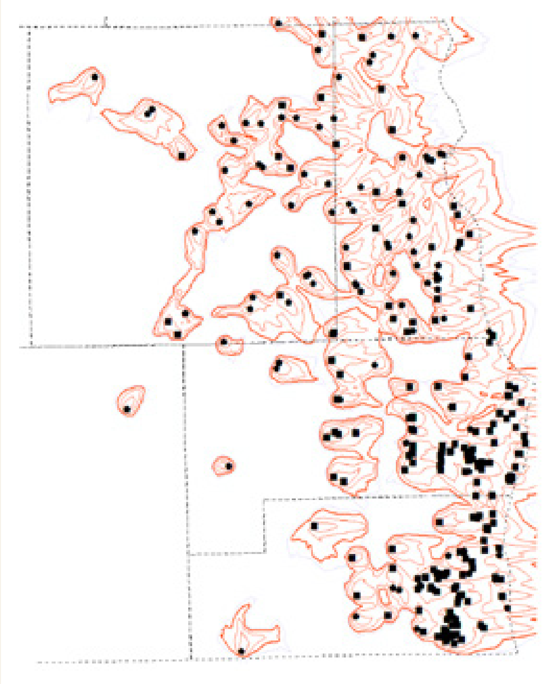


FIGURE 2. Illustrative map of estimated path distance (showing selected path distance isopleths from NR538 coal ash sites) in Kenosha, Milwaukee, Racine, and Waukesha counties.



ties and both closed and active landfills,[30] solid waste transfer facilities, and EPA Superfund sites.[31] We analyzed these both as a grouping of all non-NR538 sources together, and by looking at non-NR538 sources individually.

To analyze the relationship between molybdenum levels and potential sources of contamination, we looked at both the Euclidian distance and estimated near surface groundwater flow path distance. We analyzed both by proximity to all coal ash disposal sites regardless of size as well as proximity to coal ash disposal sites that used >500 tons of coal ash. Larger sites are more likely to cause extensive contamination, and 500 tons was close to the median project size.

Groundwater flow is complex, and determined by a large number of parameters. In general however, it has been found to flow downgradient and perpendicular to water table contour lines in southeast Wisconsin.[32] Thus, we approximated flow paths based on water table topographical data from the Wisconsin Geological and Natural History Survey.

This data was used in conjunction with ESRI ArcGIS's path distance tool to allow simultaneous simulation of approximate groundwater flow paths from a large number of sources on a regional scale.

The path distances modeled in this way are representative of general flow trends from any given point. They are calculated as step-wise additive travel costs from a given point in any given direction, using water table aspect as the determinant of cost. By using a linear horizontal cost factor, which ascribes a travel cost linearly proportional to the relative angle between motion and aspect, this functionally results in smaller path distances when traveling in the same direction as water table aspect, and larger path distances in other directions.

It is important to note that this approximation does not account for flow rate, flow path impedance, dispersion, or other factors that influence true groundwater flow, as this is outside the scope of this study. The use of a linear horizontal factor was chosen partly to account for the lack of this information; by allowing for small amounts of higher-cost travel in directions against the estimated groundwater flow, such a method is likely to result in decreased precision but increased accuracy.

Spatial interpolation of molybdenum values was also conducted in the area where robust molybdenum data existed. This area was defined as the minimum convex polygon, inversely buffered two observations from spatial extreme (95.68% of data points retained). Interpolated data was an average of nearest-neighbor and kriging interpolation methods (performed with ESRI ArcGIS).

Additional water sampling was conducted on Sept. 29, Sept. 30, and October 21st around the Yorkville School and the Highway 59 landfill. Private wells with available well construction reports were chosen based on proximity to the school and geology of the screened portion of the drinking well. Water samples were taken from indoor or outdoor taps without any filters installed. Cold water was run for 2-5 minutes before samples were collected to flush out the water pipes. Samples were shipped to Eurofins Eaton Analytical's Monrovia, CA, laboratory for analysis within 12 hours of sampling.

ESRI ArcMap 10.2.2[33] tools were used to calculate distances, and R[34] was used for statistical analyses.

Appendix C: Research Results

When the DNR was unable to point to the nearby coal ash landfills as the definitive sources of molybdenum contamination, it suggested that the molybdenum was likely either naturally occurring or coming from multiple anthropogenic sources.[24] Since the evidence points away from natural sources being the cause (see Appendix A), we conducted an analysis to see if higher levels of molybdenum contamination were associated with proximity to anthropogenic sources.

The data we obtained from the DNR included a total of 1,222 tests of molybdenum levels from 967 unique wells (Table 2) in Kenosha, Milwaukee, Racine, and Waukesha counties. The values we found ranged from undetectable to 221 ppb, with a mean of 49.66 ppb (SD = 46.03). Over 45% of all wells had molybdenum levels exceeding the current state and EPA enforcement standard of 40 ppb, and one in every five wells exceeded the DHS "health advisory level" of 90 ppb.

TABLE 2. SUMMARY OF MOLYBDENUM LEVELS FROM PRIVATE WELL TESTS REPORTED TO THE WISCONSIN DNR.

	# TESTS (% OF TOTAL)	MEAN (SD) TEST RESULT, PPB
0 ppb	64 (7%)	--
< 20 ppb	318 (33%)	11.03 (4.48)
20-40 ppb	143 (15%)	30.25 (5.72)
40-90 ppb	225 (23%)	61.12 (14.53)
90-120 ppb	129 (12%)	104.95 (8.47)
> 120 ppb	88 (9%)	146.55 (22.24)

We also obtained information for 578 coal ash beneficial reuse (NR538) projects reported by We Energies ranging in year from 1988 through 2012. No data were found on NR538 sites for the years 1990, 1991, 1993, 1995, or 1998 (Table 3). These projects used a total of 1.6 million tons of coal ash. Of those NR538 sites, we were able to confidently geocode 399 projects (1.07 million tons) to a four-county region in southeastern Wisconsin: Kenosha, Milwaukee, Racine, and Waukesha (Table 4). Some projects were located outside of this region while other project descriptions were too vague for those projects to be geocoded.

