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Flambeau Mine: Water Contamination and Selective "Alternative Facts"

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“The facts are really not at all like fish on the fishmonger’s slab. They are like fish swimming about in a vast and sometimes inaccessible ocean; and what the historian catches will depend partly on chance, but mainly on what part of the ocean he chooses to fish in and what tackle he chooses to use---these two factors being, of course, determined by the kind of fish he wants to catch. *By and large, the historian will get the kind of facts he wants.”*

Edward Hallett Carr [What is History? 1961]

Flambeau Mine: Water Contamination and Selective “Alternative Facts”[1]

Editor’s Note: *Bob Moran was nearly finished with this report at the time of his premature death in May 2017. I was asked to attempt to finish Bob’s report. I have attempted to do so while retaining all of Bob’s analyses and conclusions, with as little of mine as necessary to complete the report. In addition, Bob typically inserted more humor and wit than is typical of my writing, and I apologize to Bob for not being able to add those elements which I know from his notes he fully intended to do.*

– David M. Chambers, Ph.D., P. Geop., May 2019

Part-I: Summary.

1 - Roughly 20 years after the cessation of active mining, Flambeau Mine *ground waters* are contaminated by past Flambeau Mining Company (FMC) activities. FMC data confirm that, as a minimum, *dissolved* concentrations of the following constituents significantly exceed FMC’s baseline concentrations (1987-88): copper, iron, manganese, zinc, sulfate, alkalinity, hardness, total dissolved solids, specific conductance (field). Interestingly, these are practically the only parameters routinely reported by FMC in their quarterly monitoring.

2 - These ground waters are also being contaminated with numerous additional metals and metal-like elements (e.g. aluminum, arsenic, chromium, lead, nickel, uranium, etc.) as a result of FMC operations. These have degraded, and continue to degrade, local ground and surface water quality, as shown by analytical data from waste rock leachates, selected FMC

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[1] This project was undertaken by Dr. Robert E. Moran in February 2017 at the request of, and with initial funding provided by, the Wisconsin Sierra Club, Wisconsin Resources Protection Council and Deer Tail Press. Dr. Moran published a summary of his initial findings in April 2017 (https://remwater.org/projects/flambeau-mine-ladysmith-wisconsin-u-s/) and continued work on a more detailed report to be issued later the same year. Upon the premature death of Dr. Moran, the project was completed by Dr. David M. Chambers and research assistant Laura J. Gauger, with funding provided by Deer Tail Press and Deer Tail Scientific, Duluth, Minnesota, U.S.A.

monitoring data, and the Discharge Monitoring Reports for the permitted effluents. Drawing reliable, quantitative conclusions about these constituents is difficult as FMC has been allowed to characterize the water quality using data that are not representative of the actual, chemically-unstable ground waters.

3 - Geochemical and water quality data from similar massive sulfide deposits, worldwide, routinely contain elevated concentrations of trace constituents such as: aluminum, antimony, arsenic, barium, cadmium, copper, chromium, cobalt, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, zinc, sulfate, sulfide, nitrate, ammonia, boron, fluoride, chloride, natural radioactive constituents (sometimes uranium, radium, thorium, potassium-40, gross alpha and beta). Thus Flambeau ground and surface waters likely contain such chemical constituents, but *analytical results for many of these constituents were never reported from filtered samples and no data from unfiltered samples were released in monitoring reports (for ground waters) available to the public.* All similar massive sulfide deposits generate degraded water quality in the long-term.

4 - Flambeau Mine whole rock analyses of *waste rock samples* reported in the 1989 Environmental Impact Report (EIR) for the project confirm that these rocks also contain many of the trace elements mentioned above, including uranium (Foth, 1989a – Appendix 3.5-O). Antimony was not reported, but should have undergone further analysis as it often substitutes for arsenic in numerous sulfide minerals identified in Great Lakes massive sulfide ores. FMC failed to report similar detailed analyses for the Flambeau *ores* in the 1989 EIR, which would have shown much higher trace element concentrations than the concentrations reported for the waste rock.

5 - The Wisconsin Department of Natural Resources (DNR) allowed FMC to leave out of the EIR (1989) all of the detailed ground water quality data from the 1970s and the detailed interpretations of the long-term pumping tests that were conducted in 1971. This selective release of data was justified by FMC consultant Foth & Van Dyke as follows: “The previous groundwater sampling program was conducted according to state-of-the-art procedures that existed in the early 1970's. However, the science of groundwater monitoring has changed since that time. In addition, quality control concerns pertain to some of these data as well**.** As a result**,** much of the data generated by that program is not acceptable by current standards. This includes all groundwater quality data, for example” (Foth, 1987). As will be explained later, these comments by an unnamed author are technically false, and were clearly written by someone who had not conducted detailed hydrogeological and water quality studies during the 1970s.

6 - For decades, some of the most relevant data and the most significant water-related impacts at the Flambeau Mine site have been withheld from public view. Parameter concentrations from most FMC wells are not quantitatively-reliable due to: failure to collect unfiltered samples; inadequate well construction, well development and purging; and, unacceptable sampling procedures. Frequently, important chemical constituents were missing from analyses, inappropriate analytical detection limits were employed, and crucial data were not reported. Most importantly, the DNR allowed FMC to inappropriately restrict the list of chemical constituents monitored in waters from wells, waste rock, pit leachates, and the

influent waters to the mine's waste water treatment plant (WWTP). FMC permit reports and subsequent public documents were based on these inadequate data.

7 - FMC wells within the backfilled pit have *median* dissolved concentrations as high as the following (2014-16): Copper = 503 µg/L; Iron = 14,000 µg/L; Manganese = 33,500 µg/L; Zinc = 1,200 µg/L; Arsenic = 23 µg/L; Sulfate = 1,600 mg/L; Alkalinity = 610 mg/L; Hardness = 2,150 mg/L; Total Dissolved Solids = 3,110 mg/L; Specific Conductance = 3,180 µS/cm. These values greatly exceed baseline data and relevant water quality standards and aquatic life criteria. FMC's "baseline" ground water data report that uranium was detected in between 64% to 100% of their samples, depending upon the well producing zone, yet uranium was not included in the routine monitoring.

8 - Ground waters in contact with sulfide-rich rocks and backfilled waste are chemically-unstable and complex. When samples are lifted to the surface (by bailing, pumping, etc.) and exposed to the atmosphere, the compositions change rapidly, often within seconds or minutes. Dozens of formerly-dissolved metals and metal-like constituents begin to form micro-particles which gradually clump together, reducing their concentrations as the precipitates form and fall to the bottom of the sample containers. When these chemically-unstable waters are *filtered in the field*, this mix of particles plus trapped trace constituents is removed from the water sample, prior to being acidified and sent to the lab for analysis. Thus, the concentrations of these metals and metal-like elements originally dissolved in such ground waters are greatly reduced when reported later in the laboratory analyses. All routine FMC ground water monitoring data are from filtered samples, from which some, if not most of the chemical components have been removed, thereby lowering the original concentrations. [The same is routinely true for older wells in contact with sulfide-rich rocks – such as many of the FMC wells constructed in the 1970s.]

9 - Because chemical components in mine-impacted ground waters are transported as both dissolved and particulate forms (sediments, colloids, chemical precipitates), interpretation of the FMC data is largely meaningless without having data from both filtered and unfiltered samples[2].

10 - The west end of the Flambeau pit is within roughly 140 ft. of the Flambeau River. Thus, Wisconsin regulators should have required FMC to report all water quality constituents from both ground and surface waters that have relevant standards and criteria (during both baseline and routine monitoring), to determine whether FMC releases might be damaging to any of the relevant water uses: human consumption; aquatic life; agricultural and irrigation. Such data would have required collection of both *field-filtered & acidified and unfiltered & acidified samples for analysis of a much wider list of chemical constituents than reported by FMC, employing appropriate detection limits.* Unfiltered sample data are especially relevant where impacts to aquatic life may be anticipated. *Fish and macroinvertebrates are capable of*

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[2] **Editor's Note:** Groundwater samples are typically measured as filtered (dissolved) as opposed to unfiltered (total). This is traditionally because it is assumed the material through which the groundwater travels will act to filter out any suspended material, which Dr. Moran points out is not the case. Depending on the use of the groundwater (e.g. drinking water, and water moving from an aquifer into a surface water), suspended material could be transmitted to groundwater users.

ingesting both dissolved and particulate forms of potentially-toxic chemicals discharged into aquatic environments, which can then be concentrated up the food chain.

11 - FMC has incorrectly defined baseline conditions, thereby biasing later conclusions. Exploration drilling has been conducted at Flambeau since roughly 1968. Thus, hundreds or more exploration boreholes (down to depths of more than 800 ft.), together with road and site construction, trenches, dozens of monitoring wells, piezometers, geotechnical borings, and possibly tunnels have been constructed at the site prior to actual mining of ore. Such activities increase sediment loads and create pathways interconnecting the various horizontal and vertical portions of the local rocks, introducing atmospheric oxygen and other gases, microbes, and surface water, all of which alter the original baseline water quality and geochemical conditions. Hence, FMC's ground water quality data collected in 1971-72 and again in 1987-88, both of which the company refers to as "baseline," actually represent water quality that has been altered and somewhat degraded by these pre-mining activities.

In addition, it appears that filtered samples were the only sources for all of FMC's "baseline" ground water data. As such, much of the metal data would have been reported as "less than detection limit", thus FMC was incorrectly allowed to remove these metals from their future monitoring.

12 - All of the FMC wells and piezometers drilled in the 1970s were constructed prior to initiation of any active mining. Yet, as mentioned earlier, no data from these earliest wells were included in the 1989 EIR or 1990 Environmental Impact Statement (WDNR, 1990). A number of these older 4-inch diameter wells still exist and are characterized as "active" by the Wisconsin DNR but are no longer monitored except for reporting ground water elevation (WDNR, 2017b). In addition, several 1980s-vintage wells have been replaced by FMC, sometimes under questionable circumstances, breaking the historical data continuity.

13 - Because FMC had already constructed numerous wells and other excavations into sulfide-rich rocks by the early 1970s, they and the Wisconsin DNR clearly should have known that such wells do not show evidence of contamination initially (USFS, 1990). They must "mature" geochemically to show indications of water quality degradation, which may require months or years to become evident. Thus, it was totally inappropriate for the DNR to allow FMC to reduce the list of chemical constituents determined after only a few months of monitoring--in ground waters and waters to be treated in the operating waste water treatment plant in 1993 to 1998.

14 - The water chemistry of <u>newly constructed wells</u> is often unstable due to contamination with bentonite-cement grouts and drilling additives, and via inadequate well development. Thus, replacement of original wells with new wells often artificially elevates the pH and biases the monitoring data. This would have been evident to the public if, in addition to the other parameters reported in their publicly-available documents, FMC had reported the following: field <u>and</u> lab values for pH and specific conductance; turbidity; and, total suspended solids concentrations.

15 - Where chemically-unstable waters exist, it is imperative that all wells be thoroughly developed after construction, and thoroughly evacuated prior to each subsequent sampling.

The diameter of most FMC monitoring wells currently in use (constructed for the 1989 EIR and later within the backfilled pit) is too narrow (inner diameter ≈ 2 in.) to allow adequate development (cleansing) or sampling. Screen openings are also too small to allow free passage of chemical precipitates (sediments/colloids). Thus, much of the FMC ground water data is not representative of the *in-situ* water quality.

16 - FMC avoided reporting the actual quality of waters being discharged from numerous sources of contaminants and permitted discharge points during active mining (1993-97). Misleading water quality data, or in some cases no data at all were reported from:

- Wells outside the pit – An inadequate panel of constituents was reported on a quarterly basis during mine operations and immediately after. A more extensive, but still inadequate list of trace constituents was not reported until mid-1999 (nearly two years after the mine pit was backfilled), and to the present time is reported only once per year (Foth, 1993c). Additional important chemical constituents were frequently not determined (or not made public) when samples were analyzed. These include for example: sulfide, total suspended solids (TSS), turbidity.
- Exposed pit walls, floor and ore piles – Review of company reports revealed no actual water quality data reported for waters being discharged from these sources.
- Surface Waters – Monitoring was unacceptably limited both in terms of the number and location of sampling sites and the number of constituents reported. FMC established only two sampling sites in the Flambeau River, one upstream of the project site (SW-1) and the other (SW-2) roughly 500 feet downstream of the mine pit (Foth, 1993c). No sampling was done in the mixing zones associated with either of the mine’s two engineered outfalls to the Flambeau River (Outfall-001 and Outfall-002) or immediately adjacent to the pit. Nor was any water quality data reported for a Flambeau River tributary (Stream C) that crosses the southeast corner of the mine site, where the ore crusher, rail spur and Type II waste rock stockpile were located, or at its confluence with the Flambeau River. FMC’s downstream monitoring site in the river is notably *upstream* of the Stream C confluence.
- “Low” sulfur and “high” sulfur waste rock stockpiles – No detailed data were reported. Sampling procedures approved by the Wisconsin DNR required FMC to collect leachate samples for analysis from each of the two waste rock stockpiles on a quarterly basis only. Samples were filtered prior to analysis (using 0.45 and 0.2 micron filters), and the test panel was limited to pH (lab and field), specific conductance (field), chromium (in exfiltrate from “low” sulfur waste rock only), copper, iron, manganese, sulfate, total dissolved solids, total alkalinity and total hardness (Foth, 1993c; FMC Annual Reports, 1993-1997).
- Waste water treatment plant – FMC was allowed to severely restrict the constituents being determined in the WWTP effluents after only 12 weeks of sampling, when blasting in the pit had commenced only 2 months earlier (FMC, 1993c). Thus, waters collected for treatment would have had insufficient time to evolve chemically and become suitably representative of waters in contact with sulfide-rich rocks.

17- FMC waste rocks were acidic and releasing contaminated leachates long before they were returned to the pit (both “low” sulfur and “high” sulfur types). Few data have been made public. One sample of water seeping from a **“low” sulfur** waste rock pile in 1996 had a **dissolved copper** concentration = **53,150 µg /L** (FMC, 1997c). Other waste rock leachate waters were already mildly acidic by 1994 and became more acidic by the fourth quarter of 1995 (“low” sulfide pH = 5.8; “high” sulfide pH = 5.9); by the fourth quarter of 1996 the high sulfide waste leachates had pH = 3.1, and copper concentration = 450,000 μg/L. Chromium was reported in low sulfide waste effluents and *predicted* it was reaching the water table (FMC, 1997a). At a pH of 3.1, it is clear that many other trace and minor elements would also be present in these leachates, but FMC failed to report them. In addition, the company failed to identify leachate test results as Dissolved or Total Recoverable in its 1995-1997 annual reports.

18 - FMC permit-related documents have often failed to distinguish field versus lab measurements of pH and specific conductance in ground and surface waters, or to distinguish data from filtered samples (Dissolved concentrations) versus unfiltered samples (Total concentrations).

19 - The Flambeau ore body extends under the river to the west (Schwenk, 1977), but mining was limited to the area of the mined pit, east of the river. The backfilled pit is within highly fractured rock (Yost, 1997b), is intersected by several faults (Yost pit map, 1997a; Straskraba, 1997; May & Dinkowitz, 1996), and blasting has increased the natural fracturing (Straskraba, 1997). These abundant fractures and faults presumably act as pathways for ground water migration, with the backfilled pit acting as the preferred flow path within the Precambrian bedrock.

20 - FMC hydrogeological and pit water quality data indicate that the river and pit waters are likely interconnected—at least at shallow depths—with flow directions changing seasonally as the respective water levels (head relationships) vary. Shallow ground waters from the backfilled pit are likely migrating downgradient, around, under, and possibly through the mine’s slurry cutoff and diaphragm walls into the Flambeau River and surrounding alluvial sediments. The overall hydrogeological relationships suggest that the deeper ground waters may be migrating under the river sediments via fractures and faults. It is unclear whether contaminants have or could migrate to the west side of the river via such a deep path. Over decades, FMC has failed to conduct detailed investigations to evaluate the uncertainties of this basic ground water pathway question. **Neither the actual flow pathways for ground waters exiting the backfilled pit nor the ground water-surface water interactions have been defined.**

By focusing attention on the seepage of degraded-quality pit waters into the Flambeau River but failing to provide data to clarify the probable flow of ground water below the Flambeau River, in the deeper alluvial sediments and or bedrock, FMC has diverted attention from a potential long-term problem, barely regulated.

21 - The narrative “predictions” made by FMC’s main Wisconsin consultant in the various permit-related and Annual Reports appear to be largely naïve geochemically and hydrogeologically. It is doubtful that these statements represented the opinions of FMC’s technical experts (e.g. Forth, John, 1993-1994). Such statements are most useful for obtaining permits, less so for generating quantitatively-reliable predictions.

22 - Monitoring wells located outside the pit in the downgradient flow direction show clear evidence of contamination relative to baseline concentrations and relevant standards and criteria. For example, a well located between the southwest corner of the backfilled pit and Flambeau River (MW-1000R), had dissolved manganese concentrations of 13,800 µg/L and a specific conductance of 660 µS/cm in October 2016 (FMC, 2017a).

23 - FMC has argued that degraded pit waters flow into and are diluted by the large flows of the Flambeau River, located only 140 feet from the west end of the pit (Foth, 1989d). However, as noted above, FMC has not tested and evaluated the extent to which such pit seepage is limited to shallow pathways through alluvium and fractured bedrock into the river, or whether deeper pathways under the bed of the river may be viable. Apparently no baseline or recent monitoring of wells on the west side of the river (opposite side from pit) has been conducted by FMC or the State. Thus, it is also not possible to determine whether ground waters west of the Flambeau River have been negatively impacted by FMC operations.

24 - At present, it is not possible to demonstrate that Flambeau River chemical constituent concentrations have been degraded by FMC activities. This is partly due to the totally-inadequate surface water monitoring data made public by FMC. To this day, the company only monitors the Flambeau River at the two locations cited earlier, and the test panel remains unacceptably limited[3]. Secondly, the physical relationships between the backfilled pit, the Flambeau River and the surrounding rock formations indicate that *most* of the contaminated pit water is likely migrating downgradient in the Precambrian bedrock via fractures and faults, and is not entering the river.

If, as FMC argues, contaminated pit waters are entering the River, then they are already increasing the *loads (mass)* of the various metals, metalloids, sulfate, sediments, etc. added to the Flambeau River. Had FMC monitored for an extensive list of chemical constituents during the years of active mining (1993-1997) – instead of the incorrectly-reduced list instituted roughly three months after start-up of the waste water treatment plant – increases in concentrations and masses of metals released into the Flambeau River would have been obvious. Note that an average of 11.4 million gallons per month of inadequately-treated WWTP effluents were discharged into the Flambeau River via Outfall 001 in 1993 alone, and a grand total of over 600 million gallons over the full course of WWTP operations (FMC, 1994a and 1999a).

25 - The Flambeau River also received contaminants from numerous other sources of FMC property effluents: surface inflows from Stream C; the Copper Park Lane drainage ditch and other facilities adjacent to where the ore crusher and rail spur were located; from wetlands, storm runoff; stockpiled waste rock leachates and seeps; ore stockpiles; releases from the settling ponds and surge pond; interceptor well discharges; clarifier underflow solids (sludge from the WWTP); and, inadequately-treated effluents from the WWTP. Several of these

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[3] **Editor's Note:** In late 2018, FMC requested modifications to its existing environmental monitoring plan for the Flambeau site. Changes include total elimination of the company's surface water monitoring program (FMC, 2018d – see electronic pages 192-193). As of this printing, it is unclear if FMC's request will be granted by the Wisconsin DNR.

sources are presently contributing contaminants to the Flambeau River via surface water pathways, and probably also via ground water pathways.

26 - Contaminated discharges from the southeast corner of the FMC site, also known as the “industrial outlot,” have resulted in Stream C being added to the Environmental Protection Agency impaired waters list for exceedances of acute aquatic toxicity criteria for copper and zinc and have caused the State of Wisconsin to withhold issuance of a Certificate of Completion of mine reclamation for this portion of the mine site. Since 1998, FMC has instituted six different work plans to address this soil and water contamination issue. As of fall 2016, copper levels in the Flambeau River tributary still exceed the acute toxicity criterion, despite passive water treatment (FMC, 2017b)[4].

27 - It appears that not all of FMC’s permitted discharges may have been reported. The company’s Wisconsin Pollution Discharge Elimination System (WPDES) permit authorized discharges to the Flambeau River through several different outfalls, including Outfall-001 (WWTP) and Outfall-002 (settling ponds). Review of the Discharge Monitoring Reports (DMRs) shows that on only one occasion (January 1993) did FMC report any discharges through Outfall-002. This particular DMR indicated high levels of total aluminum in the Outfall-002 effluent (daily max for total aluminum = 1,280 µg/L). Chromium, copper, lead, nickel and zinc were also detected (FMC, 1993b).

Reporting only one discharge from the settling ponds through Outfall-002 is curious, especially since FMC had stated in the 1990 EIS that the annual average discharge rate from the ponds was expected to be 29 gallons per minute. However, with the exception of the January 1993 DMR cited above, all other monthly DMRs that were reviewed (January 1993-August 1998) indicated: “Discharge occurred only through Outfall 001 during this time period.” In September 1994, torrential rains caused historic flooding of the Flambeau River in the vicinity of the mine site, yet the DMR still reported that no flow occurred through Outfall 002 for that month (FMC, 1994e).

28 - Increasing the mass of metals in the Flambeau River, either as dissolved or particulate forms (suspended or bedload sediments), has the potential to harm the aquatic biota because these organisms are capable of consuming metal-laden particulates, which can then be concentrated up the food chain. Between 1991 and 2011, FMC conducted various studies of Flambeau River sediments, macroinvertebrates, crayfish and walleye to assess potential impacts. No data from independent sources are available, but in 2009 a University of Wisconsin aquatic ecologist reviewed FMC’s sediment and biological data that had been collected to date and concluded the following:

“Inadequate baseline data and sample replication, combined with changing sampling procedures make it very difficult to draw any conclusions regarding the presence or absence of a mining-related effect on the sediment of the Flambeau River. The combined observation of statistically significant increased copper concentrations in crayfish (whole-body specimens), walleye (liver tissue) and sediment (when 2008 downstream copper

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[4] **Editor’s note**: Data submitted by FMC to the Wisconsin DNR for 2017 and 2018 (after Dr. Moran drafted his comments) demonstrate that copper concentrations in Stream C continue to exceed the acute toxicity criterion downstream of the mine site (FMC, 2017c-d, 2018b and 2018e).

measurements are included) downstream from the mine site raises the possibility of a causal relationship. Unusually high copper and zinc concentrations in a sampling site within the bed of intermittent Stream C indicate a possible entrance-point for some potential toxins into the Flambeau River" (Parejko, 2009a).

29 - The dissolved concentrations of most metals and metal-like elements in mine-impacted ground waters generally increase as water pH becomes more acidic. Thus, backfilled waste rock at Flambeau was mixed with limestone to minimize the formation of acid and release of trace constituents into the pit waters. However, the rise in pH due to the addition of limestone (or especially lime) can also generate conditions that increase the water concentrations of those trace elements that form mobile species *at elevated alkaline pHs, such as aluminum, arsenic, antimony, chromium, lead, manganese, nickel, selenium, molybdenum, uranium, vanadium, zinc, and possibly some forms of mercury, strontium, thallium and rare earth elements*. Alkaline pHs can also release some metals and metalloids from the surfaces of sediment particles, increasing their dissolved concentrations and increasing their mobility. The Flambeau Mining Feasibility Study by Pincock, Allen & Holt Inc. that is cited in the 1989 EIR (Foth, 1989a – p. 4.3-A-1) may contain detailed geochemical testing to demonstrate the potential formation of such chemical forms mobile at elevated pHs. *Feasibility studies are required to inform potential investors, but this one apparently was not released to the public.*

30 - Wastes from the FMC operation will remain onsite *forever*. While limestone was added to the waste rock as it was backfilled into the pit, the ability of the limestone to neutralize or buffer the formation of acid waters is limited and finite. After the limestone has reacted with the waste rock, its neutralizing action will diminish and the *pit waters will become increasingly acidic and the concentrations of potentially-toxic contaminants are likely to increase – assuming representative data are obtained.* As the limestone becomes coated with other chemical reaction products, the buffering action ceases. Roughly 20 years, post-closure, the deeper pit well waters at Flambeau show evidence of water quality degradation relative to baseline data and relevant standards and criteria, in spite of FMC's limestone amendment program. It is reasonable to conclude that the Flambeau ground and surface water quality will further degrade in the coming decades if current site maintenance practices continue.

31 - The original FMC permit-related documents contained simplistic statements about what activities would be done. In actuality, the public has no way of knowing precisely what was done with respect to waste disposal, addition of lime and or limestone, diversion of liquid effluents, etc., as almost all of the information was supplied by FMC or their contractors, without sustained <u>independent</u> oversight.

32 - The Wisconsin DNR failed to define viable <u>compliance measures</u> for the FMC operation as revealed by the following:

- The state-established compliance boundary for enforcement of ground water quality standards extends to the opposite (west) side of the Flambeau River from the mine. Because there is no groundwater monitoring across the Flambeau River, the boundary ignores possible impacts to the water quality of the river, and to groundwater on the west side of the river;

- The compliance wells are inadequate in number and location; only one set of nested wells (MW-1015A/B) is located anywhere near the compliance boundary;
- Some of the compliance criteria and standards applicable to the project were generated via largely-useless predictions made by FMC's consultants.

Lastly, despite numerous exceedances of the relevant ground water quality compliance standards and criteria, the DNR has taken no meaningful enforcement actions. Thus, the contaminated FMC ground waters represent a "sacrifice zone".

33 - Obviously the mining and remediation practices employed at Flambeau do not represent a *sustainable, long-term solution*. While FMC may have satisfied the State oversight and disclosure requirements, the site ground waters are contaminated, and *these waters would require expensive, active water treatment to be made suitable for most foreseeable uses.* The operating and maintenance costs for such plants are extremely high. I have worked on several projects where the present water treatment costs have been hundreds of millions of dollars, and in some cases the costs must be paid by the taxpayers.

34 - FMC and their contractors supplied all of the data and interpretations used to compile the permit-related reports and subsequent Annual Reports. Such an approach obviously reflects FMC's interests, but is likely quite different from financially-independent, public-interest science. In short, the Flambeau Mine is the poster child for a severely-flawed permitting and oversight process that has likely generated long-term public liabilities.

35 - I know of no metal-sulfide mines anywhere in the world that have operated without degrading the original water quality, long-term – even those employing modern technologies. Given this historical reality, FMC's approach has been to ensure that damaging data have not been made public.

As a minimum, a program of water quality monitoring totally independent from any financial or political control by FMC (or the DNR) should be instituted. This program would include independent sampling, sample handling, analysis and data interpretation.

36 - Flambeau ground and surface water quality is being and has been degraded—despite years of industry public relations statements touting the success of the FMC operation. Rio Tinto said in a 2013 public relations (PR) release regarding the Flambeau Mine: "Testing shows conclusively that ground water quality surrounding the site is as good as it was before mining." In efforts to encourage development of the other metal-sulfide deposits in northern Wisconsin and the Great Lakes region, the industry approach has been to simply repeat this false statement over and over, assuming that repetition will make it believed. Unfortunately, the FMC data show otherwise.

The most important comments and conclusions of this report have been summarized here. Part-II of the report contains additional details, tables and figures that add to and support those comments.

Part-II: Discussion.

The Flambeau Mine was a Rio Tinto/Kennecott project located near Ladysmith, Wisconsin, U.S.A., operated by their subsidiary, Flambeau Mining Company (FMC) in the 1990s. This report focuses on *technical* aspects rather than whether FMC has complied with *regulatory requirements*, mostly because an overly-legalistic approach seems to have brought us to the present unacceptable Flambeau situation.

As I am a hydrogeologist/geochemist, my comments are largely focused on aspects of the Flambeau Mine operation relating to water quality and geochemistry. My comments are based on:

- Review of thousands of pages of the relevant Flambeau Mine historical and modern documents, most of which were prepared by FMC or their contractors, without sustained independent oversight.
- More than 45 years of applied hydrogeology and geochemical experience at hundreds of sites, worldwide. My detailed resume and most publicly-available papers (several in Castellano) are available at: remwater.org.

Flambeau ground and surface water quality is being and has been degraded—despite years of industry public relations statements touting the success of the FMC operation. Rio Tinto said in a 2013 public relations (PR) release regarding the Flambeau Mine: “Testing shows conclusively that ground water quality surrounding the site is as good as it was before mining.” The industry approach has been to simply repeat this false statement over and over, assuming that repetition will make it believed. Unfortunately, the FMC data show otherwise.

Even before FMC began active mining at Flambeau (1993), its managers were aware of the potential ground water contamination problems associated with mining such a massive sulfide deposit, and the associated legal and financial consequences. As a wholly-owned subsidiary of Kennecott Copper Corp., they would have been informed about the various legal actions brought by the State of Utah and the U.S. EPA over contamination from the various Kennecott operations located to the west of Salt Lake City, and the threatened CERCLA/Superfund listing of these facilities (REM personal experience).

Given this unpleasant worldwide reality, together with the presence of exceptionally-high percentages of sulfide in the Flambeau rocks located within 140 feet of a large, biologically-rich river, FMC faced a daunting task in obtaining their operating permits. Having reviewed thousands of pages of their documents, it appears one main strategy has been to ensure that *damaging data have not been made readily-available to the public.*

Background.

Flambeau Deposit: The Flambeau Deposit was discovered near Ladysmith, Wisconsin in 1968 by Bear Creek Mining Company (BCMC), the exploration arm of Kennecott Copper Corporation. It was described as a medium-sized copper-rich massive sulfide orebody that was extensively supergene enriched. The company defined “massive sulfide” to contain greater than 50 weight percent sulfides.

FMC reported that the chief mineral in the Flambeau Deposit was pyrite (iron sulfide), comprising 60% of the mineralization. Chalcopyrite (copper iron sulfide) was reported at 12% and sphalerite (zinc iron sulfide) at 2.5%. The presence of galena (lead sulfide), gold and silver was also noted (May, 1977).

The top of the Flambeau Deposit was just 15 to 40 feet below surface. The orebody averaged 50 ft. in width over a strike length of about 2,400 ft. and extended to an average depth of 800 ft. below surface. Reserves were estimated at 5.5 million tons (May, 1977; WDNR, 2017a).

In terms of relevant topography, the Flambeau River meanders within 140 feet of the project site and crosses over the west end of the Flambeau Deposit (May, 1977; Schwenk,1977).

Permitting & Regulation: FMC initially attempted to permit the Flambeau Mine in the mid-late 1970s. The original plan called for a 2-phase operation: 11 years of open-pit mining followed by 11 years of underground mining. The ore was to be concentrated on site, with tailings stored in a diked facility about 2 miles south of the ore body. The open pit was projected to be 55 acres at the surface and about 285 feet deep. FMC planned to "rehabilitate" it as a lake at the end of operations (WDNR, 1976).

A four-volume "Preliminary Environmental Impact Report" prepared by BCMC was issued in 1974, followed by a "Preliminary Environmental Report" from the Wisconsin DNR (1975) and a "Draft Environmental Impact Statement" from the U.S. Army Corps of Engineers (1976). The "Final Environmental Impact Statement" for the project was released by the Wisconsin DNR in early 1976. As reported by FMC (1977): "Both the Wisconsin EIS and the Corps Draft EIS [were] an abridged edition of the original EIR with some additional data prepared by the WDNR. Much of the original EIR data was omitted, as were the results of the continuing environmental studies conducted since June 1974." When the Wisconsin DNR was contacted in 2017 for a copy of the 1974 "Preliminary Environmental Impact Report" prepared by Bear Creek Mining Company, so that it might be reviewed for the present report, the Department was unable to locate the document.[5]

Citizen opposition and metals prices caused FMC to withdraw their proposal in late 1976. They reinitiated permitting efforts in the mid-late 1980s with a scaled-back open-pit proposal (no underground component) that called for removing only the enriched, upper 150-200 feet of the orebody. The Scope of Study (1987), Environmental Impact Report (1989) and Mining Permit Application (1989) for the smaller project were prepared by FMC consultant Foth & Van Dyke (Green Bay, WI), and the project was finally permitted in January 1991. But continued public opposition and an August 1991 court injunction forced the Wisconsin DNR to prepare a Supplemental EIS regarding endangered species that had been discovered in the Flambeau River near the mine site (WDNR, 1992a), halting mine construction in the interim. The SEIS was completed in April 1992, and site construction resumed the following month.

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[5] **Editor's Note:** In March 2018 (after Dr. Moran's passing), **r**esearch librarians at the University of Minnesota-Duluth were able to locate a copy of the 1974 Preliminary Environmental Impact Report that had been on file at the now-closed Mt. Senario College Library in Ladysmith, Wisconsin. The copy was subsequently acquired and donated to the Wisconsin Historical Society (BCMC, 1974).

Production: Blasting, crushing and shipping operations commenced at the Flambeau site in May 1993. All of the crushed ore was shipped by rail to Canada for further processing. As reported in *Minerals Yearbook*: “Three different ores were produced – about 363,000 tons of direct smelting copper ore, 136,000 tons of gold-bearing gossan ore, and the rest being a copper milling ore. The direct smelting ore and the gossan were processed at Noranda’s Horne smelter in Rouyn, Quebec, and the copper milling ore was sent to Falconbridge’s facilities in Timmins, Ontario” (USGS, 1997). As a result of this off-site processing of the ore, there are no tailings storage facilities at Flambeau.

The Flambeau Mine extracted ore from the open pit between 1993 and 1997, only 4 years as compared to the original life-of-mine (LOM) that was intended to be 22 years. The pit, as constructed, was 35 acres in size and mined to a depth of roughly 220 feet. Only the relatively shallow high-grade ore was extracted. No underground mining occurred, although FMC did advance the idea of “driving short tunnels into the [west] pit wall” to extract additional ore – a method known as “undercut and fill” (FMC, 1994f). In a March 1997 memo to the Wisconsin DNR, the company reiterated that horizontal drilling or vertical drilling in the benches of the west end of the mine (closest to the river) might be employed during the course of backfill operations to recover remnant pockets of ore (FMC, 1997b). No detailed description of what the company actually did, however, could be found in their 1997 Annual Report or anywhere in the public record.

According to figures available from the Wisconsin DNR, the Flambeau Mine open pit produced about 1.9 million tons of ore *averaging* 9.5% copper and 0.175 ounces per ton gold. Marketable quantities of silver (3.3 million ounces) and zinc (900 tons) were also reported (WDNR, 2012a and 2017a).

At the end of operations, the unlined Flambeau pit was backfilled with waste rock, some of it mixed with limestone. In addition, the filter sands and sludge from the mine’s waste water treatment plant were deposited into the pit. According to *Minerals Yearbook*: “The company estimates that 1.8 to 2.7 million tons [of ore], averaging 2% to 3% copper, remain below the 69-meter maximum depth of the open pit” (USGS, 1997).

Do the Rocks at the Flambeau Mine Contain Chemical Constituents that would Generate Water Contamination if Exposed to the Atmosphere and Water?

FMC documents refer to Flambeau as being a *massive sulfide deposit*, with portions containing more than 50 percent sulfide by weight, and others greater than 20 percent sulfide (May, 1977; Schwenk, 1977).

In the 1990 Environmental Impact Statement for the Flambeau project, issued by the Wisconsin DNR using Flambeau Mining Company data, FMC chose not to present actual data on the sulfide percentages in the specific rock types and zones to be mined--unlike most comparable metal-sulfide mine EISs in the U.S. and Canada at that time. Instead they chose to define only two categories of waste rock: “Type I” with sulfur contents less than 1%; “Type II” with sulfur greater than 1% (WDNR, 1990). Then in subsequent descriptions, FMC disingenuously referred to these waste rock categories as *low* sulfide and *high* sulfide wastes.

At the Zortman-Landusky Mine in Montana, we discovered that waste rock containing *as little as 0.2% sulfide generated acidic, metalliferous drainage*. This company went bankrupt in 1996 due to unanticipated water treatment expenses, leaving clean-up costs to the taxpayers (BLM, 1995 and 1996).

Ground Waters in Sulfide-Rich Rocks: Massive sulfide deposits, like those at Flambeau merit some special attention:

- The massive sulfide Rio Tinto deposits of southern Spain—for which the Kennecott parent company is named—have generated (and continue to generate) acidic and contaminated waters for thousands of years (Davis et al., 2000).
- The lowest mine water pHs ever reported, pH = - 3.6, were from the massive sulfide deposits of the Iron Mountain/Richmond Mine, a present Superfund site in northern California (Nordstrom & Alpers, 1999).
- Sulfide deposits continue to undergo oxidation even after being submerged under water, simply at slower rates. This is the case at Flambeau, where ground waters have not gone anoxic as predicted by Foth and FMC.
- All similar massive sulfide deposits generate degraded water quality in the long-term.

As long as unweathered sulfide-rich rocks remain buried, away from contact with atmospheric gases, oxygenated water and certain bacteria, acid-forming reactions do not normally occur. Once the sulfide-rich rocks are exposed, either naturally via erosion, or after human exploration activities and excavation, then these reactions begin.

Rock Geochemical Data: Geochemical and water quality data from similar massive sulfide deposits, worldwide, routinely contain elevated concentrations of trace constituents such as: aluminum, antimony, arsenic, barium, cadmium, copper, chromium, cobalt, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, zinc, sulfate, sulfide, nitrate, ammonia, boron, fluoride, chloride, natural radioactive constituents (sometimes uranium, radium, thorium, potassium-40, gross alpha and beta). Thus Flambeau ground and surface waters likely contain such chemical constituents, but *analytical results for many of these constituents were never reported from filtered samples and no data from <u>unfiltered samples</u> were released in monitoring reports (for ground waters) available to the public.*

Flambeau Mine whole rock analyses of *waste rock samples*, reported in the 1989 Environmental Impact Report for the project, confirm that these rocks also contain many of the trace elements mentioned above, including uranium. See Table 1 – Reported Flambeau waste rock composition. Antimony was not reported, but should have undergone further analysis as it often substitutes for arsenic in numerous sulfide minerals identified in Great Lakes massive sulfide ores. FMC failed to report similar detailed analyses for the Flambeau *ores* in the 1989 EIR, which would have shown much higher trace element concentrations than the concentrations reported for the waste rock.

Acidic Water Quality: From the time that FMC discovered the Flambeau deposit until it began active mining, the technical literature reflected great uncertainty about the ability to accurately predict the onset and extent of acidic water quality (MEND, 1991). Most reliable investigators argued that this could only be done in a qualitative manner, thus they recommended that *truly conservative* approaches be employed during these years (Price, 1997). Choosing to construct an open pit mine in fractured sulfide rocks with extremely high sulfide concentrations within roughly 140 feet of a high-quality river, where the river waters freely mixed with the pit ground waters (depending on changing hydrogeologic conditions) does not qualify as a conservative approach. A *conservative* reading of the geochemical literature from the 1970s through the 1990s would have suggested that these deposit wastes, pit walls, and any proposed underground workings would almost inevitably generate acidic conditions that would mobilize unacceptably-high concentrations of potentially-toxic trace and minor elements and sulfate. *Of course, once a mining company has invested millions of dollars to locate and permit a deposit, it is human nature to believe the "facts" one wishes to believe.*

Backfilling of waste rock and CUF solids into pit: As part of the Flambeau reclamation plan, roughly 4 million tons of "Type I" and 4.6 million tons of "Type II" waste rock were backfilled into the mine pit at the end of operations (Foth, 1997a). Clarifier underflow (CUF) solids from the mine's waste water treatment plant which, based on the original design criteria for the plant, were to be produced at a rate of up to 124 tons per day, were temporarily stored with the Type II waste rock during operations and later deposited in the pit (Foth, 1997a; WDNR, 1990). FMC reports that over 30,000 tons of limestone were added to the sulfide-bearing waste in an attempt to neutralize and buffer groundwater contacting the backfilled materials (FMC, 2001a).

In previous decades, few metal-sulfide operations had returned the waste rock into the pits (backfilled) because it was costly to move rock twice. The few examples of which I am aware (e.g. the Midnite Uranium Mine in eastern Washington; now a Superfund site) created long-lasting sources of ground and surface water contamination as the waste rock became part of the local aquifer, and reacted with the pit waters. A few other metal-sulfide mine operators have returned wastes into the pit, but these are normally in arid regions where the impacts of contaminated wastes would be limited.

Sulfide-Rich Waters: Sampling, Sample Handling, and Checks on Data Quality.

The public often assumes that problems in laboratory analyses are the main sources of uncertainty in mine environmental studies, which is incorrect. The main sources of error and data uncertainty occur in the field, resulting from inadequate sampling and sample handling procedures.

Interpretation of such chemically-complex, unstable waters as found at Flambeau requires that numerous checks on data quality be performed (e.g. ion balances; comparisons of dissolved versus total concentrations; ratios of field specific conductance (S.C.) to total dissolved solids (TDS); analyses from statistically-relevant "blind" replicates; determinations of turbidity and suspended solids on ground waters to determine the quality of well development, etc.). Such data quality checks require reporting detailed ground water quality data from both filtered and unfiltered samples (appropriately preserved) that include all major, minor and trace constituents, combined with detailed field measurements of water temperature, pH, and specific conductance.

It is beyond the scope of this paper to discuss detailed aspects of water chemistry and sample handling. More complete discussions of these topics can be found in Hem (1985), Freeze & Cherry (1979), Driscoll (1986) and USGS (2017). In addition, Moran (2011 and 2014) presents detailed descriptions of sampling procedures and analytical details useful for evaluating baseline water quality. The situation at Flambeau, however, warrants discussion of several key concepts.

Filtered vs. Unfiltered Samples: Ground waters in contact with sulfide-rich rocks are very complex chemically, physically and microbiologically. The chemical compositions of such complex waters change whenever ground water is lifted from depth and exposed to the normal atmosphere. For example, ground waters found at 100 ft. below the land surface are under roughly three times the atmospheric pressure to be found at the surface. Simply lifting such a ground water from a depth of 100 ft. (during sampling) reduces the pressure on the water and its contents, releasing previously-dissolved gases (and introducing others), which then begins a chain of other chemical changes that occur within seconds to minutes---reducing the dissolved concentrations of many of the formerly-dissolved chemical constituents.

Aluminum, iron and manganese are the metals/metal-like elements (metalloids) most commonly found at the highest concentrations in metal-sulfide waters. As the chemical changes described above commence, these three constituents begin to form compounds that come out of solution forming small particles, which gradually clump together (called precipitates) and begin to fall to the bottom of the sampling container. Because the surfaces of these precipitates all contain mild electrical charges, they attract the other metals and metalloids that are charged; e.g. arsenic, antimony, copper, lead, mercury, selenium, uranium, etc.), trapping them on and/or within the iron, aluminum and manganese precipitates, reducing their concentrations as the precipitates form and fall to the bottom of the sample containers.

When chemically-unstable waters are *filtered in the field*, this mix of aluminum-iron-manganese particles plus trapped trace constituents is removed from the water sample, prior to being acidified and sent to the lab for analysis. Thus, the concentrations of these metals and metal-like elements originally dissolved in the ground waters are greatly reduced when reported later in the laboratory analyses.

Theoretically, such filtered waters represent the concentrations of the “dissolved” chemical constituents, similar to waters that have been “treated” at a municipal water treatment plant, intended for public consumption. In fact, ground waters transport chemicals in both dissolved and tiny particulate forms (colloids), and most families using private wells or springs and all farms, livestock, wildlife, fish and vegetation, etc. *use and consume unfiltered water.* Obviously, FMC understood the colloidal transport aspect because they directed that samples of leachates from the waste rock piles be filtered first through 0.45-micrometer filters, and later through even finer filters with a 0.2-micrometer pore size. They did the same with samples of untreated runoff being pumped from a detention basin to a gravel pit during site reclamation. When FMC switched from using a 0.45-micrometer filter in March 1998 to a 0.2-micrometer pore size in May 1998, reported iron concentrations in the detention basin water samples dropped from 320 to 180 µg/L (FMC, 1998b).

Because analytical results are often compared to regulatory standards for drinking water, independent investigators, in addition to collecting unfiltered samples for analysis, *also* routinely collect water samples that are filtered in the field (through 0.45-micrometer filters), followed immediately by addition of acid in the field, as described above. Thus, scientists routinely have analytical data from ***both filtered and unfiltered (and acidified) samples*** when conducting a detailed study such as should have been performed at Flambeau. [In the routine language of water quality studies, analytical data from **filtered samples** are referred to as **"Dissolved" (D) concentrations** and those from **unfiltered samples** as **"Total" (T) concentrations**.]

For a comparison of water quality standards and guidelines established by various governmental agencies, please see Table 2 – Water quality standards. You will notice the following:

- **Drinking Water.** The official tables with drinking water standards provided by the EPA, Health Canada and State of Wisconsin do not indicate if said standards are expressed as Dissolved or Total concentrations. In practice, *Dissolved* constituent concentrations typically are compared to these standards, even though water from private wells normally is not filtered prior to consumption.
- **Aquatic Life.** There is disagreement in the technical literature as to whether Dissolved or Total constituent concentrations should be compared to aquatic life criteria. EPA metals criteria recommendations have varied inconsistently over decades in this regard. Fish and macroinvertebrates are capable of ingesting both dissolved and particulate forms of chemicals discharged into aquatic environments, which can then be concentrated up the food chain. Thus, recommendations to compare Dissolved constituent concentrations to aquatic life criteria have been met with controversy.

