Groundwater Impacts from Coal Combustion Ash Disposal Sites in Wisconsin

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GROUNDWATER IMPACTS FROM COAL COMBUSTION ASH DISPOSAL SITES IN WISCONSIN

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Introduction

The State of Wisconsin's Department of Natural Resources (WDNR) regulates both coal-powered electric generating plants and the corresponding ash disposal sites. These sites range from active, engineered landfills to closed, unlined disposal sites located in abandoned bedrock quarries, wetlands, and sand & gravel pits. The disposal of coal combustion by-products (CCB) in unlined sites was only an accepted practice in Wisconsin prior to the promulgation of administrative codes and the establishment of procedures for siting and constructing waste disposal facilities. Chapter NR180, Wisconsin Administrative Code for Solid Waste Management was promulgated in 1988. Solid waste disposal, environmental monitoring, and beneficial reuse are currently regulated under administrative code chapters referred to as the NR500 series (NR500-NR590).

Groundwater quality standards for regulating solid and hazardous waste facilities are specified under Chapter NR140, Wis. Adm. Code. Groundwater quality is measured against the enforcement standard (ES) and the preventive action limit (PAL) for substances that are of public health concern. The enforcement standards are roughly equivalent to the federal maximum contaminant levels (MCLs). The preventive action limit is generally 10% of the ES for all substances that have carcinogenic, mutagenic, teratogenic properties or interactive effects and 20% of the ES for other compounds. Enforcement standards and preventive action limits for boron became effective on January 1, 1999. Samples from potable drinking water wells generally are not filtered, and represent total values for compounds and are regulated under Safe Drinking Water Standards in Chapter 809. The regulatory standards for some groundwater contaminants have changed over time and while others have been only recently been codified.

The primary purpose of this paper is to analyze groundwater quality data from a wide variety of Wisconsin CCB disposal sites and to compare and contrast these results with water quality data from the two detailed study sites: the WE Energies Highway 59 and Cedar Sauk landfills. The data was also examined to determine possible trends or similarities between different sites and among various disposal site categories.

Wisconsin Groundwater Quality Data

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To evaluate of the impact of CCB disposal sites on groundwater quality, it became necessary to identify both active and closed CCB monofills in Wisconsin that have active groundwater monitoring. All groundwater quality data for solid waste facilities that is reported to the WDNR is recorded in the Groundwater and Environmental Monitoring System (GEMS) database. The GEMS database is one of the largest in the nation, containing over 10,994,294 analytical results from 18,467 active and 4,259 inactive monitoring points.

From the 22 identified CCB monofill landfills in GEMS, 12 sites (6 active and 6 closed) were chosen based on size, known groundwater impacts, and the completeness of their data sets. A Monitoring Data Summary by Parameter report was reviewed for each of these 12 sites to determine the most impacted monitoring wells at each site. Four compounds were identified as the most commonly detected at levels that exceeded the State of Wisconsin's groundwater protection standards. These compounds include boron, sulfate, arsenic and selenium. Elevated levels of manganese were detected at about half the sites and there were sporadic exceedances of lead, chromium and mercury at several sites. Typically, 3 or 4 downgradient monitoring wells would account for the majority of the exceedances at each site. From there, a Summary Exceedance Report detailing all parameters and results was generated for the most impacted well at each site. The report listed the lowest and highest reported sample results and calculated the mean of all samples collected. A summary of these findings is listed in Table 2.

It must be acknowledged that this analysis is intended as a broad attempt to categorize groundwater quality data that is strongly influenced by a large number of variables, most of which are not easily quantified and not addressed in this study. The type and concentrations of contaminants available for release into a groundwater system are directly related to the coal source, the combustion method employed by the generating plant, and environmental conditions of the disposal site. This information is often difficult to obtain or unavailable, especially for older, long closed sites.

In addition, the groundwater monitoring data presented are the mean value of all available data for the most impacted well at the facility. Some of the wells represented are no longer in service. The location of the well can strongly influence the results and some of the monitoring points were actually screened through or just below the waste mass. Especially with regards to the older, closed sites, the mean can be skewed higher by older data that recorded values that have since declined, in some cases dramatically. Even given these constraints, some interesting results can be discerned from the groundwater quality data.

Measurable quantities of boron were recorded in at least one downgradient monitoring well at all the sites reviewed, including active sites that were constructed with clay liners. However, the boron concentrations tended to be rather low at active lined sites, with 2 sites recording mean values at concentrations below the Wisconsin groundwater standard (0.960 mg/l) for boron. That is in stark contrast to several closed sites that have mean concentrations of boron over 10 times the mean concentration of even the highest value at an active site.