TABLE 3. SUMMARY OF ALL AVAILABLE COAL ASH REUSE DATA AS REPORTED BY WE ENERGIES, 1988-2012.

YEAR	# PROJECTS	TOTAL TONS USED
1988	6	4,572
1989	5	10,400
1990	DATA MISSING	
1991	DATA MISSING	
1992	2	20,000
1993	DATA MISSING	
1994	32	4,696
1995	DATA MISSING	
1996	12	31,317
1997	26	92,562
1998	DATA MISSING	
1999	66	149,793
2000	28	73,192
2001	14	65,565
2002	31	142,124
2003	27	106,541
2004	52	68,821
2005	64	83,940
2006	59	195,855
2007	25	8,062
2008	48	104,959
2009	37	147,284
2010	24	208,243
2011	7	26,331
2012	13	72,769
TOTAL	**578**	**1,617,026**

No records were found for the years 1990, 1991, 1993, 1995, or 1998. A total of 399 projects, using 1,065,364 tons of coal ash, were able to be mapped in Kenosha, Milwaukee, Racine, and Waukesha counties.

In general, our analysis found that wells closer to known coal ash reuse sites, particularly those larger than 500 tons, tended to have higher molybdenum levels than wells farther away. A similar trend was not evident when looking at other potential anthropogenic sources (landfills, Superfund sites, wastewater treatment plants, hazardous waste facilities, solid waste transfer facilities, and sites with WPDES permits) when considered together.

Our study found statistically significant correlations between molybdenum levels in private drinking wells and decreased distance to coal ash reuse sites larger than 500 tons. The statistically significant correlations held for both Euclidian (linear) distance and approximated groundwater flow (Figure 12, Figure 13; Spearman rho = -0.18 and -0.28, respectively; $p < 0.001$ for both).

There is a certain amount of inaccuracy and imprecision in distances used for the study relative to the corresponding real-world distances due to limitations of this study. This is because we were unable to visually confirm the geocoding location results of all coal ash disposal sites and test well locations, and because groundwater flow path distance is an educated approximation based on prior studies using a similar process. Small changes in the latitude or longitude used in the mapping can result in substantial changes in distances from disposal sites, particularly in groundwater path distance. To check for the potential impact of this spatial imprecision, as well as potential impact from non-random distribution of well sampling data, we conducted corresponding statistical analyses based on interpolated molybdenum values. The results of these analyses showed that general trend was robust: wells closer to NR538 disposal sites tended to have higher levels of molybdenum.

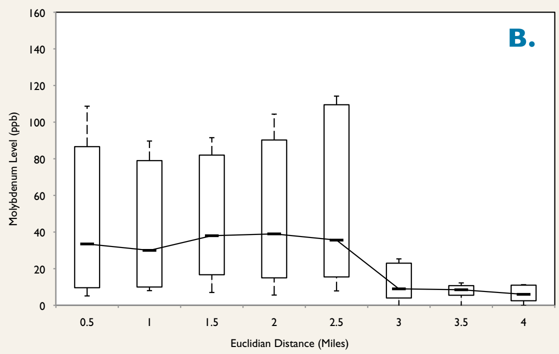
To check for more general trends that would be even less sensitive to data inaccuracies and imprecisions, we also compared molybdenum values from the closest 50% of wells to larger disposal sites to the farthest 50% of wells, both in terms of linear distance and groundwater flow path distance. In both cases the closest 50% of wells had significantly higher average molybdenum test results than the more distant wells (Mann-Whitney U test; $p<0.001$ for all comparisons). The difference was more pronounced when looking at shallow groundwater flow path distance compared to Euclidean distance, as expected. There was a starker contrast when com-

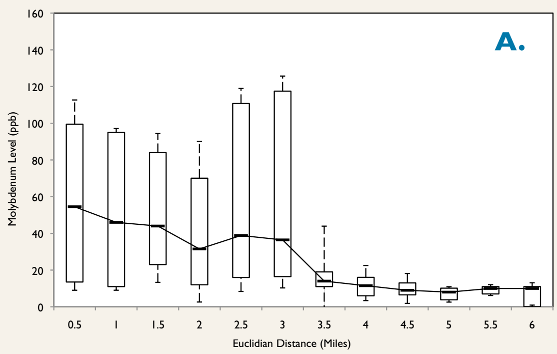
TABLE 4. SUMMARY OF COAL ASH BENEFICIAL REUSE LOCATED IN SE WISCONSIN AS REPORTED BY WE ENERGIES 1988-2012.

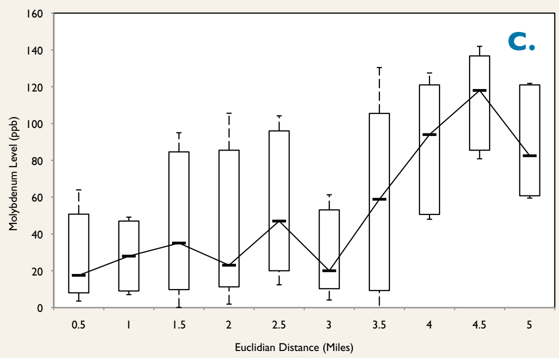
		# PROJECTS	TOTAL TONS USED
Type of Ash	Bottom Ash	265	1,004,928
	Fly Ash	134	60,436
Project Size	< 500 Tons	189	37,503
	500-1,000 Tons	42	29,533
	1,000-5,000 Tons	106	272,347
	> 5,000 Tons	62	725,981
Total	Records able to be geocoded in region	399	1,065,364

FIGURE 3. Molybdenum levels (ppb) versus Euclidian distance (miles). Boxplots show median, interquartile range, and standard deviation from mean for private drinking water well tests of molybdenum in proximity to:

A. Large (>500 Ton) NR538 Coal Ash Sites
B. All NR538 Coal Ash Sites
C. Other Potential Anthropogenic Sources







paring median values, which was also expected since small clusters of wells with exceptionally high or low molybdenum levels can influence average values.