Flambeau Inadequacies. Unfortunately, among the thousands of pages of Flambeau ground water quality data made public by FMC over decades, the data have generally not been clearly identified as either Dissolved or Total. If one does painfully wade through these thousands of pages or is able to track down some of the original laboratory reports it becomes obvious that ***few Total analytical data (unfiltered samples) for ground waters have been made public*** by FMC in the relevant monitoring and permitting documents.

Instead, almost all of the publicly-available FMC ground water monitoring data reflects analyses of **filtered samples**, from which some, if not most of the chemical components have been removed by the filtering, thereby lowering the original concentrations. This pertains to data beginning in the 1970-71 period through the data submitted for the 1989-90 EIR/EIS, continuing to the present. FMC and their consultants should have been thoroughly aware that all comparable ground water studies and reports were based (and are) on the collection of both filtered and unfiltered samples (Hem, 1970 and 1985). This would have been especially true after the passage of the National Environmental Policy Act (NEPA, 1970) and the Clean Water Act (CWA, 1972).

Because chemical components in mine-impacted ground waters are transported as both dissolved and particulate forms (sediments, colloids, chemical precipitates), interpretation of the FMC data is largely meaningless without having data from both filtered and unfiltered samples.

While few analytical data are available for unfiltered ground water samples at Flambeau, there are several interesting exceptions:

- The 1992 FMC Annual Report (857 pages!) includes an appendix with laboratory result sheets for quarterly ground water quality testing in 11 different monitoring wells that year. While none of the results were identified as Dissolved or Total for the first three quarters, a single round of data for the fourth quarter was reported as *Totals*. When these limited data were summarized in the main body of the report alongside data from the first, second and third quarter sampling events (Tables 4-1, 4-2 and 4-3 in the FMC report), however, there was no mention/discussion of Dissolved versus Total measurements (FMC, 1993a).

  This same 1992 Annual Report also failed to include most of the detailed trace metals/ metalloids one would expect in such waters (a number of which were reported in the limited baseline test panel made public in the 1989 EIR), especially when pHs are acidic. An interesting exception was arsenic, which FMC tested in a single well (MW-1010P). Detectable concentrations ranging from 4.3 to 8.8 μg/L were reported between April and October 1992, even though the lab pHs were 7 or above. It is unclear from the report if any of these were in fact Total determinations (unfiltered samples), but, more importantly, this report failed to answer one of the most basic questions: what was the Total arsenic concentration (or other Total trace metal concentrations) in the April 1992 water from MW-1000, which had a pH of 2.6? All else being equal, it clearly would have been much higher than for the water from MW-1010P described above, which had pHs of 7 and above.

- The summary tables for Flambeau River surface water data that appear in FMC's annual reports do not indicate if any of the reported values are Total or Dissolved. Perusal of a number of original laboratory result sheets in the public record suggests the reported values were Totals, although confirmation from the company would be helpful[6]. In addition, FMC has reported limited data for surface waters in a small Flambeau River tributary that crosses the southeast corner of the mine site (Stream C) and an associated passive water treatment system (biofilter) as Total Recoverable. Unfortunately, the company has failed in most cases to report *Dissolved* concentrations *in tandem* with surface water Totals. As explained by Hem (1985): "In one way or another solid particulates may carry a substantial part of the minor element load in surface water. … An analysis of a suspended sediment-water mixture which reports only total metal concentrations is entirely useless in studies of trace-metal geochemistry because it does not differentiate between the fractions held in dissolved form and those in adsorbed or precipitated form. If a "total" metal determination is made … it must at least be supplemented by a determination of the dissolved fraction on a separate aliquot filtered at the time of collection."

- *Apparently* the metal analyses for FMC's waste water treatment plant effluent were reported as Total Recoverable concentrations, as mandated by state regulators in the

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[6] Effective Fall 2015, even the printouts from FMC's contract laboratory remarkably fail to indicate whether the reported values are Dissolved or Total (FMC, 2015a).

company's Wisconsin Pollution Discharge Elimination System (WPDES) permit. Waste rock leachate analyses, however, were reported as Dissolved, as clearly shown in the 1993 and 1994 FMC annual reports.

Field Testing of Water: As explained by Hem (1970): "Examination of water in the field is an important part of hydrologic studies. Certain properties of water, especially its pH, are so closely related to the environment of the water that they are likely to be altered by sampling and storage, and a meaningful value can be obtained only in the field. Other properties of water such as its specific conductance are easily determined in the field with simple equipment, and the results are useful in supplementing information obtained from analyses of samples and as a guide to which sources should be sampled for more intensive study."

- ***pH.*** Most natural waters have a pH between about 6.5 and 8.5, but numerous exceptions occur outside this range. *Because the pH scale is an exponential scale, a solution with a pH of 3 is actually ten times as acid as a solution with a pH of 4, and one hundred times as acid as one with a pH of 5.*

  The importance of determining and clearly identifying field pH versus lab pH is succinctly explained by Hem (1970): "A pH measurement taken at the moment of sampling may represent the original equilibrium conditions in the aquifer satisfactorily, but if the water is put into a sample bottle and the pH is not determined until the sample is taken out for analysis some days, weeks, or months later, the measured pH may have no relation to the original conditions. Besides gains or losses of carbon dioxide, the solution may be influenced by reactions such as oxidation of ferrous iron, and the laboratory pH can be a full unit different from the value at the time of sampling. A laboratory determination of pH can be considered as applicable only to the solution in the sample bottle at the time the determination is made."

- ***Specific Conductance.*** The most basic measurement of how much chemical material is *dissolved* in water is specific conductance (S.C.). S.C. is a measure of how easily an electrical current will move through water. The greater the quantity of *dissolved* matter in the water, the higher the S.C., which is measured in units called microsiemens per centimeter, but here shortened to µS/cm. Sediment *particles* in water do not carry an electrical charge, thus S.C. measurements are not affected by these particles. S.C. is easily measured in the field using a portable meter, which allows one to estimate the total dissolved solids concentrations (TDS) that will be reported by the lab, thus serving as a routine check on data quality. Higher S.C. measurements indicate higher total dissolved solids concentrations. **For both experts and the general public, two of the best simple, inexpensive "fingerprints" for detecting signs of acid rock drainage (ARD) are field specific conductance and sulfate.**

Flambeau Inadequacies. While FMC annual reports issued prior to 2010 indicate that pH and conductivity were being measured in the field, the summary tables for ground water and Flambeau River surface water data that appear in more recent annual reports do not indicate if the reported values are field or lab. Nor do any of the summary tables include data for a third important field parameter: water temperature.

Construction and Development of Monitoring Wells: FMC ground water well drilling, completion, development and monitoring procedures have further aggravated the complexity discussed above, and have led to an extremely biased picture of actual, *in-situ*, ground water quality, both in the backfilled pit and outside. The major biasing factors are:

- ***Well Maturity.*** Because FMC had already constructed numerous wells and other excavations into sulfide-rich rocks by the early 1970s, they and the Wisconsin DNR clearly should have known that newly-constructed boreholes/wells drilled into unoxidized sulfide deposits do not show evidence of contamination initially (USFS, 1990). As such wells "mature", the various geochemical reactions, aided by the growth of bacterial populations, begin to show evidence of water quality degradation. Often these processes require months or years to become evident.

  Apparently the WDNR accepted that the initial "benign" FMC water quality data warranted significant reductions in the list of regularly-monitored constituents. For example, the wells that FMC sampled to establish what they considered baseline conditions were constructed between September 16 and October 4, 1987; the first samples were collected for analysis on October 15, 1987, and by February 1988 a number of constituents had already been dropped from the initial test panel "for lack of detects at significant concentrations" (Foth, 1989a – Section 3.6). Eliminated constituents included aluminum, beryllium, cobalt, molybdenum, thallium, tin and titanium.

  A second consideration regarding newly-constructed wells (baseline or routine monitoring) – drilled into any rock type – is that they often yield unreliable water quality data due to well construction and development problems (e.g. contamination from bentonite-cement grouts; inadequate development, etc.). Thus, replacement of original wells with new wells often artificially elevates the pH and biases the monitoring data. Such problem wells often require extensive development and cleaning before field pH, S.C. and TSS data return to "normal"; sometimes they never do. This can create severe breaks in the historic data continuity when original wells (often of much larger diameter) are replaced by new smaller-diameter wells, as was the case at Flambeau.

- ***Well Diameter.*** Where chemically-unstable waters exist, it is imperative that all wells be thoroughly developed after construction, and thoroughly evacuated prior to each subsequent sampling.

  Most FMC monitoring wells currently in use (constructed for the 1989 EIR and later within the backfilled pit) have an inner diameter of only 2 inches (See Table 3 – Physical details of ground water monitoring wells). While common in normal ground water situations, this is not adequate in such unstable chemical situations as found at Flambeau. The wells are too narrow to allow adequate development (purging/cleaning) or sampling, remove drilling additives (foams, gels, petroleum distillate polymer-based muds), sediments particles and chemical precipitates—in such chemically-unstable waters. The screen openings are also too small to allow free passage of chemical precipitates (sediments/colloids) in such small-diameter wells. Thus, much of the FMC ground water data is not representative of the *in-situ* water quality.

Many of these uncertainties would have been obvious to a knowledgeable reader if FMC had reported detailed ground water quality data from both filtered and unfiltered samples (appropriately-preserved), which included all major, minor and trace constituents, combined with detailed field and lab measurements of water temperature, pH, and specific conductance (S.C.). While determinations of Total Suspended Solids (TSS) and turbidity would normally be included to evaluate well development and aid interpretation of well data, FMC has provided no such measurements in its technical reports.

Clearly the factors mentioned above have resulted in fewer constituents detected and much lower determined concentrations in FMC ground water data than if Flambeau samples had been collected from larger diameter wells, purged and sampled correctly.

Interestingly, many of the FMC wells from the 1970s (which FMC failed to include in their baseline reporting for the 1989 EIR) had 4-inch diameter casings; no completion records are available for the majority of other wells that have "disappeared."

What Are "Baseline" Conditions for the Water Resources at Flambeau?

Determining whether water resources at a mine site have been impacted requires the existence of statistically-representative baseline data, especially for water quality, and mining companies have been aware of this for decades. Unfortunately, FMC has incorrectly defined baseline conditions at Flambeau, thereby biasing later conclusions.

Ideally, baseline conditions are those that existed prior to any mining-related or other industrial activities. FMC reports state that exploration drilling has been conducted at Flambeau since roughly 1968. Thus, hundreds or more exploration and geophysical boreholes (down to at least 800 feet BLS), together with road and site construction, trenches, dozens of monitoring wells and piezometers, and possibly tunnels have been constructed at the site prior to actual mining of ore. Such activities increase sediment loads and create pathways interconnecting the various horizontal and vertical portions of the local rocks, introducing atmospheric oxygen and other gases, microbes, and surface water, all of which alter the original baseline water quality and geochemical conditions. Hence, the 1987-88 data presented by FMC as baseline water quality data in their 1989 Environmental Impact Report (Foth, 1989a – Section 3.6 & Appendix 3.6-H) and 1990 Environmental Impact Statement (WDNR, 1990) actually represent water quality that has been altered and somewhat degraded by these exploration-phase activities. Inevitably such changes increase the concentrations of most of the sediments, metals/metalloids and sulfate relative to true pre-exploration baseline in such ground waters.

Most metal-mine projects with which I have familiarity, both domestically and internationally, begin with company-compiled baseline data that may appear to be extensive, but which inevitably suffer from huge gaps that make ascribing technical and legal responsibility for later impacts extremely difficult. The same is true for the Flambeau baseline data, which was compiled by FMC and their consultants. For example, a comparison of the 1989 EIR baseline data reported by FMC – ground water and surface water – with test panels later adopted for routine monitoring shows that many trace constituents detected and reported in 1989 were lost to follow-up monitoring (e.g., uranium and aluminum) and others were never determined to begin with or at least reported publicly (e.g., antimony).

Baseline Surface Waters: Because the west end of the Flambeau pit is within roughly 140 ft. of the Flambeau River, Wisconsin regulators should have required FMC to report all water quality constituents from both ground and surface waters that have relevant standards and criteria (during both baseline and routine monitoring), to determine whether FMC releases might be damaging to any of the relevant water uses: human consumption; aquatic life; agricultural and irrigation (see Table 2 – Water quality standards). Such data would have required collection of both *field-filtered & acidified and unfiltered & acidified samples for analysis of a much wider list of chemical constituents than reported by FMC, employing appropriate detection limits*[7]*.* See Table 4 – Flambeau River surface water quality data, for a compilation of FMC's Flambeau River baseline and routine surface water data.

Another issue regarding FMC's baseline surface water monitoring program involves sampling site locations. A comparison of diagrams from FMC's 1989 EIR (Foth, 1989a) and 1991 Updated Monitoring Plan (Foth, 1991) shows that the locations of important, fundamental monitoring stations (e.g. the company's upstream and downstream monitoring sites in the Flambeau River) were changed by FMC after baseline studies were completed, hampering determination of Flambeau Mine contributions. Most notably, the downstream sampling site currently used by the company (SW-2) is roughly 3 river-miles upstream of the original site used for baseline determinations. While now closer to the project site, SW-2 is still roughly 500 feet downstream of the backfilled pit and upstream of the discharge point of Stream C, a small Flambeau River tributary that crosses the FMC property and historically has been used as a conduit for conveying contaminated storm water runoff from the mine site to the Flambeau River (Chambers & Zamzow, 2009). FMC has established no river sampling stations adjacent to or immediately downstream of the backfilled pit. See Figure 1 – Flambeau River surface water sampling stations.

No baseline water quality data were obtained for small streams crossing the FMC property – not even Stream C, considered "navigable" in the 1990 EIS. Thus, when elevated copper and zinc levels were reported post-mining in Stream C and it was added to the EPA impaired waters list (USEPA, 2014), FMC could claim that elevated concentrations resulted from natural mineralized sources[8]. Flow data is also lacking for Stream C, making it difficult to assess how the disturbance and loss of wetlands caused by the construction of the mine's

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[7] The summary table of Flambeau River surface water quality data provided by FMC in their 1989 Environmental Impact Report does not indicate if the 1987-88 baseline concentrations were Total or Dissolved. Nor were any original laboratory sheets provided (Foth, 1989a – Table 3.7-5).

[8] **Editor's Note:** FMC's claim that elevated copper concentrations reported post-mining in Stream C could have resulted from natural mineralized sources is undercut by a recently-discovered FMC report from 2004, in which the company stated: "Concern has been raised about the copper levels found in intermittent Stream C near the industrial outlot at the Flambeau Mine site. ... Recent Stream C water quality data have shown levels of copper ranging from 18 to 30 ug/L. In 2003, FMC evaluated the potential sources of the copper and determined that the rail spur area was the most likely source of the copper" (FMC, 2004). The report also notes that "… historical data have shown naturally elevated zinc concentrations in water upstream of the bio-filter and railroad spur and in Meadowbrook Creek" but there is no discussion as to what dates this data was collected, so it is not clear whether the report is implying there is pre-mine data for these areas. If there is pre-mine data for these areas, it has not been made available by Kennecott.

high-sulfur waste stockpile, and the rail spur in the stream's headwaters, may have impacted stream hydrology.

Baseline Ground Waters: A review of company documents reveals confusing, disorganized well designations, monitoring, etc., not intended to provide an easily-understood summary. For example, it appears FMC may have confounded well/boring numbers. In addition, routine monitoring included only data from filtered samples, at least for publicly-available data. As explained earlier, this is problematic for several different reasons: (1) interpretation of water quality data is largely meaningless without having data from both filtered and unfiltered samples; and (2) much of the metal data would have been reported as "less than detection limit", thus FMC was incorrectly allowed to remove these metals from their future monitoring.

Constituents reported were incomplete, neglecting numerous parameters for which regulatory standards and criteria existed---as described above for surface water data. In addition, while most of the present U.S. water quality standards and criteria were in existence prior to the 1991 approval of the Flambeau operating permits, a few standards and criteria have changed since the Flambeau Mine was operational (some weakened, some became more restrictive). Nevertheless, the Wisconsin DNR did not update the monitoring required by FMC, except for arsenic in ground waters. Of note is that the health standards for both antimony and uranium were revised by EPA during the operation of the mine.

For a summary of "baseline" (1987-88) and recently reported ground water data from wells of interest at Flambeau, please see Table 6 – Ground water quality data. You will notice that baseline ground water testing at Flambeau also failed to include sulfide, total suspended solids (TSS), and turbidity. Consultant's reports incorrectly argued these determinations were not useful (Foth, 1987). Sulfide would be expected in waters contacting sulfide ores and in the water treatment plant effluents, and is toxic to aquatic organisms; TSS and turbidity are extremely useful for determining whether wells had been adequately developed, or when chemical precipitates were forming.

More importantly, the DNR allowed FMC to leave out of the EIR (1989) all of the detailed ground water quality data from the 1970s and the detailed interpretations of the long-term pumping tests that were conducted in 1971. This selective release of data was justified by FMC consultant Foth & Van Dyke as follows: "The previous groundwater sampling program was conducted according to state-of-the-art procedures that existed in the early 1970's. However, the science of groundwater monitoring has changed since that time. In addition, quality control concerns pertain to some of these data as well**.** As a result**,** much of the data generated by that program is not acceptable by current standards. This includes all groundwater quality data, for example" (Foth, 1987).

These comments by an unnamed author are technically false, and were clearly written by someone who had not conducted detailed hydrogeological and water quality studies during the 1970s. Inclusion of the 1970s FMC data would have been highly useful in determining the evolution of baseline ground water quality at the FMC site, and such data were often utilized in numerous ground water studies during the 1970s (e.g. Cherry et al., 1973; Konikow & Bredehoeft, 1974; Moran & Wentz, 1974; Moran, 1976). It is my experience that the reliability (precision and accuracy) of the water quality analyses throughout the 1970s, especially within the U.S. Geological Survey, was often much greater than for data presented in the 1987-88 FMC studies, especially where chemically-unstable ground waters were involved. This is due to the common use of atomic absorption (A.A.) analytical procedures in the 1970s as opposed to inductively-coupled plasma spectroscopy (ICP); the latter suffers from severe interferences from colloidal iron, manganese, and aluminum. Where interference problems developed with ICP analyses in the 1970s, one would often reanalyze using A.A. techniques to obtain better detection limits and better precision and accuracy, techniques which FMC/Foth failed to employ.

Regarding the long-term pump test information (1971): the techniques commonly used today to interpret such aquifer/pump tests were well known in the early 1970s (Kruseman & de Ridder, 1970; Davis & DeWiest, 1966; Walton, 1962). However, the actual interpretations of these long-term pump tests were not included in the FMC EIR (1989). I will leave to the reader the much simpler explanations for why these data were not included in the EIR.

These issues would have been obvious to the public had FMC been required to report water quality data from several of these 1970s wells (larger-diameter than the 1987-88 baseline wells) as part of the 1989 EIR. A number of these wells are still in existence and characterized as “active” by the Wisconsin DNR (See Table 3 – Physical details of ground water monitoring wells). Maps showing well locations are included in the 1975 Preliminary Environmental Report (WDNR, 1975), 1976 Draft Environmental Impact Statement (USACE, 1976) and 1976 Mining Permit Application (FMC, 1976), but there is no realistic way to compare FMC ground water data from the 1970s with data from the 1980s and more recent as many older wells have “disappeared,” and, for the ones that still exist, FMC currently reports ground water elevation only.

Another inadequacy of FMC’s baseline ground water monitoring program involves private wells near Flambeau. Per the terms of a 1988 agreement between FMC and the local governments, a number of these wells were to be monitored prior to construction of the mine (exact dates unclear), and the company made a “guarantee” that if any of these wells failed because of the mine, the company would provide an alternate source of water. But when the “Well Guarantee Location Map” is examined, the designated areas covered by the guarantee appear to be primarily up-gradient of the mine operation (Kennecott, 1988). Additionally, the parameters reported were inadequate, including only field pH, field conductivity, acidity, chemical oxygen demand, iron, hardness, alkalinity and chlorides. I assume these samples were filtered, even though such well waters would normally be consumed from the tap, unfiltered. It bears repeating that even the 1970 edition of the most widely-used water quality reference (Hem, 1970) described the importance of collection and analysis of both filtered and unfiltered samples. No recent private well data have been made public in the company’s annual reports, even though a number of private homes are located directly across the river from the mine site, with contaminated ground water from the backfilled pit possibly headed in that direction.

Waste Rock / Waste Handling.

The original FMC permit-related documents contained simplistic statements about what activities would be done. In actuality, the public has no way of knowing precisely what was *done with respect to waste disposal, addition of lime and or limestone, diversion of liquid effluents, etc., as almost all of the information was supplied by FMC or their contractors, without sustained* <u>*independent*</u> *oversight.*

FMC documents suggest that the various categories of waste rock were carefully extracted from the pit, sorted by sulfide concentration, stored on the rim above the pit, and later returned to the pit in an equally precise manner. In practice, however, quantitatively-accurate sorting of mine waste using heavy equipment during actual mining is a process filled with inherent errors, and it appears waste rock sulfide contents were not analyzed by FMC in detail until 1996, when backfill operations commenced. Previously all waste simply fell into two categories identified by FMC as "Type I" and "Type II":

- Type I – glacial till, sandstone, saprolite, and waste rock with an assumed sulfur content less than 1%; total volume estimated at 4 million tons (Foth, 1997a). FMC apparently expected runoff from the Type I stockpile to be relatively benign, so they constructed two unlined settling ponds next to the stockpile, and the mine permit called for routing the effluent, without treatment, to either the Flambeau River or an adjacent wetland for mitigation.

- Type II – till, sandstone, sludge from the mine's waste water treatment plant, saprolite and materials excavated from the pit with an assumed sulfur content of greater than 1%; total volume estimated at 4.6 million tons (Foth, 1997a). Runoff from the Type II stockpile was routed to the mine's waste water treatment plant.

The lower sulfide-content waste rock (Type I) was stacked on the N-NW rim of the pit, directly on the land surface without a liner underneath. The higher sulfide-content waste (Type II) was stockpiled on the S-SE rim of the pit, on top of a 60-mil synthetic-membrane liner (See Figure 2 – Flambeau Mine schematic). Most such synthetic liners become torn or perforated during operations, thus they leak. The "Liner Repair Documentation" sections in FMC's 1994, 1995, 1996 and 1997 annual reports describe numerous rips and tears in these liners. Clearly some runoff and or seepage from these waste stockpiles would have been released into the local waters. Were the *ground waters* under the stockpiles ever monitored for field pH and S.C.? If so, FMC has not made the data public.

The site monitoring plan approved by the Wisconsin DNR required FMC to collect leachate samples for analysis from the Type I and Type II waste rock stockpiles on a quarterly basis only. Samples were filtered prior to analysis (using 0.45 and 0.2 micron filters), and the test panel was limited to pH (lab and field), S.C. (field), chromium (in exfiltrate from "low" sulfur waste rock only), copper, iron, manganese, sulfate, total dissolved solids, total alkalinity and total hardness (Foth, 1993c; FMC Annual Reports, 1993-1997). In addition to reporting data from stockpile leachates, FMC monitored and provided limited data from three seeps that appeared in the Type I waste rock stockpile (FMC, 1996b and 1997c).

FMC waste rocks were acidic and releasing contaminated leachates long before they were returned to the pit (both "low" sulfur and "high" sulfur types). Few data have been made public. In October 1996, water sampled from one of the seeps in the "low" sulfur waste rock pile had a dissolved copper concentration = 53,150 μg /L. Between January 1996 and June

1997, reported copper concentrations in the same seep averaged 9,300 μg /L (range = 532 - 53,150 μg/L; median = 5,020 μg/L; n = 85; FMC, 1997c). Other waste rock leachate waters were already mildly acidic by 1994 and became more acidic by the fourth quarter of 1995 (“low” sulfide pH = 5.8; “high” sulfide pH = 5.9; FMC, 1996a); by the fourth quarter of 1996 the “high” sulfide waste leachates had pH = 3.1, and copper concentration = 450,000 μg/L. Chromium was reported in “low” sulfide waste effluents and *predicted* it was reaching the water table (FMC, 1997a). At a pH of 3.1, it is clear that many other trace and minor elements would also be present in these leachates, but FMC failed to report them. In addition, the company failed to identify leachate test results as Dissolved or Total Recoverable in its 1995-1997 annual reports.

Foth issued a report in July 1989 entitled, “Prediction of Chromium, Copper and Iron Concentration in Vadose Zone Water Reaching the Water Table Beneath the Unlined Type I Stockpile for the Kennecott Flambeau Project” (Foth, 1989b). Processes such as these are too complicated to **predict** reliable concentrations. One should instead rely on actual test data—which were not made public by FMC.

As mentioned earlier, sludge from waste water treatment plant operations (Clarifier underflow solids—CUF) were mixed with waste rock in the Type II stockpile and eventually disposed in the mine pit. Final sludge volumes were not disclosed by FMC in its 1997 backfilling plan, but the 1990 EIS projected roughly 45,000 cubic yards of “metal and sulfur enriched sludge” (up to 124 tons per day) would be produced over the life of the mine. In addition, the company anticipated its lime slaking operation at the WWTP would generate up to 1.1 tons of grit per day (including unreacted lime) (WDNR, 1990). FMC anticipated several different mechanisms by which the co-disposal of CUF solids might “impact the geochemistry of the Type II material after saturation.” They explained: “First, the CUF solids may introduce excess alkalinity in the form of unreacted lime, and second, the sludges contain iron oxyhydroxides that may become more soluble under anoxic conditions” (FMC, 1996e).

FMC utilized a 4,000 gallon “CUF truck” to routinely dispose of the sludge within the 27-acre footprint of the Type II stockpile during the four years of mine operations but apparently did not record disposal location coordinates. In October 1996, when the company devised a workplan for analyzing the composition of Type II materials in efforts to determine appropriate limestone amendment rates, FCM stated that only two samples of CUF solids would be included in the analysis, one “from the deposition location currently in use” (CUF-1) and the second from a previous deposition location (CUF-2), but they added: “Should it not be possible to identify a prior deposition location, then two samples will be taken from the current location” (FMC, 1996e). When sampling was conducted in November 1996, the Type II stockpile sample location map shows that CUF-2 was taken just 75 feet southwest of the CUF-1 (current deposition) site, in an area of the stockpile where clarifier solids deposition had ceased only three months earlier (Foth, 1997a). Foth/FMC’s apparent uncertainty regarding where the bulk of the CUF solids that had been generated by the WWTP over the previous 45 months were stored would have complicated later efforts to control for likely ground water contamination from such materials.

Test results supplied by FMC for leach extraction and anoxic column studies performed on CUF solids lacked many of the important oxyanions and other parameters of interest (Foth, 1997a); if such constituents were determined, the data was not made public. A review of company reports also revealed: (1) no actual water quality data reported for waters being discharged from the exposed pit walls, floor or ore piles; and (2) only limited data for Type I and Type II waste rock stockpile leachates (see above). No data were made public for ground waters beneath the two stockpiles.

Limestone: Finite Buffering Capacity.

Wastes from the FMC operation will remain onsite <u>forever</u>. While limestone was added to the waste rock as it was backfilled into the pit, the ability of the limestone to neutralize or buffer the formation of acid waters is limited and finite. After the limestone has reacted with the waste rock, its neutralizing action will diminish and the <u>pit waters will become increasingly acidic and the concentrations of potentially-toxic contaminants are likely to increase – assuming representative data are obtained</u>. As the limestone becomes coated with other chemical reaction products, the buffering action ceases. Roughly 20 years, post-closure, the deeper pit well waters at Flambeau show evidence of water quality degradation relative to baseline data and relevant standards and criteria, in spite of FMC's limestone amendment program. It is reasonable to conclude that the Flambeau ground and surface water quality will further degrade in the coming decades if current site maintenance practices continue[9].

FMC is depending on limestone added during backfill operations and expected development of anoxic conditions deep within the backfilled pit to control for the production of acid mine drainage at the Flambeau site. In its 1997 backfill plan, the company outlined expectations as follows: "Placement of stockpiled Type II material in the bottom of the open pit, and its subsequent saturation as the groundwater table recovers, will result in the Type II material being located in an environment in which future oxidation and consequent acid generation is controlled. Because the Type II material will be below the future water table, oxygen entry will be limited, and anoxic conditions will develop. During the period of groundwater recovery, groundwater gradients will be directed towards the open pit so that very little release of water from the pit is expected. As the groundwater table recovers, the pore water of the Type II material will rapidly become anoxic, and increased mixing of pore water with groundwater will occur" (Foth, 1997a).

While the dissolved concentrations of most metals and metal-like elements in mine-impacted ground waters generally increase as water pH becomes more acidic, many of these chemical constituents have forms that are mobile in waters under a wide range of pH conditions, and

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[9] **Editor's Note:** Dr. Moran's conclusions take on particular significance in light of a November 2018 request from FMC to scale back its existing environmental monitoring plan at Flambeau. Changes include a reduction in ground water monitoring frequency and parameters for wells located within the backfilled pit, between the pit and Flambeau River, and other wells at the site. The company also proposes to abandon 20 wells currently listed as active by the Wisconsin DNR, including two that are located immediately alongside the north wall of the backfilled pit (MW-1003/P) and four of the five remaining wells from the 1970s that were of interest to Dr. Moran due to their 4-inch (as opposed to 2-inch) diameter casings and close proximity to the backfilled pit (FMC, 2018d – see electronic pages 20 and 60). As of this printing, it is unclear if FMC's request will be granted by the DNR.

do *not* require the formation of acidic conditions to be released into the environment. Hence, waters can be contaminated without generating net acid conditions. For decades, authors have reported increased chemical constituent concentrations in neutral and especially alkaline pH waters (e.g. Banks et al., 2002).

In their early reports, FMC stated that large volumes of lime would be added to the waste rock prior to returning the wastes to the pit (backfilling). Later, FMC altered the backfilling plan to amend the waste rock with limestone rather than lime (FMC, 1996c). Lime, instead of limestone in equal volumes, reacts more rapidly and generates much higher pHs, and it is more effective at buffering the expected acidity from the sulfide-rich wastes, pit walls and pit floor. Lime addition, however, can also generate conditions that increase the water concentrations of those trace elements that form mobile species *at elevated pHs, such as aluminum, arsenic, antimony, chromium, manganese, nickel, selenium, molybdenum, uranium, zinc, etc.* It's reasonable to assume that this is one of the reasons FMC altered their pit backfilling plan to utilize limestone. Also, lime is more expensive than limestone by volume.

Backfill operations commenced at Flambeau in late August 1996 and concluded in October 1997, based on work plans supplied by FMC's consultant (Foth, 1996b and 1997a-c). Freshly mined Type II material (in-pit) and stockpiled Type II material (on the side of the pit) were backfilled first, and limestone application rates were modified on several different occasions.

During the first two months of backfill operations, FMC focused on in-pit Type II material and amended it at a rate of 4.0 - 4.9 pounds limestone per ton (FMC, 1996d and 1997a). They began backfilling stockpiled Type II materials in mid-October 1996, and, based on sampling results and oxygen transport modeling, switched to using limestone application rates of 17.2 - 20.6 lb/ton through the first week of November, when weather conditions precluded continuation of backfill operations until the following spring (FMC, 1996f and 1997a – Appendix A). FMC records show that approximately 1.5 million pounds (750 tons) of limestone were added to 117,400 tons of Type II waste (in-pit and stockpiled) in 1996, yielding an average application rate of 12.7 pounds limestone per ton Type II waste for the year (see below).

1996 FMC Backfill Activities:

	Limestone (lbs)	Rock (yds^3)	Rock (tons)*
Type II In-Pit Material[a]	775,580	49,904	114,529.68
Type II Stockpiled Material[b]	714,880	1,256	2,882.52
	========	=====	========
Total	1,490,460	51,160	117,412.20

* short tons, rock density = 170 lbs/ft^3

Conversion of yd^3 to tons: $yds^3 = 27\ ft^3/yds^3 \times 170\ lbs/ft^3 \times tons/2000\ lbs = 2.295\ tons/yds^3$

Then: 1,490,460 lbs / 117,412.2 tons = **12.69** lbs of limestone/ton (short) of Type II waste.

a. FMC 1996 Annual Report, Appendix A, Table 3-1.
b. FMC 1996 Annual Report, Appendix A, Table 3-2.

When backfill operations resumed in the spring (March-May 1997), it appears FMC utilized a flat application rate of 20.1 pounds limestone per ton Type II backfill (FMC, 1998a). For the remainder of Type II backfill operations (May-Sep 1997), a variable limestone application rate was utilized, based on paste pH and conductivity test results. Three “classes” of materials were identified: Class A (paste pH > 5.0 s.u. and paste conductivity < 2,200 µS/cm); Class B (paste pH ≤ 5.0 s.u. and paste conductivity < 2,200 µS/cm, or paste pH > 5.0 s.u. and S.C. ≥ 2,200 µS/cm); Class C (paste pH ≤ 5.0 s.u. and conductivity ≥ 2,200 µS/cm). Limestone application rates were established for Class A and Class B materials based on placement elevation in the pit: Class A = 5.2 lb/ton (below 1,045 ft. MSL) to 9.6 lb/ton (at or above 1,065 ft. MSL); Class B = 9.4 lb/ton (below 1,045 ft. MSL) to 13.8 lb/ton (at or above 1,065 ft. MSL). Rates for Class C materials varied, taking into account not only placement elevation, but the results of alkali demand testing on individual samples (Foth, 1997b). It is unclear why this more specific approach to determining limestone application rates was not utilized by FMC at the onset of backfill operations.

A paucity of data exists in the public record regarding the implementation and effectiveness of FMC’s various backfilling formulas. Foth stated: “The results of the [1997] paste parameter testing, grid classification, pit placement elevations, and limestone application rate determinations will be documented on test pit classification and limestone application worksheets” (Foth, 1997b), but no such data were disclosed in the company’s annual reports, nor were the relative volumes of the three “classes” of Type II waste or the calculated limestone application rates for the Class C (lowest pH and highest S.C.) materials.

FMC started to backfill the Type I materials in July 1997. The 1990 EIS had stated: “Lime will not be added to [the low sulfur waste rock] materials since they are not acid producing” (WDNR, 1990). This, however, did not turn out to be the case. As addressed in its 1997 Resident Project Representative Manual for Type I Waste Rock Backfill, Foth determined that an undisclosed amount of Type I materials would require limestone amendment, even though a drilling program conducted in early 1996 (FMC, 1996b) revealed that sulfur contents within the stockpile averaged only 0.18% (range = .04 - 0.89%; median = 0.10%; n = 60).

FMC used the same classification system for Type I waste as they did for Type II (Classes A, B and C, as characterized above). Limestone application rates were established for Class A materials (6.9 lb/ton) and Class B (11.1 lb/ton), based on class only (not placement elevation). In terms of Class C materials, application rates were once again calculated using the results of alkali demand testing. Any Type I waste rock with a paste pH ≥ 6.5 s.u. was deemed to require no alkali amendment (Foth, 1997c).

As was the case for Type II materials, critical details involving the Type I backfilled waste (e.g. paste pH and conductivity test results, Class C limestone application rates, and the relative volumes of the various “classes” of Type I waste and how much of the waste required no amendment) were not disclosed by FMC in their annual reports.

Both of FMC’s Type I and Type II work plans called for sampling and determining paste parameters for *in-place amended waste rock* and performing leach extraction tests to aid in “documenting the performance of the alkali amendment program,” but again, no such data could be located for review. In light of other mines proposed in sulfide ore bodies in the Great Lakes region that call for lime or limestone amendment of backfilled waste to control for the production of acid mine drainage, it would be instructive to have these data.

The backfilling of the Flambeau open pit was completed in 1997. FMC stated that over 30,000 tons of limestone were added to the sulfide-bearing waste rock (FMC, 2001a), although the exact distribution between the Type I and Type II waste was not disclosed. By 2001, the groundwater table reportedly had "recovered significantly" (FMC, 2002), but it took until October 2010 for some of the shallower wells in the monitoring program to have sufficient water recovery for sampling.

Limestone and lime will react faster than sulfides and silicates; hence long-term problems may not be averted. At some point in the foreseeable future, the effective buffering capacity of the limestone added to the waste rock is likely to be consumed, and the pH could decline significantly. This would cause the quality of the ground waters migrating from the backfilled pit to become extremely degraded and impacts to the quality of the Flambeau River will likely be obvious.

Waste Water Treatment Plant Operations and Discharge of Effluent to Flambeau River.

FMC operated a waste water treatment plant at the Flambeau Mine site between March 1993 and August 1998. It was designed to treat contaminated waters from the open pit, Type II ("high" sulfur) waste rock stockpile, crushed ore storage area, haul road and maintenance road. See Figure 2 – Flambeau Mine schematic and Figure 3 – Waste water treatment plant and other mine features.

The WWTP used a three-stage process: (1) lime treatment for acid neutralization and initial metal removal; (2) sulfide precipitation of metals; and (3) filtration (Foth, 1993a). Effluent from the WWTP was regulated through a Wisconsin Pollution Discharge Elimination System permit (WPDES Permit No. WI-0047376-1) issued in 1991 (WDHA, 1991), modified in 1992 (WDNR, 1992b), and renewed (and modified again) in 1996 (FMC, 1995b; WDNR, 1996). Treated water was discharged to the Flambeau River through a man-made channel designated Outfall-001.

A second outfall to the Flambeau River, designated Outfall-002 and located upstream of Outfall-001, was constructed for discharging untreated water from two unlined side-by-side settling ponds that received runoff from the mine's "low" sulfur waste rock stockpile. Collection of these waters in settling ponds prior to discharge would lower the suspended sediment concentrations, but it is misleading to refer to this approach as "treatment". As will be discussed later, FMC found it necessary to install liners beneath the two settling ponds in late 1995. Shortly thereafter, they also began pumping the settling pond effluent to the waste water treatment plant, apparently because WPDES limits were not being met.

Wisconsin regulators set limitations for Flambeau WWTP effluent (Outfall-001) and settling pond effluent (Outfall-002) at unreasonably-high concentrations in the WPDES permit for numerous constituents (e.g. aluminum, arsenic, cadmium, chromium (total/+3/+6), copper, lead, mercury, nickel, selenium, silver, zinc, total suspended solids). See Table 5 – Initial effluent limits. *Clearly the regulators were persuaded that these trace elements would be present at high concentrations in the Flambeau effluents*, and mandated that FMC should submit unfiltered samples (Total Recoverable data) to the lab to demonstrate permit compliance.

The effluent limits for permitted FMC discharges were so high that these outfalls represented significant sources of contaminants to the Flambeau River and to local ground waters. FMC documents are unclear about the actual routes and fates of some of these waters.

In addition, the WPDES permit failed to place *any* effluent limitations on many constituents of interest, a number of which are known to be presently contributing to degraded ground water quality at the mine site (e.g. manganese, iron, sulfate).

Based on the WPDES effluent limitations or lack thereof, it is clear that these waters likely contained high concentrations of numerous, trace constituents---concentrations much higher than most of the relevant U.S. or Canadian water quality standards or criteria (see Table 2 – Water quality standards). If Total Recoverable concentrations (from unfiltered samples) of these constituents were at or near the effluent limitations, the discharged waters would be potentially toxic to numerous forms of aquatic life.

Outfall-001: Unfortunately, FMC reports for the WWTP effluent discharged through Outfall-001 do not reveal the detailed chemical compositions of the effluent. For the first 3 months of WWTP operations, the company reported only the constituents listed in Table 5 – Initial effluent limits, instead of a more comprehensive panel. But even this limited panel was quickly reduced.

According to the terms of Flambeau's WPDES permit: "In the *first twelve analyses* of the treated effluent conducted on a weekly frequency, if [a cited] substance is not consistently detected using the [specified] analytical method …, or is consistently detected at a concentration at or below the level of concern, no additional monitoring of the substance will be required unless indicated by a demonstration of effluent toxicity" (WDNR, 1992b). In July 1993 (just 3 months into WWTP operations with roughly 60 months of water treatment to go) FMC informed the Wisconsin DNR that the following parameters no longer required monitoring: aluminum, arsenic, beryllium, chromium, hexavalent chromium, nickel, selenium and silver (FMC, 1993c). These constituents were subsequently dropped from the required panel in August of 1993.

The chemical composition of waters contacting sulfide-rich rocks evolves and degrades with time. Thus, it was totally inappropriate for the DNR to allow FMC to severely restrict the constituents being determined in the WWTP effluents after only 12 weeks of sampling, when blasting in the pit had commenced only 2 months earlier. These waters would have had insufficient time to evolve chemically and become suitably representative of waters in contact with sulfide-rich rocks.

The WWTP test panel was cut back again in 1996 so that for roughly the last year of operations, FMC was required to report only hardness, pH, D.O., TSS, TDS, total copper, total mercury, and total zinc in the WWTP effluents (WDNR, 1996).

When available Discharge Monitoring Reports (DMRs) are reviewed for the time period of March 1993 – August 1998, the median copper concentration reported by FMC for WWTP effluent was 19 µg/L (range = 7 - 50 µg/L; n = 62) and the median zinc level was < 17 µg/L (range = < 10 - 232 µg/L; n = 62). It would be instructive to have other medians for other metals of concern, but the data simply was not made public by FMC in its DMR reports.

FMC's 1996 and 1997 annual reports state that the WWTP discharged an average of 502,000 and 414,000 gallons per day through Outall-001 to the Flambeau River, in these years, respectively. Over the entire course of WWTP operations, a grand total of over 600 million gallons of effluent were reported (FMC, 1999a). Considering even the limited data available for metal concentrations in the effluent (e.g., the median copper concentration cited above), metals loading to the river cannot be dismissed as insignificant.

In addition to reporting concentrations of select constituents in the Outfall-001 effluent, the company's WPDES permit also called for Whole Effluent Toxicity (WET) testing of the effluent every 2 months. Test species included Ceriodaphnia dubia (a species of water flea), Pimephales promelas (the fathead minnow), and Daphnia magna (another species of water flea). A perusal of available reports (time period April 1993 - April 1998) showed that, for acute toxicity testing in 100% (undiluted) effluent, *D. magna* had a median survival rate of 100% (range = 68 - 100 %; n = 29), as did *P. promelas* (range = 90 - 100%; n = 44).

Survival rates for the third test species, *C. dubia*, however, proved problematic for FMC. In September 1993, results of the acute toxicity testing in undiluted effluent (using samples collected by FMC) showed the water flea had a survival rate of only 35% (IPS, 1993). FMC initially attributed the low survival rate to a malfunctioning valve in the WWTP associated with the dilute polymer feed to the sulfide treatment process. As reported by FMC, the valve "had become stuck in the open position allowing an increased flow of dilute polymer" which the company believed might have caused the positive toxicity result (FMC, 1993d). However, several months later the *C. dubia* acute survival rate in undiluted effluent (using Wisconsin DNR split samples) plummeted once more, this time to 10%, as compared to a survival rate of 100% in a Flambeau River control sample (IPS, 1994).

FMC initiated what they referred to as a "Toxicity Reduction Evaluation" in December 1993 to try to determine what was causing the *C. dubia* toxicity (FMC, 1994b). They eventually concluded that, unlike river water, the WWTP effluent "was deficient in constituents which reduce the bioavailability of metals ions [and], as a result, *C. dubia* was affected by metal ions at low concentrations in 100% effluent." They researched the issue further and concluded that citric acid, if added to the water treatment process, could "simulate this characteristic of the Flambeau River" by serving as an organic complexing agent to reduce bioavailable copper (FMC, 1994c-d and 1995a). The Wisconsin DNR approved FMC's request to add citric acid to the WWTP process in September 1994. Later, it was rather disingenuously suggested by some that the reason for the *C. dubia* toxicity was because the WWTP effluent was too clean.

Despite the use of citric acid in the water treatment process, FMC reported an acute survival rate of 25% for *C. dubia* in January 1995, 50% in late February 1995, and 54% in April 1995. No information regarding any attempts by FMC to further research the problem could be located. To the contrary, FMC claimed in its April 1995 WET submittal to the Wisconsin DNR that test results indicated "*no evidence of toxicity … in accordance with Flambeau's WPDES* *permit compliance criterion*" (FMC, 1995c). From a strictly legal standpoint, their claim was true, since the company's WPDES permit had defined "toxic" as a survival rate of less than 50% after acute exposure to undiluted effluent (WDNR, 1992b). Hence, the 54% survival rate that FMC reported for *C. dubia* in April 1995 was considered "acute toxicity negative."

FMC continued to discharge WWTP effluent to the Flambeau River until August 1998, when the plant was decommissioned and Outfall-001 was removed as part of site reclamation. As described in FMC's reclamation plan, surface water flows in the southeast corner of the project site were then adjusted to direct stormwater runoff to a newly-constructed biofilter located in the area of the former surge pond. The outlet from the biofilter, in turn, "direct[ed] water to the existing intermittent Stream C channel located in that area of the site" (AES, 1997). The effectiveness of this passive water treatment system will be discussed later.

Outfall-002: FMC constructed two side-by-side unlined settling ponds, each with a surface area of 1.4 acres and depth of about 18 feet, alongside the mine pit and "low" sulfur waste rock stockpile. The ponds (combined storage capacity 7 million gallons) were designed to collect and clarify runoff from the mine's "low" sulfur waste rock stockpile before discharge to the Flambeau River through Outfall-002 (Foth, 1992b). The WPDES permit for the project imposed the same discharge limitations on Outfall-002 as for Outfall-001 (See Table 5 – Initial effluent limits).