The highest mean boron concentration among all sites was recorded at the Cedar Sauk Landfill (mean 101 mg/l). This value is well above the next highest mean concentrations (69 mg/l and 30.7 mg/l, respectively) for either active or closed sites. The GEMS database documents that the highest recorded boron concentration in groundwater monitoring wells (as high as 186 mg/l) were recorded at wells W-3 and W-3A at the Cedar Sauk Landfill. These elevated boron concentrations were most likely influenced by the boron concentrations in the original coal source and the transmissivity of the disposal environment. Data from EPRI database (January 2004) on the boron content of various coals from different regions of the country indicates that the range of boron content can vary considerably.

Table 1

Boron Concentrations in Coal, by USGS Region

Coal Type	Summary Statistics (mg/kg dry weight) Median	Average	Std. Dev.	Maximum Detected	Minimum Detected	Number of Data Points	Number of Nondetect Values
Eastern Bituminous	25	41	43	201	0.26	60	4
Eastern Interior (Illinois Basin) Bituminous	100	113	57	214	11	47	1
Northern Great Plains Lignite	0.5	53	68	150	126	10	6
Northern Great Plains Subbituminous	29	62	99	353	22	22	3
Rocky Mountain Subbituminous	43	56	22	80	39	5	0

Source: EPRI PISCES Database (January, 2004)
Notes: The concentrations presented in the tables were calculated using one half of the detection limits for all nondetected values. Nondetected values (represented by one half the detection limit) greater than two times the highest detected concentration were removed from the data set before statistics were applied.

All data that are designated as "poor" or "unacceptable" quality in the PISCES Database were excluded from all calculations. All "unknown" quality data were included in the calculations.
Coal analyses are for "as-fired" or "as-received" coals and are presented on a dry weight basis.

As with boron, sulfate was detected in measurable quantities at downgradient wells at all the sites studied. Unlike boron, however, elevated sulfate levels were common among most sites including the active, engineered landfills. The mean sulfate value was above the Wisconsin enforcement standard (ES) of 250 mg/l at 10 of the 12 sites studied. Only one site, the NSP-Woodfield Landfill, had a downgradient well that never recorded a value above the ES. Two active landfills had mean values at (or above) the mean values for most of the closed sites.

Most active sites had mean arsenic values just below the Wisconsin enforcement standard of 10 ug/l. The one active site that had a mean arsenic value above 10 ug/l was the Highway 32 Landfill (30 ug/l). However, the mean was calculated from only 2 data points, so they may not be representative of the actual arsenic concentrations near the landfill. The arsenic levels at other monitoring wells downgradient of the Highway 32 Landfill were significantly lower.

The results that most stand out are the extremely elevated mean arsenic values at three of the closed sites, Edgewater 1-4 (364 ug/l), Nelson Dewey (197 ug/l), and Alliant-Columbia (40 ug/l). The one thing that all these sites have in common is that CCB waste was sluiced to the site before they closed. None of the other parameters studied has such a close correlation with the waste disposal method. In addition, at least one study site, the Highway 59 Landfill, had very low values of arsenic (mean of 3.04 ug/l) in spite of having a documented significant release into a transmissive subsurface environment. All this suggests that the elevated arsenic levels are more related to the coal source or combustion process rather than hydrogeologic conditions.

Selenium rarely exceeds concentrations of 1 ug/l in natural surface or groundwater (Hem, 1992), so it is useful in determining potential releases from CCB disposal sites. Low levels of selenium were detected at all the study sites, with the lowest mean concentrations occurring in the active sites. However, only two sites, the Cedar Sauk Landfill (77 ug/l) and the Nelson Dewey Landfill (78.8 ug/l), had mean selenium values that exceeded the Wisconsin enforcement standard of 50 ug/l. While they had similar mean values, the Cedar Sauk Landfill had some of the highest selenium values (up to 730 ug/l) of any landfill in the study. Other than their elevated selenium levels, the two sites have little in common. This suggests that the coal source may be the dominant factor in determining whether or not excessive selenium contamination will be a problem at any given site.

Site Specific Studies

To further illustrate the nature of groundwater contamination from CCB disposal sites, two landfills, the Cedar Sauk Ash Landfill and Highway 59 Ash Landfill, were examined in detail. WE Energies, formerly the

Wisconsin Electric Power Company (WEPCO), operated both landfills. Both sites were located in old nonmetallic mine sites, neither was constructed with a liner, and both were closed by 1980. These sites were chosen based on their identification by the US Environmental Protection Agency (US EPA) as examples of sites where there was proven or potential damage involving the placement of coal combustion wastes in sand and gravel pits or mines (US EPA, 2000). A third Wisconsin site not included in this study, the Lemberger Landfill in the Town of Franklin, was also identified by the US EPA. The Lemberger Landfill accepted municipal, industrial waste, and power plant ash during its life. Due to the nature of the disposal methods, it was determined that groundwater impacts from contaminants in the municipal and industrial waste could not be separated from potential impacts from coal ash. Given these uncertainties, this site was determined to be unsuitable for any study attempting to quantify the impacts of CCB disposal on groundwater and was therefore not included in this report.