TABLE 5. Mean and median molybdenum levels (ppb) in the 50% of wells nearest to and farthest from large (>500 tons) coal ash reuse sites.

	Euclidean Distance		Groundwater Flow Path Distance	
	Near	Far	Near	Far
Mean (SD)	55.2 (44.3)	44.2 (47.2)	59.5 (47.7)	39.8 (42.1)
Median	46.3	23.0	48.0	20.0

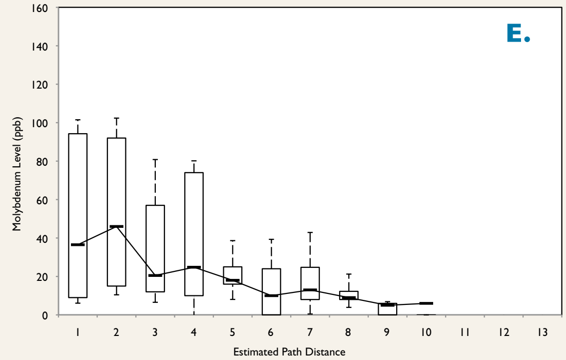
There were also 123 unique private drinking wells that had test results for arsenic. Details on analysis of arsenic levels, including results, are included as Appendix D.

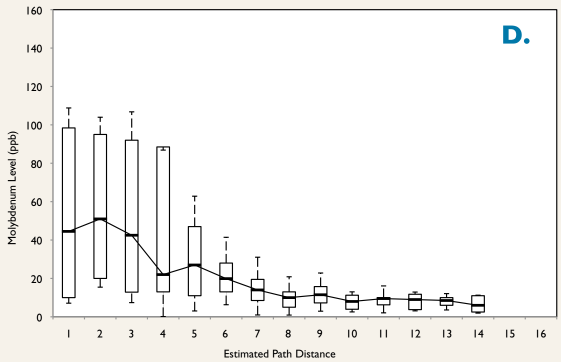
Need for more information

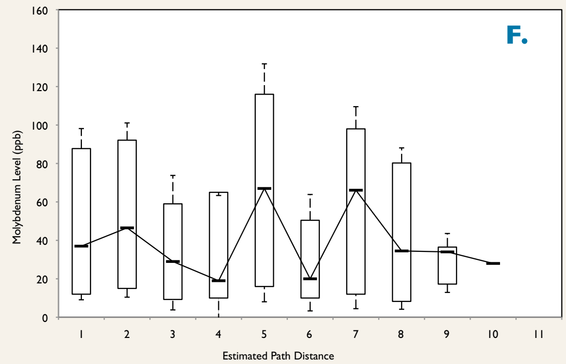
Due to the nature of our investigation and the limited available information, much more evaluation is required. While we can't definitively point to a sole cause of the molybdenum contamination in southeastern Wisconsin, the analysis conducted provides strong evidence that the coal ash spread throughout the region was at the very least contributing to the drinking water

FIGURE 4. Molybdenum levels (ppb) versus relative estimated path distance. Boxplots show median, interquartile range, and standard deviation from mean for private drinking water well tests of molybdenum in proximity to

D. Large (>500 Ton) NR538 Coal Ash Sites
E. All NR538 Coal Ash Sites
F. Other Potential Anthropogenic Sources







contamination. As a result, there is an urgent need to conduct more in-depth research to fill in the information gaps and fully investigate the potential connection between the reuse of coal ash wastes and groundwater contamination in this area.

Indeed, the biggest challenge faced in conducting this research was the lack of complete information. The coal ash disposal sites included in this analysis were only those for which we were able to find records, reported to DNR's Milwaukee field office by We Energies, and only for years ranging from 1988 to 2012. However, environmental coal ash disposal and reuse has been happening in the region since at the least the 1950s.[35] Of the data we did have, a number of project descriptions were too vague to locate confidently; there were 524,029 tons of coal ash disposed in projects for which we found records, but were unable to locate. There was also at least 27,500 tons of flue gas desulphurized gypsum applied to fields in the region from 2010 to 2012.