Review of the 1993-98 DMRs shows that on only <u>one</u> occasion (January 1993, at the outset of the monitoring program) did FMC report any discharges through Outfall-002. This particular DMR indicated high levels of total aluminum in the Outfall-002 effluent (daily max for total aluminum = 1,280 µg/L). Chromium, copper, lead, nickel and zinc were also detected (FMC, 1993b).

Reporting only one discharge from the settling ponds through Outfall-002 is curious, especially since FMC had stated in the 1990 EIS that the annual average discharge rate from the ponds was expected to be 29 gallons per minute. With the exception of the January 1993 DMR cited above, however, all other monthly DMRs indicated: "Discharge occurred only through Outfall 001 during this time period." Even in September 1994, when torrential rains caused historic flooding of the Flambeau River in the vicinity of the mine site, the DMR reported that no flow occurred through Outfall 002 for that month (FMC, 1994e). See Figure 4 – Mine pit during flood stage conditions.

With no reporting of any flow from Outfall-002 in the monthly DMRs, it also follows that, even though the WPDES permit called for Whole Effluent Toxicity testing of effluent from the 002 outfall every 2 months, no such reports could be located.

In addition to the absence of surface water and WET testing data for the settling ponds and their effluent, there is a ground water consideration that appears to have gone unaddressed by FMC. The company stated in the 1990 EIS: "More than 10% of the runoff water [directed to the settling ponds] is anticipated to percolate through the bottom of the ponds" (WDNR, 1990). Were the *ground waters* beneath the settling ponds ever monitored? If so, no such data can be found in the public record.

In September 1995, FMC approached the DNR with a plan to line the settling ponds. As will be discussed later, pit wall instability had become a problem at Flambeau, and FMC believed that subsurface seepage from the unlined settling ponds might be contributing to instability along the north wall of the open pit (FMC, 1995d). Liners were installed in October 1995 (Foth, 1995), and a month later FMC submitted an additional plan to “refine the Outfall 002 discharge line to allow the flexibility of directing storm water contacting Type I waste rock to either the WWTP’s Surge Pond, the open pit, or, if WPDES permit limits are met, the Flambeau River” (FMC, 1995e). The plan was approved by the DNR in May 1996, but, as noted by FMC in its 1996 annual report, by April 1996 the company had already started to pump settling pond effluent to the WWTP, suggesting that WPDES limits for Outfall 002 were not being met. No water quality data for the settling pond waters pumped to the WWTP could be located.

Between April 1996 and November 1997, FMC pumped a total of about 11 million gallons of settling pond effluent/Type I runoff to the WWTP (FMC, 1997a and 1998a). Regardless, the applicable WPDES permit monitoring requirements (for WWTP effluents discharged through Outfall-001) had been cut back drastically by this time.

As part of site reclamation in 1997-1998, the PVC liner in the settling ponds was punctured and left in place, and the ponds were filled. A 1.7-acre biofilter was constructed roughly 650 feet southeast of the original settling pond location, sized for a 100-year storm event and designed to receive and clarify runoff from the south watershed of the project site before discharge to the Flambeau River (for biofilter location see Figure 1 – Flambeau River surface water sampling stations). Outfall-002 was retained to convey water leaving the biofilter to the Flambeau River and is now referred to by FMC as the “south watershed drainage channel” (AES, 1997). FMC reports that two significant precipitation events occurred in 1998 after the WWTP was shut down, generating extreme runoff which entered the Flambeau River despite the activation of contingency plans for pumping water from the biofilter to a nearby gravel pit (FMC, 1999a).

Outfalls-003 and 004: In addition to Outfalls-001 and 002, at least two company-identified outfalls existed for directing a portion of the settling pond effluent and ground waters from interception wells surrounding the mine pit to a hydric soils stockpile and to wetlands targeted for flow augmentation. Despite the fact that WPDES discharge limits were established for Outfalls-003 and 004, FMC’s discharge monitoring reports consistently showed no flow through either of them, thus the fate of these waters is unknown.

Pit Wall Instability.

According to technical reports issued in 1997, the Precambrian ore-bearing rock at Flambeau is highly fractured (both pre-mining and post-backfilling), bench scale instability occurred throughout the life of the mine due to low rock strengths, and all formations at Flambeau exhibit significant permeabilities, both vertical and horizontal (Straskraba, 1997; Yost, 1997b). To address some of the permeability issues, FMC constructed a slurry cutoff wall between the pit and Flambeau River in 1992 (Foth, 1992a and 1993b). The company also undertook an aggressive rock bolting and meshing program in 1995 in efforts to stabilize the pit walls (Yost, 1997b). All of this contrasted sharply with FMC’s public claim: “The Flambeau mine is separated from the Flambeau River by a 140-foot rock pillar stronger than the Hoover Dam" (see Figure 5 – Visitor center plaque).

Bench scale instability began early in the life of the Flambeau Mine, and by 1995 instability along the *north* wall of the pit was of major concern (Yost, 1997b). Several different engineering methods were utilized in efforts to stabilize the wall, including: (1) slope redesign; (2) buttress walls; (3) long horizontal drains (100-250') to reduce pore water pressure along fault lines; (4) vertical dewatering wells near the crest of the pit to intercept ground water flow; and (5) rock bolts, steel straps and wire mesh (FMC, 1995f and 1997a; Yost, 1997b). Because FMC believed subsurface seepage toward the north wall was contributing to pit wall instability, and that the mine's unlined settling ponds were contributing to the seepage, they also opted to line the ponds in October 1995 (FMC, 1995d; Foth, 1995).

Instability problems apparently were not limited to the north wall of the pit. FMC reports that a total of 1,500 rock bolts were installed to support both the north and south walls of the pit and that, in addition to installing horizontal drains along the north wall of the pit, short horizontal drains (40-60') were installed along the west and south walls to relieve pore water pressure (FMC, 1997a).

Despite all of the above, a major collapse involving multi-bench movement occurred along a section of Flambeau's north pit wall in March 1996. As reported by FMC in its 1996 Annual Report, the movement affected an area of the final wall from mine coordinates 40,500 east to 41,300 east and extended vertically from the 1,000' level of the mine to the crest of the pit at the 1,100' elevation. See Figure 6 – Backfilled pit cross section, for coordinate positions and elevations.

FMC's admitted solution to the pit wall instability problem was to accelerate its production rate in 1996 "in order to complete the total mining program to pit bottom by early 1997 i.e. prior to the spring thaw" (FMC, 1997a). In addition, they started to backfill the east end of the pit in August 1996, while continuing to extract ore from the west end. The last truckloads of ore were hauled from the Flambeau pit during the first week of March 1997, at which time backfill operations proceeded in earnest.

Flambeau Ground Water Quality: Within and Outside Pit.

[See Table 6 – Ground water quality data, for data supporting water quality comments. It includes FMC data reported for **filtered** samples. Also, see Figure 6 – Backfilled pit cross section, Figure 7 – Compliance boundary, and Figure 8 – Shallow potentiometric surface map, for monitoring well locations.]

Inadequacies in FMC's baseline ground water monitoring program were discussed earlier. The company's monitoring reports also fail to make public data for detailed chemical constituents, including most potentially-toxic trace elements, for ground waters during the years of active mining (1993-97), continuing until 1999 (nearly two years after the mine pit was backfilled). Reporting during this time period was limited to pH, S.C., TDS, sulfate, alkalinity, hardness, copper, iron and manganese, with data submitted on a quarterly basis.

FMC's failure to routinely report most trace metals and metal-like elements (metalloids) other than copper, iron and manganese encouraged the impression that other trace/minor constituents were not present at Flambeau, such as: aluminum, antimony, arsenic, barium, cadmium, chromium, cobalt, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, zinc, natural radioactive constituents (uranium, radium, thorium, potassium-40, gross alpha and beta). For many years, including the years of active mining, arsenic was not reported; antimony and uranium—both reported to be present in Great Lakes regional massive sulfide ores—were not reported, even though FMC's ground water baseline compilation reports that uranium was detected in between 64 to 100% of their samples, depending upon the well producing zone. Nor was aluminum reported, despite the fact that it was detected in all samples tested for baseline. Additional important chemical constituents were frequently not determined (or not made public) when samples were analyzed. These include for example: sulfide, total suspended solids (TSS), turbidity.

The Wisconsin DNR did not require FMC to report what was referred to as "an expanded suite of parameters" until *after* mining operations were complete and the pit was backfilled. When FMC finally started to report the "expanded suite" in mid-1999, the public *still* would have seen only filtered sample data, collected once per year, and the test panel was limited to the following constituents: chloride, calcium, magnesium, potassium, sodium, barium, cadmium, chromium, lead, mercury, selenium, silver and zinc. Quarterly reporting of the constituents mentioned above also continued, with arsenic added to the test panel in 1999.

As of 2017, the only ground water parameters reported by FMC on a routine basis (some quarterly, some annually) include: pH, S.C., TDS, sulfate, chloride, alkalinity, hardness, redox, calcium, magnesium, potassium, sodium, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver and zinc[10]. As discussed earlier, even though FMC fails to draw the distinction between Dissolved and Total concentrations in its annual reports, a review of original lab sheets suggests that all routine FMC ground water monitoring data are from filtered samples, from which some, if not most of the chemical components have been removed, thereby lowering the original concentrations. For a summary of "baseline" (1987-88) and recently reported ground water data from wells of interest at Flambeau, please see Table 6 – Ground water quality data.

Having additional ground water data from wells drilled by FMC in the 1970s would prove very useful in determining trends, but despite the fact that many of these older 4-inch diameter wells still exist and are characterized as "active" by the Wisconsin DNR, no data are being reported from them, publicly, except ground water elevation (WDNR, 2017b). See Table 3 – Physical details of ground water monitoring wells.

It bears repeating that ground waters within the backfilled Flambeau pit are extremely complex chemically, and the composition changes once samples are lifted from depth and exposed to the atmosphere. And, most FMC well data comes from small-diameter (2-inch) wells that are too narrow to allow adequate cleaning and purging prior to sampling. This, in combination with the fact that all samples were filtered prior to analysis, means the concentrations of these constituents are not representative of *in-situ* pit ground waters, and are not quantitatively reliable.

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[10] **Editor's note:** See Footnote 9 on page 27 regarding a possible reduction in ground water monitoring frequency and parameters at Flambeau in the future.

Still, a review of FMC ground water data demonstrates that Flambeau Mine ground waters are contaminated by past FMC activities. FMC data confirm that, as a minimum, ***dissolved*** concentrations of the following constituents significantly exceed FMC's reported baseline concentrations (1987-88): copper, iron, manganese, zinc, sulfate, alkalinity, hardness, total dissolved solids, specific conductance (field). As noted above, these are practically the only parameters routinely reported by FMC in their quarterly monitoring.

Clearly some of the increase in field conductance is due to the addition of limestone to the waste rock upon backfilling the pit, which also increases the alkalinity and hardness concentrations. However, the dissolved (D) sulfate, manganese and zinc concentrations rose *in spite of the increased alkalinity from the limestone.*

A possible mechanism for these increases was discussed earlier: While the backfilled waste rock was mixed with limestone at Flambeau to minimize the formation of acid and release of trace constituents into the pit waters, the rise in pH due to the addition of limestone (or especially lime) can also generate conditions that increase the water concentrations of those trace elements that form mobile species *at elevated alkaline pHs.* These include metals and metalloids such as *aluminum, arsenic, antimony, chromium, lead, manganese, nickel, selenium, molybdenum, uranium, vanadium, zinc, and possibly some forms of mercury, strontium, thallium and rare earth elements*. Alkaline pHs can also release some metals and metalloids from the surfaces of sediment particles, increasing their dissolved concentrations and increasing their mobility. The Flambeau Mining Feasibility Study by Pincock, Allen & Holt Inc. that is cited in the 1989 EIR (Foth, 1989a – p. 4.3-A-1) may contain detailed geochemical testing to demonstrate the potential formation of such chemical forms mobile at elevated pHs. *Feasibility studies are required to inform potential investors, but this one apparently was not released to the public.*

FMC wells within the backfilled pit have *median* dissolved concentrations as high as the following (2014-16): Copper = 503 µg/L; Iron = 14,000 µg/L; Manganese = 33,500 µg/L; Zinc = 1,200 µg/L; Arsenic = 23 µg/L; Sulfate = 1,600 mg/L; Alkalinity = 610 mg/L; Hardness = 2,150 mg/L; Total Dissolved Solids = 3,110 mg/L; Specific Conductance = 3,180 µS/cm. These values greatly exceed baseline data and relevant water quality standards and aquatic life criteria. See Figures 9a - 9f – Ground water quality graphs.

This pattern of water quality degradation between FMC "baseline" (1987-88) and recent conditions (2014-16) is shown well by comparing data from the following pairs of wells, using median values for all parameters. D = dissolved:

- **MW-1000 ("Baseline") versus MW-1000R (Recent):** both of which are shallow wells (depth = 19 - 24 ft.) located between the pit and Flambeau River, about 170 ft. from the river. The field specific conductance increased from 96 to 613 µS/cm; D sulfate increased from 14 to 90 mg/L; D manganese increased from < 50 to 9,490 µg/L.

  NB: MW-1000 was abandoned in 1992, when a slurry cutoff wall was constructed to impede water flow between the mine pit and Flambeau River and stabilize overburden. MW-1000R was drilled later the same year as a replacement. FMC claimed MW-1000 needed to be moved "since its original location was downgradient of the slurry cutoff wall system, negating the ability of the well to monitor the shallow till downgradient of the backfilled pit." MW-1000R is located approximately 100 feet east of the original location of MW-1000 (FMC, 1993a).

It is interesting to note that MW-1000 had a sulfate concentration of 410 mg/L and a pH of 2.6 when sampled in April 1992. Obviously oxidation of sulfides was already occurring as of this date, even before active mining had commenced. In October 1992, when MW-1000 was removed from routine monitoring and replaced by MW-1000R, the final sulfate concentration reported for MW-1000 remained elevated, 120 mg/L. Fortuitously, no water quality data were reported from MW-1000R until late 2010, with the exception of a single round of data reported for November 1992, shortly after the well was constructed. Thus, two of the most "sensitive" wells were removed from the monitoring program—for years.

- **MW-1000P ("Baseline") versus MW-1000PR (Recent):** both are completed in fractured bedrock (Precambrian) outside the pit (depth = 55 - 58 ft.), about 130 ft. from the river. Field specific conductance increased from 224 to 796 μS/cm; D sulfate increased from 18 to 190 mg/L; D manganese increased from 620 to 2,100 μg/L; D zinc from 48 to 380 μg/L.

  NB: MW-1000P reportedly was damaged during snow removal operations in January 1996 and replaced with MW-1000PR the following month. According to FMC, MW-1000PR was established in the same location and "constructed in the same manner" as MW-1000P (Foth, 1996a). Unfortunately, FMC reports often confound the designations for MW-1000P and MW-1000PR, attempting to give the impression that they are the exact same well, which is clearly not true.

  It is common for baseline wells to "disappear" at mining sites; I've seen this pattern dozens of times. Sometimes there is a legitimate construction reason for the removal of the original well; more often it appears to be a convenient way to disrupt the historical continuity of the data. In the case of MW-1000 and MW-1000P, FMC replaced wells that showed evidence of sulfide oxidation!

  Nevertheless, the increased and sustained or fluctuating levels of manganese, sulfate and S.C. in the downgradient replacement wells (MW-1000R and MW-1000PR) indicate pit-influenced water is slowly migrating to the southwest of the pit. Slowly increasing trends in manganese and iron since 2007 in a well located to the northwest of the backfilled pit (MW-1004P; 76 ft. deep) suggest some slow, deeper migration of pit water in that direction as well (see trend graphs in FMC annual reports). MW-1003/P, located along the north wall of the backfilled pit, is also of interest, but no water quality data for this particular nested well has been included in any of FMC's annual reports.

Comparison of selected parameters (all reported as 2014-16 median values) for the deeper wells (<u>constructed post-"baseline"</u> within the Type II ("high" sulfur) backfill) with baseline wells discussed above (MW-1000 and MW-1000P) shows greater degradation of water quality conditions despite limestone addition during backfill operations and the predicted, but as yet unrealized, existence of anoxic conditions deep within the backfilled pit:

- **MW-1013B** (84 ft. deep): field S.C. = 3,184 μS/cm; D sulfate = 1,600 mg/L; D manganese = 33,500 μg/L.

- **MW-1013C** (198 ft. deep): field S.C. = 3,116 μS/cm; D sulfate = 1,520 mg/L; D iron = 14,000 μg/L; D manganese = 9,650 μg/L; D zinc = 420 μg/L.
- **MW-1014B** (102 ft. deep): field S.C. = 2,790 μS/cm; D sulfate = 1,300 mg/L; D manganese = 11,100 μg/L; D zinc = 1,200 μg/L.
- **MW-1014C** (154 ft. deep): field S.C. = 1,025 µS/cm; D sulfate = 210 mg/L; D iron = 4,900 µg/L; D manganese = 1,700 µg/L; D zinc = 330 µg/L.

Another consideration at Flambeau involves ground waters infiltrating the Type I ("low" sulfur) waste placed *on top of* the Type II backfill. The Type I material is at roughly 1,090 – 1,070 ft. MSL, compared to 1,080 ft. MSL for the bottom of the Flambeau River (see Figure 6 – Backfilled pit cross section). FMC hydrogeological and pit water quality data indicate that the Flambeau River and pit waters are likely interconnected—at least at shallow depths---with flow directions changing seasonally as the respective water levels (head relationships) vary. Thus, *anoxic conditions will not occur in these shallower backfill waters due to inflow of oxygenated waters and oxidation by ferric iron & bacteria.*

FMC did not address this potential contamination issue in the 1990 EIS, instead claiming the Type I waste would not be acid producing or require limestone amendment. By the same token, they anticipated that, during mine operations, storm water runoff from the Type I stockpile could be effectively handled by simply directing it to settling ponds and discharging the effluent to the Flambeau River without treatment. As discussed earlier, however, on-site conditions proved otherwise. Even though sulfur contents within the Type I waste rock stockpile were reported by FMC at ≤ 0.9%, effluent from the settling ponds apparently failed to meet WPDES discharge limits, as evidenced by FMC's decision to pump millions of gallons of settling pond effluent to the WWTP for treatment instead of discharging it to the Flambeau River through Outfall-002. The "low" sulfur waste rock that was the source of this contaminated effluent is the same waste rock, some of which is now amended with limestone, that is in the shallower backfill zones at Flambeau, where anoxic conditions are not expected to occur. A review of available data from the shallower wells within the backfilled pit (all reported as 2014-16 medians) shows:

- **MW-1013** (22 ft. deep): field S.C. = 1,116 μS/cm; D sulfate = 26 mg/L; D iron = 3,740 μg/L; D manganese = 26,100 μg/L
- **MW-1013A** (44 ft. deep): field S.C. = 972 μS/cm; D sulfate = 184 mg/L; D manganese = 4,200 μg/L
- **MW-1014** (31 ft. deep): field S.C. = 677 μS/cm; D sulfate = 110 mg/L; D manganese = 1,200 μg/L
- **MW-1014A** (61 ft. deep): field S.C. = 2,198 μS/cm; D sulfate = 930 mg/L

Trend Analysis: In addition to changes in sulfate concentration and specific conductance, two markers helpful in assessing for the presence or absence of anoxic conditions in the backfilled pit are variations in iron and manganese. Elevated concentrations of both have been noted above, and trend graphs assembled by FMC show that concentrations in some of the wells within the backfilled pit have stabilized, others continue to increase, some are decreasing and others are fluctuating widely (FMC, 2017a). For example, iron in MW-1013C (198 ft. deep) has steadily increased since 1999 but appears to be stabilizing at an elevated concentration of roughly 14,000 µg/L; iron in MW-1014C (154 ft. deep) has been trending downward from a high of 15,000 µg/L in 1999 and appears to be stabilizing at roughly 5,000 µg/L. One of the shallower wells (MW-1013) has significant fluctuations in iron (range = 1,000 - 22,000 µg/L between 2005 and 2016), indicating the waste that this well is sampling is still in chemical flux. Iron concentrations in MW-1014 (31 ft. deep) have been relatively stable at concentrations below the level of detection (330 µg/L) since monitoring was initiated in late 2005.

For manganese, MW-1014B (102 ft. deep) has been trending downward from a high of 23,000 µg/L in 1999, but appears to have stabilized at what is still an elevated concentration of about 10,000 µg/L; MW-1013B (84 ft. deep) has unexplained fluctuations with concentrations ranging from 25,000 - 41,000 µg/L (2014-16); MW-1014 (31 ft. deep) is fluctuating, with concentrations ranging from 455 - 1,900 µg/L (2014-16); and MW-1013 (22 ft. deep) is slowly increasing with a reported concentration of 27,000 µg/L in October 2016. Since 2011, alkalinity levels have been relatively stable in the pit wells, except for MW-1013C, where several major fluctuations have been recorded (FMC, 2017a). This all suggests that even 20 years after closure, the pit is still experiencing some changes in chemistry.

Ground Water Flow Pathways.

FMC has not tested and evaluated the extent to which Flambeau pit seepage is limited to shallow pathways through alluvium and fractured bedrock into the Flambeau River, or whether deeper pathways under the bed of the river may be viable. Apparently no baseline or recent monitoring of wells on the west side of the river (opposite side from pit) has been conducted by FMC or the State, at least no such data are publicly available. Thus, it is also not possible to determine whether ground waters west of the Flambeau River have been negatively-impacted by FMC operations.

The Flambeau ore body extends under the Flambeau River to the west (Schwenk, 1977), but mining was limited to the area of the mined pit, east of the river. The backfilled pit is within highly fractured rock (Yost, 1997b), is intersected by several faults (Yost pit map, 1997a; Straskraba, 1997; May & Dinkowitz,1996), and blasting has increased the natural fracturing (Straskraba, 1997). These abundant fractures and faults presumably act as pathways for ground water migration, with the backfilled pit acting as the preferred flow path within the Precambrian bedrock.

As mentioned earlier, FMC hydrogeological and pit water quality data indicate that the Flambeau River and pit waters are likely interconnected—at least at shallow depths-- with flow directions changing seasonally as the respective water levels (head relationships) vary. Shallow ground waters from the backfilled pit are likely migrating downgradient, around, under, and possibly through the slurry cutoff and diaphragm walls into the Flambeau River and surrounding alluvial sediments. The overall hydrogeological relationships suggest that the deeper ground waters may be migrating under the river sediments via fractures and faults. It is unclear whether contaminants have or could migrate to the west side of the river via such a deep path. Over decades, neither FMC nor the Wisconsin DNR have conclusively eliminated the possibility of this potential deep ground water pathway.

When confronted by the public in the late 1980s regarding potential adverse impacts to ground waters across the river from the mine site, FMC consultant Foth, in coordination with BP Minerals[11], disseminated a two-part report to the public in which they stated: "Kennecott does not believe that its operations will adversely impact any groundwater or any wells, regardless of location. Nowhere is this more evident than in the case of wells located across the Flambeau River from the mine site. … Groundwater is not moving from the site toward [these wells]. The river is in the way. It is clearly impossible, then, for any activities at the mine, on one side of the river, to affect any water wells on the other side of the river" (BP & Foth, 1988). This is ground water foolishness.

In the 1989 EIR, Foth also suggested that "… all of the groundwater flowing through the Type II waste rock in the reclaimed pit will exit the pit through the Precambrian rock in the river pillar and flow directly into the bed of the Flambeau River," and that, for example, "elevated sulfate concentrations [in the ground water emanating from the Type II waste rock] will never be able to travel more than 140 feet from the reclaimed pit" (i.e., beyond the Flambeau River) (Foth, 1989d).

Contrary to the above statements from Foth, the physical relationships between the backfilled pit, the Flambeau River and the surrounding rock formations indicate that *most* of the contaminated pit water is likely migrating downgradient in the Precambrian bedrock via fractures and faults, and is not entering the river (see Figure 6 –Backfilled pit cross section).

The most informative publicly-available site hydrogeologic comments were provided by Vladimir Straskraba in 1997. As is usual, they were part of a technical report to FMC, not part of any initial permit documentation. Straskraba stated that:

- The Precambrian ore-bearing rock is highly fractured (both pre-mining and post-backfilling), and the ground water flow is dominantly east-west (E-W/NE-SW). This flow direction is roughly ten times as permeable as flow in the north-south (N-S/NW-SE) direction. As detailed by Straskraba:

  "It is believed that a strong directional permeability along the orientation of the open pit, from east to west, and from northeast to southwest will govern the ground water flow direction in the Precambrian bedrock. In addition to the natural (pre-mining) orientation of directional permeability, ground water flow near the backfilled pit wall will be impacted by the blasting-enhanced permeability within a narrow zone along the pit walls, and by slightly less compacted backfill along the pit walls. Direction of the "man-enhanced" permeability will be similar to the natural directional permeability in the Precambrian bedrock."

  Thus, as will be discussed later, the location of the single nested well (MW-1015A/B) constructed by FMC for determining compliance with the State's ground water protection

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[11] Kennecott Corporation (known as Kennecott Copper Corporation until 1980) became a subsidiary of BP Minerals in 1987, which in turn was acquired by RTZ Corporation in 1989.

law is largely useless, and is certainly inadequate to provide warning of contaminated seepage from the pit.

- Pre-mining ground water flow followed the local topography, SE to NW, discharging into the Flambeau River.
- All formations exhibit significant permeabilities, both vertical and horizontal.

As part of his analysis, Straskraba reviewed three Flambeau ground water models developed by others (King, 1987; Prickett & ETA, 1989 and 1996). His comments were appended to a fourth modeling report issued by Engineering Technologies Associates in 1998. In particular, Straskraba noted the following estimates/predictions from Prickett & ETA's 1996 report that used MODFLOW (simulation period March 1996 to July 1997, the projected end of mining):

- Total pit water inflow volumes were estimated to be about 180 to 310 gpm.
- Maximum drawdown in the western section of the pit would be 175 ft.
- The zone of influence (for the dewatered pit) would be 600 ft. west of the pit; 800 ft. south and east of the pit; 1,000 ft. north of the pit.
- Maximum drawdowns away from the mine would occur 10 years post-mining.
- Backfilled sediments would be resaturated within roughly 30 years post-closure. NB: This prediction was later modified to 15 years (ETA, 1998).

These hydrogeologic comments in combination with the pit cross section maps that appear in FMC's annual reports *indicate that significant volumes of pit ground water may be flowing downgradient below the Flambeau River, in the deeper alluvial sediments and or bedrock.* This is especially evident when the pit cross section maps are modified to show the relative position and depth of the Flambeau River (see Figure 6 – Backfilled pit cross section). However, FMC has failed to provide data to clarify the actual flow pathway(s) of these ground waters.

By focusing attention on the seepage of degraded-quality pit waters into the Flambeau River but failing to provide data to clarify the probable flow of ground water below the Flambeau River, in the deeper alluvial sediments and or bedrock, FMC has diverted attention from a potential long-term problem, barely regulated.

Impacts to Flambeau River.

[See Table 4 – Flambeau River Surface water quality data, for data supporting water quality comments.
It includes FMC data, most of which appear to be from **unfiltered** samples.
Also, see Figure 1 – Flambeau River surface water sampling stations.]

At present, it is not possible to demonstrate that Flambeau River chemical constituent <u>concentrations</u> have been degraded by FMC activities. This is partly due to the totally-inadequate surface water monitoring data made public by FMC. Secondly, the physical relationships between the backfilled pit, the Flambeau River and the surrounding rock formations indicate that most of the contaminated pit water is likely migrating downgradient in the Precambrian bedrock via fractures and faults, and is not entering the river. Nevertheless, surface water contamination issues exist at the Flambeau site.

Sources of Contaminant Loads: Monitoring wells located outside the Flambeau pit in the downgradient flow direction show clear evidence of contamination relative to baseline concentrations and relevant standards and criteria. For example, a well located between the southwest corner of the backfilled pit and Flambeau River (MW-1000R), had dissolved manganese concentrations of 13,800 µg/L and a specific conductance of 660 µS/cm in October 2016 (FMC, 2017a). FMC has argued that degraded pit waters flow into and are diluted by the large flows of the Flambeau River, located only 140 feet from the west end of the pit (Foth, 1989d).

Despite stating that Flambeau River waters and Flambeau reclaimed pit waters move back and forth depending on the seasonal hydrogeologic conditions, FMC has made public no detailed studies that evaluate and explain the interactions between local surface and ground waters and their water qualities. Such relationships would have become clear had FMC conducted (and reported) long-term, high discharge aquifer tests combined with *in situ* monitoring of field temperature, pH, S.C., and dissolved oxygen.

If, as FMC argues, contaminated pit waters are entering the Flambeau River, then they are already increasing the *loads (mass)* of the various metals, metalloids, sulfate, sediments, etc. added to the river. Had FMC monitored for an extensive list of chemical constituents in the effluent from its waste water treatment plant – instead of the incorrectly-reduced list instituted roughly three months after start-up of the WWTP – increases in concentrations and masses of metals released into the Flambeau River would have been obvious. Note that an average of 11.4 million gallons per month of inadequately-treated WWTP effluents were discharged into the Flambeau River via Outfall 001 in 1993 alone and a grand total of over 600 million gallons over the full course of WWTP operations (FMC, 1994a and 1999a). As mentioned earlier, considering the median copper concentration reported by FMC for WWTP effluent over the 5 years of plant operations was 19 µg/L (range = 7- 50 µg/L; n = 62), metals loading to the river cannot be dismissed as insignificant.

In addition to ground water contamination from the backfilled pit and inadequately-treated effluents from the WWTP, the Flambeau River received contaminants from numerous other sources of FMC property effluents: surface inflows from Stream C; the Copper Park Lane drainage ditch and other facilities adjacent to where the ore crusher and rail spur were located; wetlands, storm runoff; stockpiled waste rock leachates and seeps; ore stockpiles; releases from the settling ponds and surge pond; interceptor well discharges; clarifier underflow solids (sludge from the WWTP). Several of these sources are presently contributing contaminants to the Flambeau River via surface water pathways, and probably also via ground water pathways.

Contaminated discharges from the southeast corner of the FMC site, also known as the "industrial outlot," have resulted in Stream C being added to the Environmental Protection Agency (EPA) impaired waters list for exceedances of acute aquatic toxicity criteria for copper and zinc (USEPA, 2014) and have caused the State of Wisconsin to withhold issuance of a Certificate of Completion (COC) of mine reclamation for this portion of the mine site (WDHA, 2007). Additional information regarding the impaired status of Stream C is provided in an outside review of FMC water quality data conducted by Chambers and Zamzow in 2009 (See Table 7 – Stream C water quality data), and a Flambeau Mine surface water quality assessment conducted by the Wisconsin Department of Natural Resources as part of the impaired waters listing process (WDNR, 2012a and 2012b).

Since 1998, FMC has instituted six different work plans to address soil and water contamination issues in the industrial outlot. As of fall 2016, copper levels in the Flambeau River tributary still exceed the acute toxicity criterion (ATC), despite passive water treatment (FMC, 2017b)[12].

The various work plans implemented by FMC are listed on the following page, along with some of the pertinent monitoring results for Stream C gleaned from FMC reports. The referenced Stream C sampling site, SW-C1, is located where focused runoff leaves the mine site, and SW-C6 is at the stream's confluence with the Flambeau River (see Figure 10 – Flambeau Mine surface water sampling stations). Reported ATCs are hardness-adjusted, based on Wisconsin regulatory formulae[13].

FMC has also reported elevated copper concentrations at SW-C9, a Stream C sampling site *upstream* of where the passive water treatment system drains into the stream. SW-C9, which has registered lower but sometimes higher copper concentrations than reported at SW-C1, is in the industrial outlot, near the former location of the mine's rail spur and "high" sulfur waste rock stockpile.

Inadequate surface water monitoring data: Government and commercial investigators usually collect both filtered and unfiltered samples as part of similar mining-related investigations, but the monitoring plans approved by the Wisconsin DNR for FMC had no such requirement (Foth, 1991 and 1993c). As noted earlier, it appears the Flambeau River surface water data provided by FMC in its annual reports are from unfiltered samples only. While unfiltered sample data are especially relevant where impacts to aquatic life may be anticipated, FMC's failure to report Dissolved concentrations in tandem with the Totals limits the utility of the data (Hem, 1985).

In addition, the surface water test panel employed by FMC was/is unacceptably limited. According to the company's 2000 Annual Report, only the following parameters were determined for Flambeau River water samples between July 1991 and April 1999, including the years of active mine operations: field conductivity, field pH, aluminum, arsenic, beryllium, cadmium, chromium, chromium VI, copper, dissolved oxygen, hardness, lead, mercury, nickel, selenium, silver, sulfide (not tested until November 1993), TDS, TSS and zinc. Sampling locations in the river were limited to SW-1 (upstream) and SW-2 (downstream of the mine pit but *upstream* of the Stream C confluence) and did not include the mixing zones of the mine's two engineered outfalls (Outfall-001 and Outfall-002) or Stream C (see Figure 1 – Flambeau River surface water sampling stations). In addition, unacceptably-high detection limits were often employed, thus unverifiable "less than" (qualified values) were reported, e.g. sulfide < 2 mg/L. Notably absent from routine reporting during the entire time period were iron, manganese and sulfate (FMC, 2001a).

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[12] **Editor's note:** Data submitted by FMC to the Wisconsin DNR for 2017 and 2018 (after Dr. Moran drafted his comments) demonstrate that copper concentrations in Stream C continue to exceed the acute toxicity criterion downstream of the mine site. See Footnote 17 for details.

[13] Wisconsin Administrative Code, Chapter NR 105, ss. 105.05 and 105.06 (Nov 2008).

FMC Work Plan	**Selected Copper Concentrations Reported in Stream C after Implementation of Work Plan**[14]
1998: Construction of a 0.9-acre biofilter in the industrial outlot to passively treat contaminated storm water runoff from the mine site "before it flows to Stream C" (AES, 1997)	**Jun 2002** [15] (FMC, 2003) - SW-C1: Cu = 30 µg/L (T/D not specified); Hardness-adjusted ATC = 3.7 µg/L (T) - SW-C6: Cu = 22 µg/L (T/D not specified); Hardness-adjusted ATC = 6.4 µg/L (T)
Nov 2003: Removal of rail spur in the industrial outlot and excavation of contaminated soils beneath it (Foth, 2003)	**Jun 2005** (FMC, 2005) - SW-C1: Not Reported - SW-C6: Cu = 36 µg/L (T); Hardness-adjusted ATC = 5.1 µg/L (T)
Jun 2006: Excavation of drainage ditch leading to biofilter; replacement of drainageway with limestone cobbles; removal of 4-10 inches of soils in 2.2-acre area within outlot, covering with crushed limestone gravel and paving with asphalt (Foth, 2005 and 2006)	**Oct 2008** (Foth, 2008b) - SW-C1: Cu = 77 µg/L (T); Hardness-adjusted ATC = 4.4 µg/L (T) - SW-C6: Not Reported
Nov 2008: Excavation and removal of soils in a drainage ditch along a roadway in the outlot (Copper Park Lane) considered a potential source of copper to Stream C (Foth, 2008a)	**Jun 2011** (WDNR, 2012b) - SW-C1: Cu = 23 µg/L (T/D not specified); Hardness-adjusted ATC = 5.6 µg/L (T) - SW-C6: Cu = 22 µg/L (T/D not specified) Hardness-adjusted ATC = 6.6 µg/L (T)
Mar 2012: Replacement of the 0.9-acre biofilter with an infiltration basin (Foth, 2011)	**Oct 2013** (FMC, 2014) - SW-C1: Cu = 81 µg/L (T); Hardness-adjusted ATC = 6.2 µg/L (T) - SW-C6: Not Reported
Jun 2016: Conversion of the infiltration basin to a flow-through wetland area, apparently due to the infiltration basin's inability to handle spring melt volumes and its need to be pumped in order to avoid overtopping[16] (Foth, 2015; WDNR, 2013)	**Oct 2016** [17] (FMC, 2017b) - SW-C1: Cu = 12 µg/L (T/D not designated); Hardness-adjusted ATC = 3.2 µg/L (T) - SW-C6: Not Reported

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[14] Between implementation of successive work plans, all copper concentrations reported by FMC at SW-C1 and SW-C6 exceeded the hardness-adjusted ATC. Examples shown here are among the highest reported concentrations.

[15] No water quality data for Stream C prior to June 2002 could be located in the public record. It is also unclear if the copper concentrations reported for SW-C1 and SW-C6 in June 2002 were Total or Dissolved. Between 2003 and 2006, no additional SW-C1 data and only limited SW-C6 data could be located in the public record. See Table 7 – Stream C water quality data, for more details.

[16] An April 2013 email string between the Wisconsin DNR and FMC regarding the near over-topping of infiltration basins at the Flambeau Mine site included photo documentation and the following statement from the DNR: "On a broader issue, we clearly cannot continue responding frantically every spring when the North and East Basins fill up to capacity. That is not a viable management strategy. The basin waters may infiltrate eventually, but they are clearly having difficulty handling the spring melt volumes. With shifting global weather patterns accentuating extreme weather events, I don't see this situation getting much better in the future. I think it is time to discuss the installation of some sort of engineered emergency overflow system. Whether it is a simple rip-rapped apron or some sort of culvert, we need something in place to prevent overtopping of the sidewalls in these intense events" (WDNR, 2013).

[17] **Editor's Note:** Copper concentrations at SW-C1 in Stream C continue to exceed Wisconsin's hardness-adjusted ATC for copper. Among the highest reported concentrations are the following:

06/2017 (FMC, 2017c): Cu = 14.6 µg/L (T/D not designated); Hardness-adjusted ATC = 3.7 µg/L (T);
09/2017 (FMC, 2017d): Cu = 17.1 µg/L (T/D not designated); Hardness-adjusted ATC = 7.9 µg/L (T);
07/2018 (FMC, 2018b): Cu = 14.7 µg/L (T/D not designated); Hardness-adjusted ATC = 5.3 µg/L (T);
09/2018 (FMC, 2018e): Cu = 22.0 µg/L (T/D not designated); Hardness-adjusted ATC = 7.1 µg/L (T).

It is unclear if FMC will continue to monitor Stream C water quality in the future. A recently proposed plan from the company to scale back environmental monitoring at the Flambeau site makes no mention of the stream (FMC, 2018d).

Iron, manganese and sulfate were finally added to the Flambeau River surface water monitoring program in late 1999, but at the same time FMC stopped reporting all other trace metals in river water except for copper and zinc (FMC, 2001a). In 2013, monitoring was cut back even further, when manganese and sulfate were once again dropped from the test panel despite elevated concentrations of both constituents in wells within the backfilled pit and between the pit and river.

Hence FMC's recent surface water reports, filed biannually on a voluntary basis, do not report data for minor elements **other than** copper, zinc and sometimes iron concentrations. Sulfate remains unreported despite the fact that Foth and FMC have acknowledged it as a key indicator parameter for tracking the movement of contaminated ground waters (Foth, 2004)[18]. For a summary of the FMC data (historic and current), please see Table 4 – Flambeau River surface water quality data.

Even if FMC started to report a broader panel of Flambeau River constituents, the issue of sample site location still exists, impacting whether *representative data* are obtained. The company's routine sampling of river waters remains limited to SW-1 and SW-2, with no samples collected for analysis immediately adjacent to the backfilled pit.

For a brief time (2007-2012), FMC was required to report limited water quality data from a Flambeau River sampling site (SW-3) immediately below the mouth of Stream C (WDHA, 2007; Foth, 2007; see Figure 10 – Flambeau Mine surface water sampling stations). As observed by Chambers and Zamzow (2009), the copper concentration at SW-3 was nearly double Wisconsin's hardness-adjusted chronic water quality criterion during the Spring 2008 sampling event, while the copper level at SW-2 was below the standard. Additional data would be helpful to determine trends.

In addition to the inadequacies in FMC's surface water monitoring program cited above, other limiting factors must be considered. For example, there are no U.S. aquatic life criteria for manganese, even though the technical literature has long described significant toxicity to numerous aquatic species (Reimer, 1999), prompting other governments (e.g., British Columbia, CA) to establish such guidelines (MELP, 2001). Shortcomings such as these further complicate regulation and enforcement issues.

Impacts to River Sediments and Aquatic Species: Both FMC and the State have assumed that dilution by Flambeau River waters has and will continue to render pit inflow contaminant concentrations unimportant. What impact does seepage of degraded-quality pit waters and discharges of contaminated storm water runoff into the Flambeau River have on various species of fish, clams, macroinvertebrates, etc.? Have the sulfate concentrations of the Flambeau River increased such that wild rice growth might be harmed if it was used as a source of irrigation water?

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[18] **Editor's Note:** Flambeau River surface water data submitted by FMC to the Wisconsin DNR between May 2017 and Oct 2018 (after Dr. Moran drafted his comments) also included manganese, but sulfate remained unreported (FMC, 2018a and 2019). Future monitoring of surface water quality is uncertain due to a recent proposal from FMC to totally eliminate the company's river monitoring program. See Footnote 3 on page 7.

Between 1991 and 2011, FMC conducted various studies of Flambeau River sediments, macroinvertebrates, crayfish and walleye. Results from the FMC studies can be found in the company's annual reports, where FMC consistently claimed the data indicated no adverse impacts from mine activities. Notably lacking from the reports, however, were any statistical analyses of the data.

No data from independent sources are available. In 2009, however, a University of Wisconsin aquatic ecologist, Dr. Ken Parejko[19], reviewed FMC's sediment, macroinvertebrate, crayfish and walleye data that had been collected to date, and authored 4 separate reports in which he analyzed the company's study design and performed statistical analyses of the data (Parejko, 2009a-d). He found numerous sampling and reporting issues such as: (1) insufficient baseline data; (2) changes in sampling locations; (3) inconsistency in sampling methodology; (4) insufficient replication; (5) insufficient spatial and temporal co-location of sampling sites; and (6) unacceptable levels of reporting errors. This prompted him to coauthor a supplementary report with specific recommendations for augmenting FMC's biological, sediment, surface water and ground water monitoring program (Chambers et al., 2009). Said recommendations, however, were not implemented by the company.

FMC ended its sediment monitoring program in 2008, macroinvertebrate sampling in 2006, and crayfish and walleye sampling in 2011. Hence, no recent data exists in the public record, limiting the present review to the follow comments:

- **River and Tributary Sediments*.*** FMC collected limited baseline data for Flambeau River sediments in 1988 and proceeded to test river sediments on an annual basis between 1991 and 2000 and again in 2006. After the 2006 data was collected, FMC's consultant stated: "Data from the years of sediment analysis indicate that, in general, no increase or decrease in parameter concentration in sediments is occurring. Moreover, downstream samples continue to compare favorably with upstream sediment samples indicating no impacts due to mine activities during the closure time window" (Blue Iris, 2006). Parejko, after evaluating the company's study design and doing a statistical analysis of the data, drew a different conclusion. He stated:

  "Because of lack of baseline information, and [various] sampling issues (most importantly, lack of within-site replication), and also when considering the results of statistical analyses … which show in some cases significantly higher downstream than upstream metal concentrations in sediment, the statement from the 2006 sediment report that there is "no increase or decrease in parameter concentration in sediments ... [and that] downstream samples continue to compare favorably with upstream sediment samples" is questionable. It is also certainly not possible, especially given the limitations of the monitoring outlined above, to state with any reasonable certainty whether there has or has not been impacts due to mine activities" (Parejko, 2009a).

  In 2008, the company was required to test Flambeau River sediments once again and to expand the testing to include Stream C because of evidence the stream "could be

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[19] Professor Emeritus, Department of Biology, University of Wisconsin-Stout.

carrying potentially toxic levels of some substances into the Flambeau River" (Parejko, 2009a). As noted by Parejko, the one-time sampling event in Stream C showed "very high copper concentrations compared with those found in Flambeau River sediments at any other time or place in the FMC study." He concluded: "Unusually high copper and zinc concentrations in a sampling site within the bed of intermittent Stream C indicate a possible entrance-point for some potential toxins into the Flambeau River".

- **Walleye, Crayfish and Endangered Species.** As mentioned earlier, increasing the mass of metals in the Flambeau River, either as dissolved or particulate forms (suspended or bedload sediments), has the potential to harm the aquatic biota because these organisms are capable of consuming metal-laden particulates, which can then be concentrated up the food chain. No Flambeau River walleye or crayfish data from independent sources are available and, once again, Parejko provides the only outside review of data submitted by FMC to the Wisconsin DNR. He drew the following conclusion: "Based on both visual inspection of the data and statistical analyses, there appears to have been an increase in walleye liver copper concentrations subsequent to mining, with downstream concentrations being significantly higher than upstream concentrations. This suggests a possible mining effect. The same can be said for crayfish whole-body specimens … although the elevation in copper levels appeared to be less pronounced in crayfish." (Parejko, 2009d). FMC has submitted no new walleye or crayfish data to the State of Wisconsin since 2011.

  In addition, it appears no follow-up studies have been conducted on various endangered clam and dragonfly species that were discovered in the vicinity of the mine site in the early 1990s and which were the subject of a 1991 Supplemental EIS (WDNR, 1992a). Have they survived? As pointed out by Parejko: "… the lack of follow-up studies on the fate of endangered and threatened species identified in and around the Flambeau River prior to mining is unacceptable" (Parejko, 2009b).