Cedar Sauk Ash Landfill

Background

The Cedar Sauk Ash Landfill (WDNR License # 603) located in the Town of Cedarburg, Ozaukee County, was operated as a disposal site from 1969 through 1979. The fly and bottom ash was generated by the Port Washington Power Plant (WEPCO, 1985). During this time approximately 650,000 cubic yards of ash was disposed of on 25 acres of a 42-acre site. Prior to its development as a landfill, the parcel was used as a sand and gravel pit. The landfill was sited before Wisconsin's solid waste disposal laws were enacted so the site was not constructed with either a liner or a leachate collection system.

In response to approval conditions from the WDNR, WEPCO installed and began monitoring a series of monitoring wells in late 1978. The initial results indicated elevated levels of boron, sulfate and selenium in wells downgradient of the landfill. Follow-up inspections of the closed landfill in 1980 and 1981 revealed vegetative stress characteristic of boron toxicity in the wetland vegetation downgradient of the landfill. Analysis of plant tissue collected from the visibly impacted plants showed boron concentrations from between 300 and 1,600 mg/l. Healthy plant tissue sampled in the area had boron levels between 7 and 61 mg/l (WEPCO, 1982). WEPCO concluded that precipitation percolating through the waste mass and a water table near the base of the landfill were likely the cause of these impacts and they proposed some remedial actions.

In 1983, WEPCO proposed a groundwater mitigation plan to the WDNR consisting of 3 groundwater extraction wells to be placed downgradient of the fill area. The water was to be pumped into Mole's Creek after flowing over rock-filled trench. The WDNR approved the action and the system began operating on September 7, 1984.

During the first 5 years of its operation, the extraction well system seemed to operating well and the contaminant levels in the downgradient monitoring wells dropped. However, by 1990 the levels of all contaminants began to rise again in spite of the extraction system (WEPCO, 1995). Based on groundwater modeling of the system, WEPCO concluded that the capture zone of the 3 extraction wells was inadequate to capture all groundwater contamination migrating from the landfill. To address this problem, WEPCO installed an engineered cap over the landfill in the summer of 1997 consisting of recompacted clay, 30-mil PVC geomembrane and a rooting layer with 2 feet of general fill and 6 inches of topsoil. The cap work was completed on October 3, 1997 and the groundwater extraction system was permanently abandoned.

Geology and Hydrogeology

The Cedar Sauk Landfill is located in an area of hummocky end moraine and glacial outwash deposits from the last of the glacial advances of the Lake Michigan Lobe some 13,000 to 14,000 years before present. The

underlying unconsolidated glacial sediments generally consist of poorly to moderately well sorted sand and gravel deposited on and beneath glacial ice by meltwater streams near the ice margin (WGNHS, 1997). These deposits and underlying tills are assigned to the Oak Creek Formation. Underlying the Wisconsonian-aged glacial deposits is a relatively thick deposit of Silurian dolostone of the Niagaran Series. This massive dolomitic limestone has a highly irregular erosional surface and contains numerous fractures and solution features. Cross-sections based on borings near and beneath the landfill area show that the landfill was sited on a bedrock knob of Niagaran dolostone. The sand and gravel mining operation removed the unconsolidated material over the bedrock allowing waste to be placed directly on the fractured rock. North and east of the bedrock high, towards Mole's Creek, the sand and gravel outwash deposits thicken from absent to 25 feet thick beneath the landfill to over 50 feet thick near the creek.

There are two major aquifers present at the site: the upper sand and gravel outwash deposits and the lower, Niagaran dolostone (WEPCO, 1995). The sand and gravel aquifer is generally unconfined and forms the water table. To the east of the landfill, near Mole's Creek, the sand and gravel unit is underlain by silty clay to clayey silt glacial till unit. Beneath the landfill this unit is either absent due to mining or directly underlain by bedrock.

Groundwater flow in the Niagaran dolostone is primarily through an extensive network of fractures and solution features (including paleokarst) in the bedrock. This aquifer is considered a regional aquifer and is used by private water supply wells in the Town. However, beneath the landfill and elsewhere along the bedrock knob, it is in contact with the upper sand and gravel aquifer and the water table can occur within both units. Groundwater within both the sand and gravel aquifer and the Niagaran bedrock flows from the west to the east and southeast. Mole's Creek is considered a groundwater discharge point for shallow groundwater that flows from the landfill area. Groundwater table elevations within the shallow, unconfined sand and gravel aquifer range from 808 feet above mean sea level (MSL) at the southwest corner of the fill area to 779 along Mole's Creek. There are no strong vertical gradients at any of the nested monitoring wells, although wells west and within the fill area tend to have slight downward gradients and wells to the east trend to have slightly upward vertical gradients.

Groundwater Quality

The Cedar Sauk Landfill has had an extensive groundwater monitoring system in place since 1978. As might be expected, most of the contamination is concentrated in the sand and gravel aquifer that discharges into Mole's Creek. The most common elevated parameters include boron, sulfate and selenium.