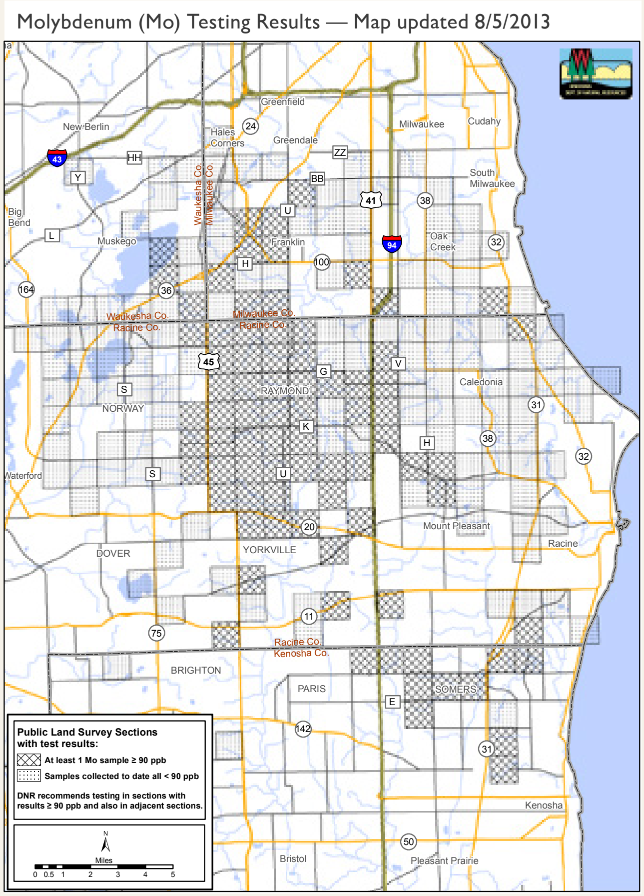
Similarly, well test result data are incomplete. The wells that do have molybdenum tests are essentially a random sample from private homeowners who decided to have their water tested. The distribution of testing is thus influenced by a number of factors, including recommendations from the WDNR for testing (Figure 14). This is markedly different than a systematic sampling that tested wells at various distances from known disposal sites. For example, there are no wells within a quarter mile of known fly ash disposal sites, and there are regions in southeastern Racine and Kenosha counties with high densities of coal ash reuse project sites with no or very few well test results. Furthermore, there were relatively few wells tested for multiple signature elements of coal ash contamination, including molybdenum, boron, sulfate, and arsenic, which could help to identify coal ash as the cause of the contamination. The data available show a positive, but not statistically significant correlation between molybdenum levels and both boron ($p=0.27$) and sulfate ($p=0.31$), but these correlations are based on very few data points. It is worth noting however, that for 18 of the 19 wells where both molybdenum and boron data where available and where molybdenum levels exceeded the state Enforcement Standard, boron levels also exceeded the state Preventive Action Limit.

The lack of complete information about coal ash sites and the non-systematic nature of molybdenum data in the region could help to explain deviations from the general trend of wells closer to reuse sites having higher molybdenum levels. For example, there is a second peak in median molybdenum levels in the two- to three-mile Euclidian distance range from known large disposal sites that is caused by three clusters of wells with very high molybdenum levels. It is entirely possible that these clusters are affected by undocumented coal ash disposal sites. Similarly, there are median molybdenum levels markedly lower than that the anticipated trend for all sites at path distances ranging from 0 to 5,000 and from 25,000 to 30,000. Clustering of well test data with low molybdenum values in both of those ranges may account for the deviations from anticipated trend; when spatially interpolated molybdenum data points are for analysis as opposed to individual well test results, these deviations are significantly reduced.

A final important gap in information that limited our analysis was the lack of access to data about the depth to which the drinking water wells in the region were sealed off from the groundwater by a grouted casing. By necessity, we had to group together all these wells, which could be drawing water from different sources of groundwater. This could help explain why two wells in very close proximity could have very different molybdenum levels.

A comparison between wells drawing water from the shallower sand/gravel layer that are more susceptible to contamination and wells extending deeper into the limestone layer would be helpful in assessing coal ash's role in the observed elevated molybdenum levels. Indeed, we note that this region is also largely underlain by a 100- to 150-foot thick layer of low permeability clay,[36] which would tend to limit the movement of contaminants from these reuse sites. However, Lourigan and Phelps noted the presence of vertical fractures in the region that could greatly aid downward movement of contaminated water through clay layers.[24] Moreover, the presence of intermediate sand layers[24] further aids the migration of contaminants, particularly where the sand layer is in direct contact with the groundwater

FIGURE 5. Map showing areas where WDNR recommends private well water testing for molybdenum.



aquifers. For example, a brief review of well construction reports near North Cape and Raymond, Wisconsin, where particularly high levels of molybdenum (>100 ppb) are within two miles of known large reuse project sites, show that there are course sand and gravel layers starting as shallow as 50 feet below ground surface that extend as deep as 185 feet with limestone formations starting somewhere between 140 feet to 200 feet below ground surface.

Groundwater flow speeds of 2.8, 0.28, and 0.03 feet per day have been estimated or measured in southeast Wisconsin through sand/gravel, stony clay, and clay soil types, respectively.[24,36,37] Given these speeds, it is reasonable that contaminants leached from nearby reuse project sites from 1999 to 2005 could reach the limestone/dolomite aquifer and spread to the contaminated wells by 2013, particularly with the help of fractures in the clay layer. We emphasize that to establish causation that a particular well is contaminated by coal ash from a particular reuse project, site-specific analyses of the geology would be required; the information presented here is simply to show that contamination of wells within the distance range suggested in our analysis is possible. Furthermore, localized variations in geologic profiles may also help to explain why some wells very close to reuse sites do not show elevated molybdenum levels; if a site is located entirely on clay with no fracture or shallow sand layer, contamination will be unlikely even with a very close proximity.

Conclusion

To our knowledge, this is the first study showing the extent of molybdenum contamination of drinking water wells in southeastern Wisconsin. It is also, to our knowledge, the first study to examine the extent of coal ash waste being disposed of into the environment as reuse projects, as well as the first to examine the potential for contamination from those projects.

We found that both drinking water contamination from molybdenum and the disposal of coal ash into the environment were widespread in southeastern Wisconsin. In general, wells closer to known coal ash disposal sites had statistically higher molybdenum levels than wells further away. Based on the trends identified, the substantial deviation from typical groundwater levels, and lack of positive evidence pointing to a natural source or other anthropogenic source in the region, this suggests coal ash as the most likely source of molybdenum contamination in the area. However, the lack of information available makes a definitive determination of causation impossible, and a more targeted study that addresses the limitations encountered here is necessary.