- **Wild Rice.** In 1944, Dr. John Moyle issued a widely-cited report linking sulfate levels in excess of 10 mg/L in wild rice waters to decreased rice production. Consistent with those findings, a 10 mg/L sulfate standard was approved by the EPA for the Fond du Lac Band of Lake Superior Chippewa (USEPA, 2001), the Grand Portage Band of Lake Superior Chippewa (USEPA, 2005) and the State of Minnesota (Minn. R. 7050.0224) to protect natural stands of wild rice. The south fork of the Flambeau River, *upstream* of the Flambeau Mine, has been identified by the Great Lakes Indian Fish and Wildlife Commission as a wild rice water (GLIFWC, 2015 and 2017). While the section of the river downstream of the mine has not been so-designated, the predictable long-term increase in sulfate concentrations in the river due to Flambeau Mine activities is likely negative. As mentioned earlier, FMC stopped reporting (publicly) sulfate data in the Flambeau River in 2013, despite elevated sulfate concentrations measured in the backfilled Flambeau pit and wells between the pit and river.

EIS Predictions.

FMC and their consultants were allowed and apparently encouraged to generate all sorts of predictions regarding future pit water quality concentrations, ground water flow patterns, chemistry of waters leaching from the waste rock, etc. in the various permit reports. Such prediction/simulation models can be useful in better understanding the hydrogeologic/ hydrochemical *processes* at work in a semi-quantitative manner—provided the numerous assumptions employed are realistic. However, decades of experience with such predictions and the subsequent realities have shown that they are extremely poor at generating reliable, quantitative results. **It is clear that such predictive models are most useful for obtaining permits, not for generating quantitatively-reliable predictions.**

In fact, decades of experience at mine sites, worldwide, have shown that simply evaluating the **long-term, historical outcomes at large numbers of similar mine sites** is a much better predictor of future outcomes at another site, such as Flambeau. Such an historical, comparative approach of evaluating a large population of similar mines has the strength of being based on **statistical principles**. Whereas, attempting to make quantitative predictions about future water quality, for example, at a specific individual site (often called a deterministic prediction) is based on a population of one. Most reliable scientists consider the making of deterministic predictions to be fraught with tremendous percentages of uncertainty and error—especially as the years into the future increase.

The narrative “predictions” made by Foth & Van Dyke in Section 4.3.4.2 of the 1989 EIR (Impacts on Groundwater Quality, pp. 4.0-6 – 4.0-14) are largely naïve geochemically and hydrogeologically. It is doubtful that these statements represented the opinions of Kennecott/FMC’s technical experts.

Clearly the numerous quantitative predictions made by Foth & Van Dyke and others demonstrate how inaccurate such simulation approaches can be. For example, the ground water flow models assumed the Precambrian rock to act as porous media, not fractured rock, hence the predictions for pit re-filling were significantly incorrect (FMC, 1999a).

FMC’s ground water quality data also demonstrate how unreliable predictive modeling can be. When seeking its permits to mine, the company offered modeling that predicted relatively low concentrations of copper (14 µg/L), iron (320 µg/L) and manganese (550 µg/L) in contact water leaving the backfilled pit. In addition, sulfate concentrations were predicted to reach 1,100 mg/L (Foth, 1989d). See Table 8 – Projected ground water quality. Now that actual concentrations are being measured (see Table 6 – Ground water quality data), individual FMC wells within the backfilled pit have *median* dissolved concentrations as high as the following (2014-16)[20]:

- Copper = 503 µg/L
- Iron = 14,000 µg/L

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[20] **Editor’s note:** Additional information regarding predicted versus measured ground water quality at the Flambeau site can be found in a November 2018 report submitted by FMC to the Wisconsin DNR (FMC, 2018d – see data table on electronic page 12).

- Manganese = 33,500 µg/L
- Sulfate = 1,600 mg/L

Unfortunately, several of the Flambeau Mine ***permit stipulations*** *were based on these inaccurate simulation results.* For example, secondary to Foth's prediction that manganese concentrations in backfilled pit ground waters would be roughly 550 µg/L for close to 4,000 years, the Flambeau Mine permit incorporated a 550 µg/L compliance limit for manganese in wells located between the mine pit and Flambeau River (WDHA, 1991 – p. 92; Foth, 1989c – pp. 20-29). Now that the pit has been backfilled and samples are being collected for analysis, 7 of the 8 wells within the backfill have *median* manganese concentrations (2014-16) ranging from 1,200 to 33,500 µg/L, significantly exceeding Foth's prediction. In addition, two of the three wells between the pit and river have reported *median* manganese concentrations of 2,100 to 9,500 µg/L (See Table 6 – Ground water quality data). It appears, however, that no meaningful enforcement action has been taken by the Wisconsin DNR.

Compliance Boundary.

This report has focused on *technical* aspects of the FMC operation rather than whether FMC has complied with *regulatory requirements*, mostly because an overly-legalistic approach seems to have brought us to the present unacceptable Flambeau situation. Nevertheless, since FMC routinely states in its annual reports that "Flambeau remains in full compliance with its permit standards" and the Flambeau River "remains fully protected," a brief discussion of compliance measures established for the mine by the State of Wisconsin is in order.

Wisconsin DNR administrative rules call for establishing a so-called "compliance boundary" for enforcement of ground water quality standards at mine sites. The boundary is set at a *maximum* of 1,200 feet[21] from "the outermost limit at which waste from a facility has been stored or disposed of, or permitted or approved for storage or disposal" (Wisconsin Administration Code, NR 182.075).

The FMC compliance boundary is about 3.5 miles long, encircles the entire mine site and crosses the Flambeau River southwest of the backfilled pit, disregarding possible impacts to the water quality of this river (see Figure 7 – Compliance boundary). This was a notable point of contention prior to the 1990 permit hearing, when the Office of Public Intervenor within the Wisconsin Department of Justice argued that the compliance boundary west of the pit should be the Flambeau River (Falk, 1989).The Office cited, among other things, that Foth itself had characterized the Flambeau River as "the most logical compliance boundary" in its <u>Prediction of Groundwater Quality Downgradient of the Reclaimed Pit for the Kennecott Flambeau Project</u>, dated July 1989. After the Public Intervenor made her argument, however, Foth released a revised version of the groundwater quality report, dated December 1989, that no longer included the above reference to the Flambeau River. The report also claimed that

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[21] Chapter NR 182 of the Wisconsin Administrative Code specifies that the horizontal distance to the compliance boundary, where ground water standards are enforced, "shall be 1,200 feet from the outer waste boundary, unless reduced pursuant to s. NR 140.22(3), or at the boundary of property owned or leased by the applicant, whichever distance is less."

locating the boundary “beyond the river” meant exceedances of applicable ground water quality standards would not occur “at the point of standards application” (Foth, 1989d).

The Wisconsin DNR rejected the Public Intervenor’s request to make the Flambeau River the western perimeter of the compliance zone. Hence the approved boundary extended across the river. At the same time, however, the Department did not require FMC to locate any ground water monitoring wells west of the river to check for compliance with standards. It appears they accepted Foth’s assertion that “… all of the groundwater flowing through the Type II waste rock in the reclaimed pit will exit the pit through the Precambrian rock in the river pillar and flow directly into the bed of the Flambeau River” and therefore “it will not be possible” for exceedances to occur at the compliance boundary (Foth, 1989d). This, however, is inconsistent with Straskraba’s findings discussed earlier. In addition, the Flambeau River is only about 5 feet deep in the vicinity of the 225-foot deep mine pit (See Figure 6 – Backfilled pit cross section).

As explained by Chambers and Zamzow (2009): “If all, or part, of the groundwater contamination is not entering the Flambeau River, as is presently assumed by FMC, then it is going under the river towards the 1,200-foot compliance boundary. There appears to be insufficient monitoring to determine either the quantity of groundwater movement, the quantity of contamination entering the Flambeau River, and/or the groundwater contamination migrating toward the southwest groundwater compliance boundary.”

FMC has tried to justify its failure to monitor ground water quality west of the Flambeau River by asserting that contaminants like sulfate “will never be able to travel more than 140 feet from the reclaimed pit,” i.e., beyond the Flambeau River (Foth, 1989d). But without any monitoring wells west of the river, the company’s theory cannot be proven or disproven.

Besides its failure to locate any ground water monitoring wells *west* of the Flambeau River. FMC established only one nested well (MW-1015A/B) in the vicinity of the compliance boundary *east* of the river (roughly 750 ft. NW of the backfilled pit), and it was not installed until January 2001 (FMC, 2000; FMC, 2001b). Thus, there is no reliable baseline for this well. Several wells would have been needed to define the actual ground water plume. In addition, it appears this one compliance boundary well was located inappropriately, outside the main ground water flow path identified by FMC and their consultants. See Figure 7 – Compliance boundary, for monitoring well locations relative to the compliance boundary.

Despite all of the above, Foth has asserted that contaminated ground waters emanating from the backfilled mine pit and entering the bed of the Flambeau River “will pose no threat to the Flambeau River” (Foth, 1989d). As discussed earlier, however, FMC’s surface water monitoring program is inadequate to define potential impacts due to, among other things, inappropriate monitoring locations, an inadequate list of monitored chemical constituents, and unclear reporting of Dissolved versus Total and Field versus Lab test results. This, in combination with FMC’s failure to submit any new biomonitoring or river sediment data to the Wisconsin DNR since 2011, especially when earlier studies suggested a possible mining effect, brings into question the company’s claim that the river “remains fully protected.”

A separate but related issue involving compliance at Flambeau was discussed earlier: the fact that some of the ground water compliance criteria and standards applicable to the project were generated via largely-useless predictions made by FMC's consultants (see Table 8 – Projected ground water quality). Despite numerous exceedances of these and other relevant standards and criteria, the DNR has taken no meaningful enforcement actions. Thus, the contaminated FMC ground waters represent a "sacrifice zone." See Table 9 – Exceedances of ground water quality standards, for a compilation of exceedances of various Wisconsin ground water quality enforcement standards (ES) and Preventive Action Limits (PAL) reported by FMC in 2015 for wells at the Flambeau site.

FMC "Control" of Data & Information.

All technical water-related data [water quality, hydrogeology, geochemical, etc.--baseline and routine monitoring] used to evaluate the Flambeau Mine operations were generated by FMC and or their consultants. As such, none of the data and information used to prepare these FMC reports were generated by financially or politically-independent sources.

Analytical data do exist for a few "split" (duplicate) ground water quality samples that were analyzed by DNR labs, but apparently most if not all samples were collected by FMC personnel or their consultants. As discussed earlier, most mining water quality errors come from the sampling and sample handling processes, not the analytical procedures. The only water-related Flambeau data I have seen generated by independent sources were surface water data collected by the DNR in 2010-11 related to Stream C, long after Flambeau had been closed and remediated (WDNR, 2012a and 2012b).

Normally the "final" wording of mining EISs and related documents is written by consultants who are usually project managers, not the technical experts of either the mining or consultant companies. In this way, the actual report authors control the final opinions and language that appear in the EISs and related documents. Of course, such report preparation is overseen, directed, and edited by the mining company managers and all efforts are paid for by the mining company. In many cases, the efforts of State and Federal regulators are also paid for by the company.

FMC, being a subsidiary of Kennecott Copper Corp., was fully aware of several important technical details regarding the environmental chemistry associated with mining such a massive sulfide deposit as Flambeau, which were not made clear to the public in either their permitting documents (1989-1990) or their subsequent Annual Reports. Weak regulatory oversight allowed an inadequate baseline and follow-up monitoring program to be implemented by FMC, marked by, among other things: unacceptably limited baseline water quality data; narrow-diameter monitoring wells that provide data of non-representative quality; inappropriate analytical detection limits for some constituents; an inadequate list of constituents determined; water treatment effluent limits that were too high to prevent discharge of contaminated waters and quantify the effluent concentrations of most trace elements; and, reporting of few if any analytical data from unfiltered ground water samples. For a more complete listing of the inadequacies in FMC's monitoring program, please see the Appendix.

Conclusions.

DeMatties (1996) states that Flambeau is only one of 13 massive sulfide deposits in northern Wisconsin. Thus, industry's touting of Flambeau as an environmental success will only promote development of these and other metal-sulfide deposits around the Great Lakes region.

Because the public has no Flambeau water-related data from independent sources, it is instructive to consult the literature from other metal-sulfide mines, worldwide, regarding commonly-encountered water quality and geochemical issues that have routinely surfaced.

Evidence of the pervasive impacts associated with mining sulfide ores can be had by reading Todd and Struhsacker (1997). This study was commissioned by the mining industry in the mid-1990s in an attempt to favorably influence mining legislation in the State of Wisconsin (U.S.A.). It was intended to show "…that a mining operation has operated in a sulfide ore body in the United States and Canada for at least 10 years without polluting groundwater or surface water from acid drainage at the tailings site or at the mine site or from release of heavy metals." It was also intended to show "… that a mining operation that operated in a sulfide ore body in the United States or Canada has been closed for at least 10 years without polluting groundwater or surface water from acid drainage at the tailings site or at the mine site or from the release of heavy metals." Data from hundreds of mine sites from the U.S. and Canada were investigated. **A careful reading of the details in this paper shows that the authors were unable to locate any sites that totally complied with the criteria at the time the paper was published.**

Yes, some of the sites investigated by Todd and Struhsacker employed older technologies, but in more than 45 years of applied hydrogeology and geochemistry, I know of no metal-sulfide mines anywhere in the world that have operated without degrading the original water quality, long term--even those employing modern technologies. Nevertheless, mining industry executives and public relations staff have consistently spread a "commercial myth": that metal-sulfide mining can be conducted without degradation of water quality (Rio Tinto, 2013; Mining Minnesota, 2013).

The alternative for modern sulfide-rich mines has been to operate active (not passive) water treatment plants to make these effluents suitable for other uses. Several such plants are now operating at metal-sulfide sites, possibly forever. The operating and maintenance costs for such plants are extremely high. I have worked on several projects where the present water treatment costs have been hundreds of millions of dollars, and in some cases the costs must be paid by the taxpayers.

Given this unpleasant worldwide reality, together with the presence of exceptionally-high percentages of sulfide in the Flambeau rocks located within 140 feet of a large, biologically-rich river, FMC faced a daunting task in obtaining their operating permits. Having reviewed thousands of pages of their documents, it appears one main strategy has been to ensure that *damaging data have not been made readily-available to the public.*

For decades, some of the most relevant data and the most significant water-related impacts have been withheld from public view. Parameter concentrations from most FMC wells are not quantitatively-reliable due to: failure to collect unfiltered samples; inadequate well construction, well development and purging, and, unacceptable sampling procedures. Frequently, important chemical constituents were missing from analyses, inappropriate analytical detection limits were employed, and crucial data were not reported. Most importantly, the DNR allowed FMC to inappropriately restrict the list of chemical constituents monitored in waters from wells, waste rock, pit leachates, and the influent waters to the waste water treatment plant. FMC permit reports and subsequent public documents were based on these inadequate data.

FMC and their contractors supplied all of the data and interpretations used to compile the permit-related reports and subsequent Annual Reports. Such an approach obviously reflects FMC's interests, but is likely quite different from financially-independent, public-interest science. In short, the Flambeau Mine is the poster child for a severely-flawed permitting and oversight process that has likely generated long-term public liabilities.

As a minimum, a program of water quality monitoring totally independent from any financial or political control by FMC (or the DNR) should be instituted. This program would include independent sampling, sample handling, analysis and data interpretation.

Obviously the mining and remediation practices employed at Flambeau do not represent a *sustainable, long-term solution*. While FMC may have satisfied the State oversight and disclosure requirements, the site ground waters are contaminated, and *these waters would require expensive, active water treatment to be made suitable for most foreseeable uses.*

Flambeau ground and surface water quality is being and has been degraded—despite years of industry public relations statements touting the success of the FMC operation. Rio Tinto said in a 2013 public relations (PR) release regarding the Flambeau Mine: "Testing shows conclusively that ground water quality surrounding the site is as good as it was before mining." In efforts to encourage development of the other metal-sulfide deposits in northern Wisconsin and the Great Lakes region, the industry approach has been to simply repeat this false statement over and over, assuming that repetition will make it believed. Unfortunately, the FMC data show otherwise.

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APPENDIX

Appendix. Inadequacies in FMC's Water Quality Monitoring Programs

Program	Inadequacy	Learn More
Ground Water	All routine FMC ground water monitoring data are from filtered samples, from which some, if not most of the chemical components have been removed, thereby lowering the original concentrations.	pp. 16-18
	FMC was allowed to inappropriately reduce the number of parameters in ground water quality testing before well chemistry had matured.	p. 20
	FMC failed to report most trace metals and metal-like elements (metalloids) other than copper, iron and manganese in ground waters during the years of active mining (1993-97), continuing until 1999 (nearly two years after the mine pit was backfilled). FMC reports consistently encouraged the impression that other trace/minor constituents were not present at Flambeau. When the company started to report an "expanded suite" of constituents in mid-1999, the public *still* saw only filtered sample data, and the test panel remained unacceptably limited, failing to include, for example, aluminum, antimony and uranium.	pp. 35-36
	The number and location of monitoring wells along the mine's "compliance boundary" (where ground water standards are enforced by the state) are inadequate. There is only one nested well along the entire 3.5-mile boundary encircling the mine site, and it appears to be positioned outside the main ground water flow path identified by FMC.	pp. 50-51
	FMC has not tested and evaluated the extent to which Flambeau pit seepage is limited to shallow pathways through alluvium and fractured bedrock into the Flambeau River, or whether deeper pathways under the bed of the river may be viable. No monitoring wells have been positioned across the river from the mine site.	pp. 40-42
	Most of the FMC monitoring wells currently in use have an inner diameter of only 2 inches. While common in normal ground water situations, this is not adequate in such unstable chemical situations as found at Flambeau. The wells are too narrow to allow adequate development (purging/cleaning) or sampling in such chemically-unstable waters.	pp. 20-21
	FMC's backfill plans (utilizing limestone) called for sampling and determining paste parameters for in-place amended waste rock and performing leach extraction tests to aid in "documenting the performance of the alkali amendment program," but no such data can be located in the public record.	pp. 27-30
	Besides FMC's failure to report numerous metals in ground waters, other important chemical constituents were frequently not determined (or not made public) when samples were analyzed. These include for example: sulfide, total suspended solids (TSS) and turbidity. Incomplete analyses prevent reliable checks on data quality.	pp. 23, 36
	FMC's baseline data was inadequate (constituents; detection limits; no data from 1960s (true baseline); 1970s water quality data not integrated with 1980s data; detailed interpretations of long-term 1970s pumping tests not included in the company's 1989 Environmental Impact Report).	pp. 21-24
	FMC has failed to distinguish reported metals concentrations in ground waters as Dissolved versus Total in any of the company's annual reports. Recent reports also fail to define field versus lab determinations of pH and specific conductance.	pp. 17, 19-20
	Some of the ground water compliance standards applicable to the Flambeau project were generated via inaccurate and largely-useless predictions made by FMC's consultants.	pp. 49-50, 52
Waste Rock Leachate	FMC reported leachate water quality from its waste rock stockpiles on a quarterly basis only, and the samples were filtered prior to analysis; the test panel was unacceptably limited; and there was no public reporting of ground water quality beneath the waste rock stockpiles.	pp. 25-26
Waste Water Treatment Plant Effluent	The Wisconsin DNR allowed FMC to severely restrict the constituents determined in the WWTP effluents after only 12 weeks of sampling, when blasting in the pit had commenced only 2 months earlier. These waters would have had insufficient time to evolve chemically and become suitably representative of waters in contact with sulfide-rich rocks.	p. 31
	FMC's WPDES permit inadequately defined "toxic" as a test organism survival rate of less than 50% after acute exposure to undiluted effluent. This meant, for example, that the 54% survival rate reported for *C. dubia* in April 1995 was reported as "acute toxicity negative."	pp. 32-33

Appendix. Inadequacies in FMC's Water Quality Monitoring Programs (cont.)

Program	Inadequacy	Learn More
Waste Water Treatment Plant Sludge	It appears FMC did not routinely record disposal location coordinates when transporting sludge from the WWTP to the Type II ("high" sulfur) waste rock stockpile during plant operations. This would have complicated later efforts to control for likely ground water contamination from such materials during backfill operations.	p. 26
Settling Pond Effluent	FMC failed to report water quality data for untreated waters discharged from the mine's two settling ponds directly to the Flambeau River, even though the company had estimated the annual discharge rate would be 29 gallons per minute. FMC eventually found it necessary to pump these waters to the mine's WWTP, even though they consisted of runoff from the mine's "low" sulfur waste rock stockpile that FMC had maintained would require no treatment. No water quality data characterizing the runoff pumped from the settling ponds to the WWTP could be located in the public record.	pp. 33-34
Flambeau River	Routine sampling of Flambeau River surface waters has been and continues to be limited to two locations in the river: SW-1 (upstream) and SW-2 (downstream of the mine pit but *upstream* of the Stream C confluence). FMC established no river sampling stations adjacent to or immediately downstream of the backfilled pit or in the mixing zones of the mine's two engineered outfalls.	pp. 22, 44, 46
	FMC failed to report all water quality constituents that have relevant standards and criteria (during both baseline and routine monitoring), to determine whether FMC releases might be damaging to any of the relevant water uses: human consumption; aquatic life; agricultural and irrigation. For tested parameters, unacceptably-high detection limits were often employed, thus unverifiable "less than" (qualified values) were reported.	pp. 22, 44, 46
	FMC failed to include sulfate, iron and manganese in their surface water test panel during the years of active mining, continuing until late 1999 (two years after the mine pit was backfilled). *For both experts and the general public, one of the best simple, inexpensive "fingerprints" for detecting signs of acid rock drainage is sulfate (another is specific conductance).* Yet sulfate was once again removed from the test panel in 2013.	pp. 44, 46
	The state-established "compliance boundary" for the enforcement of ground water quality standards at the mine site crosses the Flambeau River, disregarding possible impacts to the water quality of the river.	pp. 50-51
	FMC has discontinued their program of testing Flambeau River sediments, macroinvertebrates, crayfish and walleye for metals accumulation despite the fact that some of the data collected between 1991 and 2011 suggested a possible mining effect.	pp. 46-48
	FMC has conducted no follow-up testing to determine the fate of endangered species found in the Flambeau River near the mine site prior to operations.	p. 48
	FMC has failed to distinguish reported metals concentrations in surface waters as Dissolved versus Total in the summary tables of "Historical Surface Water Results" found in the company's annual reports.	p. 18
	FMC has failed to define field versus lab determinations of pH and specific conductance in any of the company's recent annual reports; field measurements were not integrated with analytical data.	pp. 19-20
Stream C	FMC failed to provide baseline or adequate follow-up data for the water quality of Stream C, a small Flambeau River tributary that crosses the FMC property and has been used as a conduit for conveying contaminated storm water runoff from the mine site to the river. The stream was added to the EPA impaired waters list in 2012 for exceedances of acute aquatic toxicity criteria for copper and zinc.	pp. 22, 43-45
General	All technical water-related data [water quality, hydrogeology, geochemical, etc. – baseline and routine monitoring] used to evaluate the Flambeau Mine operations were generated by FMC and or their consultants. As such, none of the data and information used to prepare these FMC reports were generated by financially or politically-independent sources.	p. 52

FIGURES

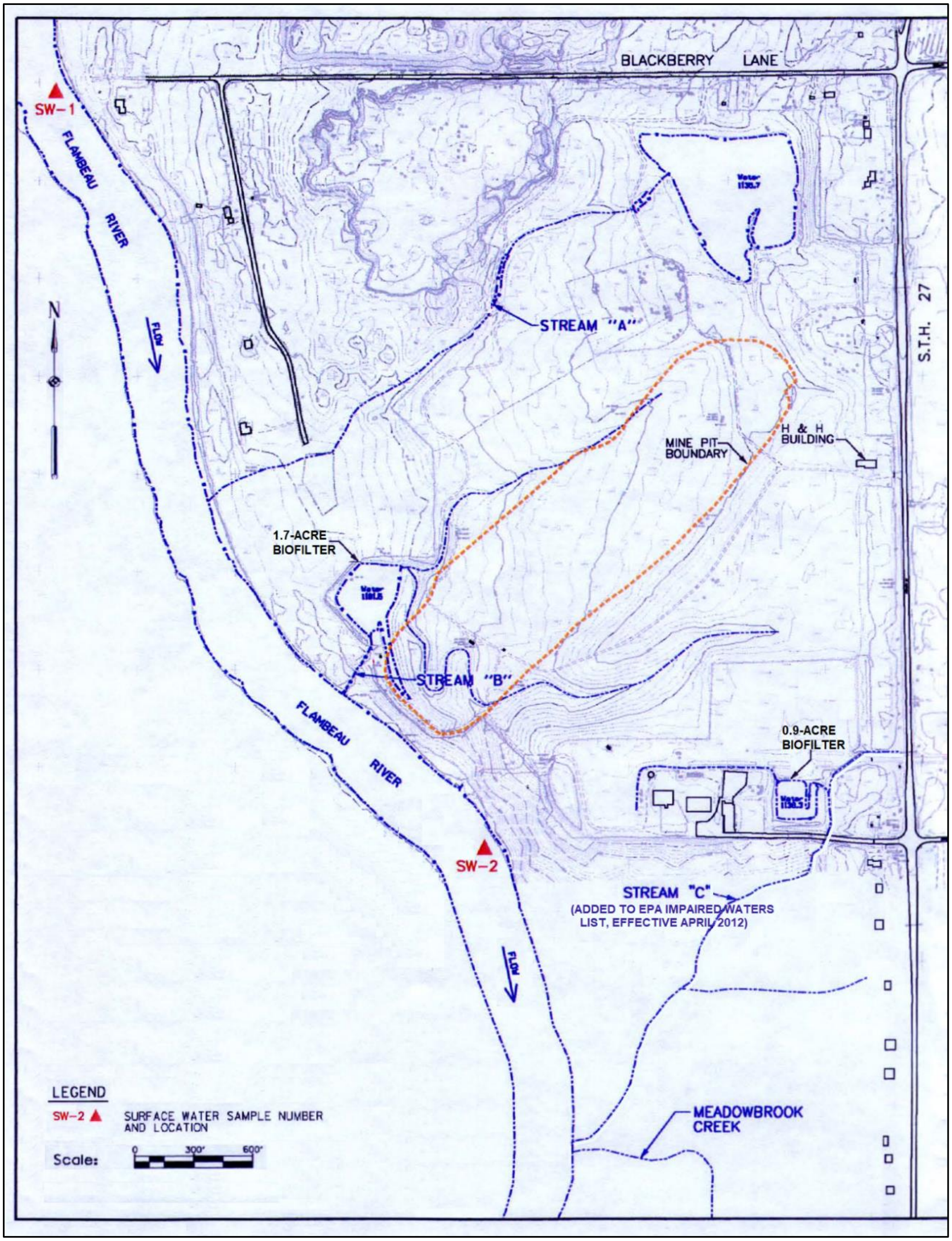


Figure 1. Locations of Flambeau River surface water sampling sites established by FMC in 1991 and reported in the company's annual reports on a routine basis (SW-1 and SW-2). Also shown are three small tributaries (Streams A, B and C) that cross the FMC property and two biofilters that were constructed in 1998 as part of site reclamation (Figure adapted from Figure 6 *in:* Flambeau Certificate of Completion Stipulation Monitoring Plan, Foth, 2007).

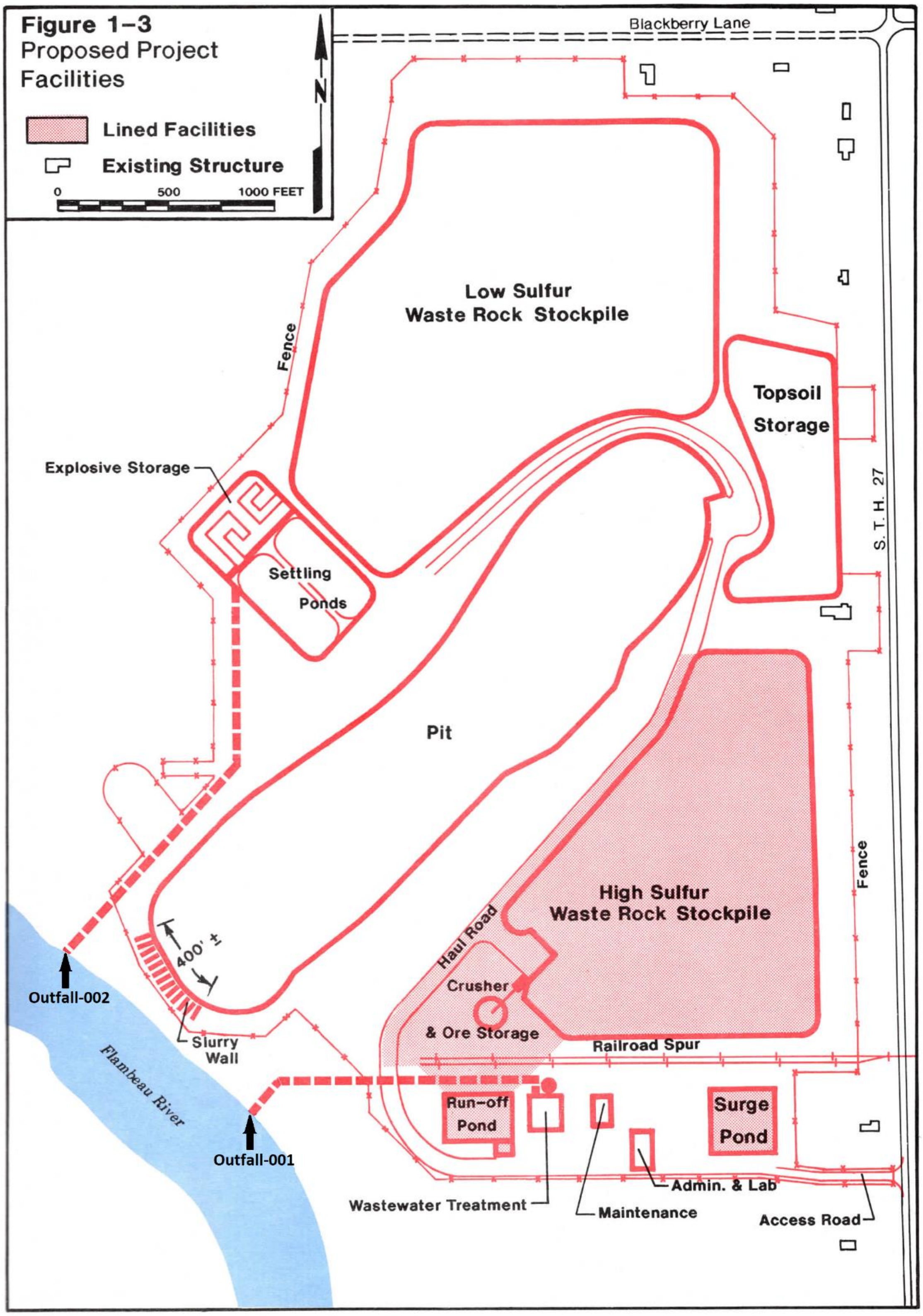
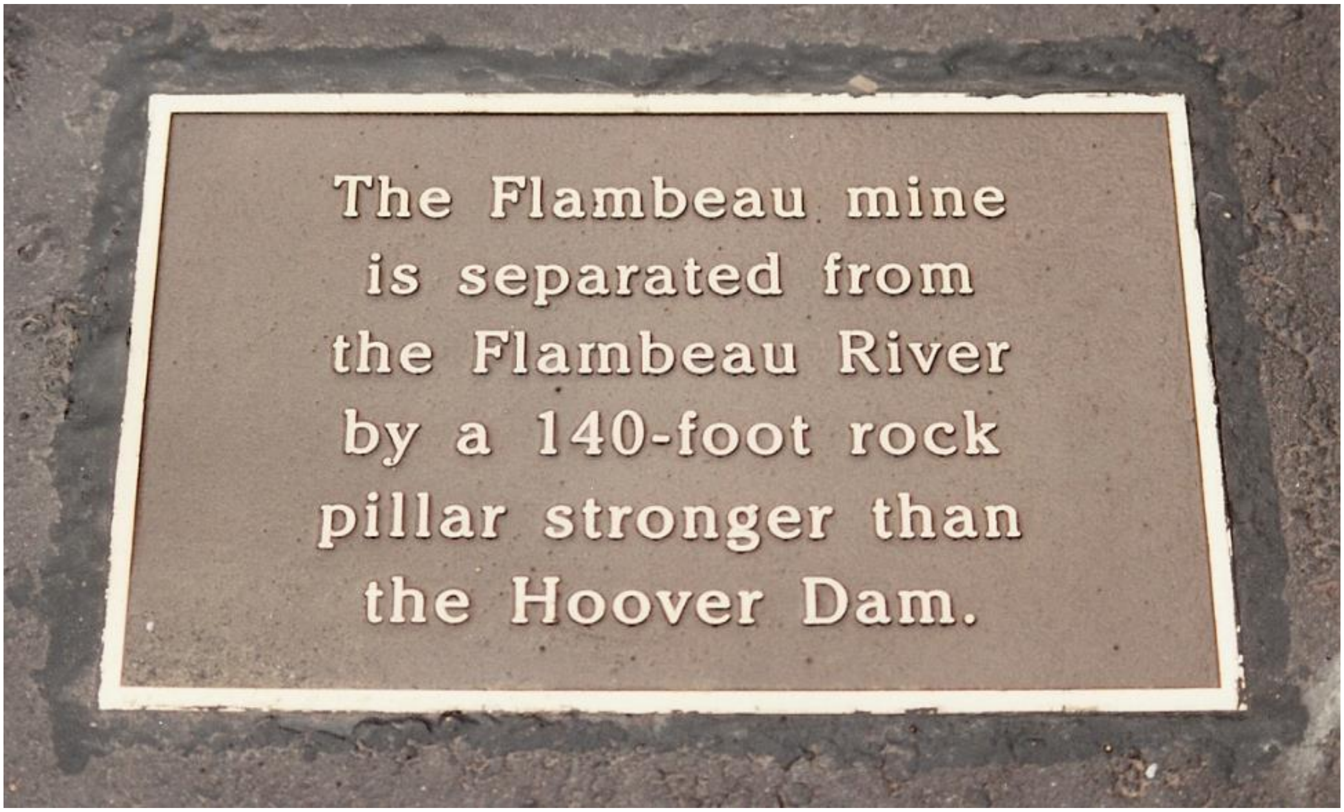


Figure 2. Flambeau Mine schematic (Adapted from Figure 1-3 *in:* Final Environmental Impact Statement for Flambeau Mining Co. Copper Mine, Wisconsin DNR, 1990).

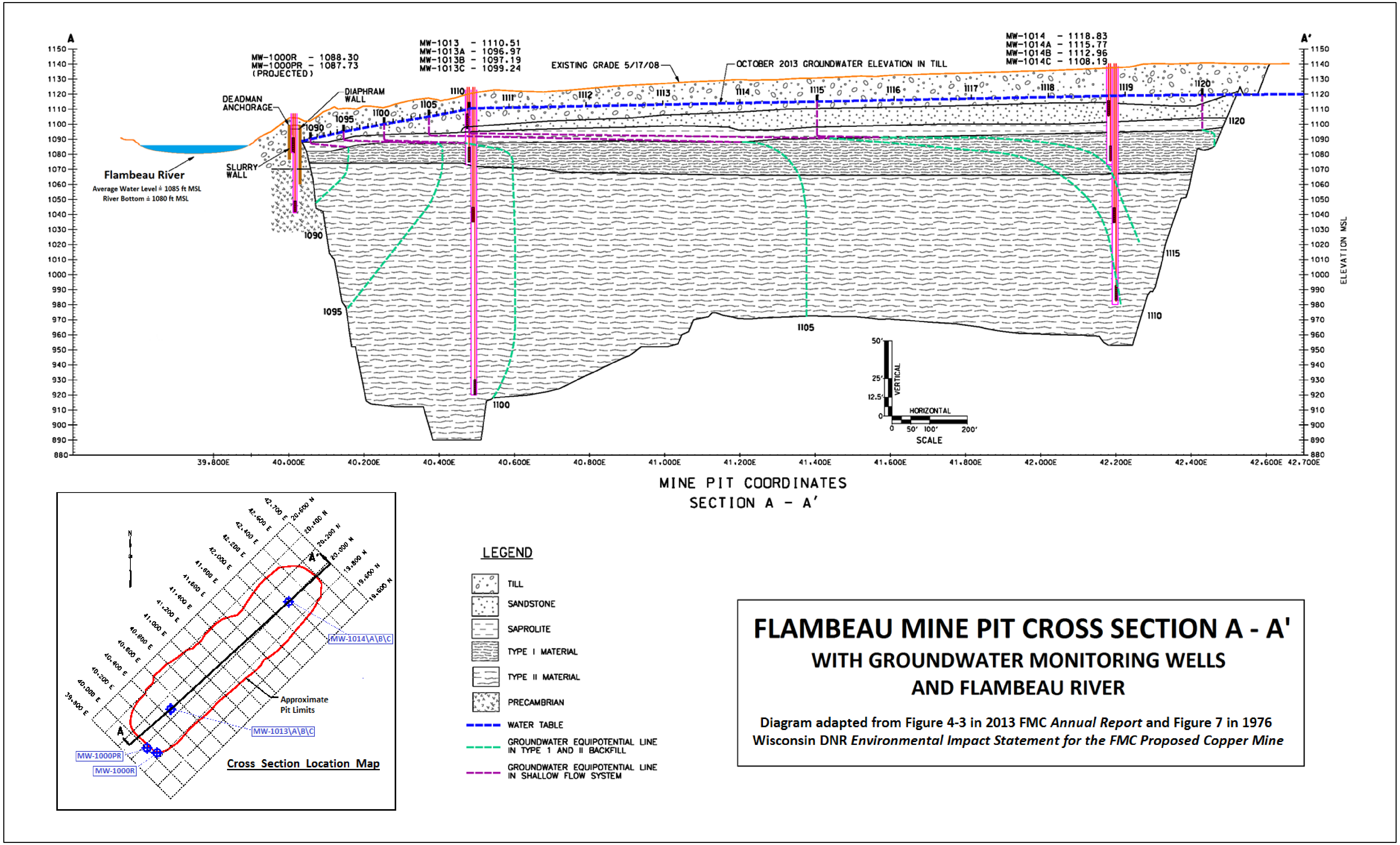
Figure 3. Top photo shows FMC waste water treatment plant, runoff pond, surge pond and other mine features, including the “high” sulfur waste rock stockpile and crushed ore storage area. Bottom photo shows the Flambeau Mine pit and nearby Flambeau River (1995).

Figure 4. Flambeau mine pit during flood stage conditions in Flambeau River (Photo by Bob Olsgard, September 17, 1994).



The Flambeau mine
is separated from
the Flambeau River
by a 140-foot rock
pillar stronger than
the Hoover Dam.

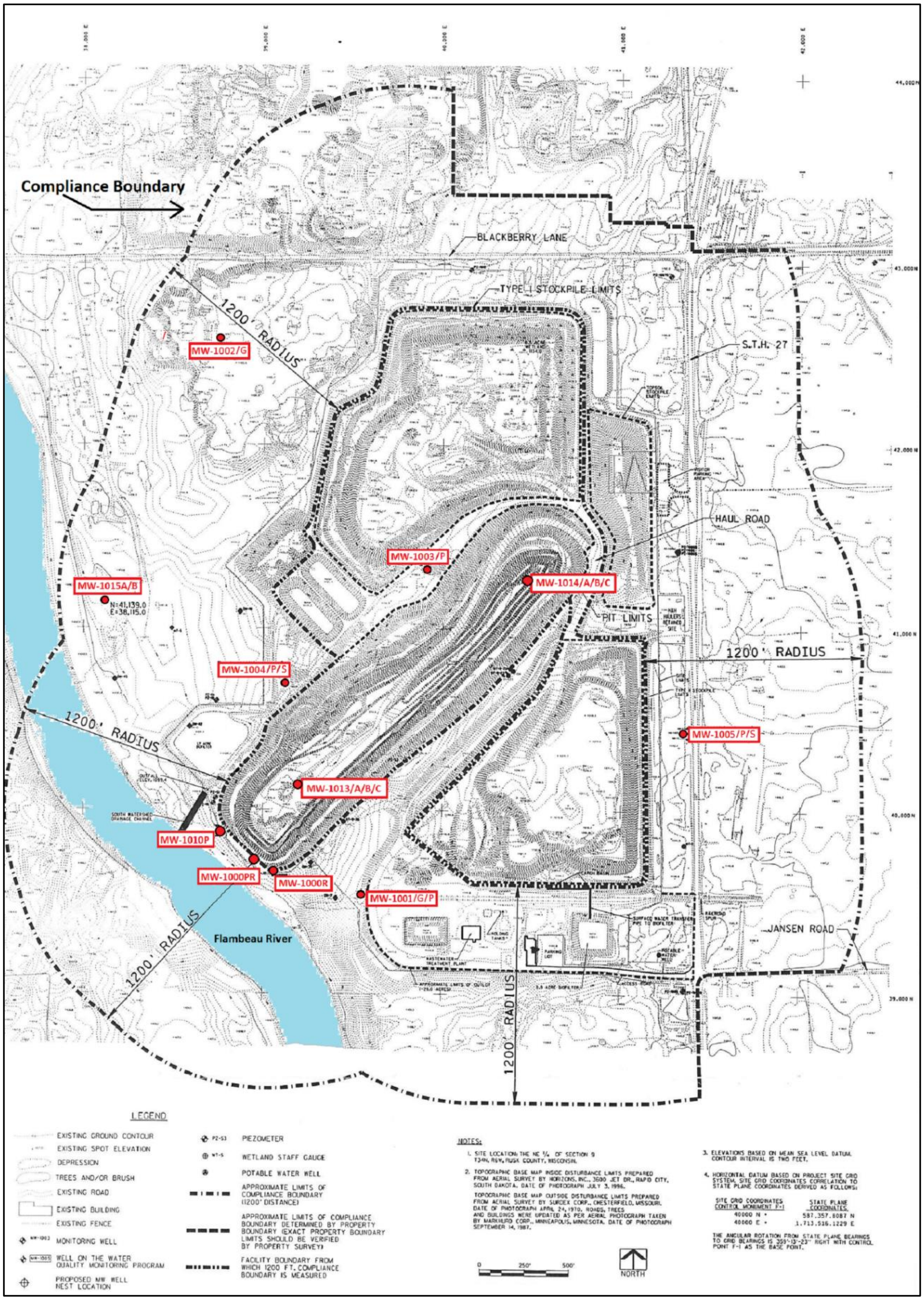
Figure 5. Plaque posted near visitor center at Flambeau Mine site during mine operations (circa 1995).



FLAMBEAU MINE PIT CROSS SECTION A - A'
WITH GROUNDWATER MONITORING WELLS
AND FLAMBEAU RIVER

Diagram adapted from Figure 4-3 in 2013 FMC *Annual Report* and Figure 7 in 1976 Wisconsin DNR *Environmental Impact Statement for the FMC Proposed Copper Mine*

Figure 6. Flambeau Mine backfilled pit cross section with groundwater monitoring wells. Relative position and depth of Flambeau River is also shown (140 ft. from pit; approximately 5 ft. deep in vicinity of the 225-ft. deep backfilled pit). (Figure adapted from Figure 4-3 *in:* 2013 Annual Report, FMC, Jan 2014 and Figure 7 *in:* Environmental Impact Statement for the FMC Proposed Copper Mine, Wisconsin DNR, 1976).



NOTES:

1. SITE LOCATION: THE NE ¼ OF SECTION 9 T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP INSIDE DISTURBANCE LIMITS PREPARED FROM AERIAL SURVEY BY HORIZONS, INC., 3600 JET DR., RAPID CITY, SOUTH DAKOTA. DATE OF PHOTOGRAPH JULY 3, 1996.

   TOPOGRAPHIC BASE MAP OUTSIDE DISTURBANCE LIMITS PREPARED FROM AERIAL SURVEY BY SURDEX CORP., CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPH APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORP., MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPH SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,536.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

Figure 7. State of Wisconsin-established compliance boundary for enforcement of ground water quality standards at Flambeau Mine plus current monitoring well (MW) locations (Adapted from Figure 1 *in:* Groundwater Monitoring Well Nest Installation at Compliance Boundary, FMC, 2000).