The highest levels of both dissolved boron and sulfate were recorded at monitoring wells W-3 and W-3A. These nested wells were located within the waste mass and both wells were screened in ash. The data from these two wells is of limited usefulness because they were only sampled from August of 1979 until June of 1983, while the site was closed but inadequately capped. During this limited period, boron levels ranged from 11 to 186 mg/l in well W-3A and sulfate ranged from 520 to 1923 mg/l in well W-3. Both these levels are well above the Wisconsin enforcement standard (ES) of 0.96 mg/l for boron and 250 mg/l for sulfate. While consistently elevated, the levels could vary considerably even from one month to the next. There were even some distinct seasonal trends over the four years of sampling. This pattern suggests that mobilization of both sulfate and boron were related to periodic inputs of precipitation infiltrating through the ash (WEPCO, 1995).

A detailed review of all groundwater quality data from the site indicated that monitoring well W-4 was the best candidate to represent groundwater impacts from the landfill. W-4 is an active well that has groundwater quality data stretching from August of 1979 to the present. It is located on the eastern edge of the fill area and is screened in the shallow sand and gravel unit. The data indicates that is has been significantly impacted by disposal practices. In fact, the highest levels of selenium, up to 730 ug/l, recorded at the site were from well W-

4. The groundwater quality trends from this well are also very similar to general water quality trends found in other downgradient wells.

The pH values from well W-4 were very consistent and only varied between pH 6.7 to 7.6, with a mean value of pH 7.07, essentially neutral. This is in contrast to the leachate results from wells W-3 and W-3A, where the results were slightly alkaline with pH values between 6.8 and 8.7 with a mean of pH 7.8. These results mirror the results of the larger study presented in this paper, again suggesting that the buffering capacity of even sandy soils at the site were adequate to neutralize the low-level alkalinity in the leachate.

Boron concentrations were consistently elevated at well W-4 with levels between 6 and 140 mg/l, well above the ES of 0.96 mg/l. What is most remarkable about these concentrations is the way they responded to site activity. The boron levels steadily climbed as the site was being filled up to its final grades, going as high as 112 mg/l. However, when the site was finally closed and the relief well system was activated in 1984, the boron levels dropped dramatically from 52 mg/l to 6.8 mg/l in the space of 3 months. The levels fluctuated, but stayed relatively low until they began creeping back up starting in 1993. The exact cause of this upward trend in spite of the continued operation of the relief well extraction system was evaluated (WEPCO, 1995), but an exact cause was not determined. It was suggested that the well system was no longer effectively capturing most of the contamination coming from the landfill.

The boron concentrations reached their peak in August of 1997, when the relief well system was shut down and the new geomembrane cap was being installed. However, after 1997, the boron levels dropped rapidly and dramatically, from a high of 140 mg/l to a low of 14 mg/l in 2003. This drop was mirrored by the sulfate levels, which decreased from 1070 mg/l in 1997 to 262 mg/l in 2003. Clearly, reducing infiltration through the waste mass by installing a geomembrane cover has effectively reduced contaminant concentrations downgradient of the landfill.

While the boron and sulfate at well W-4 reacted in similar ways to the remedial measures at the landfill, selenium levels reacted a bit differently. While selenium levels in W-4 were generally elevated, with levels as high as 980 ug/l, before the site was closed, the selenium concentrations dropped sharply after the site was closed and the relief well system was operational in 1984. Within 3 months (September, 1984 to December, 1984, the same period mentioned with the boron and sulfate results), the selenium levels dropped from 240 ug/l to 12 ug/l and they never recovered. These results suggest that selenium does not stay in solution as readily than either sulfate or boron.

Highway 59 Ash Landfill

Background

The Highway 59 Ash Landfill (License number 918) is located southeast of intersection of state trunk highways 59 (Arcadian Avenue) and 164 in the Town of Waukesha, in Waukesha County. The landfill was sited in a former sand and gravel quarry, which had ceased operation in 1940. The quarry was operated into a hillside, and had a 1.5 acres pond that was approximately ten feet deep and covered 1.5 acres. Coal ash disposal occurred at the site from 1969 to 1978. The facility was originally licensed in 1970, and covered approximately 30 acres. The CCB wastes were derived from eastern bituminous coal fly ash and bottom ash from their Valley Power Plant. Approximately 500,000 cubic yards of solid waste (Class F ash) were deposited in this landfill. The ash has pozzolanic properties but is not self-cementitious (Ladwig, 1989). Waste thickness ranged from less than 10 ft in the southern one-half of the site to more than 40 ft in the northern one-half. Approximately 8,000 cubic yards of ash was deposited below the water table in the pond on the northern portion of the site, and 30,000 yards in the southern portion of the site behind an earthen dike constructed on clay till.