Such a study is urgently needed given the toxicity of coal ash leachate, the extent of the potential contamination, and the fact that this type of coal ash reuse has become increasingly popular in Wisconsin and the United States. This analysis focused on molybdenum, as there was a fairly robust dataset available because the DNR recommended that residents in the area test for it. Molybdenum is also an indicator of potential contamination from a host of other toxic metals with more serious health implications found in coal ash waste. If the widespread elevated levels of molybdenum are indeed due, even in part to coal ash disposal, residents are also likely exposed to more acutely dangerous toxics like arsenic, lead, hexavalent chromium and mercury.

Appendix D: Arsenic Analysis

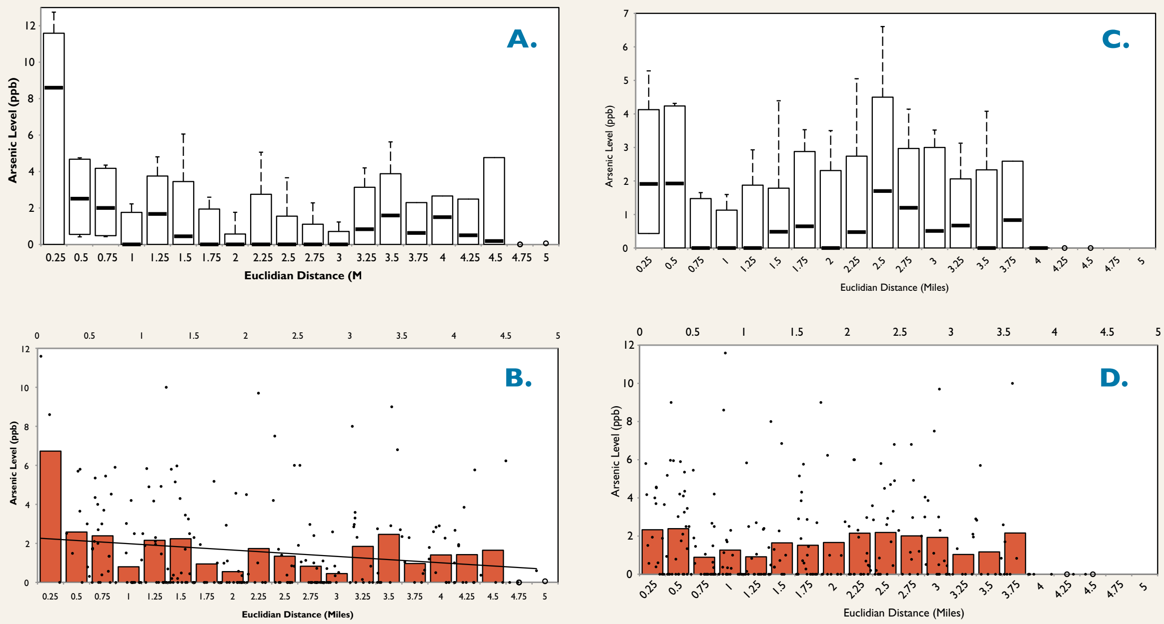
In order to determine the extent to which molybdenum contamination could be an indicator for other types of groundwater contamination, we conducted an assessment of arsenic levels in southeastern Wisconsin. This analysis used the same coal ash reuse (NR538) dataset as the molybdenum analysis, along with data from the WNDR on 123 unique private drinking wells that had test results for arsenic.[38]

There are added complications when conducting this analysis with arsenic, as opposed to molybdenum, however. For example, the limit of detection for arsenic for the majority of these private well tests (5 ppb) is quite high relative to the state PAL (1 ppb) and ES (10 ppb), as compared to tests for the other elements. As a result, there was a far higher proportion of non-detects with arsenic than with other elements, and any gradation in arsenic levels cannot be seen until quite high concentrations are present. For this reason, it is not unexpected that a correlation of arsenic levels would be only found with fly ash sites (as opposed to with all NR538 sites), as arsenic levels are up to 10 times higher in fly ash than in bottom ash.[37, 38, 39, 40]

Additionally, arsenic may not travel very far from sources before being bound up by soil particles.[38] The distance scales at which the correlation analyses are conducted should realistically reflect arsenic's ability to spread from a point source. Since the precise applicable extent is impossible to determine without more in depth hydrogeological study, we chose a conservative two-mile linear distance cut-off for analysis. Finally, arsenic does not necessarily leach and spread in the same conditions as molybdenum; for example while molybdenum is more easily

FIGURE 6. Arsenic levels (ppb) versus Euclidian distance (miles). Boxplots show median, interquartile range, and standard deviation from mean. Scatter plots show all test results, significant linear regressions, and mean values. For groundwater wells from 25 to 250 feet of depth within 5 miles of:

A, B NR538 Fly Ash Sites (linear regression: $p < 0.05$)
C, D Other Potential Anthropogenic Sources (no significant trend)



mobilized in basic conditions than acidic conditions, the leachability of arsenic from fly ash can be vary in either type of environment.[41]

Conducting a proximity analysis with similar methods as with the molybdenum study, we found significant negative correlations between arsenic levels within two miles of fly ash disposal sites for both linear distance from those sites and estimated groundwater flow path distance. Similar relationships did not exist for other potential non-NR538 sources, with the exception of a small negative correlation with linear distance to landfill sites (no negative correlation existed between landfills and groundwater path distance to arsenic measurements within 2 miles).