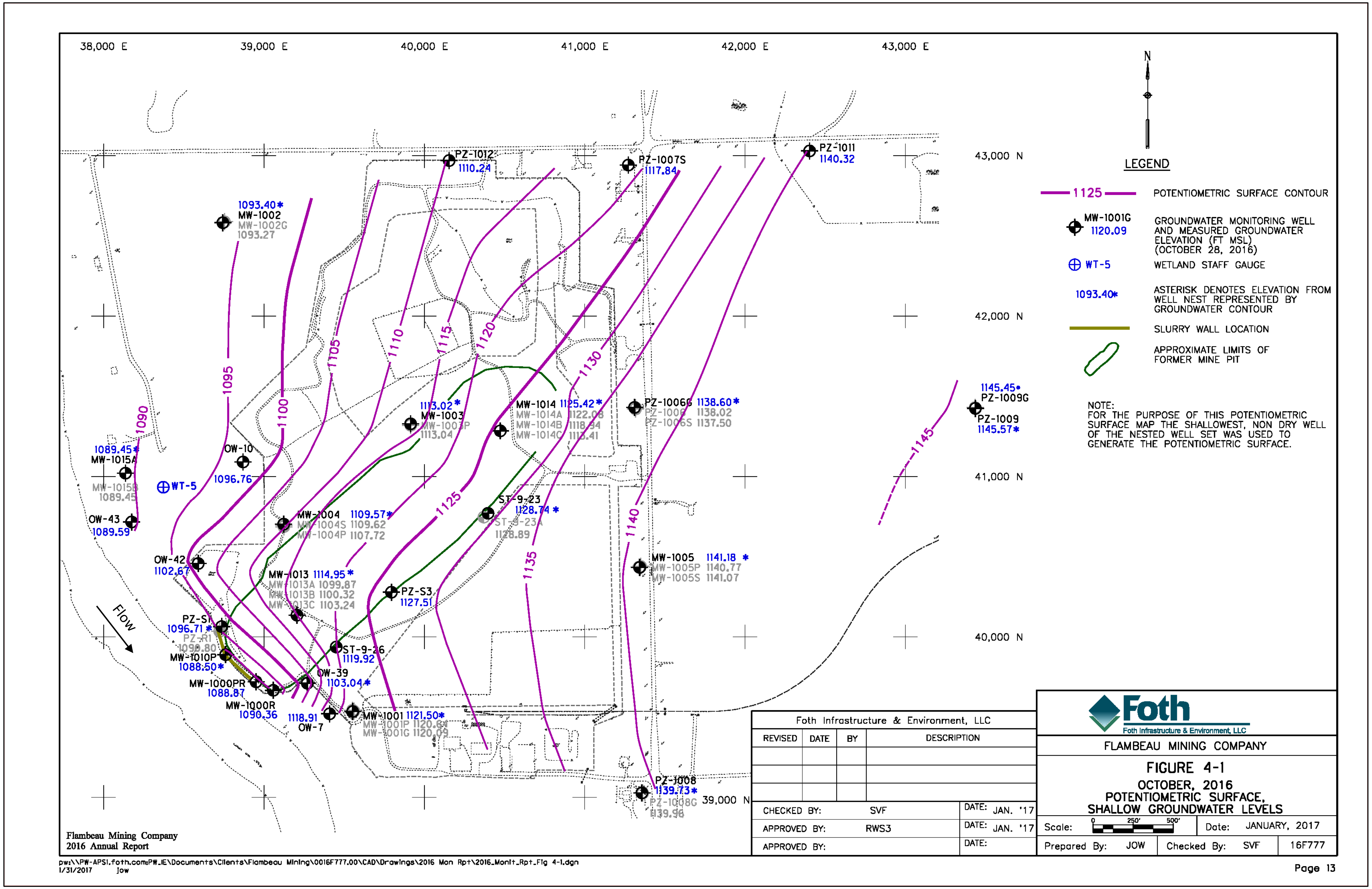
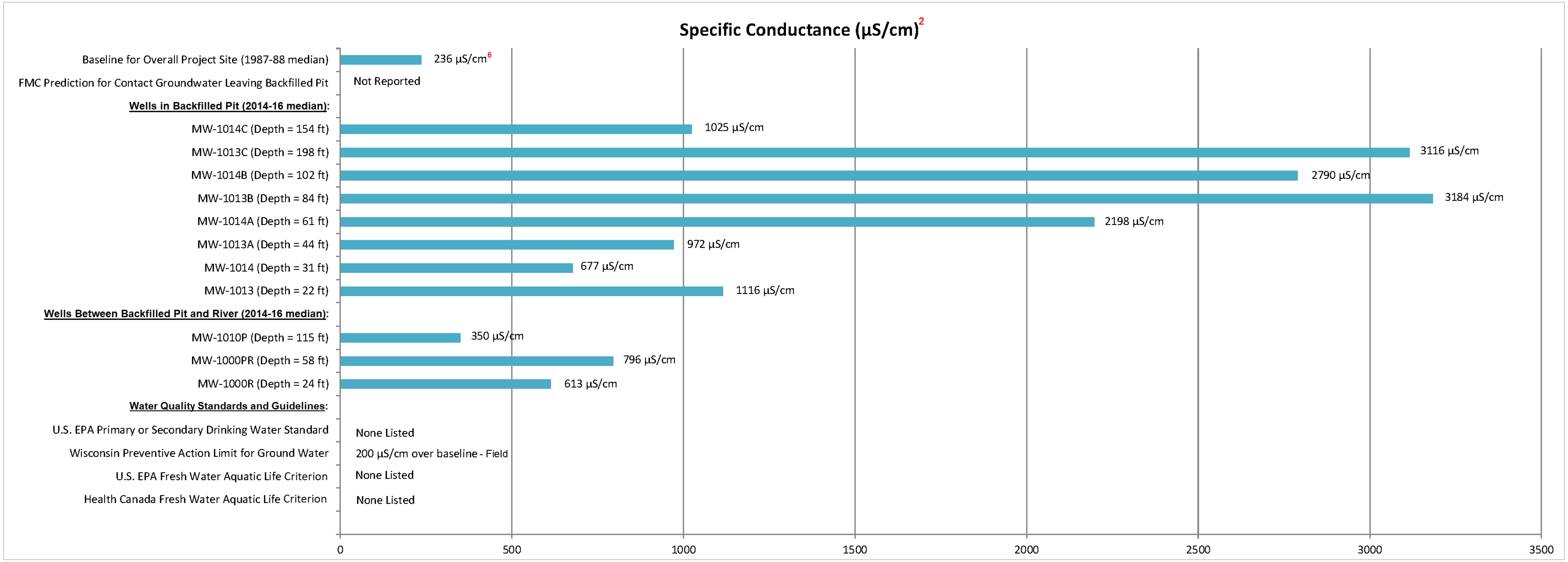


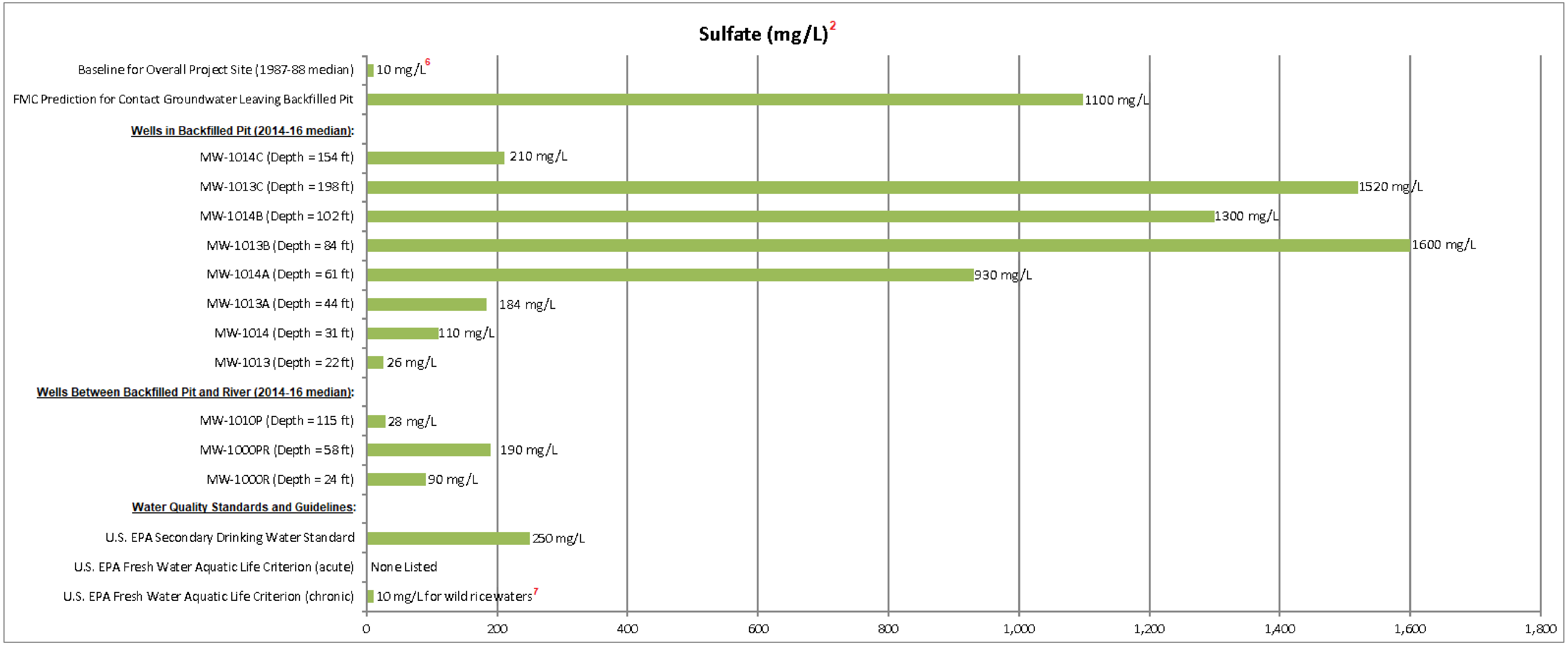
Figure 8. Flambeau Mine shallow potentiometric surface map showing locations of active ground water monitoring wells (Figure 4-2 *in:* FMC 2016 Annual Report).

Figure 9a. MEDIAN (2014-16)[1] Flambeau Mine ground water SPECIFIC CONDUCTIVITY measurements[2] compared to baseline (1987-88)[3], predictive modeling (1989)[4], and relevant water quality standards[5]



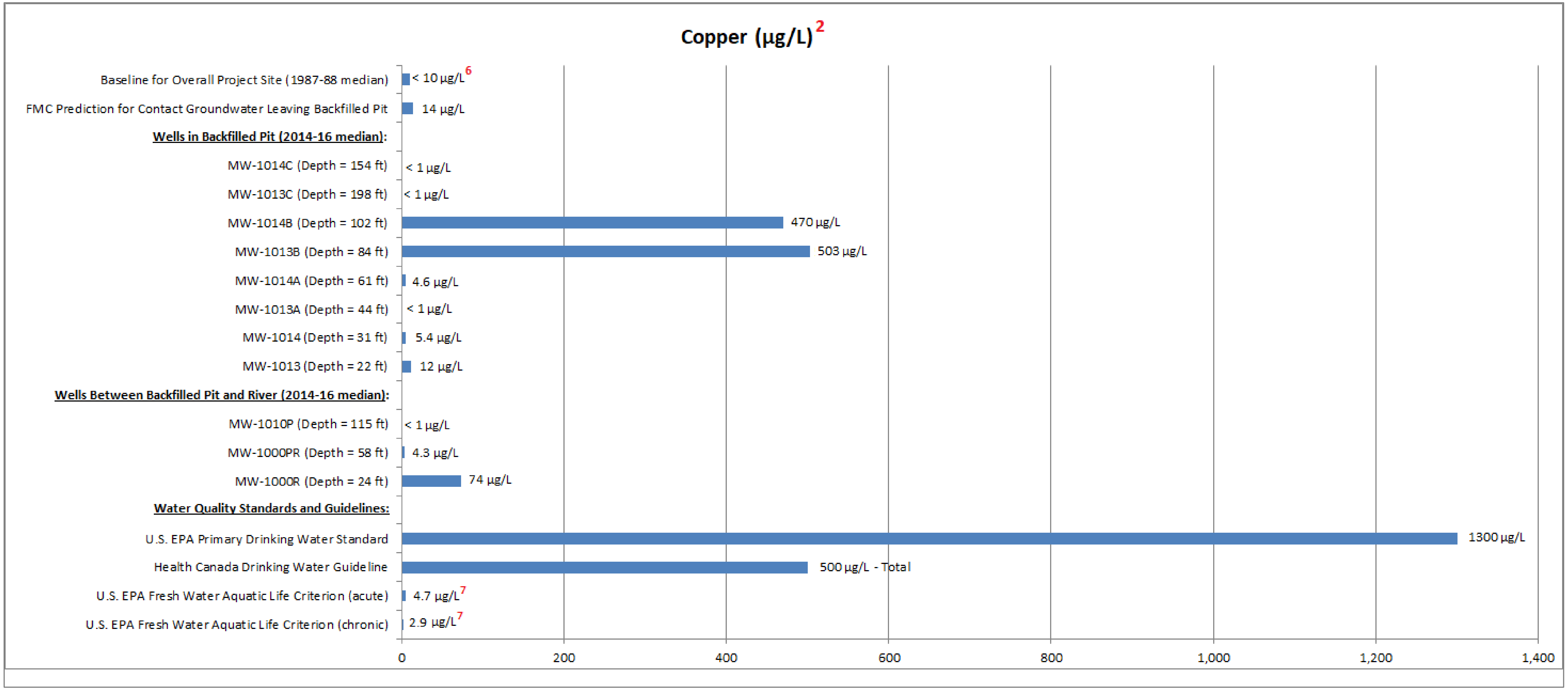
1. Specific conductivity is measured in ground water by FMC on a quarterly basis. Reported measurement for each individual well is a 2014-16 median value (n = 12) determined by author using historical data presented *in:* 2016 Annual Report, FMC, Jan 2017. For details, see Table 6 – Ground water quality data.
2. There was no "field" or "lab" designation for baseline (1987-88) measurements of specific conductance (S.C.) reported by FMC in their 1989 Environmental Impact Report. Nor was there any such designation for later S.C. values reported in the summary table of "Historical Groundwater Results – Quarterly Parameters" found in FMC's 2016 annual report and used for preparation of the present figure. Perusal of other FMC documents suggests reported values are "field." Any measurements clearly designated as "field" or "lab" by U.S. EPA or other government authorities in regulatory documents have been so indicated.
3. Baseline median determined by author using data presented *in:* Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, 1989. For details, see Table 6 – Ground water quality data.
4. Figures for projected ground water quality of contact water leaving the Flambeau backfilled pit were provided by Foth *in:* Mining Permit Application for the Flambeau Project, Volume 2, Appendix L, Dec 1989. Also see Table 8 – Projected ground water quality.
5. For details, see Table 2 – Water quality standards.
6. Baseline Median = 236 µS/cm; Range = 84 - 954 µS/cm; n = 192; 100% detects.

Figure 9b. MEDIAN (2014-16)[1] Flambeau Mine ground water SULFATE concentrations[2] compared to baseline (1987-88)[3], predictive modeling (1989)[4], and relevant water quality standards[5]



1. Sulfate concentrations are measured in ground water by FMC on a quarterly basis. Reported concentration for each individual well is a 2014-16 median value (n = 12) determined by author using historical data presented *in:* 2016 Annual Report, FMC, Jan 2017. For details, see Table 6 - Ground water quality data.
2. There was no “Total” or “Dissolved” designation for baseline (1987-88) concentrations of sulfate reported by FMC in their 1989 Environmental Impact Report. Nor is there any such designation for later values reported in the summary tables of “Historical Groundwater Results” found in the company’s annual reports. Perusal of other FMC documents suggests reported values are Dissolved. Any concentrations clearly designated as “Total” or “Dissolved” by U.S. EPA or other government authorities in regulatory documents have been so indicated.
3. Baseline median determined by author using data presented *in:* Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, 1989. For details, see Table 6 – Ground water quality data.
4. Figures for projected ground water quality of contact water leaving the Flambeau backfilled pit were provided by Foth *in:* Mining Permit Application for the Flambeau Project, Volume 2, Appendix L, Dec 1989. Also see Table 8 – Projected ground water quality.
5. For details, see Table 2 – Water quality standards.
6. Baseline Median = 10 mg/L; Range = < 5 - 48 mg/L; n = 193; 75% detects.
7. This criterion is specific for wild rice waters and was approved by U.S. EPA for the Fond du Lac Band of Lake Superior Chippewa, Grand Portage Band of Lake Superior Chippewa, and State of Minnesota. See Table 2 – Water quality standards, for more details.

Figure 9c. MEDIAN (2014-16)[1] Flambeau Mine ground water COPPER concentrations[2] compared to baseline (1987-88)[3], predictive modeling (1989)[4], and relevant water quality standards[5]



1. Copper concentrations are measured in ground water by FMC on a quarterly basis. Reported concentration for each individual well is a 2014-16 median value (n = 12) determined by author using historical data presented *in:* 2016 Annual Report, FMC, Jan 2017. For details, see Table 6 - Ground water quality data.

2. There was no "Total" or "Dissolved" designation for baseline (1987-88) concentrations of copper reported by FMC in their 1989 Environmental Impact Report. Nor is there any such designation for later values reported in the summary tables of "Historical Groundwater Results" found in the company's annual reports. Perusal of other FMC documents suggests reported values are Dissolved. Any concentrations clearly designated as "Total" or "Dissolved" by U.S. EPA or other government authorities in regulatory documents have been so indicated.

3. Baseline median determined by author using data presented *in:* Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, 1989. For details, see Table 6 – Ground water quality data.

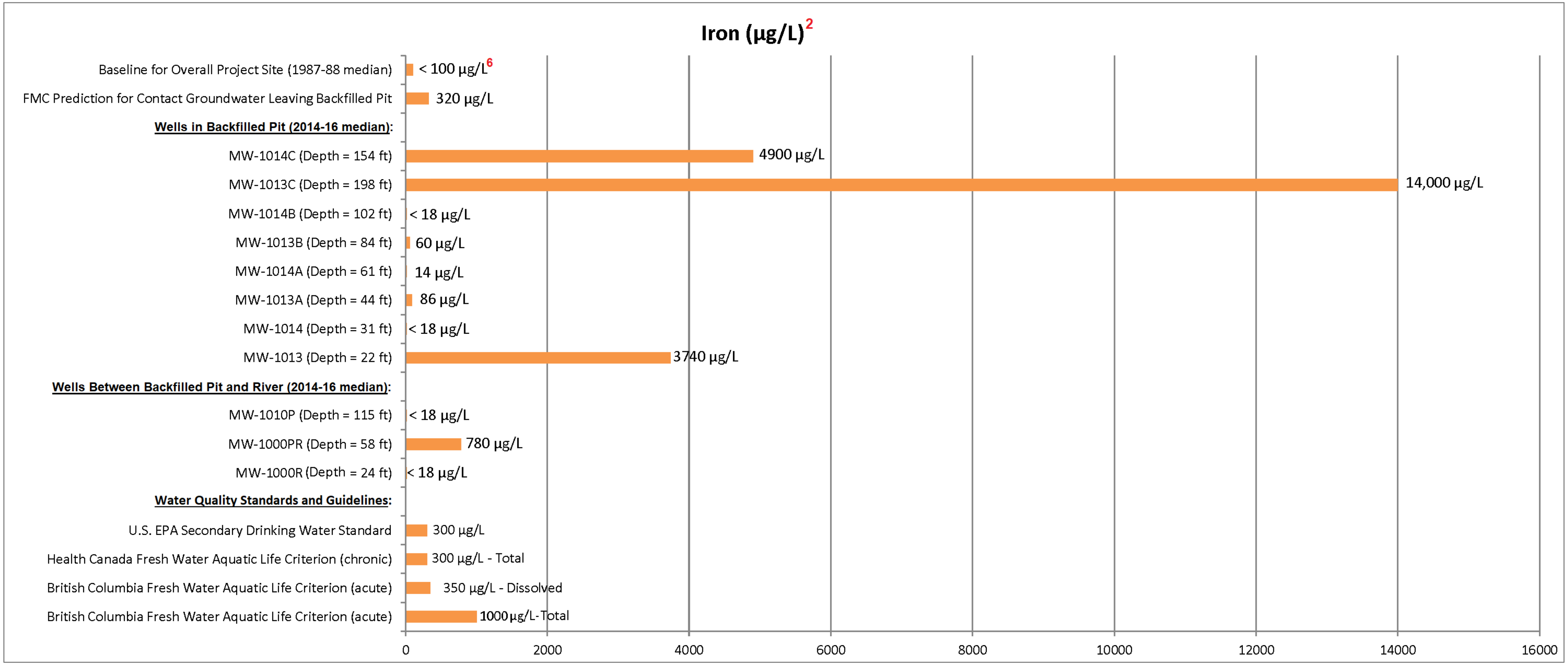
4. Figures for projected ground water quality of contact water leaving the Flambeau backfilled pit were provided by Foth *in:* Mining Permit Application for the Flambeau Project, Volume 2, Appendix L, Dec 1989. Also see Table 8 – Projected ground water quality.

5. For details, see Table 2 – Water quality standards.

6. Reported baseline median was a non-detect (< 10 µg/L); Range = < 5 - 85 µg/L; n = 193; 39% detects.

7. Values shown here were calculated for the Flambeau River, in the vicinity of the Flambeau Mine site, using EPA's Biotic Ligand Model (BLM). For details, see Table 2 – Water quality standards.

Figure 9d. MEDIAN (2014-16)[1] Flambeau Mine ground water IRON concentrations[2] compared to baseline (1987-88)[3], predictive modeling (1989)[4], and relevant water quality standards[5]



[1] Iron concentrations are measured in ground water by FMC on a quarterly basis. Reported concentration for each individual well is a 2014-16 median value (n = 12) determined by author using historical data presented *in:* 2016 Annual Report, FMC, Jan 2017. For details, see Table 6 - Ground water quality data.

[2] There was no "Total" or "Dissolved" designation for baseline (1987-88) concentrations of iron reported by FMC in their 1989 Environmental Impact Report. Nor is there any such designation for later values reported in the summary tables of "Historical Groundwater Results" found in the company's annual reports. Perusal of other FMC documents suggests reported values are Dissolved. Any concentrations clearly designated as "Total" or "Dissolved" by U.S. EPA or other government authorities in regulatory documents have been so indicated.

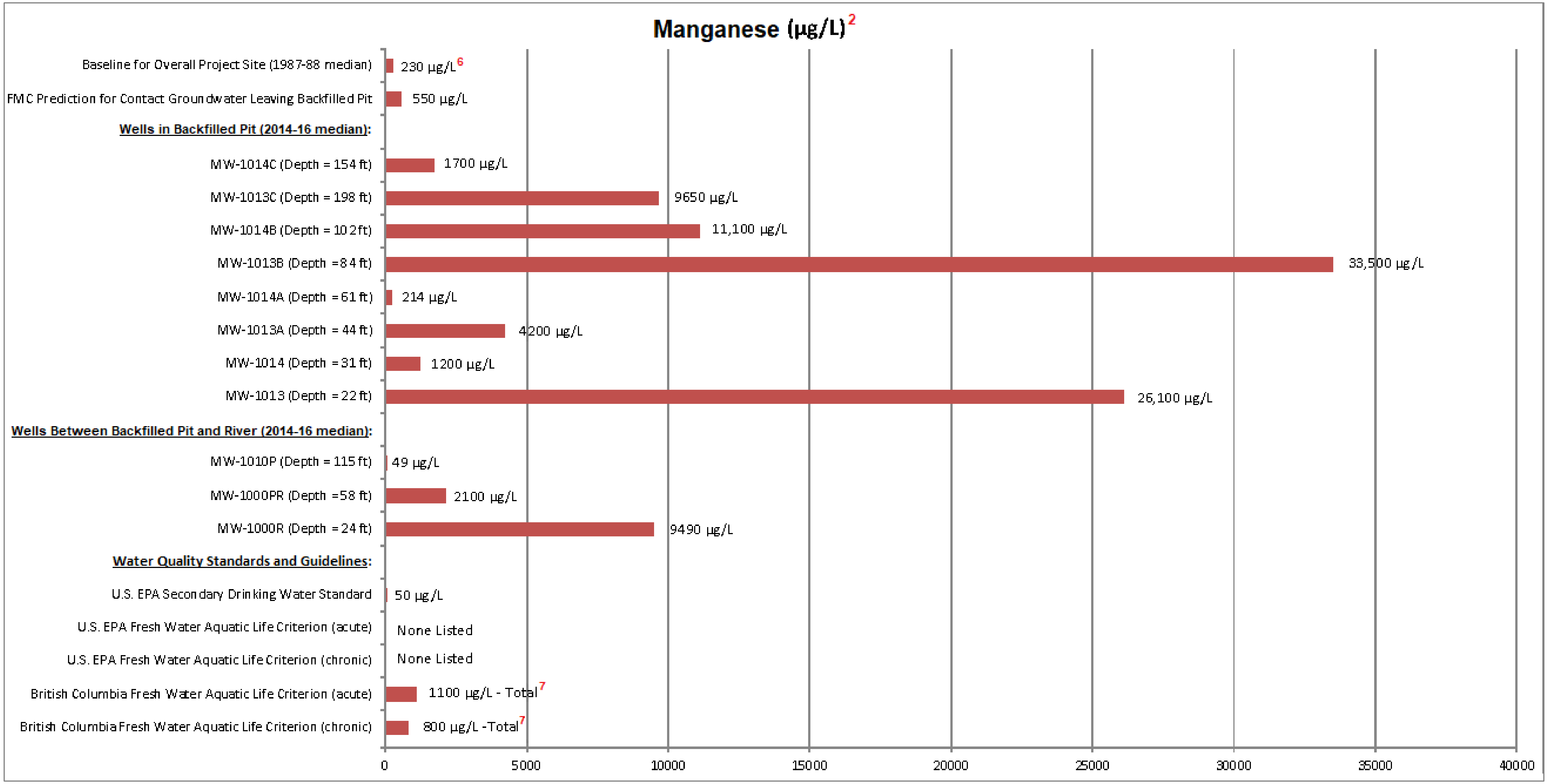
[3] Baseline median determined by author using data presented *in:* Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, 1989. For details, see Table 6 – Ground water quality data.

[4] Figures for projected ground water quality of contact water leaving the Flambeau backfilled pit were provided by Foth *in:* Mining Permit Application for the Flambeau Project, Volume 2, Appendix L, Dec 1989. Also see Table 8 – Projected ground water quality.

[5] For details, see Table 2 – Water quality standards.

[6] Reported baseline median was a non-detect (< 100 µg/L); Range = < 60 - 21,000 µg/L; n = 193; 46% detects.

Figure 9e. MEDIAN (2014-16)[1] Flambeau Mine ground water MANGANESE concentrations[2] compared to baseline (1987-88)[3], predictive modeling (1989)[4], and relevant water quality standards[5]



[1] Manganese concentrations are measured in ground water by FMC on a quarterly basis. Reported concentration for each individual well is a 2014-16 median value (n = 12) determined by author using historical data presented *in:* 2016 Annual Report, FMC, Jan 2017. For details, see Table 6 - Ground water quality data.

[2] There was no "Total" or "Dissolved" designation for baseline (1987-88) concentrations of manganese reported by FMC in their 1989 Environmental Impact Report. Nor is there any such designation for later values reported in the summary tables of "Historical Groundwater Results" found in the company's annual reports. Perusal of other FMC documents suggests reported values are Dissolved. Any concentrations clearly designated as "Total" or "Dissolved" by U.S. EPA or other government authorities in regulatory documents have been so indicated.

[3] Baseline median determined by author using data presented *in:* Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, 1989. For details, see Table 6 – Ground water quality data.

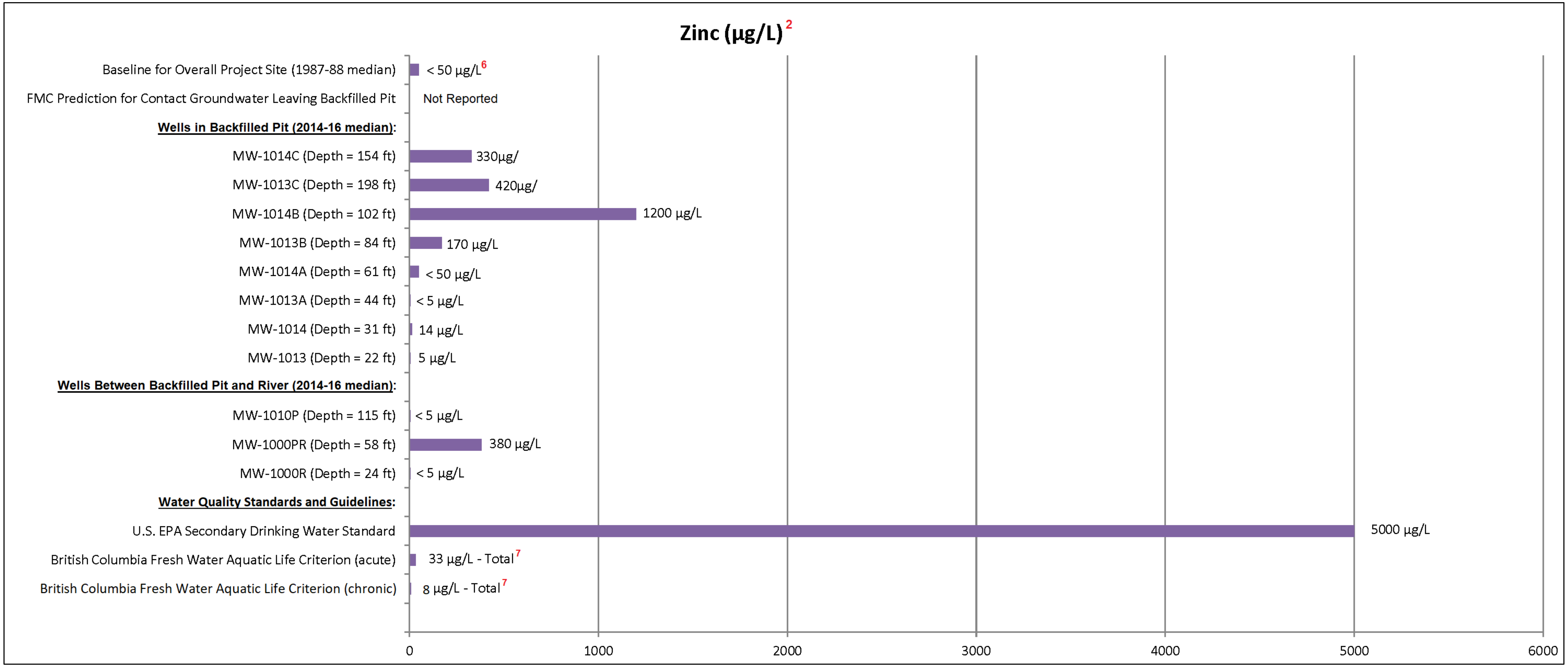
[4] Figures for projected ground water quality of contact water leaving the Flambeau backfilled pit were provided by Foth *in:* Mining Permit Application for the Flambeau Project, Volume 2, Appendix L, Dec 1989. Also see Table 8 – Projected ground water quality.

[5] For details, see Table 2 – Water quality standards.

[6] Baseline Median = 230 µg/L; Range = < 50 - 1400 µg/L; n = 193; 72% detects.

[7] Hardness-dependent toxicity; reported value is for a hardness of 50 mg/l.

Figure 9f. MEDIAN[1] (2014-16) Flambeau Mine ground water ZINC concentrations[2] compared to baseline (1987-88)[3], predictive modeling (1989)[4], and relevant water quality standards[5]



1. Zinc concentrations are measured in ground water by FMC on a quarterly basis. Reported concentration for each individual well is a 2014-16 median value (n = 12) determined by author using historical data presented *in:* 2016 Annual Report, FMC, Jan 2017. For details, see Table 6 - Ground water quality data.
2. There was no "Total" or "Dissolved" designation for baseline (1987-88) concentrations of zinc reported by FMC in their 1989 Environmental Impact Report. Nor is there any such designation for later values reported in the summary tables of "Historical Groundwater Results" found in the company's annual reports. Perusal of other FMC documents suggests reported values are Dissolved. Any concentrations clearly designated as "Total" or "Dissolved" by U.S. EPA or other government authorities in regulatory documents have been so indicated.
3. Baseline median determined by author using data presented *in:* Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, 1989. For details, see Table 6 – Ground water quality data.
4. Figures for projected ground water quality of contact water leaving the Flambeau backfilled pit were provided by Foth *in:* Mining Permit Application for the Flambeau Project, Volume 2, Appendix L, Dec 1989. Also see Table 8 – Projected ground water quality.
5. For details, see Table 2 – Water quality standards.
6. Reported baseline median was a non-detect (< 50 µg/L); Range = < 10 - 1800 µg/L; n = 193; 23% detects.
7. Hardness-dependent toxicity; reported value is for a hardness ≤ 90 mg/l.

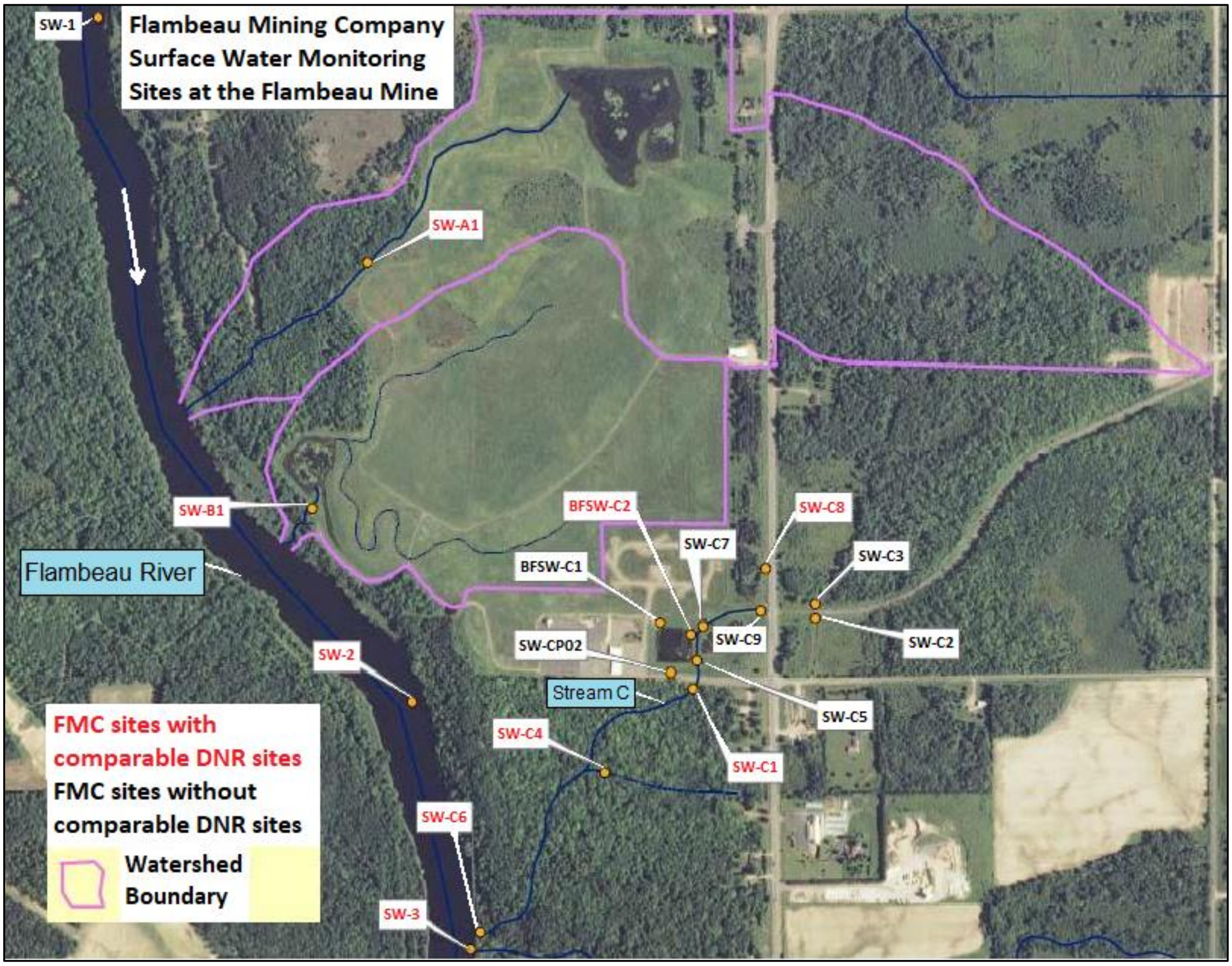
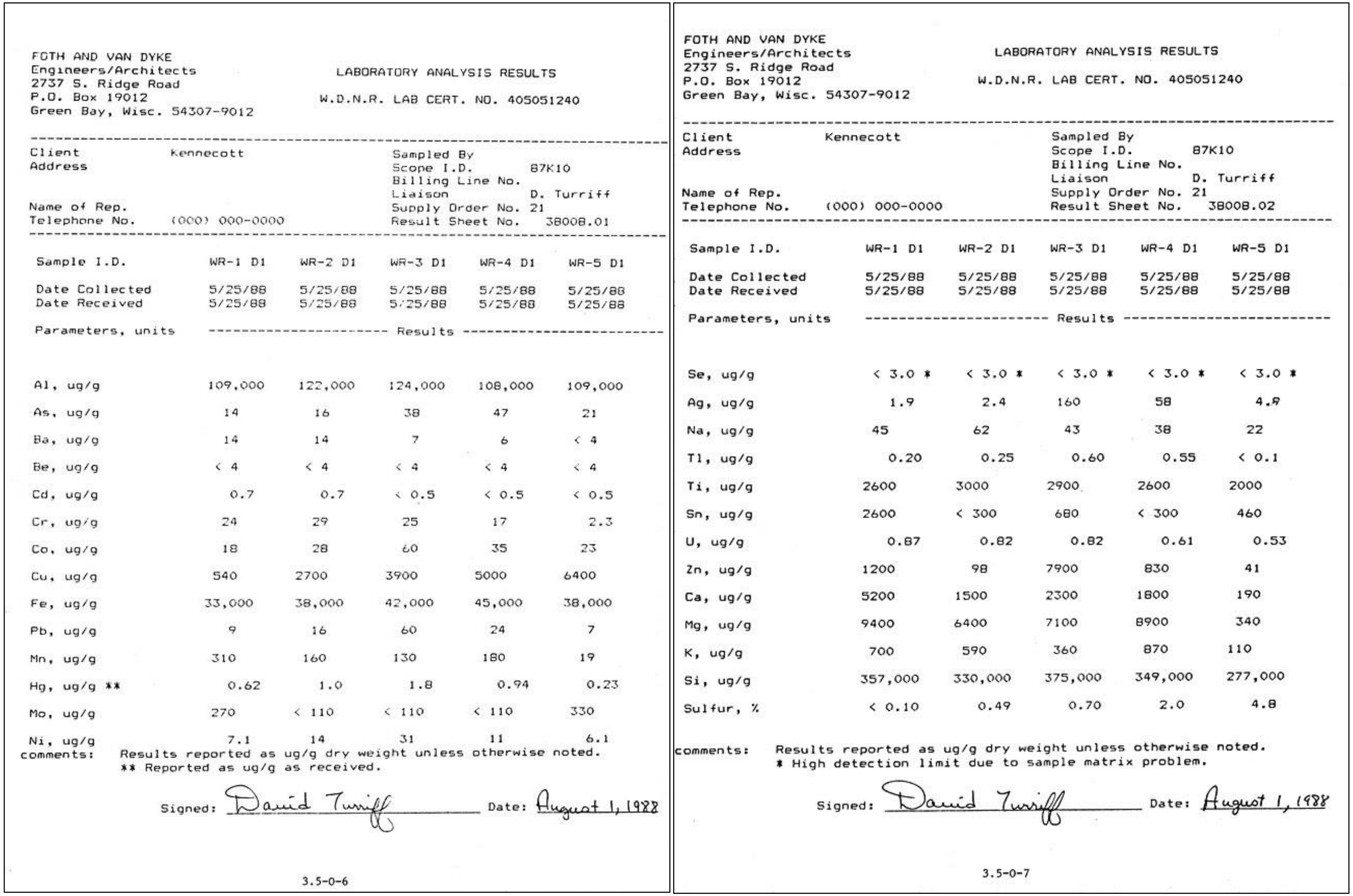


Figure 10. This map shows various historic and current surface water monitoring stations at the reclaimed Flambeau Mine site, some of which were sampled by the Wisconsin DNR in 2010-2011 when evaluating Stream C for inclusion on the EPA's 303(d) list of impaired waters (Adapted from Figure 3 *in:* Surface Water Quality Assessment of the Flambeau Mine Site, WDNR, 2012a).

TABLES



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LABORATORY ANALYSIS RESULTS

W.D.N.R. LAB CERT. NO. 405051240

Client	Kennecott	Sampled By	
Address		Scope I.D.	87K10
		Billing Line No.	
		Liaison	D. Turriff
Name of Rep.		Supply Order No.	21
Telephone No.	(000) 000-0000	Result Sheet No.	38008.01

Sample I.D.	WR-1 D1	WR-2 D1	WR-3 D1	WR-4 D1	WR-5 D1
Date Collected	5/25/88	5/25/88	5/25/88	5/25/88	5/25/88
Date Received	5/25/88	5/25/88	5/25/88	5/25/88	5/25/88
Parameters, units	Results				
Al, ug/g	109,000	122,000	124,000	108,000	109,000
As, ug/g	14	16	38	47	21
Ba, ug/g	14	14	7	6	< 4
Be, ug/g	< 4	< 4	< 4	< 4	< 4
Cd, ug/g	0.7	0.7	< 0.5	< 0.5	< 0.5
Cr, ug/g	24	29	25	17	2.3
Co, ug/g	18	28	60	35	23
Cu, ug/g	540	2700	3900	5000	6400
Fe, ug/g	33,000	38,000	42,000	45,000	38,000
Pb, ug/g	9	16	60	24	7
Mn, ug/g	310	160	130	180	19
Hg, ug/g **	0.62	1.0	1.8	0.94	0.23
Mo, ug/g	270	< 110	< 110	< 110	330
Ni, ug/g	7.1	14	31	11	6.1

comments: Results reported as ug/g dry weight unless otherwise noted.
** Reported as ug/g as received.

Signed: David Turriff Date: August 1, 1988

3.5-0-6

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LABORATORY ANALYSIS RESULTS

W.D.N.R. LAB CERT. NO. 405051240

Client	Kennecott	Sampled By	
Address		Scope I.D.	87K10
		Billing Line No.	
		Liaison	D. Turriff
Name of Rep.		Supply Order No.	21
Telephone No.	(000) 000-0000	Result Sheet No.	38008.02

Sample I.D.	WR-1 D1	WR-2 D1	WR-3 D1	WR-4 D1	WR-5 D1
Date Collected	5/25/88	5/25/88	5/25/88	5/25/88	5/25/88
Date Received	5/25/88	5/25/88	5/25/88	5/25/88	5/25/88
Parameters, units	Results				
Se, ug/g	< 3.0 *	< 3.0 *	< 3.0 *	< 3.0 *	< 3.0 *
Ag, ug/g	1.9	2.4	160	58	4.9
Na, ug/g	45	62	43	38	22
Tl, ug/g	0.20	0.25	0.60	0.55	< 0.1
Ti, ug/g	2600	3000	2900	2600	2000
Sn, ug/g	2600	< 300	680	< 300	460
U, ug/g	0.87	0.82	0.82	0.61	0.53
Zn, ug/g	1200	98	7900	830	41
Ca, ug/g	5200	1500	2300	1800	190
Mg, ug/g	9400	6400	7100	8900	340
K, ug/g	700	590	360	870	110
Si, ug/g	357,000	330,000	375,000	349,000	277,000
Sulfur, %	< 0.10	0.49	0.70	2.0	4.8

comments: Results reported as ug/g dry weight unless otherwise noted.
* High detection limit due to sample matrix problem.

Signed: David Turriff Date: August 1, 1988

3.5-0-7

Table 1. This table, from Appendix 3.5-O of Flambeau Mining Company's 1989 Environmental Impact Report, shows concentrations of select elements tested and reported by FMC in five waste rock (WR) composite samples. According to FMC, the five samples, WR-1 through 5, "represented the range of sulfide mineralization, from least to most, expected in the waste rock" (Foth, 1989a). Notably absent from the reported test panel were several trace elements routinely found in similar massive sulfide deposits, worldwide, including antimony.