Numerous active private water supply wells are located around the landfill with the exception of the southern side where railroad & utility corridors and low marshy terrain limited construction. Most private wells in the area serve family residences, but there are a few two-family buildings and businesses with wells. Immediately west of the ash landfill is an old abandoned unlicensed (Pre-regulation) municipal waste dump operated by the City of Waukesha in the 1950's and 1960's. An old abandoned foundry sand waste disposal site lies directly west of the City's waste site. Monitoring data from these two sites were used to refine the groundwater flow patterns in the area and evaluate the migration of the CCB contaminant plume.

Geology & Hydrogeology

The geological setting of this site is generally similar to the Cedar Sauk site. There are unconsolidated glacial deposits below the site that range from 90-150 feet in thickness. These deposits were subdivided into four units: an upper sand and gravel unit (suitable as an aquifer), a sandy glacial-till (diamicton) unit, a silty clay unit, and a lower sand and gravel unit (also suitable as an aquifer). The lower sand & gravel unit is in direct contact with the weathered bedrock north of the site. The underlying bedrock is also Silurian Dolomite, which serves as the primary aquifer for the City of Waukesha and many Town of Waukesha. The CCB ash landfill is located upgradient of both of the two other disposal sites mentioned above. The thorough evaluation of the limits of fill and the careful placement of monitoring wells between the ash landfill and the other nearby sites made the task of evaluating the water quality impacts complex but possible.

The groundwater monitoring around the landfill was initiated 1970's. WEPCO initiated a hydrological investigation in 1988, which included the installation of 13 additional monitoring wells and piezometers and the sampling of four private water supply wells adjacent to the site. A report to the Department in 1989 indicated elevated concentrations of sulfate and boron in private water supply wells to the west of the site. There were no NR140 water quality standards for boron at the time of the investigation in 1989. Subsequent groundwater monitoring consisted of sampling 20 monitoring wells and private water supply wells on a regular basis.

Groundwater Evaluation

The time vs. concentration (TvC) plots for various monitoring wells and private drinking water supply wells show a variety of interesting trends. There is a decrease in sulfate levels for shallow wells near the landfill, but boron levels are increasing. This appears to document the continued migration of the high mobility of boron ions. The data for this site showed a close correlation between the occurrence of boron and high levels of sulfate. Molybdenum occurred in the CCB leachate in the low ug/l range. Although it does not have a NR140 standard, it served as a marker for leachate contamination from this site. This distinction was essential for discriminating between leachate contamination from CCB materials, and background levels of sulfate and/or the potential commingling of leachate plumes from the other two waste sites.

The highest levels of both boron and sulfate in monitoring wells were recorded in monitoring well nest W-8, which was located in native materials downgradient and in close proximity to the ash disposed of in the former quarry pond. The sulfate levels are usually three orders of magnitude higher than the boron, but some plots show sulfate concentrations decreasing while the boron have climbed (In Figures 1 & 2: Well W-8A in black, W-8B in blue, and W-8C in red).

The monitoring wells and shallow piezometers are screened in the sand and gravel units. The sand & gravel units southeast, southwest, west, and northwest of the ash site show contamination above enforcement standards

for sulfate and boron. Nine piezometers were completed in the bedrock in order to evaluate deeper groundwater impacts. The migration of CCB contaminates into the deep aquifer may have been hastened by a private water supply well (WJAC) near the western edge of the ash fill. The business operating the well may have been pumping it on a regular basis to wash the numerous cars on their sales lot. This well was the first impacted private well near the landfill. The concentration of sulfates made the water undrinkable and bottled water was supplied up until the time the well was abandoned and the facility placed on city water.

Elevated concentrations of sulfate and boron have been detected in deeper bedrock piezometers primarily northwest of the site. This information confirms that there is northwestern component to the contamination plume, which was not identified in the early stages of the off-site investigation. This component of flow may have been influenced by the installation of a higher capacity water supply well for a large retail store north-northwest of the landfill. This bedrock well has since been abandoned and the building connected to municipal water.

Remediation

WEPCO retained Natural Resources Technology, Inc. and Science & Technology Management, Inc. to evaluate various remedial action alternatives. An environmental contamination assessment (ECA) report was submitted in 1995. Between 1995 and 1998, WEPCO submitted additional reports assessing the degree and extent of the contamination from the landfill. In 1999 WEPCO submitted a remediation plan that included removal of the saturated ash from the northern portion of the site and replacement of ash above the seasonal high groundwater elevation (excess ash was reburned in their Pleasant Prairie Power Plant). It has been noted that several samples of leachate from the on-site basin constructed for dewatering the ash showed molybdenum values two orders of magnitude higher than other samples.

The majority of landfill area was recapped with a synthetic geomembrane. Although ash fill covers about 26 acres, only 19 acres were recapped due to presence of buildings and other structures; some of the remaining ash landfill was covered by asphalt and is being used for parking. The cover design consists of 3-inches of existing cover fill, a 4-inch sand bedding layer, a 30-mil PVC geomembrane, a geocomposite drainage layer (consisting of geotextile and geonet), 2-feet of general fill, and 6-inches of topsoil.