It should be noted that studies have indicated the potential for naturally high arsenic levels near the study region, specifically near Lake Geneva. Similar unidentified natural sources could interfere with correlation analyses with the potential anthropogenic sources that we conducted. It has been suggested that elevated arsenic levels near Wind Lake, which is within the study area of this report, also stem from natural sources. However, this conclusion did not consider NR538 sites in the region, and was based primarily on a lack of any other obvious anthropogenic sources and the findings of the Lake Geneva studies.[42, 43,44,45] Furthermore, arsenic is not easily mobilized in natural conditions, so levels tend to be low in groundwater.[38]

The finding here of a correlation between fly ash NR 538 sites and groundwater arsenic levels shows that there is significant cause for concern regarding current practices of "reusing" fly ash in the environment. This is especially true considering that, which much of the date used for this analysis, a sample with no arsenic will show the same result as a sample with 4 times the state preventive action limit. More testing is urgently needed to determine the extent to which existing NR538 coal ash sites are causing or contributing to groundwater arsenic contamination, and the safeguards that should be put in place to prevent such contamination in the future.

Appendix E: Other Potential Sources of Contamination

As discussed in Appendix B, we looked at spatial relationships between private well testing locations and potential anthropogenic sources of molybdenum contamination other than NR538 sites: landfills, Superfund sites, hazardous waste storage facilities, solid waste storage and transfer facilities, WDPES permittee locations, and wastewater treatment facilities. These sites were considered both in the aggregate, and independently.

When examining potential non-NR538 anthropogenic sources of molybdenum independently, we note that certain categories of such sources are limited in quantity near molybdenum well testing data. In particular, 293 of the 399 NR538 coal ash sites identified are within two miles of the area (minimum convex polygon, "MCP") containing all molybdenum observations, along with 70 landfills. In contrast, there are only two wastewater treatment facilities in that same area. Similarly, in the area where there is robust data on molybdenum levels (a two-observation inverse-buffered MCP, containing 95.8% of the data points), there are 142 NR538 sites, but only one industrial WPDES permittee, one wastewater treatment facility, and one Superfund site (Table 6).

Furthermore, the average distance (for both Euclidean or groundwater flow path) from wells with molybdenum levels > 90 ppb to the nearest non-NR538 site was close to twice the distance to the nearest NR538 sites (Figure 7). This is important because, as discussed in Appendix B, long-range contaminant movement may be impeded by hydrogeologic features of the region. Given this and the fact that wells with very high molybdenum levels are much closer to NR538 sites than to other potential anthropogenic sources, it stands to reason that NR538 sites are a more likely source of contamination than are the other potential anthropogenic sources.

As expected, when considered in the aggregate, there was no trend of increasing molybdenum levels with closer groundwater flow proximity to one of these sites as existed with NR538 sites. Similarly, no such trend existed for any non-NR538 anthropogenic source taken individually, with the exception of solid waste storage and transfer facilities. However it should be noted that there is significant correlation between those facilities and NR538 coal ash sites, especially within the 95.8% MCP: 4 out of the 5 of those facilities were within 1 mile of a NR538 coal ash site, and 3 of 5 were within 0.5 miles of a NR538 coal ash site.

TABLE 6. Number of potential anthropogenic source sites within four-county region (Kenosha, Milwaukee, Racine, and Waukesha), within 2 miles of the minimum convex polygon containing all molybdenum observations, and within the 95.8% minimum convex polygon (two-observation inverse-buffered).

Source category	4 County Region	< 2 miles of 100% MCP	95.8% MCP
All NR538 Sites	399	293	142
Large NR538 Sites	210	141	75
Landfills	109	70	8
Solid Waste Storage and Transfer	20	14	5
Hazardous Waste	25	17	5
Industrial WPDES	17	11	1
Superfund	12	8	1
Wastewater Treatment	10	2	1

FIGURE 7. Mean distances of all molybdenum observations, and molybdenum observations greater than 90 ppb, to potential anthropogenic source sites within four-county region (Kenosha, Milwaukee, Racine, and Waukesha) based on: 1. Euclidian Distance; and 2. Estimated Groundwater Flow Path Distance.