Table 2. Water Quality Standards and Guidelines*

Constituent T = Total D = Dissolved	Units	United States			Great Lakes Initiative		Canada					Wisconsin							
		Drinking Water Standard[1,2]	Fresh Water Aquatic Life Criteria[3]		Fresh Water Aquatic Life Criteria[4]		Drinking Water Guide[5]	Irrigation Guide[6,7]	Livestock Guide[6,7]	Fresh Water Aquatic Life Guide[7,8]		Ground Water[9]		Drinking Water (All Sources)[10]		Surface Waters[12]			
												Enforcement Standard	Preventive Action Limit[11]	Enforcement Standard	Maximum Contam. Level Goal	Fresh Water Aquatic Life Criteria[13]			
																Warm Water Fishery		Cold Water Fishery	
			Acute	Chronic	Acute	Chronic				Acute	Chronic					Acute	Chronic	Acute	Chronic
Alkalinity	mg/l			20[17]									100 over Baseline						
Aluminum	µg/l	50 - 200[2]	750 (T)[18]	87 (T)[18]			200 (D)[19]	5000 (T)	5000 (T)[19]	100 (D)[19, 20]	100 (T)[20] 50 (D)[19, 20]	200	40						
Ammonia (as N)	mg/l		17 (T)[21]	1.9 (T)[21]						19.2 (T)[19, 22]	1.2 (T)[19, 22]	9.7	0.97			20[23]	4.4[24]	13[23]	4.4[24]
Antimony	µg/l	6					6					6	1.2	6	6				
Arsenic	µg/l	10	340	150			10[25]	100 (T)	25 (T)		5 (T)[26]	10	1	10	0				
Arsenic III	µg/l				340	148										340 (T)	152 (T)	340 (T)	148 (T)
Asbestos	MFL	7[27]										7	0.7	7[27]	7[27]				
Barium	mg/l	2					1					2	0.4	2	2				
Beryllium	µg/l	4						100	100			4	0.4	4	4				
Boron	mg/l						5 (T)[19]	0.5 - 6 (T)[19]	5 (T)[19]	29	1.2 (T)[19]	1	0.2						
Cadmium	µg/l	5	0.94[28, 29]	0.43[28, 29]	2.1[28, 30]	1.4[28, 30]	5	5.1	80	0.288 (D)[19, 28]	0.127 (D)[19, 28]	5	0.5	5	5	4.6 (T)[28]	1.4 (T)[28]	2.0 (T)[28]	1.4 (T)[28]
Calcium	mg/l												25 over Baseline						
Chloride	mg/l	250[2]	860	230			250[31]	100[19]	600[19]	600[19]	150[19]	250	125			757	395	757	395
Chlorine	mg/l	4[32]	.019	.011			See[33]				.0005[34]			4[32]	4[32]	.019 (T)[35]	.007 (T)[35]	.019 (T)[35]	.007 (T)[35]
Chromium (tot)	µg/l	100					50					100	10	100	100				
Chromium (III)	µg/l		323[28, 36]	42[28, 36]	1022[28, 30]	49[28, 30]		5	50		8.9 (T)					1022 (T)[28]	75 (T)[28]	1022 (T)[28]	49 (T)[28]
Chromium (VI)	µg/l		16	11	16	11		8	50		1.0 (T)					16 (T)	11 (T)	16 (T)	11 (T)
Cobalt	µg/l							50	1000	110 (T)[19]	4 (T)[19]	40	8						
Coliforms (fecal)		See[37]					0	100 per 100 ml							0				
Coliforms (tot)		5.0%[37]					0	1000 per 100 ml				0	0						
Conductivity (field sp.)	µS/cm												200 over Baseline						
Copper	µg/l	1300[38]	4.7[39]	2.9[39]	7.3[28, 30]	5.2[28, 30]	500 (T)[19]	200 (T)[19]	300 (T)[19]	7 (T)[19, 28]	2 (T)[28]	1300	130	1300[40]	1300	8.1 (T)[28]	5.7 (T)[28]	8.1 (T)[28]	5.7 (T)[28]
Cyanide (free)	µg/l	200	22	5.2	22	5.2					5	200	40	200	200	46	11.5	22	5.2
Cyanide (weak-acid dissociable)	µg/l									10 (T)[41]	5 (T)[41]								
Fluoride	mg/l	4.0					1.5 (T)(acute)[19] 1.0 (T)(chron)[19]	2.0 (T)(acute)[19] 1.0 (T)(chron)[19]	2.0 (T)(acute)[19] 1.0 (T)(chron)[19]	0.4 (T)[19, 42]	0.12	4	0.8	4	4				
Hardness	mg/l												100 over Baseline						
Iron	µg/l	300[2]		1000[14]			300[31]	5000 (T)		1000 (T)[19] 350 (D)[19]	300 (T)	300	150						
Lead	µg/l	15[38]	30[28, 36]	1.2[28, 36]			50 (T)(acute)[19] 10 (chronic)[5]	200 (T)	100 (T)[19]	34 (T)[19, 28]	1 (T)[28] - 5 (T)[19,28]	15	1.5	15[40]	0	55 (T)[28]	14 (T)[28]	55 (T)[28]	14 (T)[28]

Table 2. Water Quality Standards and Guidelines (cont.)

Constituent **T = Total** **D = Dissolved**	**Units**	**United States**			**Great Lakes Initiative**		**Canada**					**Wisconsin**							
		Drinking Water Standard[1,2]	**Fresh Water Aquatic Life Criteria**[3]		**Fresh Water Aquatic Life Criteria**[4]		**Drinking Water Guide**[5]	**Irrigation Guide**[6,7]	**Livestock Guide**[6,7]	**Fresh Water Aquatic Life Guide**[7,8]		**Ground Water**[9]		**Drinking Water (All Sources)**[10]		**Surface Waters**[12]			
												Enforcement Standard	**Preventive Action Limit**[11]	**Enforcement Standard**	**Maximum Contam. Level Goal**	**Fresh Water Aquatic Life Criteria**[13]			
																Warm Water Fishery		**Cold Water Fishery**	
			Acute	**Chronic**	**Acute**	**Chronic**				**Acute**	**Chronic**					**Acute**	**Chronic**	**Acute**	**Chronic**
Magnesium	mg/l												25 over Baseline						
Manganese	µg/l	50 [2]					50 [31]	200 (T)		1100 (T) [19,28]	800 (T) [19, 28]	50 [43] 300	25 [43] 60						
Mercury	µg/l	2	1.4	0.77			1 (T)(acute) [19]	2 (T)(acute) [19]	3 (T)(acute) [19]		.002 (T) [19, 44]	2	0.2	2	2				
Mercury II	µg/l				1.69	0.91										0.83 (T)	0.4 (T)	0.83 (T)	0.4 (T)
Molybdenum	µg/l						250 (T)(acute) [19]	50 (T)(acute) [19] 10 - 30 (T)(chron)[19]	50 - 80 (T)(acute) [19] 500 [6]	2000 (T) [19]	73 [8] 1000 (T) [19]	40	8						
Nickel	µg/l		270 [28, 36]	29 [28, 36]	261 [28, 30]	29 [28, 30]		200 (T)	1000		25 (T) [28]	100	20	100	100	261 (T) [28]	29 (T) [28]	261 (T) [28]	29 (T) [28]
Nitrate (as N)	mg/l	10	Total N = 0.38 [45]				10		100 [19]	33 [19]	3 [19]	10	10	10	10				
Nitrite (as N)	mg/l	1					1		10 [19]	.06 [19, 46]	.02 [19, 46]	1	1	1	1				
pH	s.u.	6.5 - 8.5 [2]		6.5 - 9.0 [14]			7.0 - 10.5 [15]				6.5 - 9.0								
Radionuclides- Gross Alpha		15 pCi/l					0.5 Bq/l							15 pCi/l [16]	0 [16]				
Radionuclides- Gross Beta		4 mrem/yr					1.0 Bq/l							4 mrem/yr	0				
Radium		5 pCi/l [47]					0.5 Bq/l							5 pCi/l [47]	0 [47]				
Selenium	µg/l	50		1.5 - 3.1 [48]		5	10 (T)[19]	10 (T)[19]	30 (T)[19]		1 (T)	50	10	50	50		5.0		5.0
Silver	µg/l	100 [2]	1.0 [28, 36]							0.1 (T) [19, 49]	0.05 (T) [19, 49]	50	10						
Sodium	mg/l						200 [31]						10 over baseline						
Sulfate	mg/l	250 [2]		10 [50]			500 [31]		1000		218 [19, 28]	250	125						
Sulfide	mg/l			.002			.05 [31]												
Total Dissolved Solids	mg/l	500 [2]					500 [31]	500 - 3500	3000				200 over Baseline						
Thallium	µg/l	2									0.8	2	0.4	2	0.5				
Turbidity	NTU/ FTU	0.3 - 5 NTU [51]	1.3 FTU [45]				5 NTU [19, 52]	Increase over baseline of 10 NTU or 20% [19, 53]	Increase over baseline of 5 NTU or 10% [19, 54]	8 NTU over baseline[19,55]	2 NTU over baseline [19, 55]			1 - 5 NTU [56]					
Uranium	µg/l	30					20	10 (T)	200	33 (T)	15 (T)			30	0				
Vanadium	µg/l							100 (T)	100			30	6						
Zinc	µg/l	5000 [2]	70 [28, 36]	70 [28, 36]	67 [28, 30]	67 [28, 30]	5000 (T) [19]	1000 - 5000 (T) [19]	2000 (T) [19]	33 (T) [19, 57]	7.5 (T) [19, 57]	5000	2500			66 (T) [28]	66 (T) [28]	66 (T) [28]	66 (T) [28]

* Please note the following:

- Any concentrations clearly designated as Total (T) or Dissolved (D) by government authorities in regulatory documents have been so indicated.
- In cases where aquatic life criteria are not clearly designated as Total or Dissolved, there is disagreement in the technical literature as to whether total or dissolved constituent concentrations should be compared to the criteria. EPA metals criteria recommendations have varied inconsistently over decades as to the use of total vs. dissolved concentrations. Since fish and macroinvertebrates are capable of ingesting both dissolved and particulate forms of chemicals discharged into aquatic environments, recommendations to compare dissolved constituent concentrations to aquatic life criteria have been met with controversy.
- In cases where drinking water standards are not clearly designated as Total or Dissolved, dissolved constituent concentrations typically are compared to the standards even though water from private wells normally is not filtered prior to consumption.
- In the present table, hardness-dependent standards and criteria, unless otherwise indicated, were normalized to a hardness of 50 mg/l to allow the presentation of representative values.

Table 2. Footnotes and Links

1. United States Environmental Protection Agency (EPA). *See* Table of Regulated Drinking Water Contaminants (Oct 2016) *at* https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants. EPA has established enforceable water quality standards called "Maximum Contaminant Levels" (MCL) for drinking water contaminants. **Note:** Cited EPA drinking water standards in the present table are MCLs unless otherwise noted.

2. U.S. EPA. *See* Secondary Drinking Water Standards (Mar 2017) *at* https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals. EPA has established non-mandatory "Secondary Maximum Contaminant Levels" (SMCL) for certain contaminants with aesthetic considerations, such as taste, color, and odor.

3. U.S. EPA. *See* National Recommended Water Quality Criteria - Aquatic Life Criteria Table (Mar 2017) *at* https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table.

4. U.S. EPA. *See* About the Great Lakes Initiative *at* https://www.epa.gov/gliclearinghouse/about-great-lakes-initiative and 40 CFR Parts 9, 122, 123, 131, and 132 (7-1-13 Edition) *at* https://www.gpo.gov/fdsys/pkg/CFR-2013-title40-vol23/pdf/CFR-2013-title40-vol23.pdf.

5. Health Canada. *See* Guidelines for Canadian Drinking Water Quality - Summary Table (Feb 2017) *at* http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/index-eng.php. **Note:** Cited Health Canada drinking water guidelines in the present table are health-based "Maximum Acceptable Concentrations" unless otherwise noted.

6. Health Canada. *See* Water Quality Guidelines for the Protection of Agriculture: Irrigation, Livestock – Summary Table (2006) *at* http://st-ts.ccme.ca/en/index.html?chems=all&chapters=2.

7. *See* Canadian Water Quality Guidelines (1987) *at* http://www.ccme.ca/files/Resources/supporting_scientific_documents/cwqg_pn_1040.pdf.

8. Health Canada. *See* Water Quality Guidelines for the Protection of Aquatic Life: Freshwater and Marine – Summary Table (2015) *at* http://st-ts.ccme.ca/en/index.html?chems=all&chapters=1.

9. State of Wisconsin. *See* Chapter NR 140 – Groundwater Quality (Feb 2017), Wisconsin Administrative Code *at* http://docs.legis.wisconsin.gov/code/admin_code/nr.

10. State of Wisconsin. *See* Chapter NR 809 – Safe Drinking Water (Mar 2016), Wisconsin Administrative Code *at* http://docs.legis.wisconsin.gov/code/admin_code/nr. Wisconsin has adopted: (a) enforceable water quality standards called "Maximum Contaminant Levels" (MCL) for drinking water contaminants; and (b) non-enforceable "Maximum Contaminant Level Goals" (MCLG).

11. *See* Chapter 160 – Groundwater Protection Standards (Apr 2017), Wisconsin Statutes, s. 160.15 *at* http://docs.legis.wisconsin.gov/statutes/statutes/160. Exceedances of Preventive Action Limits (PAL) may trigger a variety of different regulatory responses, as defined in Chapter NR 140, Wisconsin Administrative Code.

12. The Flambeau Mine Environmental Impact Statement (1990) classified the Flambeau River as a "warm water sport fishery." The upstream surface water station in the river had median baseline (1987-88) values of 52 mg/l for hardness and 6.8 for pH (field).

13. State of Wisconsin. *See* Chapter NR 105 – Surface Water Quality Criteria and Secondary Values for Toxic Substances (July 2010), Wisconsin Administrative Code *at* http://docs.legis.wisconsin.gov/code/admin_code/nr.

14. *See* Quality Criteria for Water, 1986 ("Gold Book") *at* http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=00001MGA.txt for narrative statement.

15. Designated as "Other Value" (not a Maximum Acceptable Concentration).

16. Excluding radon and uranium.

17. The chronic toxicity criterion of 20mg/l is a minimum value except where alkalinity is naturally lower, in which case the criterion cannot be lower than 25% of the natural level.

18. pH-dependent toxicity; reported value is for pH 6.5 - 9.0.

19. This criterion was established for use in British Columbia, by the Ministry of Environment, Lands and Parks. *See* Approved Water Quality Guidelines *at* https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines

20. Aluminum criterion is pH-dependent; reported value is for pH ≥ 6.5.

21. Freshwater criteria for ammonia are pH, temperature and life-stage dependent. *See* Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater (2013) *at* https://www.epa.gov/sites/production/files/2015-08/documents/aquatic-life-ambient-water-quality-criteria-for-ammonia-freshwater-2013.pdf. Reported value is for Total Ammonia Nitrogen (TAN) at pH 7.0 and temperature 20˚C.

22. Temperature and pH-dependent toxicity; reported value is for Total Ammonia Nitrogen (TAN) at pH 7.0 and temperature 20˚C. *See* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/nitrogen-overview.pdf

23. Acute criterion is pH and temperature-dependent; reported value is for ammonia nitrogen at pH 7.5 (temperature not specified).

24. Chronic criterion is pH and temperature-dependent; reported value is for ammonia nitrogen at pH 7.5 and temperature ≤ 14.5˚C.

25. As Low As Reasonably Achievable (ALARA).

26. *See* Canadian Water Quality Guidelines for the Protection of Aquatic Life – Arsenic (2001) *at* http://ceqg-rcqe.ccme.ca/download/en/143.

27. 7 million fibers per liter (MFL); fiber > 10 micrometers.

28. Hardness-dependent toxicity; reported value was calculated for a hardness of 50 mg/l.

29. *See* Aquatic Life Ambient Water Quality Criteria – Cadmium (2016) *at* https://www.epa.gov/sites/production/files/2016-03/documents/cadmium-final-report-2016.pdf.

30. Reported value was calculated from formula embodied in EPA's Great Lakes Initiative.

31. Aesthetic Objective (AO) value.

32. Maximum Residual Disinfectant Level (MRDL), as Cl_2. The MRDL is the highest level of a disinfectant allowed in drinking water.

33. Canada has no Maximum Acceptable Concentration for chlorine in drinking water, but, according to Health Canada, free chlorine concentrations in most Canadian drinking water distribution systems range from 0.04 to 2.0 mg/l.

34. Guideline has been derived for reactive chlorine species.

35. Total residual.

36. Reported value was calculated from formula embodied in EPA's Aquatic Life Criteria document.

37. No more than 5.0% samples total coliform-positive (TC-positive) in a month. For water systems that collect fewer than 40 routine samples/month, no more than 1 sample can be total coliform-positive/per month.

38. Action Level. Lead and copper are regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps.

39. Freshwater criteria are calculated using the Biotic Ligand Model (BLM). *See* Aquatic Life Ambient Freshwater Quality Criteria – Copper (2007) *at* https://www.epa.gov/wqc/aquatic-life-criteria-copper#2007. Also *see* Draft Technical Support Document: Recommended Estimates for Missing Water Quality Parameters for Application in EPA's Biotic Ligand Model (Mar 2016) *at* https://www.epa.gov/sites/production/files/2016-02/documents/draft-tsd-recommended-blm-parameters.pdf. Reported value was calculated using available median Flambeau River baseline (1987-88) constituent concentrations for the upstream surface water station. FMC did not provide 1987-88 baseline data for its current downstream surface water station (SW-2).

40. Action Level. As defined in Chapter 809, Wisconsin Administrative Code, "Action level" is the concentration of lead or copper in water which determines, in some cases, the treatment requirements that a public water system is required to complete.

Table 2. Footnotes and Links (cont.)

41. This criterion was established for use in British Columbia, Canada by their Ministry of Environment, Lands and Parks. *See* Water Quality Criteria for Cyanide *at* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/cyanide-or.pdf. The term weak-acid dissociable cyanide refers to the analytical method of the Provincial Environmental Laboratory. Weak-acid dissociable cyanide includes only free cyanide, simple cyanides and weak-acid dissociable metallocyanides such as zinc- and cadmium-cyanide complexes.

42. Hardness-dependent toxicity; reported value was calculated for a hardness of 10 mg/l. *See* Ambient Water Quality for Fluoride *at* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/fluoride-or.pdf

43. The State of Wisconsin has two different groundwater quality enforcement standards for manganese: 300µg/l as a “Public Health” groundwater quality enforcement standard (PAL = 60 µg/), and 50 µg/l as a “Public Welfare” groundwater quality enforcement standard (PAL = 25 µg/).

44. Toxicity is dependent on the percentage of methyl mercury present; reported value is for when MeHg constitutes 5 % of the total mercury concentration. *See* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/mercury-or.pdf

45. *See* Ambient Water Quality Criteria Recommendations – Nutrient Criteria for Rivers and Streams in Nutrient Ecoregion VIII (Dec 2001) *at* https://www.epa.gov/sites/production/files/documents/rivers8.pdf. Reported values for total nitrogen and turbidity are aggregate reference conditions for rivers and streams in Nutrient Ecoregion VIII (Nutrient Poor Largely Glaciated Upper Midwest and Northeast), which includes Rusk County, Wisconsin.

46. Guideline varies with ambient concentration of chloride; reported value is for low chloride water (< 2 mg/L). *See* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/nitrogen-overview.pdf

47. Radium-226 and Radium-228 combined.

48. *See* Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater (2016) *at* https://www.epa.gov/sites/production/files/2016-07/documents/aquatic_life_awqc_for_selenium_-_freshwater_2016.pdf. Selenium chronic criteria: 1.5 µg/l (lentic) and 3.1 µg/l (lotic).

49. Hardness-dependent toxicity; reported value is for a hardness ≤ 100 mg/l.

50. This criterion is specific for wild rice waters and was approved by U.S. EPA for:
(1) State of Minnesota (1973). *See* Minnesota Administrative Rules, 7050.0224, Subparts 1 and 2: Specific Water Quality Standards for Class 4 Waters of the State – Agriculture and Wildlife *at* https://www.revisor.mn.gov/rules/7050.0224/
(2) Fond du Lac Band of Lake Superior Chippewa (2001). *See* Water Quality Standards Regulations: Fond du Lac Band of the Minnesota Chippewa Tribe *at* https://www.epa.gov/wqs-tech/water-quality-standards-regulations-fond-du-lac-band-minnesota-chippewa-tribe
(3) Grand Portage Band of Lake Superior Chippewa (2005). *See* Water Quality Standards Regulations: Grand Portage Band of the Minnesota Chippewa Tribe *at* https://www.epa.gov/wqs-tech/water-quality-standards-regulations-grand-portage-band-minnesota-chippewa-tribe

51. Criteria apply to *treated* drinking water. For systems that use conventional or direct filtration, at no time can turbidity go higher than 1 NTU, and samples for turbidity must be less than or equal to 0.3 NTU in at least 95 percent of the samples in any month. Systems that use filtration other than the conventional or direct filtration must follow state limits, which must include turbidity at no time exceeding 5 NTU.

52. Guideline is for *raw* drinking waters of exceptional clarity (≤ 5 NTU) which normally do not require treatment to reduce natural turbidity. Induced turbidity should not exceed 1 NTU and the total turbidity should not exceed 5 NTU at any time. *See* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/turbitity-or.pdf

53. Change from background of 10 NTU when background ≤ 50 NTU; Change from background of 20% when background > 50 NTU.

54. Change from background of 5 NTU when background is ≤ 50 NTU; Change from background of 10% when background is > 50 NTU. See https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/turbitity-or.pdf

55. Stated guidelines apply to all waters during clear flows or in clear waters. When background is ≥ 8 NTU during high flows or in turbid waters, different criteria apply. *See* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/turbitity-or.pdf

56. For *treated* drinking water, the enforcement standard for the monthly turbidity average is 1 NTU; for public water systems that are required to filter but have not yet installed filtration, the enforcement standard for the 2-day average is 5 NTU.

57. Hardness-dependent toxicity; reported value is for a hardness ≤ 90 mg/l.

Table 3. Flambeau Mine Ground Water Monitoring Wells Listed as "Active" by Wisconsin Department of Natural Resources (2017)

(For well locations, see Figure 6 – Backfilled pit cross section, Figure 7 – Compliance Boundary, and Figure 8 – Shallow potentiometric surface map)

ID Number assigned by FMC[1]	Date Installed[2]	Depth (ft)[2]		Casing Diameter (in)[2, 4]	Gradient Position Relative to Mine Pit[5]	Ground Surface Elevation (ft MSL)[2]	Elevation of Screened Interval (ft MSL)[2]	Geologic Unit[6]	Current Parameter Category[7]	Status[5]	Is Water Quality Data Currently Being Reported?[8]
		Well (Ground surface to borehole bottom)	Well Casing (Ground surface to tip of well screen)[3]								
MW-1000R[9]	11/12/1992 (adjusted in 1999)[10]	24.5	23.9	1.89 I.D.	Down SW	1104	1091 – 1081	Till, Precambrian	A, B, C	Active	Yes
MW-1000PR[11, 12]	02/19/1996 (adjusted in 1999)[10]	59.8	57.8	1.94 I.D.	Down SW	1103	1050 – 1045	Precambrian	A, B, C	Active	Yes
MW-1001	09/28/1987	33.0	32.5	2	Side/Down	1141	1118 – 1108	Till	A	Active	No
MW-1001G	09/25/1987	52.0	51.5	2	Side/Down	1141	1095 – 1090	Till, Sandstone	A	Active	No
MW-1001P	10/02/1987	-	94.5	2	Side/Down	1141	1051 – 1046	Precambrian	A	Active	No
MW-1002	09/21/1987	16.0	15.5	2	Side/Up NW	1102	1096 – 1086	Sand, Gravel	A, B, C	Active	Yes
MW-1002G	09/22/1987	52.0	51.5	2	Side/Up NW	1102	1055 – 1050	Sand, Gravel	A, B, C	Active	Yes
MW-1003	09/16/1987 (adjusted in 1999)[10]	29.6	29.0	1.96 I.D.	Down	1132	1113 – 1103	Sandstone	A	Active	No
MW-1003P	10/03/1987 (adjusted in 1999)[10]	75.7	75.7	1.89 I.D.	Down	1133	1062 – 1057	Precambrian	A	Active	No
MW-1004	09/30/1987 (adjusted in 1999)[10]	12.9	12.9	1.96 I.D.	Down	1115	1112 – 1102	Sand, Gravel	A, B, C	Active	Yes
MW-1004S	09/30/1987 (adjusted in 1999)[10]	29.7	27.0	1.96 I.D.	Down	1115	1093 – 1088	Sandstone	A, B, C	Active	Yes
MW-1004P	10/05/1987 (adjusted in 1999)[10]	76.4	75.9	1.89 I.D.	Down	1115	1042 – 1037[6]	Precambrian	A, B, C	Active	Yes
MW-1005	09/29/1987	18.5	18.0	2	Up SE	1142	1134 – 1124	Till	A, B, C	Active	Yes
MW-1005S	09/29/1987	51.5	50.3	2	Up SE	1142	1097 – 1092	Sandstone	A, B, C	Active	Yes
MW-1005P	10/04/1987	-	91.0	2	Up SE	1142	1056 – 1051	Precambrian	A, B, C	Active	Yes
MW-1010P[12]	06/04/1991 (damage/repair in 1992)[13]	115.4	115.4	2 I.D.	Down SW	1097	995 – 990[6]	Precambrian	A, B, C	Active	Yes
MW-1013	09/14/1998	22.9	21.5	1.89 I.D.	In Pit SW	1118	1107 – 1097	Pit Backfill[14]	A, B, C	Active	Yes
MW-1013A	09/14/1998	45.0	43.6	1.89 I.D.	In Pit SW	1118	1085 – 1075	Pit Backfill[14]	A, B, C	Active	Yes
MW-1013B	09/15/1998	85.0	83.5	1.89 I.D.	In Pit SW	1118	1045 – 1035	Pit Backfill[14]	A, B, C	Active	Yes
MW-1013C	09/11/1998	199.0	198.0	1.89 I.D.	In Pit SW	1118	930 – 920	Pit Backfill[14]	A, B, C	Active	Yes
MW-1014	09/16/1998	32.0	31.0	1.89 I.D.	In Pit NE	1137	1116 – 1106	Pit Backfill[14]	A, B, C	Active	Yes
MW-1014A	09/16/1998	62.0	61.0	1.89 I.D.	In Pit NE	1137	1086 – 1076	Pit Backfill[14]	A, B, C	Active	Yes
MW-1014B	09/17/1998	103.0	102.0	1.89 I.D.	In Pit NE	1137	1045 – 1035	Pit Backfill[14]	A, B, C	Active	Yes
MW-1014C	09/22/1998	154.5	154.0	1.89 I.D.	In Pit NE	1137	993 – 983	Pit Backfill[14]	A, B, C	Active	Yes
MW-1015A	01/11/2001	65.0	63.0	1.92 I.D.	Down W	1099	1041 – 1036	Till[15]	A, B, C	Active	Yes
MW-1015B	01/10/2001	152.0	148.0	1.92 I.D.	Down W	1099	956 – 951	Precambrian[15]	A, B, C	Active	Yes
PZ-1A	10/30/1987	6.3	6.3	2	Down	1104	1099 – 1097	Sand, Gravel	A	Active	No
PZ-1B	10/30/1987	2.9	2.9	2	Down	1104	1103 – 1101	Sand, Gravel	A	Active	No
PZ-1006	09/24/1987	10.0	10.0	2	Up	1148	1143 – 1138	Till	A	Active	No
PZ-1006G	09/24/1987	33.0	33.0	2	Up	1147	1119 – 1114	Till	A	Active	No
PZ-1006S	09/23/1987	53.8	52.0	2	Up	1148	1101 – 1096	Sandstone	A	Active	No
PZ-1007S	11/08/1988	64.0	48.0	2	Up	1153	1110 – 1105	Sandstone	A	Active	No
PZ-1008	11/10/1988	31.0	17.0	2	Up	1145	1138 – 1128	Till	A	Active	No
PZ-1008G	11/09/1988	55.4	54.2	2	Up	1145	1096 – 1091	Sand, Gravel	A	Active	No
PZ-1009	11/12/1988	25.0	18.4	2	Up	1153	1144 – 1134	Till	A	Active	No
PZ-1009G	11/11/1988	50.3	50.3	2	Up	1152	1107 – 1102	Till	A	Active	No
PZ-1011	04/18/1991	51.5	47.5	2.00 I.D.	Up	-	1114 – 1104[6]	Till	A	Active	No
PZ-1012	04/17/1991	37.0	36.4	2.00 I.D.	Side/Up	-	1111 – 1101[6]	Till	A	Active	No
PZ-R1	01/07/1988	230.0	220.0	1.25	Down	1101	901 – 881	Precambrian	A	Active	No
PZ-S1	12/08/1987	-	40.0	2	Down	1102	1067 – 1062	Precambrian	A	Active	No
PZ-S3	10/30/1987	53.0	33.5	2	Up	1129	1100 – 1095	Sandstone	A	Active	No

Table 3. Flambeau Mine Ground Water Monitoring Wells Listed as “Active” by Wisconsin Department of Natural Resources (2017) (cont.)

ID Number assigned by FMC[1]	Date Installed[2]	Depth (ft)[2]		Casing Diameter (in)[2, 4]	Gradient Position Relative to Mine Pit[5]	Ground Surface Elevation (ft MSL)[2]	Elevation of Screened Interval (ft MSL)[2]	Geologic Unit[6]	Current Parameter Category[7]	Status[5]	Is Water Quality Data Currently Being Reported?[8]
		Well (Ground surface to borehole bottom)	**Well Casing** (Ground surface to tip of well screen)[3]								
OW-7	07/16/1970	80	57[16] 20[16]	4	Side/Down	-	1088 – 1078[6] 1120 – 1115[16]	Till	A	Active	No
OW-10	07/23/1970	90	53[17] 20[17]	4	Down	1112	1069 – 1059 1097 – 1092[17]	Till	A	Active	No
OW-39	09/07/1972	44	44	4	Side/Down	1117	1107 – 1073	Till	A	Active	No
OW-42	09/09/1972	42	42	4	Down	1100	1090 – 1058	Sand, Gravel	A	Active	No
OW-43	09/03/1972	78	78	4	Down	1100	1090 – 1022	Sand, Gravel	A	Active	No
ST-9-23	06/21/1973 (adjusted in 1999)[10]	52.4	38.9	1.47 I.D.	Up	1139	1105 - 1100	Sandstone	A	Active	No
ST-9-23A	06/22/1973 (adjusted in 1999)[10]	20.9	19.4	1.47 I.D.	Up	1139	1125 – 1120	Sand, Gravel	A	Active	No
ST-9-26	06/25/1973 (adjusted in 1999)[10]	53.5	24.2	0.94 I.D.	Up	1123	1104 – 1099	Till	A	Active	No

Footnotes and Links:

[1] A perusal of historic Flambeau Mining Company (FMC) documents suggests ID number prefixes mean the following: MW = Monitoring Well; PZ = Piezometer; OW = Observation Well; ST = Soil Test boring into which a piezometer was installed.

[2] Monitoring Well Construction Logs submitted by FMC to Wisconsin Department of Natural Resources (DNR). Individual logs can be found in: (1) Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, Appendices 3.5-C, 3.5-D, 3.5-E, 3.5-H and 3.5-I, 1989; (2) 1991 Annual Report, FMC, Jan 1992; (3) Updated Monitoring Plan for the Flambeau Project, Foth & Van Dyke, 1991; (4) 1996 Annual Report, FMC, Jan 1997; (5) Monitoring Well Construction & Soil Boring Logs – Backfill Wells, FMC, 1999; (6) 1999 Annual Report, FMC, Jan 2000; and (7) Well Construction Documentation (MW-1015A/MW-1015B), FMC, 2001.

[3] FMC construction logs indicate that for all wells in the present table, with the exception of OW-7 and OW-10, the tip of the well screen coincides with the tip of the well casing.

[4] Well casing diameters are reported exactly as shown in FMC construction logs. FMC distinguished between Inner Diameter and Outer Diameter when listing casing diameters in some, but not all of its construction logs. In addition, some measurements were reported as whole numbers but others to the hundredths place.

[5] Wisconsin DNR Groundwater and Environmental Monitoring System (GEMS) On The Web (GOTW) Public Access *at* https://dnr.wi.gov/wastemgmt/gotw/webpages/UserAgreement.aspx; County = Rusk; Facility Name = Flambeau Mining Co - Kennecott Mining Site; License Number = 3180 (copy made Mar 27, 2017).

[6] 1993 Annual Report, FMC, Jan 1994, Figure 4-1.

[7] The following Parameter Categories were derived from information provided in: (1) Operational Phase and Long Term Care Quality Assurance Plan – Flambeau Mining Company, Foth & Van Dyke, Nov 1993, pp. 16-20; (2) 1993 Annual Report, FMC, Jan 1994, Figure 4-1; (3) Tables of “Historical Groundwater Results – Quarterly Parameters” found in FMC annual reports; and (4) Tables of “Historical Groundwater Results – Annual Parameters” found in FMC annual reports:

Category A = **Quarterly** reporting of: Groundwater Elevation.
Category B = **Quarterly** reporting of: Specific Conductance (field), pH (field*), TDS, Iron, Manganese, Sulfate, Copper, Total Alkalinity, Total Hardness, color (field), odor (field), turbidity (field); Arsenic added to quarterly monitoring program in 2004. **NB:** FMC does not specify in its annual reports if metal concentrations reported on a quarterly basis are Total or Dissolved. Perusal of other FMC documents suggests they are Dissolved.
Category C = **Annual** reporting of: Arsenic, Barium, Cadmium, Calcium, Chloride, Chromium**, Lead, Magnesium, Mercury, Potassium, Selenium, Silver, Sodium, Zinc. **NB:** (1) Category C testing did not commence until 1999 (after mine pit backfilled). Prior to that time, FMC was required to report results for Category A and B parameters only; (2) FMC does not specify in its annual reports if metal concentrations reported on an annual basis are Total or Dissolved. Perusal of other FMC documents suggests all are Dissolved.

* FMC’s approved monitoring plan calls for reporting field and lab pH on a quarterly basis, but, as of 2010, the company reports only one value in its annual reports and does not designate if it is field or lab. Perusal of other FMC documents suggests they are reporting field values.

**FMC’s approved monitoring plan calls for reporting Total Chromium on an annual basis from designated wells, but it appears they are reporting Dissolved.

[8] Third Quarter 2016 Groundwater Environmental Monitoring Report (Quarterly and Annual Parameters), FMC, Sep 2016.

[9] MW-1000R was constructed as a replacement for MW-1000 in November 1992. MW-1000, constructed in October 1987 (Well Casing Depth = 19 ft; Casing Diameter = 2 in; Elevation of Screened Interval = 1091-1081 ft MSL) was abandoned as a result of the construction of a slurry cutoff wall system between the proposed mine pit and Flambeau River. As described by FMC, MW-1000R is “located approximately 100 feet east of the original location of MW-1000. MW-1000 needed to be moved since its original location was downgradient of the slurry cutoff wall system, negating the ability of the well to monitor the shallow till downgradient of the backfilled pit. MW-1000R is positioned to accomplish this intent” (1992 Annual Report, FMC, Jan 1993). MW-1000R (Well Casing Depth = 15.7 ft; Casing Inner Diameter = 1.94 in; Elevation of Screened Interval = 1095 – 1085 ft MSL) was adjusted in 1999 (see footnote 10). According to FMC, MW-1000R remained dry until 4th quarter 2010, when it rebounded. First water samples were collected for analysis in October 2010.

[10] As reported by FMC: “During 1998, the final landform was established on the Flambeau Mine site. With the establishment of the final topography, ten monitoring wells and piezometers (ST-9-26, MW1000R, MW1000PR, MW1003, MW1003P, MW1004, MW1004S, MW1004P, ST-9-23A and ST-9-23) were adjusted. Well adjustments involved work at the well/ground surface interface which included extending or shortening the well casing, replacement of protector pipes, and re-establishing well seals” (1999 Annual Report, FMC, Jan 2000). Figures reported for adjusted wells in the present table were obtained from the 1999 construction logs found in FMC’s 1999 Annual Report.

[11] MW-1000PR was constructed as a replacement for MW-1000P in February 1996. MW-1000P, constructed in October 1987 (Well Casing Depth = 55 ft; Casing Diameter = 2 in; Elevation of Screened Interval = 1049 – 1044 ft MSL) reportedly was damaged during snow removal operations in January 1996. According to Foth, MW-1000PR was established in the same location and "constructed in the same manner" as MW-1000P (Replacement of MW-1000P, Foth, Mar 1996). The 1996 construction log shows the following: Well Casing Depth = 53 ft; Casing Inner Diameter = 1.94 in; Elevation of Screened Interval = 1052 – 1047 ft MSL. MW-1000PR was adjusted in 1999 (see footnote 10).

[12] In late 1992, a slurry cutoff wall system, including a concrete diaphragm wall component with panel depths ranging from 8 feet at both ends of the wall to 28 feet in the center, was constructed between the proposed mine pit and Flambeau River (Slurry Cutoff Wall System Preconstruction Report, Foth, Jul 1992; Construction Documentation Report – Slurry Cutoff Wall System, Foth, Mar 1993). MW-1000PR and MW-1010P are located BETWEEN the slurry cutoff wall system and Flambeau River but extend DEEPER than the system.

[13] MW-1010P was damaged and repaired in October 1992 (1992 Annual Report, FMC, Jan 1993). FMC, however, did not include a copy of the 1992 construction log in its annual report. Figures reported for MW-1010P in the present table are from the original 1991 construction log.

[14] Monitoring Well Construction & Soil Boring Logs – Backfill Wells, FMC, Jun 1999.

[15] Groundwater Monitoring Well Nest Installation at Compliance Boundary, FMC, Dec 2000; Well Construction Documentation (MW-1015A/MW-1015B), FMC, Jun 2001.

[16] The 1970 construction log for OW-7 (7-T) that appears in the 1989 Environmental Impact Report for the Flambeau project does not indicate ground surface elevation, but it does show the well was screened at two different elevations (15-20 ft beneath the surface and 47-57 ft beneath the surface) while the casing itself extended to 62 ft beneath the surface.

[17] The 1970 construction log for OW-10 (10-T) that appears in the 1989 Environmental Impact Report for the Flambeau project shows the well was screened at two different elevations (15-20 ft beneath the surface and 43-53 ft beneath the surface) while the casing itself extended to 62 ft beneath the surface.

Table 4. FMC Surface Water Quality Data: “Baseline” (1987-88), Historic, and Recently Reported Constituent Concentrations in Flambeau River
(For sampling station locations, see Figure 1 – Flambeau River surface water sampling stations)

Years	FMC Surface Water (SW) Sampling Station[1]	pH (s.u.)	Specific Conductance (µS/cm)	Redox (mV)	Dissolved Oxygen (mg/l)	Total Dissolved Solids (mg/l)	Total Suspended Solids (mg/l)	Sulfate (mg/l)	Sulfide (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Nitrogen (mg/l)			Total Organic Carbon (mg/l)
												Ammonia	Nitrate/Nitrite	Total Kjeldahl	
		No field or lab designation from FMC, except as noted[2]			No field or lab designation from FMC, except as noted			No total or dissolved designation from FMC[3]							
1987-88[4] “Baseline” MEDIAN[5]	SW-Upstream	**6.8** (field) (6.3 - 8.0) n = 12	**146** (field) (109 - 179) n = 12	-	**10.4** (field) (6.5 - 11.8) n = 10	**100** (36 - 140) n = 12	**5** (1 - 13) n = 12	**10** (< 5 - 15) n = 12	-	**7** (2 - 9) n = 10	**0.2** (< 0.1 - 0.2) n = 12	**0.2** (< 0.1 - 2.2) n = 11	**0.13** (< .05 - 0.35) n = 10	**< 1** (< 1 - 2) n = 11	**11.2** (9.0 - 18.1) n = 11
	SW-Downstream	**7.0** (field) (6.2 - 7.9) n = 11	**138** (field) (101 - 177) n = 11)	-	**10.2** (field) (6 - 11.9) n = 10	**100** (21 - 140) n = 11	**5** (2.5 - 15) n = 11	**11** (< 5 - 15) n = 11	-	**6** (3 - 9) n = 9	**0.2** (< 0.1 - 0.2) n = 11	**0.1** (< 0.1 - 0.4) n = 10	**0.1** (< .05 - 0.34) n = 9	**< 1** (< 1 - 2) n = 11	**10.6** (0.26 - 23.1) n = 10
1991-92[6] Pre-Production MEDIAN[5]	SW-1	**7.1** (field) (6.7 - 7.9) n = 6	**94** (field) (74 - 134) n = 6	-	**10.4** (6.2 - 12) n = 6	**90** (86 - 140) n = 6	**4** (< 1 - 14) n = 6	-	-	-	-	-	-	-	-
	SW-2	**7.1** (field) (6.2 - 8.0) n = 6	**110** (field) (69 - 144) n = 6	-	**10** (6.5 - 12) n = 6	**108** (85 - 140) n = 6	**2** (< 1 - 7) n = 6	-	-	-	-	-	-	-	-
1993-97[6] Production Phase MEDIAN[5]	SW-1	**7.4** (field) (6.5 - 8.6) n = 20	**112** (field) (59 - 203) n = 20	-	**9.0** (5.3 - 12.1) n = 20	**95** (16 - 120) n = 20	**2** (< 1 - 10) n = 20	-	**< 2** (< 2 - < 2) n = 15	-	-	-	-	-	-
	SW-2	**7.4** (field) (6.5 - 8.2) n = 20	**122** (field) (82 - 274) n = 20	-	**9.5** (6.1 - 12.9) n = 20	**96** (63 - 150) n = 20	**2** (< 1 - 13) n = 20	-	**< 2** (< 2 - < 2) n = 15	-	-	-	-	-	-
1998-2000[6] Post-Reclamation MEDIAN[5]	SW-1	**7.6** (field) (6.5 - 8.7) n = 8	**128** (field) (110 - 167) n = 8	-	**8.4** (6.3 - 11.5) n = 8	**78** (38 - 180) n = 7	**5** (< 1 - 8) n = 7	**7.7** (5.2 - 8.6) n = 3	**< 2** (< 2 - < 2) n = 5	-	-	-	-	-	-
	SW-2	**7.4** (field) (5.5 - 8.3) n = 8	**132** (field) (97 - 168) n = 8	-	**8.6** (7.3 - 11.5) n = 8	**85** (28 - 110) n = 7	**5** (3 - 12) n = 7	**7.9** (5.2 - 8.4) n = 3	**< 2** (< 2 - < 2) n = 5	-	-	-	-	-	-
2001-2012[7] Post-Reclamation MEDIAN[5]	SW-1	**7.4** (6.3 - 8.8) n = 25	**113** (45 - 169) n = 25	-	-	-	-	**6.1** (< 2.5 - 10) n = 25	-	-	-	-	-	-	-
	SW-2	**7.5** (6.0 - 8.8) n = 25	**110** (44 - 169) n = 25	-	-	-	-	**6.3** (< 5 - 11) n = 25	-	-	-	-	-	-	-
2013-16[7] Post-Reclamation MEDIAN[5]	SW-1	**7.1** (6.3 - 7.5) n = 7	**93** (53 - 121) n = 7	**146** (62 - 253) n = 7	**9.6** (8.7 - 14.5) n = 7	-	**2.6** (< 1 - 4.3) n = 7	-	-	-	-	-	-	-	-
	SW-2	**7.2** (5.9 - 7.5) n = 7	**91** (53 - 119) n = 7	**166** (64 - 255) n = 7	**9.9** (8.3 - 18.7) n = 7	-	**2.8** (1.3 - 4.5) n = 7	-	-	-	-	-	-	-	-
Oct 2017[8] **Post-Reclamation**	SW-1	**7.3**	**107**	**124**	**8.1**	-	**2.4**	-	-	-	-	-	-	-	-
	SW-2	**7.4**	**106**	**159**	**8.2**	-	**2.4**	-	-	-	-	-	-	-	-
Oct 2018[8] **Post-Reclamation**	SW-1	-	-	-	-	-	**3.0**	-	-	-	-	-	-	-	-
	SW-2	-	-	-	-	-	**3.2**	-	-	-	-	-	-	-	-

Sample Cell:

146	=	**Median**
(109-179)	=	(range)
n = 12	=	number of values
-	=	no available data

Table 4. FMC Surface Water Quality Data: “Baseline” (1987-88), Historic, and Recently Reported Constituent Concentrations in Flambeau River (cont.)