As part of the remediation plan, WE Energies paid for the abandonment of contaminated private water supply wells and the connection to municipal water from the City of Waukesha. The restoration of clean water to the affected citizens was only possible through the cooperation of the local Town and City of Waukesha officials. WE Energies supplied bottled water to residents with affected wells after contamination was detected. Long-term environmental sampling of the monitoring network which consists of wells and piezometers as well as numerous private water supply wells. The WDNR conditionally approved the remedial option selected by WEPCO. The Remedial Design Report was submitted on May 1999.

WE Energies made a case for not excavating the 30,000 cubic yards of saturated ash along the southern portion of this landfill. WDNR recommended the removal of these materials since they seemed to represent an additional source of leachate generation. The WDNR included additional environmental sampling of private water supply wells as a condition of approving the remedial action plan. The monitoring frequency for downgradient water wells is currently being increased in response to movement of the plume of CCB contaminants.

FIGURE 1

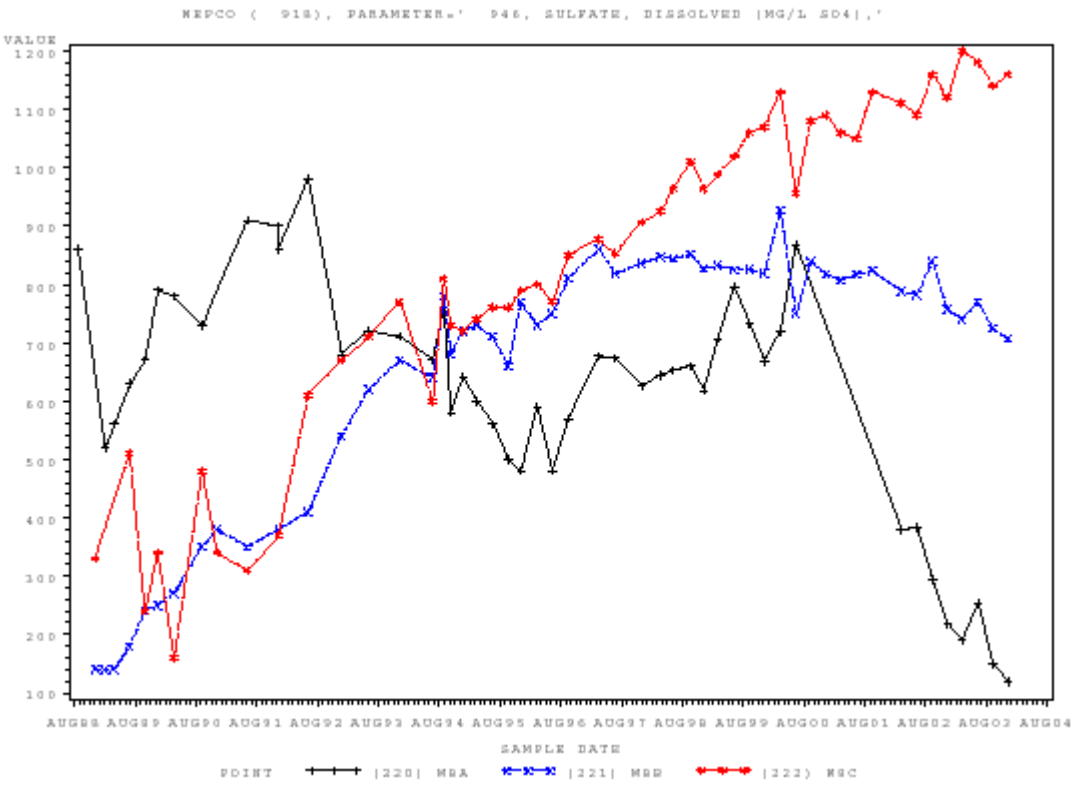
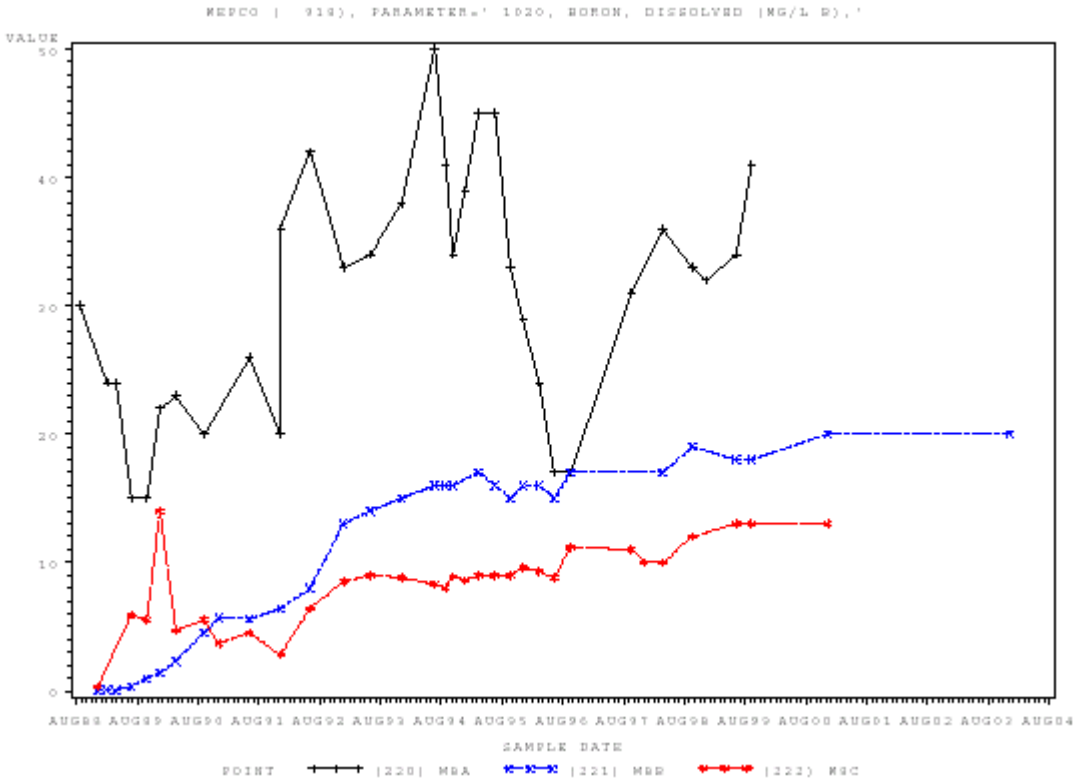