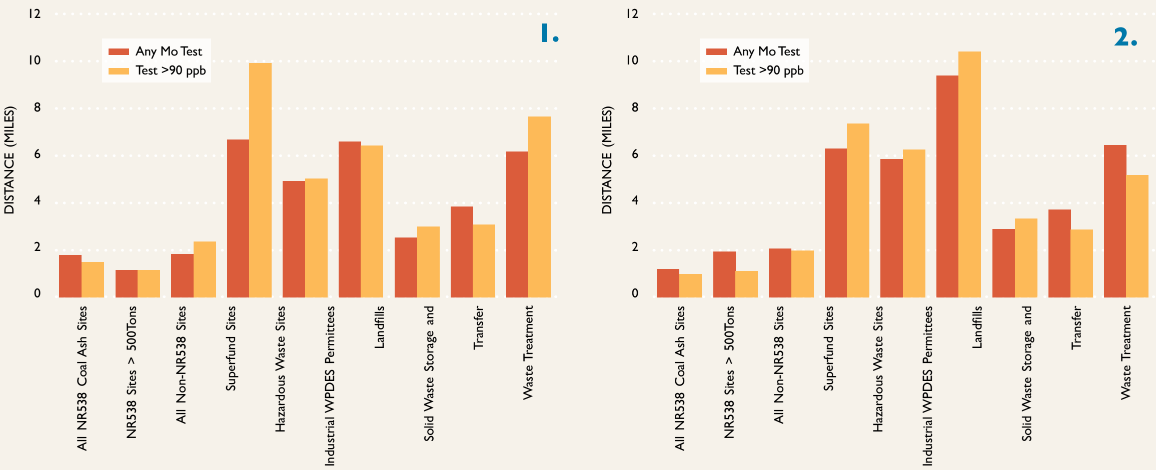
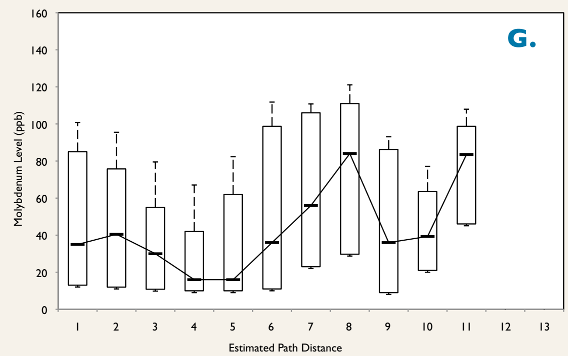
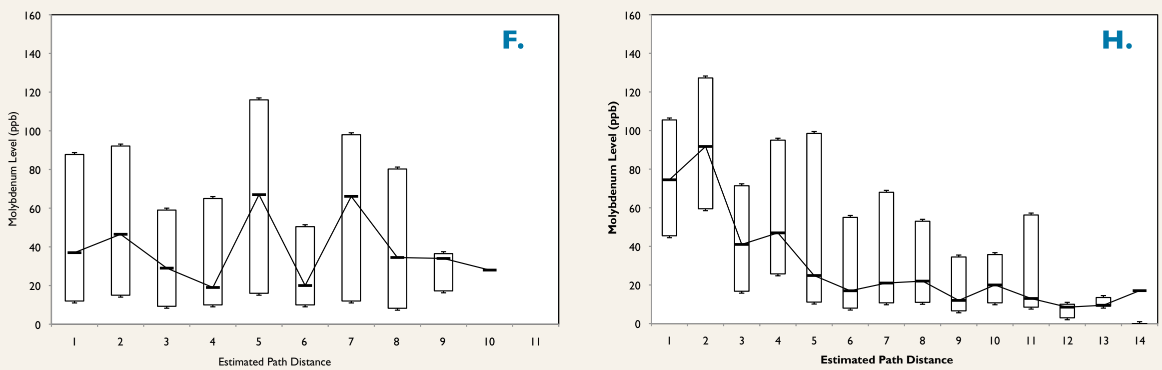


FIGURE 8. Molybdenum levels (ppb) versus relative estimated path distance. Boxplots show median, interquartile range, and standard deviation from mean for private drinking water well tests of molybdenum in proximity to:

F. All Potential Anthropogenic Sources
G. All Landfill Sites
H. All Solid Waste Storage and Transfer Facilities





In sum, our examination of other potential anthropogenic sources shows that these sources tend to be much farther from contaminated drinking water wells than NR538 sites, and do not show the same trend of decreasing distance to wells with higher molybdenum levels that we see with NR538 sites. This investigation serves to strengthen the evidence pointing to coal ash as the most likely anthropogenic source of the region's molybdenum contamination.

Appendix F: Specific Deficiencies of Wisconsin's Beneficial Reuse Rule

Overview of Wisconsin's Beneficial Reuse Rule

In Wisconsin, coal ash is considered an industrial byproduct, not a hazardous waste. Wisconsin exempts the generation, use, transportation, or storage of coal ash from waste disposal standards when the proposed user complies with Wisconsin Administrative Code Chapter NR 538, "Beneficial Use of Industrial Byproducts." Chapter NR 538 establishes five categories of industrial byproducts. Industrial wastes like coal ash are characterized based on the amount of metals leached from the waste in a water leach test and then categorized accordingly. Each category requires the parameters of the leached sample to be at or below the concentration limit set forth in the chapter (NR 538.08).

This categorization determines regulatory requirements for the use of industrial byproducts like coal ash, as well as the ways in which they may be used. Category 1 is the least toxic, with the lowest concentration of leached metals, and can be used in the widest variety of reuse applications and utilized for almost any fill application in any volume. In contrast, category 5 waste is the most toxic, contains the highest concentrations of metals, and has the most restricted use. Because the leach test specified in the Wisconsin regulations cannot reliably determine the amount of metals leaching from coal ash, the categorization is irrelevant to coal ash and consequently unable to properly protect public safety.

Unfortunately, regulation of coal ash use under NR 538 is insufficient in many ways to protect against impacts to drinking water, and therefore human and environmental health. Some of those deficiencies, as well as suggestions to address them, are detailed here.

1. Insufficient water resource protections

The rule contains general performance standards prohibiting beneficial reuse where it would have detrimental effects on surface waters or groundwater quality (NR 538.04(3) and (4)) or create a nuisance or environmental pollution (NR 538.12(2)(e)). However, given the rule's lack of safeguards on placement of coal ash and the lack of monitoring requirements (see below), it is difficult to determine whether these performance standards are being met. Thus, stronger and more specific limits on where coal ash can be placed are needed to protect water resources.

Current Requirements:

- Non-category 1 ashes may not be placed below the water table, into permanent standing water or areas that need to be dewatered prior to placement. NR 538.12(2)(b).
- Certain covered fill uses for non-category 1 ash over 5,000 cubic yards must be placed at least 3 feet above the groundwater table ***at the time the material is placed*** [emphasis added] and 200 feet from a private or public water well without property owner's consent. NR 538.12(2)(b) and (c).
- When using ash as unbonded surface course material, the use area must be separated from navigable surface waters by a vegetated 25 foot buffer. NR 538.10(9).