Years	FMC Surface Water (SW) Sampling Station[1]	Alkalinity, tot (mg/l) (as $CaCO_3$)	Hardness, tot (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Aluminum (µg/l)	Antimony (µg/l)	Arsenic (µg/l)	Barium (µg/l)	Beryllium (µg/l)	Cadmium (µg/l)	Chromium, tot (µg/l)	Chromium VI (µg/l)
				No total or dissolved designation from FMC[3]											
1987-88[4] “Baseline” MEDIAN[5]	SW-Upstream	**48** (27 - 60) n = 11	**52** (37 - 71) n = 12	**15** (10 - 17) n = 12	**4.1** (2.9 - 4.5) n = 12	-	**6.4** (6.0 - 8.1) n = 6	**74** (45 - 111) n = 5	-	**< 5** (< 5 - < 5) n = 12	**< 500** (< 500 - < 1000) n = 6	**< 1** (< 1 - 1) n = 6	**< 0.6** (< 0.3 - < 1) n = 8	**< 5** (< 5 - < 5) n = 12	**< 50** (< 50 - < 50) n = 12
	SW- Downstream	**43** (30 - 60) n = 10	**58** (37 - 64) n = 11	**16** (11 - 19) n = 11	**4.0** (2.7 - 4.4) n = 11	-	**6.3** (5.1 - 8.4) n = 5	**46** (42 - 58) n = 4	-	**< 5** (< 5 - < 5) n = 11	**< 500** (< 500 - < 1000) n = 5	**< 1** (< 1 - < 1) n = 5	**< 0.3** (< 0.3 - < 1) n = 7	**< 5** (< 5 - < 5) n = 11	**< 50** (< 50 - < 50) n = 11
1991-92[6] Pre-Production MEDIAN[5]	SW-1	-	**48** (23 - 100) n = 6	-	-	-	-	**310** (80 - 750) n = 6	-	**< 2** (< 1 - < 2) n = 6	-	**< 0.6** (< 0.2 - < 1) n = 6	**< 0.2** (< 0.2 - 1) n = 6	**< 2** (< 1 - 2.7) n = 6	**< 20** (9 - < 20) n = 6
	SW-2	-	**42** (48 - 68) n = 6	-	-	-	-	**310** (60 - 720) n = 6	-	**< 2** (< 1 - < 2) n = 6	-	**< 0.6** (< 0.2 - < 1) n = 6	**< 0.2** (< 0.2 - 0.5) n = 6	**1** (< 1 - 2) n = 6	**10** (< 13 - < 20) n = 6
1993-97[6] Production Phase MEDIAN[5]	SW-1	-	**43** (20 - 64) n = 20	-	-	-	-	**94** (< 25 - 290) n = 20	-	**< 1.8** (< 1.4 - 2.8) n = 20	-	**< 0.3** (< .08 - < 1) n = 20	**0.2** (< 0.16 - 0.7) n = 20	**1** (< .009 - 4.3) n = 20	**< 5** (< 1.5 - < 29) n = 19
	SW-2	-	**46** (21 - 76) n = 20	-	-	-	-	**86** (< 25 - 360) n = 20	-	**< 1.8** (< 1.4 - 2.7) n = 20	-	**0.2** (< .08 - 1.2) n = 20	**< 0.2** (< 0.16 - < 1.6) n = 20	**1.3** (< .009 - 4.4) n = 20	**< 5** (< 1.5 - < 29) n = 19
1998-2000[6] Post-Reclamation MEDIAN[5]	SW-1	-	**44** (29 - 58) n = 8	-	-	-	-	**54** (< 25 - 85) n = 6	-	**< 2.4** (< 1.8 - < 3) n = 6	-	**< 0.12** (< .08 - < 0.15) n = 6	**< 0.31** (< 0.16 - 0.2) n = 6	**0.54** (< 0.61 - 1.1) n = 6	**< 3.6** (< 3.6 - < 18) n = 6
	SW-2	-	**48** (28 - 57) n = 8	-	-	-	-	**86** (57 - 160) n = 6	-	**< 3** < 1.8 - 4.3) n = 6	-	**< 0.15** (< .08 - 0.21) n = 6	**< 0.31** (< 0.16 - 0.23) n = 6	**0.8** (< 0.61 - 3.2) n = 6	**3.4** (< 3.6 - < 18) n = 6
2001-2012[7] Post-Reclamation MEDIAN[5]	SW-1	-	**46** (26 - 64) n = 22	-	-	-	-	-	-	-	-	-	-	-	-
	SW-2	-	**46** (25 - 60) n = 22	-	-	-	-	-	-	-	-	-	-	-	-
2013-16[7] Post-Reclamation MEDIAN[5]	SW-1	-	**37** (21 - 51) n = 7	-	-	-	-	-	-	-	-	-	-	-	-
	SW-2	-	**39** (22 - 52) n = 7	-	-	-	-	-	-	-	-	-	-	-	-
Oct 2017[8] Post-Reclamation	SW-1	-	**47**	-	-	-	-	-	-	-	-	-	-	-	-
	SW-2	-	**43**	-	-	-	-	-	-	-	-	-	-	-	-
Oct 2018[8] Post-Reclamation	SW-1	-	**29**	-	-	-	-	-	-	-	-	-	-	-	-
	SW-2	-	**29**	-	-	-	-	-	-	-	-	-	-	-	-

Sample Cell:

146 = **Median**
(109-179) = (range)
n = 12 = number of values
\- = no available data

Table 4. FMC Surface Water Quality Data: "Baseline" (1987-88), Historic, and Recently Reported Constituent Concentrations in Flambeau River (cont.)

Years	FMC Surface Water (SW) Sampling Station[1]	Cobalt (µg/l)	Copper (µg/l)	Iron (µg/l)	Lead (µg/l)	Manganese (µg/l)	Mercury (µg/l)	Molybdenum (µg/l)	Nickel (µg/l)	Selenium (µg/l)	Silver (µg/l)	Sulfur (mg/l)	Thallium (µg/l)	Uranium (µg/l)	Zinc (µg/l)
		No total or dissolved designation from FMC[3]													
1987-88[4] "Baseline" MEDIAN[5]	SW-Upstream	**< 50** (< 50 - < 50) n = 6	**< 10** (< 5 - 30) n = 9	**430** (200 - 510) n = 6	**< 5** (< 5 - < 5) n = 12	**< 50** (< 50 - 80) n = 5	**< 0.5** (< 0.5 - < 0.5) n = 12	**< 29** (< 29 - 67) n = 5	**10** (< 7 - < 30) n =11	**< 5** (< 5 - < 5) n = 12	**< 0.4** (< 0.4 - < 5) n = 11	**3.5** (3.1 - < 11) n = 11	**< 5** (< 5 - < 5) n = 6	**< 1** (< 1 - 11) n = 5	**< 50** (< 50 - 50) n = 12
	SW-Downstream	**< 50** (< 50 - < 50) n = 5	**< 10** (< 5 - 13) n = 8	**420** (160 - 540) n = 5	**< 5** (< 5 - < 5) n = 11	**< 50** (< 50 - 55) n = 4	**< 0.5** (< 0.5 - < 0.5) n = 11	**< 29** (< 29 - < 29) n = 4	**< 18** (< 7 - < 30) n = 10	**< 5** (< 5 - < 5) n = 11	**< 0.4** (< 0.4 - < 5) n = 10	**< 7** (2.9 - < 11) n = 10	**< 5** (< 5 - < 5) n = 5	**1** (< 1 - 9) n = 4	**< 50** (< 50 - 68) n = 11
1991-92[6] Pre-Production MEDIAN[5]	SW-1	-	**4** (< 3 - 5) n = 6	-	**< 1** (< 1 - < 3) n = 6	-	**< 0.2** (< 0.2 - < 0.2) n = 6	-	**< 20** (< 16 - < 50) n = 6	**< 2** (< 2 - < 2) n = 6	**< 0.5** (< 0.5 - < 2) n = 6	-	-	-	**10** (< 3 - 24) n = 6
	SW-2	-	**2** (< 2 - 4) n = 6	-	**1.1** (< 1 - 3) n = 6	-	**< 0.2** (< 0.2 - < 0.2) n = 6	-	**< 20** (< 16 - < 50) n = 6	**< 2** (< 2 - < 2) n = 6	**< 0.5** (< 0.5 - < 2) n = 6	-	-	-	**6** (< 3 - 20) n = 6
1993-97[6] Production Phase MEDIAN[5]	SW-1	-	**1.9** (< 1.7 - 7.8) n = 20	-	**1** (< 0.8 - 10) n = 20	-	**< .09** (< .05 - 0.7) n = 20	-	**2.8** (< 0.8 - < 20) n = 20	**< 2** (< 1.5 - 2.5) n = 20	**< 1.1** (< 0.5 - 1.6) n = 20	-	-	-	**< 12** (< 3 - 21) n = 20
	SW-2	-	**2.3** (< 1.7 - 11) n = 20	-	**1.2** (< 1 - 9.7) n = 20	-	**< .10** (< .05 - < 0.2) n = 20	-	**2.0** (< 0.75 - < 20) n = 20	**< 1.6** (< 1.5 - < 2) n = 20	**< 1.1** (< 0.5 - 1.8) n = 20	-	-	-	**8** (2 - 50) n = 20
1998-2000[6] Post-Reclamation MEDIAN[5]	SW-1	-	**0.8** (< 0.6 - 7.6) n = 8	**360** (340 - 480) n = 3	**< 2.2** (< 2 - < 2.4) n = 6	**56** (42 - 60) n = 3	**< .05** (< .05 - 0.33) n = 6	-	**< 1** (< 0.75 - 1.9) n = 6	**< 1.6** (< 1.6 - < 1.7) n = 6	**< 0.8** (< 0.47 - < 1.1) n = 6	-	-	-	**< 12** (< 12 - 43) n = 8
	SW-2	-	**< 1.4** (< 0.6 - 12) n = 8	**460** (340 - 540) n = 3	**< 2.4** (< 2 - 2.1) n = 6	**53** (38 - 89) n = 3	**< .05** (< .05 - 0.13) n = 6	-	**0.9** (< 0.75 - 3.7) n = 6	**< 1.6** (< 1.6 - 4) n = 6	**< 0.8** (< 0.47 - < 1.1) n = 6	-	-	-	**< 12** (< 12 - 89) n = 8
2001-2012[7] Post-Reclamation MEDIAN[5]	SW-1	-	**1.3** (< 0.29 - 4.4) n = 25	**490** (180 - 1900) n = 25	-	**65** (37 - 190) n = 25	-	-	-	-	-	-	-	-	**< 12** (2.2 - 28) n = 25
	SW-2	-	**0.9** (0.3 - 3.7) n = 25	**500** (170 - 1800) n = 25	-	**63** (36 - 180) n = 25	-	-	-	-	-	-	-	-	**6** (< 2 - 11) n = 25
2013-16[7] Post-Reclamation MEDIAN[5]	SW-1	-	**0.9** (< 0.7 - 1.4) n = 7	**570** (560 - 640) n = 3	-	-	-	-	-	-	-	-	-	-	**< 5** (< 3.1 - 5.8) n = 7
	SW-2	-	**1.0** (< 0.7 - 1.6) n = 7	**500** (420 - 580) n = 3	-	-	-	-	-	-	-	-	-	-	**< 5** (< 3.1 - 8) n = 7
Oct 2017[8] Post-Reclamation	SW-1	-	**< 1.1**	**740**	-	**101**	-	-	-	-	-	-	-	-	-
	SW-2	-	**< 1.1**	**660**	-	**94**	-	-	-	-	-	-	-	-	-
Oct 2018[8] Post-Reclamation	SW-1	-	**< 1.1**	**708**	-	**39**	-	-	-	-	-	-	-	-	**< 5**
	SW-2	-	**1.3**	**835**	-	**55**	-	-	-	-	-	-	-	-	**< 5**

Sample Cell:

146	=	**Median**
(109-179)	=	(range)
n = 12	=	number of values
-	=	no available data

Table 4. Footnotes

1. A comparison of diagrams from FMC's 1989 Environmental Impact Report (Foth, Apr 1989) and 1991 Updated Monitoring Plan (Foth, Jul 1991) shows that the locations of the company's upstream and downstream monitoring sites in the Flambeau River were changed by FMC after the 1987-88 baseline studies were completed, hampering determination of Flambeau Mine contributions. Most notably, the downstream sampling site currently used by the company (SW-2) is roughly 3 river-miles upstream of the original site used for baseline determinations. While now closer to the project site, SW-2 is still roughly 500 feet downstream of the backfilled pit and upstream of the discharge point of Stream C, a small Flambeau River tributary that crosses the FMC property and historically has been used as a conduit for conveying contaminated storm water runoff from the mine site to the Flambeau River. FMC has established no river sampling stations adjacent to or immediately downstream of the backfilled pit.	**5. Median determined by author.** When calculating the median, non-detection values (e.g., < 2 µg/l) were converted to values equal to half the level of detection. For example, < 2 µg/l converts to 1 µg/l. These values were inserted into a ranked list of values (smallest to largest). The mid-point value in the list was determined. If, in the present example, the mid-point value was 1 µg/l, the median was reported as < 2 µg/l. The same type of back-calculating was used to report the range. In this way, the reported median and range do not suggest actual concentrations were measured when, in reality, they were not. If there was an even number of values in the ranked list and one of the two middle values originally was a non-detection value, the two middle values were averaged and reported as a detected value.
2. Starting in 2010, the summary tables of "Historical Surface Water Results" that appear in FMC's annual reports fail to indicate if reported values for pH and specific conductance are "field" or "lab." Perusal of other FMC documents suggests the reported values are "field," although confirmation from the company would be helpful.	**6.** Source of raw data: 2000 Annual Report, FMC, Appendix B, Jan 2001.
3. The summary table of Flambeau River surface water quality data provided by FMC in their 1989 Environmental Impact Report, Table 3.7-5, does not indicate if the 1987-88 baseline concentrations were Total or Dissolved. Nor is there any such designation for later values reported in the summary tables of "Historical Surface Water Results" that appear in FMC's annual reports (1991+). Perusal of a limited number of original laboratory result sheets available in the public record suggests reported values are Totals, although confirmation from the company would be helpful.	**7.** Source of raw data: 2016 Annual Report, FMC, Appendix B, Attachment 3, Jan 2017.
4. Source of raw data: Environmental Impact Report for the Kennecott Flambeau Project, Foth, Section 3.7, Apr 1989.	**8. Editor's Note**: The October 2017 and October 2018 data were submitted by FMC to the Wisconsin DNR after Dr. Moran drafted his comments. The reported values are consistent with Dr. Moran's findings and were integrated into the present table as an update. Reported concentrations represent individual readings (not median values). Sources of raw data: 2017 Annual Report, FMC, Appendix B, Attachment 3, Jan 2018; and 2018 Annual Summary Memorandum, Foth, Attachment 3 to Attachment A, Jan 2019.

Table 5. Initial Flambeau Mine WPDES Permit Conditions for Treated (Outfall-001) and Untreated (Outfall 002) Discharges to Flambeau River[1]

Effluent Characteristic	Daily Maximum	Weekly Average Mass Limit	Duration of Sampling Requirement		Sample Type
			Outfall-001 (WWTP)	Outfall-002 (Settling Ponds)	
Flow (MGD)	-	-	Throughout Operation	Throughout Operation	Continuous
Total Suspended Solids	30 mg/l	-	Throughout Operation	Throughout Operation	Composite
Total Dissolved Solids	-	-	Throughout Operation	Sampling Not Required	Composite
Aluminum	1500 µg/l	-	First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
Arsenic	730 µg/l	-	First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
Beryllium	0.67 lb/day monthly average		First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
Cadmium	80 µg/l	0.046 lb/day	Throughout Operation	Throughout Operation	Composite
Chromium (Total or +3)	5400 µg/l	6.4 lb/day	First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
Chromium (+6)	28 µg/l	-	First 12 weeks of operation[2]	First 9 months of operation[2]	Grab
Copper	50 µg/l	-	Throughout Operation	Throughout Operation	Composite
Lead	590 µg/l	0.89 lb/day	Throughout Operation	Throughout Operation	Composite
Mercury	0.002 µg/l monthly average		Throughout Operation	Throughout Operation	Composite
Nickel	445 µg/l	1.0 lb/day	First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
Selenium	120 µg/l	-	First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
Silver	6.6 µg/l	-	First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
Sulfide	-	-	Throughout Operation	Sampling Not Required	Grab
Zinc	300 µg/l	-	First 12 weeks of operation[2]	First 9 months of operation[2]	Composite
pH	9.0 s.u.[3]	-	Throughout Operation	Throughout Operation	Continuous (Outfall-001); Grab (Outfall-002)
Hardness (mg/l as $CaCO_3$)	-	-	Throughout Operation	Throughout Operation	Composite
Acute Effluent Toxicity	-	-	Throughout Operation	Throughout Operation	-
Chronic Effluent Toxicity	-	-	Throughout Operation	Testing Not Required	-

[1] Information Source: State of Wisconsin Department of Natural Resources, WPDES Permit No. WI-0047376-1, Dec 22, 1992.

[2] If constituent is consistently not detected or is consistently detected at a concentration at or below the level of concern, no additional monitoring of the constituent is required.

[3] pH to be maintained at or within the limits of 6.0 - 9.0 s.u.

Table 6. FMC Ground Water Quality Data: "Baseline" (1987-88) and Recently Reported Constituent Concentrations in Downgradient Wells of Interest

(For well locations, see Figure 6 – Backfilled pit cross section, Figure 7 – Compliance Boundary, and Figure 8 – Shallow potentiometric surface map)

Description[1]				**pH (s.u.)**			**Specific Conductance (µS/cm)**			**Total Dissolved Solids (mg/l)**			**Sulfate (mg/l)**		
				No field or lab designation from FMC, except as noted[2]									**No total or dissolved designation from FMC, except as noted**[3]		
Monitoring Well (MW)	**Location**	**Depth (ft)**[4] **(Ground surface to tip of well screen)**	**Distance from Flambeau River (ft)**	**Median**[5]		**Recent Values: Oct 2016**[8] **June 2018**[9]	**Median**[5]		**Recent Values: Oct 2016**[8] **June 2018**[9]	**Median**[5]		**Recent Values: Oct 2016**[8] **June 2018**[9]	**Median**[5]		**Recent Values: Oct 2016**[8] **June 2018**[9]
				"Baseline" (1987-88)[6]	**Post-Reclamation (2014-16)**[7]		**"Baseline"**[6] **(1987-88)**	**Post-Reclamation (2014-16)**[7]		**"Baseline"**[6] **(1987-88)**	**Post-Reclamation (2014-16)**[7]		**"Baseline"**[6] **(1987-88)**	**Post-Reclamation (2014-2016)**[7]	
													Predicted concentration in contact ground water leaving backfilled pit: 1100 mg/l[10]		
MW-1000/ MW-1000R[11]	Between Mine Pit and River	MW-1000 19 MW-1000R 24	170	MW-1000 **6.0** (field) (5.5 - 6.6) n = 12	MW-1000R **6.1** (5.9 - 6.4) n = 12	MW-1000R **6.2** **6.2** (lab)	MW-1000 **96** (84 - 238) n = 12	MW-1000R **613** (415 - 918) n = 12	MW-1000R **659** **219** (lab)	MW-1000 **100** (33 - 250) n = 12	MW-1000R **445** (270 - 630) n = 12	MW-1000R **468** **144**	MW-1000 **14** (5 - 18) n = 12	MW-1000R **90** (51 - 280) n = 12	MW-1000R **90** **37** (D)
MW-1000P/ MW-1000PR[12]		MW-1000P 55 MW-1000PR 58	125	MW-1000P **6.2** (field) (5.8 - 6.6) n = 12	MW-1000PR **6.4** (6.1 - 6.8) n = 12	MW-1000PR **6.5** **6.7** (lab)	MW-1000P **224** (129 - 268) n = 12	MW-1000PR **796** (600 - 918) n = 12	MW-1000PR **777** **766** (lab)	MW-1000P **170** (130 - 350) n= 12	MW-1000PR **538** (514 - 580) n = 12	MW-1000PR **536** **512**	MW-1000P **18** (6 - 31) n = 12	MW-1000PR **190** (68 - 210) n = 12	MW-1000PR **149** **207** (D)
MW-1010P		115	125	**6.3** (field)[13,14] (5.2 - 7.4) n = 192 Detects: 100%	**7.5** (7.0 - 7.9) n = 12	**7.5** **7.7** (lab)	**236**[13,14] (84 - 954) n = 192 Detects: 100%	**350** (268 - 364) n = 12	**352** **364** (lab)	**190**[13,14] (14 - 1400) n = 193 Detects: 100%	**200** (140 - 220) n = 12	**212** **224**	**10**[13,14] (< 5 - 48) n = 193 Detects: 75%	**28** (20 - 30) n = 12	**30** **31** (D)
MW-1013	Backfilled Pit	22	600		**6.1** (5.9 - 6.2) n = 12	**6.1** **6.4** (lab)		**1116** (832 - 1293) n = 12	**1078** **1090** (lab)		**712** (680 - 770) n = 12	**692** **694**		**26** (5 - 31) n = 12	**17** **17** (D)
MW-1013A		44	600		**6.6** (6.4 - 6.9) n = 12	**6.6** **7.0** (lab)		**972** (677 - 1068) n = 12	**973** **892** (lab)		**628** (500 - 700) n = 12	**608** **590**		**184** (140 - 210) n = 12	**176** **149** (D)
MW-1013B		84	600		**6.2** (6.0 - 6.4) n = 12	**6.2** **6.8** (lab)		**3184** (2103 - 3456) n = 12	**3182** **3130** (lab)		**3110** (2900 - 3200) n = 12	**3080** **3080**		**1600** (1500 - 1730) n = 12	**1730** **1730** (D)
MW-1013C		198	600		**6.4** (6.2 - 6.6) n = 12	**6.4** **7.1** (lab)		**3116** (1820 - 3463) n = 12	**3130** **3060** (lab)		**2900** (2830 - 3000) n = 12	**2890** **2850**		**1520** (1480 - 1600) n = 12	**1600** **1880** (D)
MW-1014		31	2300		**6.3** (6.0 - 6.8) n= 12	**6.4** **6.8** (lab)		**677** (600 - 739) n = 12	**699** **700** (lab)		**439** (320 - 500) n = 12	**478** **490**		**110** (98 - 140) n = 12	**117** **134** (D)
MW-1014A		61	2300		**6.5** (6.4 - 6.7) n = 12	**6.6** **7.0** (lab)		**2198** (2030 - 2429) n = 12	**2188** **2130** (lab)		**1800** (1770 - 1900) n = 12	**1820** **1820**		**930** (900 - 970) n = 12	**961** **925** (D)
MW-1014B		102	2300		**6.3** (6.0 - 6.5) n = 12	**6.4** **6.7** (lab)		**2790** (2441 - 3004) n = 12	**2685** **2710** (lab)		**2540** (2400 - 2700) n = 12	**2530** **2500**		**1300** (1200 - 1400) n = 12	**1380** **1490** (D)
MW-1014C		154	2300		**6.6** (6.4 - 6.8) n = 12	**6.6** **7.0** (lab)		**1025** (947 - 1156) n = 12	**1023** **996** (lab)		**680** (610 - 714) n = 12	**700** **672**		**210** (200 - 215) n = 12	**213** **252** (D)
MW-1015A	Near Compliance Boundary	63	280		**7.0** (6.8 - 7.3) n = 12	**6.9** **7.3** (lab)		**190** (178 - 193) n = 12	**191** **193** (lab)		**120** (66 - 132) n = 12	**128** **128**		**8** (7 - 9) n = 12	**7** **8** (D)
MW-1015B		148	280		**7.6** (7.4 - 8.0) n = 12	**7.6** **7.9** (lab)		**576** (421 - 621) n = 12	**606** **587** (lab)		**287** (240 - 330) n = 12	**296** **304**		**< 2.5** (< 1 - 3.4) n = 12	**< 1** **< 1** (D)

Sample Cell:

1600 = **Median**
(1500 - 1730) = (range)
n = 12 = number of values
\- = no available data

Table 6. FMC Ground Water Quality Data: “Baseline” (1987-88) and Recently Reported Constituent Concentrations in Downgradient Wells of Interest (cont.)

	Chloride (mg/l)			Fluoride (mg/l)[15]			Nitrate + Nitrite Nitrogen (mg/l) [15]			Alkalinity, tot (mg/l) (as CaCO3)			Hardness, calc (mg/l) (as CaCO3)		
	No total or dissolved designation from FMC, except as noted [3]														
Monitoring Well (MW)	**Median [5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median [5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median [5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median [5]**		**Recent Values: Oct 2016 [8] June 2018 [9]**	**Median [5]**		**Recent Values: Oct 2016 [8] June 2018 [9]**
	“Baseline”[6] (1987-88)	**Post-Reclamation (2005-16)[7]**		**“Baseline” [6] (1987-88)**	**Post-Reclamation (2005-16) [7]**		**“Baseline” [6] (1987-88)**	**Post-Reclamation (2005-16) [7]**		**“Baseline” [6] (1987-88)**	**Post-Reclamation (2014-16) [7]**		**“Baseline” [6] (1987-88)**	**Post-Reclamation (2014-16) [7]**	
MW-1000/ MW-1000R[11]	MW-1000 **< 2** (< 1 - 10) n = 12	MW-1000R **6** (4 - 25) n = 6	MW-1000R **22** **8** (D)	MW-1000 **< 0.15** (< 0.1 - 0.2) n = 12	MW-1000R **-**	MW-1000R **-** **-**	MW-1000 **0.28** (0.21 - 0.32) n = 12	MW-1000R **-**	MW-1000R **-** **-**	MW-1000 **30** (18 - 43) n = 12	MW-1000R **200** (100 - 420) n = 12	MW-1000R **218** **72**	MW-1000 **40** (30 - 63) n = 12	MW-1000R **308** (200 - 440) n= 12	MW-1000R **329** **71**
MW-1000P/ MW-1000PR[12]	MW-1000P **1** (< 1 - 3) n = 12	MW-1000PR **19** (14 - 26) n = 12	MW-1000PR **14** **14** (D)	MW-1000P **0.2 mg/l** (< 0.1 - <0.8) n = 12	MW-1000PR **-**	MW-1000PR **-** **-**	MW-1000P **.05** (< .05 - 0.13) n = 12	MW-1000PR **-**	MW-1000PR **-** **-**	MW-1000P **96** (81 - 120) n = 12	MW-1000PR **220** (200 - 230) n = 12	MW-1000PR **221** **217**	MW-1000P **91** (63 - 150) n = 12	MW-1000PR **410** (390 - 459) n = 12	MW-1000PR **427** **384**
MW-1010P	**2** [13,14] (< 1 - 230) n = 193 Detects: 61%	**5.2** (3.9 - 6.1) n = 11	**6** **5** (D)	**0.2** [13,14] (< 0.1 - <5) n = 193 Detects: 65%	**-**	**-** **-**	**0.16** [13,14] (< .05 - 2.9) n = 193 Detects: 68%	**-**	**-** **-**	**85** [13,14] (14 - 340) n = 193 Detects: 100%	**153** (150 - 161) n = 12	**153** **160**	**92** [13,14] (2 - 1137) n = 193 Detects: 100%	**174** (167 - 192) n = 12	**192** **179**
MW-1013		**15** (11 - 18) n = 11	**13** **9** (D)		**-**	**-** **-**		**-**	**-** **-**		**606** (579 - 660) n = 12	**579** **563**		**580** (542 - 608) n = 12	**594** **574**
MW-1013A		**7** (6 - 14) n = 11	**7** **8** (D)		**-**	**-** **-**		**-**	**-** **-**		**345** (320 - 369) n = 12	**366** **340**		**464** (450 - 559) n = 12	**451** **450**
MW-1013B		**48** (< 50 - 76) n = 12	**36** **39** (D)		**-**	**-** **-**		**-**	**-** **-**		**560** (523 - 618) n = 12	**530** **589**		**2150** (2000 - 2350) n = 12	**2310** **1990**
MW-1013C		**63** (53 - 91) n = 12	**68** **50** (D)		**-**	**-** **-**		**-**	**-** **-**		**505** (480 - 580) n = 12	**483** **516**		**2060** (1940 - 2200) n = 12	**2090** **1840**
MW-1014		**30** (24 - 41) n = 12	**40** **52** (D)		**-**	**-** **-**		**-**	**-** **-**		**173** (140 - 200) n = 12	**179** **170**		**294** (270 - 341) n = 12	**339** **314**
MW-1014A		**< 25** (< 18 - < 50) n = 12	**10** **13** (D)		**-**	**-** **-**		**-**	**-** **-**		**472** (430 - 556) n = 12	**474** **483**		**1300** (1200 - 1470) n = 12	**1450** **1290**
MW-1014B		**54** (42 - 64) n = 11	**64** **47** (D)		**-**	**-** **-**		**-**	**-** **-**		**485** (466 - 555) n = 12	**466** **517**		**1800** (1700 - 2000) n = 12	**1710** **1730**
MW-1014C		**47** (35 - 64) n = 12	**64** **51** (D)		**-**	**-** **-**		**-**	**-** **-**		**271** (250 - 283) n = 12	**276** **272**		**521** (490 - 586) n = 12	**564** **534**
MW-1015A		**6** (6 - 8) n = 11	**6** **7** (D)		**-**	**-** **-**		**-**	**-** **-**		**79** (75 - 84) n = 12	**80** **84**		**88** (83 - 96) n = 12	**94** **90**
MW-1015B		**75** (58 - 87) n = 11	**75** **90** (D)		**-**	**-** **-**		**-**	**-** **-**		**180** (170 - 189) n = 12	**178** **173**		**150** (140 - 167) n = 12	**167** **147**

Sample Cell:

1600	=	**Median**
(1500 - 1730)	=	(range)
n = 12	=	number of values
-	=	no available data

Table 6. FMC Ground Water Quality Data: "Baseline" (1987-88) and Recently Reported Constituent Concentrations in Downgradient Wells of Interest (cont.)

	Redox (mV)			Chemical Oxygen Demand[15] (mg/l)			Calcium (mg/l)			Magnesium (mg/l)			Potassium (mg/l)		
							No total or dissolved designation from FMC, except as noted[3]								
Monitoring Well (MW)	**Median[5]**		**Recent Values: Oct 2016[8] June 2018[9]**	**Median[5]**		**Recent Values: June 2016[8] June 2018[9]**	**Median[5]**		**Recent Values: June 2016[8] June 2018[9]**	**Median[5]**		**Recent Values: June 2016[8] June 2018[9]**	**Median[5]**		**Recent Values: June 2016[8] June 2018[9]**
	"Baseline"[6] (1987-88)	**Post-Reclamation (2014-16)[7]**		**"Baseline"[6] (1987-88)**	**Post-Reclamation (2005-16)[7]**		**"Baseline"[6] (1987-88)**	**Post-Reclamation (2005-16)[7]**		**"Baseline"[6] (1987-88)**	**Post-Reclamation (2005-16)[7]**		**"Baseline"[6] (1987-88)**	**Post-Reclamation (2005-16)[7]**	
MW-1000/ MW-1000R[11]	MW-1000 -	MW-1000R **136** (64 - 368) n = 11	MW-1000R **146** -	MW-1000 **8** (< 5 - 18) n = 12	MW-1000R -	MW-1000R - -	MW-1000 **9.8** (8.2 - 13) n = 12	MW-1000R **67** (30 - 120) n =6	MW-1000R **65** **20** (D)	MW-1000 **2.8** (2.4 - 3.5) n = 12	MW-1000R **20** (8 - 35) n = 6	MW-1000R **20** **5** (D)	MW-1000 -	MW-1000R **1.0** (0.6 - 1.6) n = 6	MW-1000R **1.1** **0.5** (D)
MW-1000P/ MW-1000PR[12]	MW-1000P -	MW-1000PR **109** (-12 - 151) n = 11	MW-1000PR **124** -	MW-1000P **10** (< 5 - 85) n = 12	MW-1000PR -	MW-1000PR - -	MW-1000P **22** (19 - 25) n = 12	MW-1000PR **130** (110 - 160) n = 13	MW-1000PR **111** **107** (D)	MW-1000P **7.1** (5.4 - 9.9) n = 12	MW-1000PR **34** (28 - 40) n = 13	MW-1000PR **29** **28** (D)	MW-1000P -	MW-1000PR **3.7** (3.1 - 4.2) n = 11	MW-1000PR **3.2** **3.0** (D)
MW-1010P	-	**122** (58 - 228) n = 11	**122** -	**10**[13,14] (< 5 - 90) n = 193 Detects: 67%	-	- -	**23**[13,14] (8 - 95) n = 193 Detects: 100%	**46** (40 - 50) n = 12	**46** **49** (D)	**8.5**[13,14] (2.4 - 41) n = 193 Detects: 100%	**12** (11 - 14) n = 12	**13** **13** (D)	-	**2.6** (2.4 - 2.9) n = 11	**2.6** **2.6** (D)
MW-1013		**75** (35 - 127) n = 11	**55** -		-	- -		**150** (140 - 170) n = 11	**146** **150** (D)		**45** (42 - 51) n = 11	**46** **48** (D)		**3.1** (2.6 - 3.6) n = 11	**3.0** **2.6** (D)
MW-1013A		**68** (37 - 112) n = 11	**44** -		-	- -		**120** (110 - 160) n = 11	**130** **115** (D)		**43** (37 - 53) n = 11	**45** **40** (D)		**7.3** (6.4 - 8.1) n = 11	**7.1** **7.0** (D)
MW-1013B		**142** (123 - 289) n = 11	**141** -		-	- -		**630** (590 - 690) n = 13	**608** **572** (D)		**150** (130 - 150) n = 13	**138** **136** (D)		**6.4** (3.6 - 8.6) n = 11	**5.7** **5.0** (D)
MW-1013C		**59** (19 - 157) n = 11	**72** -		-	- -		**600** (550 - 630) n = 13	**561** **530** (D)		**170** (130 - 190) n = 13	**130** **125** (D)		**25** (20 - 32) n = 11	**22.1** **21.2** (D)
MW-1014		**129** (92 - 185) n = 11	**153** -		-	- -		**78** (70 - 91) n = 12	**78** **82** (D)		**26** (22 - 28) n = 12	**26** **26** (D)		**3.5** (2.9 - 3.8) n = 11	**3.2** **3.3** (D)
MW-1014A		**142** (111 - 174) n = 11	**164** -		-	- -		**330** (300 - 350) n= 13	**333** **330** (D)		**120** (110 - 130) n = 13	**115** **113** (D)		**10** (6.3 - 13) n = 11	**9.8** **9.4** (D)
MW-1014B		**156** (124 - 200) n = 11	**180** -		-	- -		**520** (470 - 610) n = 13	**497** **512** (D)		**130** (111 - 150) n =13	**111** **109** (D)		**19** (12 - 25) n = 11	**15.7** **14.4** (D)
MW-1014C		**46** (24 - 72) n = 11	**72** -		-	- -		**150** (140 - 190) n = 13	**150** **155** (D)		**38** (34 - 43) n = 13	**36** **36** (D)		**5.2** (3.6 - 5.6) n = 11	**4.6** **4.4** (D)
MW-1015A		**131** (44 - 207) n = 11	**131** -		-	- -		**21** (19 - 23) n = 12	**21** **21** (D)		**8** (8 - 10) n = 12	**9** **9** (D)		**0.7** (0.7 - 0.8) n = 11	**0.7** **0.7** (D)
MW-1015B		**13** (-90 - 152) n = 11	**101** -		-	- -		**36** (32 - 38) n = 12	**37** **34** (D)		**15** (14 - 17) n = 12	**16** **15** (D)		**6.8** (6.1 - 7.4) n = 11	**6.8** **6.2** (D)

Sample Cell:

1600	**=**	**Median**
(1500 - 1730)	=	(range)
n = 12	=	number of values
-	=	no available data

Table 6. FMC Ground Water Quality Data: “Baseline” (1987-88) and Recently Reported Constituent Concentrations in Downgradient Wells of Interest (cont.)

	Sodium (mg/l)			Aluminum (µg/l)[15,16]			Arsenic (µg/l)			Barium (µg/l)			Beryllium (µg/l)[15,16]		
	No total or dissolved designation from FMC, except as noted [3]														
Monitoring Well (MW)	Median[5]		Recent Values: June 2016 [8] June 2018 [9]	Median[5]		Recent Values: June 2016 [8] June 2018 [9]	Median[5]		Recent Values: Oct 2016 [8] June 2018 [9]	Median[5]		Recent Values: June 2016 [8] June 2018 [9]	Median[5]		Recent Values: June 2016 [8] June 2018 [9]
	“Baseline” [6] (1987-88)	Post-Reclamation (2005-16) [7]		“Baseline” [6,16] (1987-88)	Post-Reclamation (2005-16) [7]		“Baseline” [6] (1987-88)	Post-Reclamation (2014-16) [7]		“Baseline” [6] (1987-88)	Post-Reclamation (2005-16) [7]		“Baseline” [6,16] (1987-88)	Post-Reclamation (2005-16) [7]	
MW-1000/ MW-1000R[11]	MW-1000 **4.5** (3.6 - 6.1) n = 12	MW-1000R **8** (4 - 10) n = 5	MW-1000R **8** **4** (D)	MW-1000 **70** (42 - 337) n = 4	MW-1000R **-**	MW-1000R **-** **< 59** (D)	MW-1000 **< 5** (< 5 - < 5) n = 12	MW-1000R **0.27** (< -0.5 - 0.53) n = 12	MW-1000R **0.32** **< 0.28** (D)	MW-1000 **< 500** (< 500 - < 1000) n = 12	MW-1000R **26** (16 - 34) n = 6	MW-1000R **26** **25** (D)	MW-1000 **< 1** (< 1 - 1) n = 4	MW-1000R **-**	MW-1000R **-** **-**
MW-1000P/ MW-1000PR[12]	MW-1000P **15** (11 - 24) n = 12	MW-1000PR **8** (7 - 10) n = 10	MW-1000PR **8** **7** (D)	MW-1000P **104** (86 - 158) n = 4	MW-1000PR **-**	MW-1000PR **-** **170** (D)	MW-1000P **< 5** (< 5 - < 5) n = 12	MW-1000PR **6.3** (2.8 - 14.4) n = 12	MW-1000PR **8.9** **20.3** (D)	MW-1000P **< 500** (< 500 - < 1000) n = 12	MW-1000PR **39** (32 - 44) n = 13	MW-1000PR **32** **94** (D)	MW-1000P **< 1** (< 1 - < 1) n = 4	MW-1000PR **-**	MW-1000PR **-** **-**
MW-1010P	**7.8** [13,14] (1.2 - 33) n = 193 Detects: 100%	**4.5** (4.1 - 5.3) n = 10	**4** **4** (D)	**82** [13,14] (34 - 337) n = 62 Detects: 100%	**-**	**-** **< 59** (D)	**< 5** [13,14] (< 5 - 21) n = 192 Detects: 3%	**21** (18 - 25) n = 12	**19** **25** (D)	**< 500** [13,14] (< 500 - < 1000) n = 193 Detects: 0%	**44** (40 - 48) n = 12	**40** **46** (D)	**< 1** [13,14] (< 1 - 1) n = 62 Detects: 2%	**-**	**-** **-**
MW-1013		**16** (13 - 20) n= 10	**14** **13** (D)		**-**	**-** **< 59** (D)		**< 1** (0.49 - 1.1) n = 12	**0.79** **0.81** (D)		**140** (124 - 160) n = 11	**124** **158** (D)		**-**	**-** **-**
MW-1013A		**30** (19 - 35) n = 10	**31** **31** (D)		**-**	**-** **< 59** (D)		**< 1** (0.15 - < 1) n = 12	**0.15** **< 0.28** (D)		**81** (72 - 99) n = 11	**79** **84** (D)		**-**	**-** **-**
MW-1013B		**28** (19 - 35) n = 10	**25** **24** (D)		**-**	**-** **< 59** (D)		**0.7** (< 1 - < 5) n = 12	**0.61** **0.66** (D)		**< 25** (< 25 - 20) n = 13	**14** **17** (D)		**-**	**-** **-**
MW-1013C		**33** (27 - 43) n = 10	**27** **26** (D)		**-**	**-** **< 59** (D)		**21** (19 - 26) n = 12	**21.0** **19.2** (D)		**17** (< 25 - 27) n = 13	**17** **18** (D)		**-**	**-** **-**
MW-1014		**16** (9 - 23) n= 10	**13** **18** (D)		**-**	**-** **< 59** (D)		**< 1** (< 0.1 - < 1) n = 12	**0.22** **< 0.28** (D)		**40** (< 25 - 68) n = 12	**33** **42** (D)		**-**	**-** **-**
MW-1014A		**57** (40 - 63) n= 10	**46** **40** (D)		**-**	**-** **< 59** (D)		**0.5** (0.36 - < 5) n = 12	**0.51** **0.59** (D)		**< 25** (< 25 - 17) n = 13	**13** **14** (D)		**-**	**-** **-**
MW-1014B		**25** (18 - 31) n = 10	**20** **18** (D)		**-**	**-** **< 59** (D)		**0.9** (< 1 - < 5) n = 12	**0.85** **0.99** (D)		**< 25** (< 25 - 31) n = 13	**22** **22** (D)		**-**	**-** **-**
MW-1014C		**10** (8 - 12) n = 10	**10** **10** (D)		**-**	**-** **< 59** (D)		**23** (21 - 26) n = 12	**24.5** **25.4** (D)		**29** (< 25 - 35) n = 13	**30** **32** (D)		**-**	**-** **-**
MW-1015A		**3.4** (3.1 - 3.7) n = 10	**3.4** **3.3** (D)		**-**	**-** **< 59** (D)		**< 0.5** (< 0.1 - < 0.5) n = 12	**< 0.1** **< 0.28** (D)		**8.5** (7.4 - 8.9) n = 12	**7** **8** (D)		**-**	**-** **-**
MW-1015B		**54** (44 - 64) n= 10	**59** **63** (D)		**-**	**-** **< 59** (D)		**< 0.5** (< 0.1 - 0.57) n = 12	**0.1** **< 0.28** (D)		**44** (40 - 50) n = 12	**43** **46** (D)		**-**	**-** **-**

Sample Cell:

1600	=	**Median**
(1500 - 1730)	=	(range)
n = 12	=	number of values
-	=	no available data

Table 6. FMC Ground Water Quality Data: "Baseline" (1987-88) and Recently Reported Constituent Concentrations in Downgradient Wells of Interest (cont.)

	Cadmium (µg/l)			Chromium (µg/l)			Cobalt (µg/l)[15,16]			Copper (µg/l)			Iron (µg/l)		
	No total or dissolved designation from FMC, except as noted [3]														
Monitoring Well (MW)	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: Oct 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: Oct 2016 [8] June 2018 [9]**
	"Baseline" [6] (1987-88)	**Post-Reclamation (2005-16) [7]**		**"Baseline" [6] (1987-88)**	**Post-Reclamation (2005-16) [7]**		**"Baseline" [6,16] (1987-88)**	**Post-Reclamation (2005-16) [7]**		**"Baseline" [6] (1987-88)**	**Post-Reclamation (2014-16) [7]**		**"Baseline" [6] (1987-88)**	**Post-Reclamation (2014-16) [7]**	
										Predicted concentration in contact ground water leaving backfilled pit: 14 µg/l [10]			**Predicted concentration in contact ground water leaving backfilled pit: 320 µg/l [10]**		
MW-1000/ MW-1000R[11]	MW-1000 **0.8** (< 0.3 - 3.6) n = 12	MW-1000R **< 0.13** (< .09 - 0.11) n = 6	MW-1000R **< .09** **0.17** (D)	MW-1000 **< 5** (< 5 - < 5) n = 12	MW-1000R **0.53** (< 0.18 - 0.71) n = 6	MW-1000R **0.52** **< 1.0** (D)	MW-1000 **< 50** (< 50 - < 50) n= 4	MW-1000R **-**	MW-1000R **-** **-**	MW-1000 **22** (< 5 - 46) n = 12	MW-1000R **74** (26 - 140) n = 12	MW-1000R **94** **12** (D)	MW-1000 **< 100** (< 100 - 200) n = 12	MW-1000R **< 18** (< 10 - 20) n = 12	MW-1000R **20** **< 111** (D)
MW-1000P/ MW-1000PR[12]	MW-1000P **3.8** (< 1 - 19) n = 12	MW-1000PR **< 0.17** (< 0.1 - 0.66) n = 13	MW-1000PR **0.17** **0.71** (D)	MW-1000P **< 5** (< 5 - < 5) n = 12	MW-1000PR **0.57** (< 0.18 - 1.5) n = 13	MW-1000PR **0.61** **5.7** (D)	MW-1000P **< 50** (< 50 - < 50) n= 4	MW-1000PR **-**	MW-1000PR **-** **-**	MW-1000P **45** (< 10 - 85) n = 12	MW-1000PR **4.3** (< 0.26 - 15) n = 12	MW-1000PR **3.9** **35** (D)	MW-1000P **80** (< 100 - 450) n = 12	MW-1000PR **780** (250 - 3780) n = 12	MW-1000PR **842** **3070** (D)
MW-1010P	**1.1** [13,14] (< 0.1 - 24) n = 193 Detects: 73%	**< 0.17** (< .09 - < 0.26) n = 12	**< .09** **< .08** (D)	**< 5** [13,14] (< 5 - < 5) n = 193 Detects: 0%	**< 0.5** (< 0.18 - < 1.3) n = 12	**< 0.39** **< 1.0** (D)	**< 50** [13,14] (< 50 - < 50) n = 62 Detects: 0%	**-**	**-** **-**	**< 10** [13,14] n = 193 (< 5 - 85) Detects: 39%	**< 1** (< 0.26 - 0.61) n = 12	**0.6** **< 1.1** (D)	**< 100** [13,14] (< 60 - 21,000) n = 193 Detects: 46%	**< 18** (< 10 - 52) n = 12	**52** **< 111** (D)
MW-1013		**< 0.12** (< .09 - < 1.7) n = 11	**< .09** **< .08** (D)		**2.9** (< 0.67 - < 11) n = 11	**1.1** **3.5** (D)		**-**	**-** **-**		**12** (4.6 - 25) n = 12	**7.5** **16.3** (D)		**3740** (1100 - 13,000) n = 12	**7820** **13,800** (D)
MW-1013A		**< 0.12** (< .09 - < 1.7) n = 11	**< .09** **0.12** (D)		**< 0.67** (< 0.39 - < 11) n = 11	**< 0.39** **< 1.0** (D)		**-**	**-** **-**		**< 1** (< 0.26 - 3.8) n = 12	**0.3** **< 1.1** (D)		**86** (34 - 250) n = 12	**139** **< 111** (D)
MW-1013B		**< 1.7** (< 0.6 - 1.9) n = 13	**0.80** **0.74** (D)		**< 4.5** (< 0.67 - 8.3) n = 13	**1.4** **2.1** (D)		**-**	**-** **-**		**503** (380 - 610) n = 12	**494** **437** (D)		**60** (36 - 120) n = 12	**53** **210** (D)
MW-1013C		**< 1.7** (< .09 - 1.8) n = 13	**< .09** **< .08** (D)		**< 10** (< 0.39 - 32) n = 13	**< 0.39** **< 1.0** (D)		**-**	**-** **-**		**< 1** (< 0.26 - < 5) n = 12	**0.4** **29.6** (D)		**14,000** (12,700 - 14,700) n = 12	**14,200** **12,800** (D)
MW-1014		**0.24** (< 0.12 - < 1.7) n = 12	**0.10** **< 0.08** (D)		**0.42** (< 0.5 - < 11) n = 12	**0.4** **< 1.0** (D)		**-**	**-** **-**		**5.4** (4.5 - 10) n = 12	**5.0** **3.8** (D)		**< 18** (< 10 - 94) n = 12	**37** **< 111** (D)
MW-1014A		**< 1.7** (< .09 - < 1.7) n = 13	**< .09** **< .08** (D)		**< 10** (< 0.67 - 8.1) n =13	**0.59** **< 1.0** (D)		**-**	**-** **-**		**4.6** (2.4 - 7.5) n = 12	**5.1** **2.6** (D)		**14** (< 10 - 60) n = 12	**23** **< 111** (D)
MW-1014B		**2.2** (< 1.7 - 12) n = 13	**1.9** **1.9** (D)		**< 10** (< 0.67 - 35) n = 13	**0.47** **< 1.0** (D)		**-**	**-** **-**		**470** (372 - 520) n = 12	**442** **392** (D)		**< 18** (< 10 - < 90) n = 12	**26** **< 111** (D)
MW-1014C		**< 1.7** (< .09 - 4.7) n = 13	**< .09** **< .08** (D)		**< 4.5** (< 0.39 - < 11) n = 13	**< 0.39** **< 1.0** (D)		**-**	**-** **-**		**< 1** (<0.26 - 1.2) n = 12	**0.4** **< 1.1** (D)		**4900** (4520 - 5100) n = 12	**4780** **4850** (D)
MW-1015A		**< 0.17** (< .09 - 0.29) n = 12	**< .09** **< .08** (D)		**< 0.36** (< 0.18 - < 1.3) n = 12	**0.52** **< 1.0** (D)		**-**	**-** **-**		**< 1** (< 0.26 - 0.91) n = 12	**0.4** **< 1.1** (D)		**< 18** (< 10 - 110) n = 12	**16** **< 111** (D)
MW-1015B		**< 0.14** (< .09 - <0.17) n = 12	**< .09** **.09** (D)		**< 0.72** (< 0.18 - 1.4) n = 12	**0.53** **< 1.0** (D)		**-**	**-** **-**		**< 1** (< 0.26 - < 1) n = 12	**< 0.3** **< 1.1** (D)		**181** (31 - 220) n = 12	**213** **< 111** (D)

Sample Cell:

1600 = **Median**
(1500 - 1730) = (range)
n = 12 = number of values
\- = no available data

Table 6. FMC Ground Water Quality Data: "Baseline" (1987-88) and Recently Reported Constituent Concentrations in Downgradient Wells of Interest (cont.)