FIGURE 2



Conclusions

As mentioned earlier, this study was a simplified attempt to extract some meaningful conclusions out of a very large amount of groundwater monitoring data. The results can be considered fairly conservative because the means were calculated based on the most contaminated well at the site using all historical data without regard to the well's placement (including those located in the waste mass itself) or status. While much of the analysis was inconclusive, several general trends can be discerned.

First of all, it appears that the engineered, recompacted clay liners at the active sites evaluated are effective at limiting groundwater contaminate releases. They are by no means perfect and there were measurable groundwater impacts in at least one monitoring well downgradient of each landfill. However, the contaminant levels were, in most cases, an order of magnitude lower when compared with the results from the closed, unlined landfills. This is especially true with regards to arsenic and boron concentrations.

A review of groundwater quality data at both active and closed disposal sites in Wisconsin indicates that boron, sulfate, arsenic and selenium are generally the best indicators of water quality impacts from CCB disposal. Manganese was also indicative of groundwater impacts, but there weren't enough sample results to adequately characterize the connection. Of all the parameters studied, boron seemed to the best indicator of groundwater impacts. Arsenic was only useful at sites that sluiced their waste or used certain coals that were high in arsenic. Arsenic was also only found in appreciable amounts at wells that were screened within the waste or fairly close to the waste fill limits and may be documenting an ion halo effect. Further out, arsenic likely undergoes a geochemical interaction with the groundwater, complexes with iron hydroxides or organics and is therefore no longer chemically available to go into solution (Hem, 1992).

The data certainly suggests a strong connection between the practice of sluicing CCB waste and strongly elevated levels of certain compounds, including heavy metals and arsenic, in the leachate and groundwater. This problem is confined to older, closed sites, as sluicing CCB waste has not been practiced in Wisconsin since the mid-1980's.

In fact, the volumes of CCB waste disposed in Wisconsin has dropped dramatically as the power utilities have switched to dry handling and have aggressively pursued beneficial reuse options for their CCB wastes. In fact, as of 2003, WE Energies now reuses more CCB waste than they produce. This is due to a WE Energies project at their Pleasant Prairie Landfill where they are mining an old site, reburning the ash, and beneficially reusing the subsequent ash. Most ash is beneficially reused in concrete as an additive or as fill in construction projects.

As for the site specific studies, it should be noted that the results at Cedar Sauk and Highway 59 Ash Landfills were the result of a very specific set of circumstances that should not be extrapolated to any specific site or use except in a very general sense. Each disposal site was unique with respect to the geologic environment and the type and nature of the CCB waste. All of these factors combined to determine the degree and extent of contamination at each site, including the type of contaminant found.

Another factor that should be considered, especially at the Cedar Sauk Landfill, was that the most contaminated monitoring wells were located and screened in waste. In effect, they were measuring leachate quality, not groundwater. This is hardly unique to Cedar Sauk, as the statewide study revealed several other old sites where the highest contamination was from wells that were constructed within the waste mass as generally recommended by the US EPA at the time of the installation of the wells. It is also significant that some of the highest contamination levels were detected before the sites were closed and capped. These early results certainly can skew the mean values higher.