Suggested Improvements:

- Category 1 ashes should not be exempted from placement requirements. There must be a prohibition against placement of all coal ash below the water table, into permanent standing water, or into areas that need to be dewatered prior to placement. Even if the leach test was accurate for ash, it still allows category 1 ashes to leach up to 5 ppb arsenic (5 times the state PAL) and 50 ppb molybdenum (exceeds the state ES by 25%).
- A greater separation between groundwater and coal ash placement is needed (e.g., Pennsylvania requires an 8-foot separation) and the reference water table height should be the seasonal high water mark, not the water table height at the time the coal ash is placed.
- Groundwater and well separation requirements should apply to all fill uses.

- A greater separation between unbonded surface course and surface waters is needed. This is particularly true for Category 2 ashes, leachate from which currently has no limit on molybdenum levels and can contain up to 50 ppb arsenic.

2. Insufficient testing and characterization requirements

NR 538.06 and NR 538.08 contain requirements for testing coal ash and other industrial byproducts for characterization. This testing and characterization is the basis by which permissible uses and required protections are put in place. However, the testing and characterization as currently defined are insufficient to determine whether the general requirements of NR 538.04 are being met.

Current Requirements:

- Ashes are initially characterized based on a representative sample, with periodic recharacterization for some ashes based on category and use. NR 538.06(2) and (4).
- Category 1, 2, 3, or 4 ashes are characterized based on the results of a specified water leach test (ASTM D3987–85) for different chemicals depending on byproduct type and use category. NR 538.06(3)(c) and NR 538 Appendix I.
- Category 1 and 2 ashes are also characterized based on a total elemental analysis. NR 538.06(3)(d).
- There are no explicit testing requirements for Category 5 ashes.
- Limited parameters in leachate, as well as allowable levels of those parameters in leachate, vary by use category. NR 538 Appendix I.

Suggested Improvements:

- All ashes (Categories 1, 2, 3, 4, and 5) should be subject to the most accurate available test approved by EPA to assess the leaching potential of coal ash; the Leaching Environmental Assessment Framework (LEAF). Wisconsin should require coal ash to be tested using the LEAF prior to approval for any unencapsulated reuse, including usage categories. NR 538.10(2)-(13). Coal ash currently being used for beneficial use should also be required to be recharacterized using LEAF leach test.
- All ashes (Categories 1, 2, 3, 4, and 5) should be tested using the LEAF test for all parameters where beneficial use could contribute to exceedance of groundwater standards listed in NR 140, including the parameters listed in Ch. NR 538 Appendix I Table 1A.
- All ashes (Categories 1, 2, 3, 4, and 5) should be subject to total elemental analysis restrictions for all parameters listed in Ch. NR 538 Appendix I Table 1B.
- Leaching and total elemental analysis limits should be placed on Category 5 ashes such that the most toxic ashes cannot be beneficially reused.
- All ashes (Categories 1, 2, 3, 4, and 5) currently being beneficially reused should be immediately recharacterized using these methods.
- All ashes (Categories 1, 2, 3, 4, and 5) should be recharacterized on an annual basis prior to any beneficial reuse regardless of the quantity used in previous years.
- Allowable levels of contaminant parameters in leachate should be reduced to protect groundwater. For example, more stringent requirements should be put in place for arsenic and molybdenum in leachate from all ashes (Categories 1, 2, 3, 4, and 5).
- In this recommended reduction, the allowable parameter standard levels for the most restrictive use category should be at least as stringent as those currently applied to Industrial Byproduct Category 1 in NR 538 Appendix I. Less restrictive use categories would then be subject to increasingly stringent allowable parameter standard levels.

3. Insufficient Notification and Recordkeeping Requirements

As this study illustrates, coal ash is being used all across the landscape. In light of the minimal reporting requirements, most people likely have no idea about the extent of its use in their neighborhood. Furthermore, without comprehensive records of coal ash reuse it is difficult to assess the potential pollution caused by coal ash used under NR 538.

Current Requirements:

- Written notification describing the location where coal ash is being used is required only for certain uses. NR 538.14(4)
- Records of where coal ash has been utilized for certain types of beneficial reuses need to be maintained by the ash generator for only 5 years. NR 538.14(5)
- Public notice is only required for certain non-category 1 ash uses where more than 30,000 cubic yards of ash are used. NR 538.18
- Owners of property on which coal ash is used must be notified of the location, categorization, type, and volume of ash being used. However, category 1 ash projects are exempt from this requirement, and projects using less than 2,500 cubic yards need only inform the property owner that industrial byproducts are being used. NR 538.22

Suggested Improvements:

- Written notification with location and site description information to the DNR should be required for all reuse projects in order to establish a complete public record of coal ash placement.
- Records should be maintained, in perpetuity, at coal ash reuses sites because peak leaching can occur 100 years after placement of the coal ash.
- The volume threshold for public notice of coal ash uses should be lowered. The current threshold was only exceeded by 1% of the projects in the records we were able to obtain.

Property owners should be notified regarding the characterization and location of all coal ash uses on their property.

4. Insufficient Environmental Monitoring Requirements

The current rule has very minimal requirements in place to help ensure that the performance standards are being met.

Current Requirements:

- Environmental monitoring is required when coal ash is used in construction of transportation facility embankments. This monitoring consists of measuring the amount of leachate. NR 538.20
- The DNR may require environmental monitoring for uses that do not meet the specific requirements of NR 538.10.

Suggested Improvements:

- Require notifications to the DNR to include an assessment of water contamination vulnerability at the site.
- Include a provision allowing DNR to require monitoring at any coal ash reuse site based on site- and project-specific considerations.
- When monitoring is required, annual chemical analyses of leachate should be included instead of simply monitoring volume of leachate.
- Impermeable liners, groundwater monitoring, leachate collection, financial assurance and other basic landfill safeguards should be required on coal ash reuse sites above a certain size threshold.

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