Monitoring Well (MW)	Lead (µg/l)			Manganese (µg/l)			Mercury (µg/l)			Molybdenum (µg/l)[15,16]			Nickel (µg/l)[15,16]		
	No total or dissolved designation from FMC, except as noted [3]														
	Median[5]		Recent Values: June 2016 [8] June 2018 [9]	Median[5]		Recent Values: Oct 2016 [8] June 2018 [9]	Median[5]		Recent Values: June 2016 [8] June 2018 [9]	Median[5]		Recent Values: June 2016 [8] June 2018 [9]	Median[5]		Recent Values: June 2016 [8] June 2018 [9]
	"Baseline" [6] (1987-88)	Post-Reclamation (2005-16)[7]		"Baseline" [6] (1987-88)	Post-Reclamation (2014-16)[7]		"Baseline" [6] (1987-88)	Post-Reclamation (2005-16)[7]		"Baseline" [6,16] (1987-88)	Post-Reclamation (2005-16)[7]		"Baseline" [6,16] (1987-88)	Post-Reclamation (2005-16)[7]	
				Predicted concentration in contact ground water leaving backfilled pit: 550 µg/l [10]											
MW-1000/ MW-1000R[11]	MW-1000 < 5 (< 5 - < 5) n = 12	MW-1000R < 0.4 (< 0.04 - 2.2) n = 6	MW-1000R < .04 < 0.20 (D)	MW-1000 < 50 (< 50 - 110) n = 12	MW-1000R 9490 (720 - 15,000) n = 12	MW-1000R 13,800 70 (D)	MW-1000 < 0.5 (< 0.5 - < 0.5) n = 12	MW-1000R < .025 (< .013 - .022) n = 6	MW-1000R < 0.13 < 0.12 (D)	MW-1000 < 29 (< 29 - 30) n = 4	MW-1000R -	MW-1000R - -	MW-1000 < 30 (< 7 - 39) n = 9	MW-1000R -	MW-1000R - -
MW-1000P/ MW-1000PR[12]	MW-1000P < 5 (< 5 - < 5) n = 12	MW-1000PR < 1.3 (< 0.1 - 3.6) n = 13	MW-1000PR .07 0.89 (D)	MW-1000P 620 (260 - 750) n = 12	MW-1000PR 2100 (1800 - 2340) n = 12	MW-1000PR 2340 1870 (D)	MW-1000P < 0.5 (< 0.5 - < 0.5) n = 12	MW-1000PR < .025 (< .025 - .064) n = 13	MW-1000PR < 0.13 < 0.12 (D)	MW-1000P 27 (< 29 - 56) n = 4	MW-1000PR -	MW-1000PR - -	MW-1000P < 30 (< 7 - 20) n = 9	MW-1000PR -	MW-1000PR - -
MW-1010P	< 5 [13,14] n = 193 (<5 - < 5) Detects: 0%	< 1.3 (< .04 - 2.9) n = 12	< .04 < 0.20 (D)	230 [13,14] (< 50 - 1400) n = 193 Detects: 72%	49 (22 - 83) n = 12	61 58 (D)	< 0.5 [13,14] (< 0.5 - 2.4) n = 193 Detects: 1%	< .025 (< .025 - < 0.13) n = 12	< 0.13 < 0.12 (D)	< 29 [13,14] (< 29 - 78) n = 62 Detects: 35%	-	- -	< 30 [13,14] < 7 - 67) n = 141 Detects: 28%	-	- -
MW-1013		5.3 (< .04 - 23) n = 11	< .04 0.40 (D)		26,100 (24,300 - 30,300) n = 12	27,000 26,400 (D)		< .025 (< .025 - <0.13) n = 11	< 0.13 < 0.12 (D)		-	- -		-	- -
MW-1013A		2.3 (< .04 - <13) n = 11	< .04 < 0.20 (D)		4200 (1700 - 5350) n = 12	5350 3480 (D)		< .025 (< .025 - < 0.13) n = 11	< 0.13 < 0.12 (D)		-	- -		-	- -
MW-1013B		< 13 (< .04 - 28) n = 13	< .04 < 0.20 (D)		33,500 (25,000 - 41,000) n = 12	30,400 24,800 (D)		< .025 (< .025 - 0.13) n = 13	< 0.13 < 0.12 (D)		-	- -		-	- -
MW-1013C		< 13 (.08 - 15) n = 13	.08 0.73 (D)		9650 (8830 - 11,000) n = 12	10,100 9790 (D)		< .025 (< .025 - < 0.13) n = 13	< 0.13 0.16 (D)		-	- -		-	- -
MW-1014		2.1 (< .04 - < 13) n = 12	< .04 < 0.20 (D)		1200 (455 - 1900) n = 12	1270 809 (D)		< .025 (< .025 - < 0.13) n = 12	< 0.13 < 0.12 (D)		-	- -		-	- -
MW-1014A		< 13 (< .04 - 13) n = 13	< .04 < 0.20 (D)		214 (36 - 528) n = 12	292 97 (D)		< .025 (< .025 - < 0.13) n = 13	< 0.13 < 0.12 (D)		-	- -		-	- -
MW-1014B		< 10 (.07 - 160) n = 13	.07 < 0.20 (D)		11,100 (9010 - 12,000) n = 12	9760 10,100 (D)		< .025 (< .025 - < 0.13) n = 13	< 0.13 0.14 (D)		-	- -		-	- -
MW-1014C		< 10 (< .04 - 20) n = 13	< .04 < 0.20 (D)		1700 (1460 - 1860) n = 12	1860 1650 (D)		< .025 (< .025 - < 0.13) n = 13	< 0.13 < 0.12 (D)		-	- -		-	- -
MW-1015A		< 1.3 (< .04 - 2.1) n = 12	< .04 < 0.20 (D)		6 (4 - 17) n = 12	5 13 (D)		< .025 (< .025 - < 0.13) n = 12	< 0.13 < 0.12 (D)		-	- -		-	- -
MW-1015B		< 1.3 (< .04 - 3.7) n = 12	< .04 < 0.20 (D)		47 (34 - 61) n = 12	46 38 (D)		< .025 (< .025 - < 0.13) n = 12	< 0.13 < 0.12 (D)		-	- -		-	- -

Sample Cell:

1600 = Median
(1500 - 1730) = (range)
n = 12 = number of values
\- = no available data

Table 6. FMC Ground Water Quality Data: “Baseline” (1987-88) and Recently Reported Constituent Concentrations in Downgradient Wells of Interest (cont.)

	Selenium (µg/l)			Silver (µg/l)			Thallium (µg/l)[15,16]			Uranium (µg/l)[15,17]			Zinc (µg/l)		
	No total or dissolved designation from FMC, except as noted [3]														
Monitoring Well (MW)	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**	**Median[5]**		**Recent Values: June 2016 [8] June 2018 [9]**
	“Baseline” [6] (1987-88)	**Post-Reclamation (2005-16)[7]**		**“Baseline” [6] (1987-88)**	**Post-Reclamation (2005-16)[7]**		**“Baseline” [6,16] (1987-88)**	**Post-Reclamation (2005-16)[7]**		**“Baseline” [6,17] (1987-88)**	**Post-Reclamation (2005-16)[7]**		**“Baseline” [6] (1987-88)**	**Post-Reclamation (2005-16)[7]**	
MW-1000/ MW-1000R[11]	MW-1000 **< 5** (< 5 - < 5) n = 12	MW-1000R **< 1** (< 0.21 - < 2) n = 6	MW-1000R **< 0.21** **0.37** (D)	MW-1000 **< 0.4** (< 0.4 - 2.8) n = 12	MW-1000R **< 0.1** (< 0.02 - 0.81) n = 6	MW-1000R **< .016** **< 0.10** (D)	MW-1000 **< 5** (< 5 - < 5) n = 4	MW-1000R -	MW-1000R - -	MW-1000 **1** (< 1 - 5) n = 12	MW-1000R -	MW-1000R - -	MW-1000 **< 50** (< 50 - < 50) n = 12	MW-1000R **< 5** (< 3.1 - 5) n = 6	MW-1000R **< 3.1** **< 4.6** (D)
MW-1000P/ MW-1000PR[12]	MW-1000P **< 5** (< 5 - < 5) n = 12	MW-1000PR **< 1.8** (0.41 - 3.8) n = 13	MW-1000PR **0.41** **1.5** (D)	MW-1000P **< 0.4** (< 0.4 - < 5) n = 12	MW-1000PR **< 1.1** (< .016 - 1.4) n = 13	MW-1000PR **< .016** **0.59** (D)	MW-1000P **< 5** (< 5 - < 5) n = 4	MW-1000PR -	MW-1000PR - -	MW-1000P **2** (< 1 - 5) n = 12	MW-1000PR -	MW-1000PR - -	MW-1000P **48** (< 50 - 1800) n = 12	MW-1000PR **380** (280 - 650) n= 13	MW-1000PR **297** **416** (D)
MW-1010P	**< 5** [13,14] (< 5 - < 5) n = 193 Detects: 0%	**< 1.8** (< 0.21 - < 2) n = 12	**< 0.21** **< 0.32** (D)	**< 0.4** [13,14] (< 0.4 - 7.3) n = 193 Detects: 8%	**0.28** (< .016 - < 1.1) n = 12	**< .016** **< 0.10** (D)	**< 5** [13,14] (< 5 - < 5) n = 62 Detects: 0%	-	- -	**2** [13,14] (< 1 - 17) n = 193 Detects: 68%	-	- -	**< 50** [13,14] (< 10 - 1800) n = 193 Detects: 23%	**< 5** (< 5 - 22) n = 12	**8.6** **< 4.6** (D)
MW-1013		**< 2.4** (0.53 - < 12) n = 11	**0.53** **0.85** (D)		**2.5** (<.016 - < 14) n = 11	**< .016** **< 0.10** (D)		-	- -		-	- -		**5** (< 3.1 - < 50) n = 11	**< 3.1** **< 4.6** (D)
MW-1013A		**< 2.4** (< 0.2 - < 12) n = 11	**< 0.21** **< 0.32** (D)		**0.64** (< .016 - 14) n = 11	**< .016** **< 0.10** (D)		-	- -		-	- -		**< 5** (< 3.1 - < 50) n = 11	**< 3.1** **< 4.6** (D)
MW-1013B		**< 2.4** (0.88 - < 12) n = 13	**0.88** **0.57** (D)		**2** (< .016 - < 14) n = 13	**< .016** **< 0.10** (D)		-	- -		-	- -		**170** (126 - 210) n = 13	**126** **120** (D)
MW-1013C		**< 2.4** (< 0.2 - < 24) n = 13	**< 0.21** **< 0.32** (D)		**< 6.7** (< .016 - < 14) n = 13	**< .016** **0.10** (D)		-	- -		-	- -		**420** (330 - 470) n = 13	**330** **380** (D)
MW-1014		**< 2.4** (< 0.2 - < 12) n = 12	**< 0.21** **< 0.32** (D)		**1.1** (< .016 - < 14) n = 12	**< .016** **< 0.10** (D)		-	- -		-	- -		**14** (7 - 79) n = 12	**6.8** **6.0** (D)
MW-1014A		**< 2.4** (0.24 - < 12) n = 13	**0.24** **< 0.32** (D)		**< 12** (< .016 - 14) n = 13	**< .016** **< 0.10** (D)		-	- -		-	- -		**< 50** (7 - 57) n = 13	**9.0** **7.2** (D)
MW-1014B		**< 2.4** (< 2 - < 12) n = 13	**1.7** **1.6** (D)		**< 12** (< .016 - 23) n = 13	**< .016** **< 0.10** (D)		-	- -		-	- -		**1200** (990 - 2200) n = 13	**986** **1000** (D)
MW-1014C		**< 2.4** (< 0.21 - < 12) n = 13	**< 0.21** **< 0.32** (D)		**< 6.7** (< .016 - < 14) n = 13	**< .016** **< 0.10** (D)		-	- -		-	- -		**330** (270 - 560) n = 13	**267** **272** (D)
MW-1015A		**< 1.8** (< 0.2 - 2.4) n = 12	**< 0.21** **< 0.32** (D)		**< 0.18** (< .016 - < 1.1) n = 12	**< .016** **< 0.10** (D)		-	- -		-	- -		**< 5** (< 3 - < 5) n = 12	**< 3.1** **< 4.6** (D)
MW-1015B		**< 1.8** (< 0.21 - 1.9) n = 12	**< 0.21** **< 0.32** (D)		**< 0.36** (< .016 - < 1.1) n = 12	**< .016** **< 0.10** (D)		-	- -		-	- -		**< 5** (< 3 - < 5) n = 12	**< 3.1** **< 4.6** (D)

Sample Cell:

1600 = **Median**
(1500 - 1730) = (range)
n = 12 = number of values
\- = no available data

Table 6. Footnotes

1. Information source: 2016 Annual Report, FMC, Figures 4-1 and 4-2, Jan 2017.

2. FMC indicated "field" for the 1987-88 baseline pH values reported in their 1989 Environmental Impact Report (Foth, Apr 1989), but there was no "field" or "lab" designation for specific conductance (S.C.). Nor was there any such designation for pH or S.C. values reported in the summary table of "Historical Groundwater Results – Quarterly Parameters" found in FMC's 2016 annual report, used for compilation of the present table. Perusal of other FMC documents suggests reported values are "field."

3. The summary tables of ground water quality data provided by FMC in their 1989 Environmental Impact Report, Appendix 3.6-H, do not indicate if the 1987-88 baseline concentrations were Total or Dissolved. Nor is there any such designation for later values reported in the summary tables of "Historical Groundwater Results" for quarterly and annual parameters found in the company's annual reports. Perusal of other FMC documents suggests reported values are Dissolved.

4. Data was obtained from monitoring well construction logs found in the following documents submitted by FMC to the Wisconsin Department of Natural Resources: (1) Environmental Impact Report for the Kennecott Flambeau Project, Foth & Van Dyke, Appendices 3.5-C, 3.5-D, 3.5-E, 3.5-H and 3.5-I, Apr 1989; (2) 1991 Annual Report, FMC, Jan 1992; (3) Updated Monitoring Plan for the Flambeau Project, Foth & Van Dyke, Jul 1991; (4) 1996 Annual Report, FMC, Jan 1997; (5) Monitoring Well Construction & Soil Boring Logs – Backfill Wells, FMC, Jun 1999; (6) 1999 Annual Report, FMC, Jan 2000; and (7) Well Construction Documentation (MW-1015A/MW-1015B), FMC, Jun 2001. FMC construction logs indicate that, for all wells included in the present table, the tip of the well screen coincides with the tip of the well casing. See Table 3 – Physical details of ground water monitoring wells, for additional information.

5. Median determined by author. When calculating the median, non-detection values (e.g., < 2 µg/l) were converted to values equal to half the level of detection. For example, < 2 µg/l converts to 1 µg/l. These values were inserted into a ranked list of values (smallest to largest). The mid-point value in the list was determined. If, in the present example, the mid-point value was 1 µg/l, the median was reported as < 2 µg/l. The same type of back-calculating was used to report the range. In this way, the reported median and range do not suggest actual concentrations were measured when, in reality, they were not. If there was an even number of values in the ranked list and one of the two middle values originally was a non-detection value, the two middle values were averaged and reported as a detected value.

6. The source of raw data for the determination of median "baseline" groundwater constituent concentrations was FMC's 1989 Environmental Impact Report, Appendix 3.6-H. However, exploration drilling has been conducted at Flambeau since roughly 1968. Thus, hundreds or more exploration boreholes, together with road and site construction, trenches, dozens of monitoring wells, and possibly tunnels have been constructed at the site, prior to actual mining of ore. Such activities increase sediment loads and create pathways interconnecting various horizontal and vertical portions of local rocks, introducing atmospheric oxygen and other gases, microbes, and surface water, all of which alter original baseline water quality and geochemical conditions. Hence, the 1987-88 data presented by FMC as "baseline" water quality data in the 1989 EIR actually represent water quality that has been altered and somewhat degraded by exploration-phase activities. Inevitably such changes increase concentrations of most of the sediments, metals/metalloids and sulfate relative to true pre-exploration baseline in such ground waters.

7. Source of raw data for determination of median post-reclamation groundwater constituent concentrations: 2016 Annual Report, FMC, Appendix B – Attachments 1 and 2, Jan 2017.

8. Source of 2016 data: 2016 Annual Report, FMC, Appendix B – Attachments 1 and 2, Jan 2017. Reported concentrations represent individual readings (not median values).

9. Editor's Note: June 2018 data were submitted by FMC to the Wisconsin DNR after Dr. Moran drafted his comments. The reported values are consistent with Dr. Moran's findings and were integrated into the present table as an update. Concentrations represent individual readings (not median values). Metals/metalloids and sulfate concentrations were reported by FMC's laboratory as Dissolved; pH and S.C. values are "lab." Source of raw data: Environmental Groundwater Monitoring (Third Quarter 2018), FMC, Sep 2018.

10. Information source: Prediction of Groundwater Quality Downgradient of the Reclaimed Pit for the Kennecott Flambeau Project *in:* Mining Permit Application for the Flambeau Project, Foth, Volume 2, Appendix L, pp. 27-34, revised Dec 1989.

11. MW-1000 (19 ft deep; constructed October 1987) was abandoned in late 1992 as the result of the construction of a slurry cutoff wall system between the mine pit and Flambeau River. MW-1000R (24 ft deep, constructed November 1992) was drilled as a replacement. As described in FMC's 1992 annual report, MW-1000R is "located approximately 100 feet east of the original location of MW-1000. MW-1000 needed to be moved since its original location was downgradient of the slurry cutoff wall system, negating the ability of the well to monitor the shallow till downgradient of the backfilled pit. MW-1000R is positioned to accomplish this intent." According to FMC, MW-1000R remained dry until 4th quarter 2010, when it rebounded. First water samples were collected for analysis in October 2010.

12. MW-1000P (55 ft deep; constructed October 1987) reportedly was damaged during snow removal operations in January 1996. It was replaced with MW-1000PR (57 ft deep) in February 1996. According to Foth, MW-1000PR was established in the same location and "constructed in the same manner" as MW-1000P (Documentation of the Replacement of MW-1000P at the Kennecott Flambeau Mine, Foth, Mar 1996). In 1992, a slurry cutoff wall system, including a concrete diaphragm wall component, was constructed between the mine pit and Flambeau River. It appears that MW-1000P/PR is BETWEEN the concrete diaphragm wall and Flambeau River but extends DEEPER than the concrete diaphragm wall, which reportedly extends up to 25 feet beneath the surface.

13. The MW-1013/A/B/C and MW-1014/A/B/C well nests were constructed in the backfilled mine pit in September 1998; MW-1015A/B was constructed in January 2001; MW-1010P was constructed in June 1991. No specific pre-mining data for these exact locations and depths were reported by FMC. Hence, "baseline" data incorporated in the present table for these particular wells are drawn from "baseline" values reported for the overall project site by FMC in their 1989 Environmental Impact Report, Appendix 3.6-H. Median concentrations were determined for constituents measured in 22 different wells drilled to a variety of depths in 3 different substrates (overburden, shallow Precambrian rock and deep Precambrian rock) plus one Artesian well and a "tank." See Footnote-5 for details.

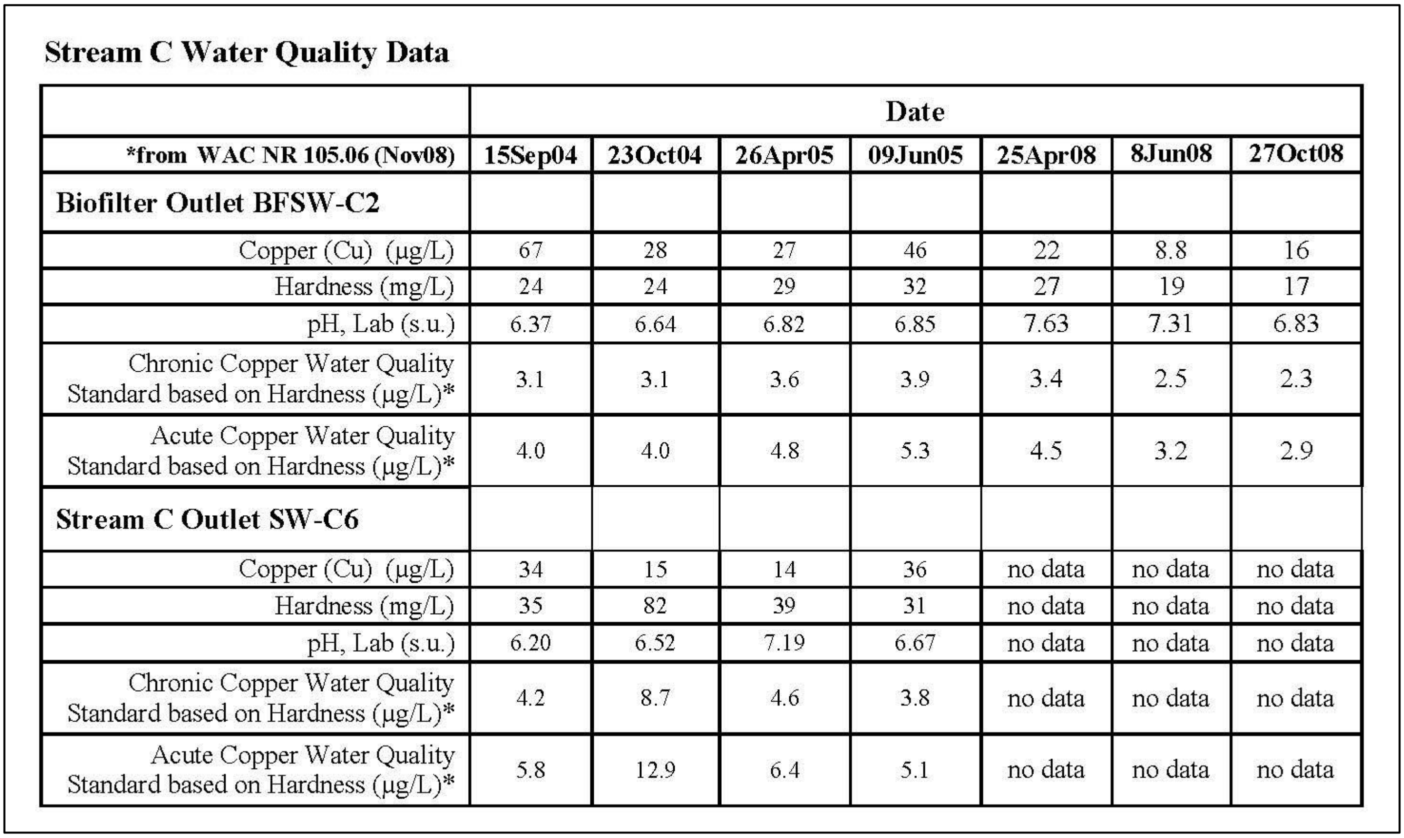
14. Baseline medians reported by Kennecott consultant Foth in the 1989 Environmental Impact Report and also incorporated into the 1990 Environmental Impact Statement issued by the Wisconsin DNR were NOT used in the present table because of how Foth accounted for non-detection data points. Their technique, as reported in the EIR, resulted in instances "where high, low, mean, and median values appear for parameters which had no detects." See Footnote-5 for how medians were determined for the present table.

15. The following constituents were included in FMC's 1987-88 baseline test program but have been lost to follow-up monitoring (or at least no such data have been included in the summary tables of "Historical Groundwater Results" found in the company's annual reports): aluminum*, beryllium, chemical oxygen demand, cobalt, fluoride, molybdenum, nickel, nitrate + nitrite nitrogen, thallium, tin, titanium, uranium.

* **Editor's Note:** FMC reported limited aluminum data to the Wisconsin DNR in two environmental monitoring reports issued in third quarter 2017 and third quarter 2018, after Dr. Moran drafted his comments. The results, which do not appear in the company's 2017 or 2018 annual reports, showed concentrations below the level of detection (59 µg/L) for all wells except MW-1004, which had an aluminum concentration of 480 µg/L in June 2017, and MW-1000PR, which had an aluminum concentration of 170 µg/L in June 2018.

16. FMC's 1989 Environmental Impact Report did not disclose any concentrations from "Deep Precambrian" baseline wells for aluminum, beryllium, cobalt, molybdenum, nickel, thallium, tin, or titanium. Concentrations were reported only for "Overburden" and "Shallow Precambrian" wells.

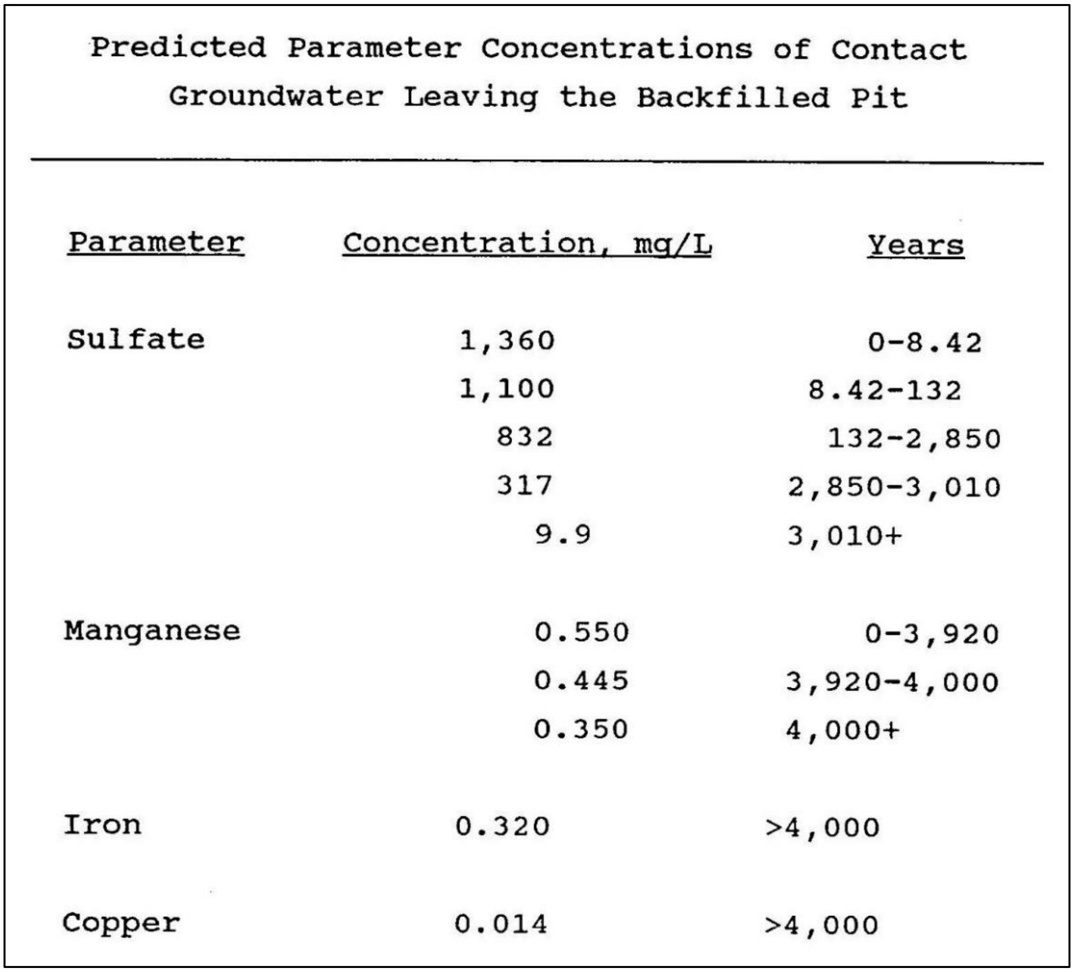
17. According to FMC's 1989 Environmental Impact Report: "Uranium was detected in approximately two thirds of the samples tested, with median and mean values in the range of 0.002 to 0.003 mg/L." They went on to state: "The mean value for uranium in groundwaters of the United States is 0.005 mg/L (USEPA, 1975), so the range at the site is low relative to average levels." However, out of 193 "baseline" tests for uranium reported by FMC, only 5 were reported for "Deep Precambrian" wells. All 5 of those tests were detects (max = 0.007 mg/L; min = 0.004 mg/L; mean = 0.006 mg/L; median = 0.006 mg/L). No follow-up concentrations were reported by FMC.



Stream C Water Quality Data

	Date						
***from WAC NR 105.06 (Nov08)**	**15Sep04**	**23Oct04**	**26Apr05**	**09Jun05**	**25Apr08**	**8Jun08**	**27Oct08**
Biofilter Outlet BFSW-C2							
Copper (Cu) (μg/L)	67	28	27	46	22	8.8	16
Hardness (mg/L)	24	24	29	32	27	19	17
pH, Lab (s.u.)	6.37	6.64	6.82	6.85	7.63	7.31	6.83
Chronic Copper Water Quality Standard based on Hardness (μg/L)*	3.1	3.1	3.6	3.9	3.4	2.5	2.3
Acute Copper Water Quality Standard based on Hardness (μg/L)*	4.0	4.0	4.8	5.3	4.5	3.2	2.9
Stream C Outlet SW-C6							
Copper (Cu) (μg/L)	34	15	14	36	no data	no data	no data
Hardness (mg/L)	35	82	39	31	no data	no data	no data
pH, Lab (s.u.)	6.20	6.52	7.19	6.67	no data	no data	no data
Chronic Copper Water Quality Standard based on Hardness (μg/L)*	4.2	8.7	4.6	3.8	no data	no data	no data
Acute Copper Water Quality Standard based on Hardness (μg/L)*	5.8	12.9	6.4	5.1	no data	no data	no data

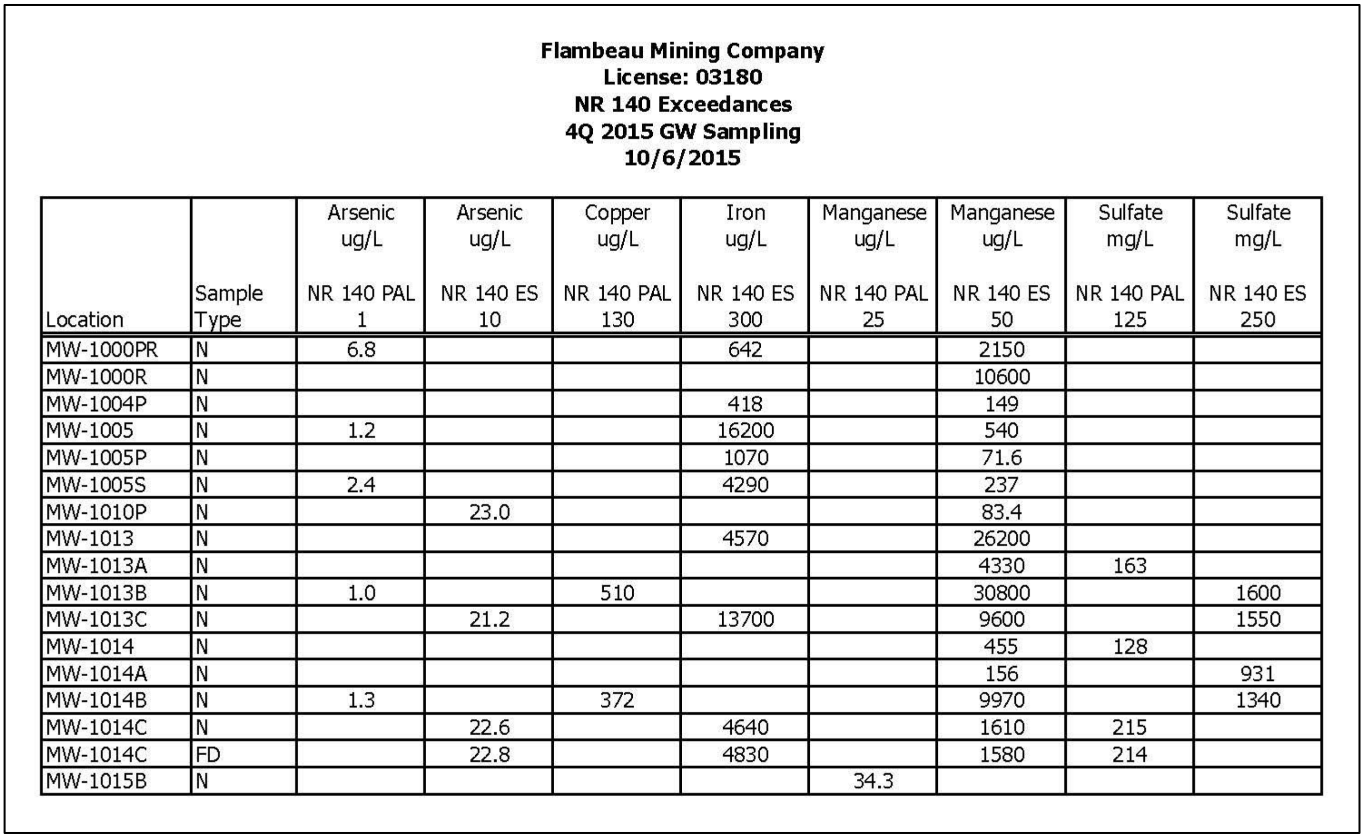
Table 7. This table, compiled by Chambers using FMC data, demonstrates how copper concentrations at the Stream C outlet to the Flambeau River (SW-C6) exceeded acute and chronic toxicity criteria despite passive treatment of stormwater runoff discharged to the stream from a biofilter (Table 1 *in:* Report on Groundwater and Surface Water Contamination at the Flambeau Mine, David M. Chambers and Kendra Zamzow, 2009).



Predicted Parameter Concentrations of Contact
Groundwater Leaving the Backfilled Pit

Parameter	Concentration, mg/L	Years
Sulfate	1,360	0-8.42
	1,100	8.42-132
	832	132-2,850
	317	2,850-3,010
	9.9	3,010+
Manganese	0.550	0-3,920
	0.445	3,920-4,000
	0.350	4,000+
Iron	0.320	>4,000
Copper	0.014	>4,000

Table 8. This table produced by FMC consultant Foth & Van Dyke shows projected ground water quality of contact water leaving the Flambeau backfilled pit. Now that the pit has been backfilled, predicted constituent concentrations can be compared to actual concentrations measured in two nested wells in the backfill (MW-1013/A/B/C and MW-1014/A/B/C). This Foth table was also referenced in Flambeau's mine permit to define applicable compliance criteria for wells located directly between the backfilled pit and Flambeau River (e.g., MW-1000R, MW-1000PR and MW-1010P) (Mining Permit Application for the Flambeau Project, Foth & Van Dyke, Volume 2, Appendix L, Table 2-5, Dec 1989).



Flambeau Mining Company
License: 03180
NR 140 Exceedances
4Q 2015 GW Sampling
10/6/2015

Location	Sample Type	Arsenic ug/L NR 140 PAL 1	Arsenic ug/L NR 140 ES 10	Copper ug/L NR 140 PAL 130	Iron ug/L NR 140 ES 300	Manganese ug/L NR 140 PAL 25	Manganese ug/L NR 140 ES 50	Sulfate mg/L NR 140 PAL 125	Sulfate mg/L NR 140 ES 250
MW-1000PR	N	6.8			642		2150		
MW-1000R	N						10600		
MW-1004P	N				418		149		
MW-1005	N	1.2			16200		540		
MW-1005P	N				1070		71.6		
MW-1005S	N	2.4			4290		237		
MW-1010P	N		23.0				83.4		
MW-1013	N				4570		26200		
MW-1013A	N						4330	163	
MW-1013B	N	1.0		510			30800		1600
MW-1013C	N		21.2		13700		9600		1550
MW-1014	N						455	128	
MW-1014A	N						156		931
MW-1014B	N	1.3		372			9970		1340
MW-1014C	N		22.6		4640		1610	215	
MW-1014C	FD		22.8		4830		1580	214	
MW-1015B	N					34.3			

Table 9. This table submitted by FMC to the Wisconsin DNR lists exceedances of various Wisconsin ground water quality enforcement standards (ES) and Preventive Action Limits (PAL) in wells at the Flambeau site. MW-1000PR, MW-1000R and MW-1010P are located between the backfilled pit and Flambeau River. The MW-1013 and MW-1014 nests are located within the backfilled pit. See Table 6 – Ground Water Quality Data, for additional data, including baseline (NR 140 Exceedances *in:* 4th Quarter 2015 Environmental Monitoring, FMC, electronic page 68, Dec. 2015).

CREDENTIALS

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Dr. Robert Moran has more than 45 years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of his technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. In addition, Dr. Moran has significant experience in the application of remote sensing to natural resource issues, development of resource policy, and litigation support. He has often taught courses to technical and general audiences, and has given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Bulgaria, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan, Mongolia, Romania, Russia, Papua New Guinea, Argentina, Bolivia, Chile, Colombia, Guatemala, Haiti, Honduras, Mexico, Peru, El Salvador, Belgium, France, Canada, Germany, Great Britain, Netherlands, Spain, United States.

EDUCATION

University of Texas, Austin: Ph.D., Geological Sciences, 1974
San Francisco State College: B.A., Zoology, 1966

PROFESSIONAL HISTORY

Michael-Moran Assoc., LLC, Partner, 2003 to present
Moran and Associates, President, 1983 to 1992; 1996 to 2003
Woodward-Clyde Consultants, Senior Consulting Geochemist, 1992 to 1996
Gibbs and Hill, Inc., Senior Hydrogeologist, 1981 to 1983
Envirologic Systems, Inc., Senior Hydrogeologist/Geochemist, 1980 to 1981
Tetra Tech Int'l. / Sultanate of Oman, Senior Hydrogeologist, 1979 to 1980
Science Applications, Inc., Geochemist/Hydrologist, 1978 to 1979
U.S. Geological Survey, Water Resources Division, Hydrologist/Geochemist, 1972 to 1978
Texas Bureau of Economic Geology, Research Scientist Assistant, 1970 to 1971

LANGUAGES

English, Spanish

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Dr. Chambers is the founder and president of the Center for Science in Public Participation, a non-profit corporation formed to provide technical assistance on mining and water quality to public interest groups and tribal governments.

David Chambers has 40 years of experience in mineral exploration and development – 15 years of technical and management experience in the mineral exploration industry, and for the past 25+ years he has served as an advisor on the environmental effects of mining projects both nationally and internationally. He has a Professional Engineering Degree in Physics from the Colorado School of Mines, a Master of Science Degree in Engineering from the University of California at Berkeley, and is a registered professional geophysicist in California (# GP 972). Dr. Chambers received his Ph.D. in Environmental Planning from Berkeley where his doctoral dissertation analyzed the U.S. Forest Service's efforts to plan for and manage minerals on the National Forests.

He has provided technical assistance to public interest groups and tribal governments on proposed, operating, and abandoned mines in Alaska, Arizona, California, Colorado, Idaho, Michigan, Minnesota, Missouri, Montana, Nevada, Oregon, South Carolina, South Dakota, Utah, Washington, Wisconsin, Canada (British Columbia, Ontario, Labrador, Yukon), Kyrgyzstan, and Northern Ireland. This assistance has included review of underground and open pit mine design, seismic stability for tailings dams, waste rock facilities design, water quality monitoring, water treatment facility design, reclamation planning, and financial assurance for mine closure. This has included the review of dozens of environmental impact studies and included analyzing the potential adverse effects on surface and groundwater quality of acid mine drainage and metals leaching from mine point discharges and seepage from mine waste storage facilities, and on proposing alternative methodologies to avoid these impacts.

Dr. Chambers has also provided technical assistance to tribal governments and public interest groups in negotiating with mine owners, mine developers, and federal and state regulators, to assist these parties in understanding the major technical implications of specific mining projects, and in providing alternatives that would lead to more environmentally responsible development. He has played a key role in negotiating complex agreements, including alternative development plans for several mine proposals in Alaska, technical studies related to EPA placer mining regulation, efforts by the mining industry and NGOs to research and regulate marine mine waste disposal, and a joint industry-NGO international effort to develop a process to define and measure performance for responsible mining practices.

Dr. Chambers has worked with the State of Alaska Departments of Natural Resources and Environmental Conservation on mining, reclamation, cyanide and solid waste regulations. He has been a member of the University of Alaska-Fairbanks School of Mineral Engineering Advisory Board; a member of the Western Governors' Association Abandoned Mine Waste Working Group; and, a member of the EPA's RCRA Policy Dialogue Committee, a group of industry, environmental and government representatives who worked to develop regulations for mining wastes under the authority of RCRA Subtitle D.

EDUCATION

Doctor of Philosophy, Environmental Planning
University of California, Berkeley, May, 1985

Master of Science, Geophysics
University of California, Berkeley, June, 1976

Professional Engineer, Physics
Colorado School of Mines, Golden, May, 1969

PROFESSIONAL AFFILIATIONS

Professional Geophysicist (Certificate # GP 972) -
California Board for Professional Engineers, Land Surveyors, and Geologists

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Laura Gauger is the founder and chair of Deer Tail Scientific, a nonprofit corporation that provides factual information about the Flambeau Mine to interested parties. The open-pit copper mine, located near Ladysmith, Wisconsin, was owned and operated by Rio Tinto/Kennecott and their subsidiary, Flambeau Mining Company. It produced ore during the 1990s and to a large extent has been reclaimed. As stated in the Deer Tail Scientific bylaws:

The mission of Deer Tail Scientific is to educate the public, government officials and tribal sovereign nations with fact-based information on: (1) the permitting, development, reclamation, environmental performance and economics of Wisconsin's Flambeau Mine; and (2) how the Flambeau Mine compares to other mines (closed, currently operating or proposed) in the Great Lakes region and beyond.

Why place such a focus on a single and quite small copper-sulfide mine that has come and gone?

Those supporting the development of new metal-sulfide mines in the Great Lakes region of the Midwest and Alaska's Bristol Bay have drawn on the example of the Flambeau Mine in efforts to convince the public and government officials that metal-sulfide mining can be done without polluting local waters. In effect, the Flambeau Mine has become the industry's calling card, vaulting it into a position of great importance in the ongoing debate over the advisability of developing new metal-sulfide mines in water-rich Minnesota, Michigan, Wisconsin and Alaska.

Over the years Gauger has collected and archived numerous technical reports issued by Flambeau Mining Company, their consultants and government agencies regarding various aspects of the Flambeau Mine operation and has made those documents available to the public on several websites she manages. She also coauthored, with Roscoe Churchill of Ladysmith, a 2007 book about the history and politics of the Flambeau Mine[1] and was a party to several legal proceedings involving the mine's environmental performance, including a Clean Water Act lawsuit filed in federal court in 2011.

Laura, who is a pharmacist by training, resides in Duluth, Minnesota.

EDUCATION

University of Wisconsin School of Pharmacy, Madison: B.S., Pharmacy, 1979

INFORMATIONAL WEBSITES

Deer Tail Scientific *at* https://deertailscientific.wordpress.com/
Deer Tail Press *at* https://deertailpress.wordpress.com/
Flambeau Mine Exposed-I *at* https://flambeaumineexposed.wordpress.com/
Flambeau Mine Exposed-II *at* https://flambeaumineexposed2.wordpress.com/

HONORS

Grassroots Citizen Advocate Award, Freshwater Future, 2013.
Hospital Pharmacist of the Year Award, Wisconsin Society of Hospital Pharmacists, 1984.
Merck Sharp and Dohme Pharmacy Award, 1979.

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[1] *The Buzzards Have Landed! – The* Real *Story of the Flambeau Mine*, Roscoe Churchill and Laura (Furtman) Gauger, Deer Tail Press, 2007, 1285 pg.; https://deertailpress.wordpress.com/on-line-access/