The documented impacts to groundwater quality at both sites were also exacerbated by the geology of the disposal sites, which included fractured bedrock and highly transmissive outwash sands and gravels with little attenuation capacity. Inadequate capping of the waste masses until recently also allowed precipitation to infiltrate through the waste mass and pick up contaminants that was then transmitted to the groundwater.

However, it is important to note that, under current rules, the siting and facility design of either of these landfills would not be acceptable if they were still operating. The State of Wisconsin has very vigorous design and monitoring standards for the very reason that many areas of the State contain high-quality shallow groundwater that is used and valued by its citizens.

It should also be noted that the remedial measures installed by WE Energies at both these sites have been effective at dramatically reducing groundwater impacts. The Cedar Sauk Landfill remediation project shows that proper capping of a CCB landfill is highly effective at reducing negative impacts to groundwater quality. Water quality at the Highway 59 site has improved, but several plumes are still migrating through both the sand & gravel and bedrock aquifers. The size and extent of the contamination makes off-site groundwater extraction difficult when balanced against the decreasingly available water resources for the City of Waukesha.

Acknowledgments

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Table 2

Parameter / Facility name	Boron (mg/l)[2]	Sulfate (mg/l)	Arsenic (ug/l)[3]	Selenium (ug/l)	Other Compounds	Status
Alliant - Columbia Landfill Lic# 2325	Range 0.18-4.3 Mean 3.2	Range 210-870 Mean 457	Range 5-170 Mean 40	Range 0.5-7 Mean 1.86	Lead - 10-140ug/l Manganese - 320-830 ug/l	Closed Sluice Site
WP&L - Rock River Landfill Lic# 0728	Range 1.3-3.7 Mean 2.2	Range 53-900 Mean 322	Range 7-11 Mean 9	Range 1-5 Mean 3		Active
WP&L - Nelson Dewey Landfill Lic# 2525	Range 2.3-28.4 Mean 9.23	Range 75-2100 Mean 1144	Range 5.5-800 Mean 197	Range 10-320 Mean 78.8	Manganese - 720-1200ug/l Chromium - 45-68 ug/l	Closed Sluice Site
WEPCO - Pleasant Prairie Landfill Lic# 2786	Range 1.7-3.6 Mean 2.8	Range 1120-1340 Mean 1215	No Data	Range 3.1-11 Mean 5.65	Mercury - 0.3-1.6 ug/l	Closed Being Mined
WEPCO - Hwy. 32 Landfill Lic# 2801	Range 0.5-3.7 Mean 0.85	Range 87-1100 Mean 447	Range 25-35 Mean 30	Range 0.9-4 Mean 2.4		Active
WP&L – Edgewater 1-4 Landfill Lic# 2524	Range 29-120 Mean 69	Range 640-2600 Mean 1661	Range 150-540 Mean 364	Range 1-8.4 Mean 4.7		Closed Sluice Site
NSP – Woodfield Landfill Lic# 3233	Range 0.17-0.24 Mean 0.24	Range 40-96 Mean 63	Range 7-11 Mean 9.5	Range 0.5-8 Mean 3	Lead - 28-38 ug/l Manganese - 380-510 ug/l	Active
Dairyland – Belvidere Landfill Lic# 2927	Range 1.4-9.1 Mean 5.25	Range 750-2000 Mean 1403	No Data	Range 2.9-30 Mean 18		Active
WPSC - Weston #3 Landfill Lic# 2879	Range 0.22-2.68 Mean 1.02	Range 51-791 Mean 210	Range 6.7-16.7 Mean 10.7	Range-91.4 Mean 23	Lead - 0-9.7 ug/l Manganese - 460-1620 ug/l	Closed
WE Energies - Cedar Sauk Landfill Lic# 0603	Range 11-186 Mean 101	Range 520-1923 Mean 1397	No Data	Range 1-730 Mean 77		Closed
WE Energies - Caledonia Landfill Lic# 3232	Range 0.2-9.3 Mean 4.37	Range 260-430 Mean 311.6	Range 1-17 Mean 5.26	Range 0.6-5 Mean 1.6	Manganese - 10-110 ug/l	Active
WE Energies - Highway 59 Landfill Lic# 0918	Range 15-50 Mean 30.7	Range 836-1170 Mean 1034	Range 2-5 Mean 3.04	Range 0.002-20 Mean 7.84	Manganese - 490-670 ug/l	Closed

1 - Values represent the range and mean of all detects listed in the GEMS database for the most impacted groundwater monitoring well for each specific parameter at the facility.
2 - Milligrams per Liter (mg/L) or parts per million (ppm).
3 - Micrograms per Liter (ug/L) or parts per billion (ppb).

Contact 608/266-2111 or DNRWasteMaterials@Wisconsin.gov for further information.

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