Technical Memorandum

Environmental Resources Management

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To:	Ms. Amanda R. Balzer, LG (Natural Resources); Mr. Kevin M. Murphy, LG (Wellhead Protection Lead) and Ms. Elaine J. Dilley, LG (Natural Resources) of the City of Redmond Public Works
cc:	Mr. Rhidian Grant, TTM Technologies, Inc.
From:	Mr. Michael Mendes, ERM-West, Inc.
Date:	20 May 2009
Subject:	EHC-M™ Treatment of Copper in Groundwater at TTM Technologies, Inc., Redmond, Washington

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ERM-West, Inc. (ERM) has prepared this Technical Memorandum on behalf of TTM Technologies, Inc. (TTM) to provide the technical analysis used for the selection of EHC-M™ as the preferred soil amendment for treatment of copper in groundwater at the TTM Redmond, Washington facility located at 17460 NE 67th Court, Redmond, Washington 98052 (the "Site"). This Technical Memorandum also provides responses to specific questions raised by the City of Redmond Public Works staff during a 12 May 2009 meeting with TTM and ERM.

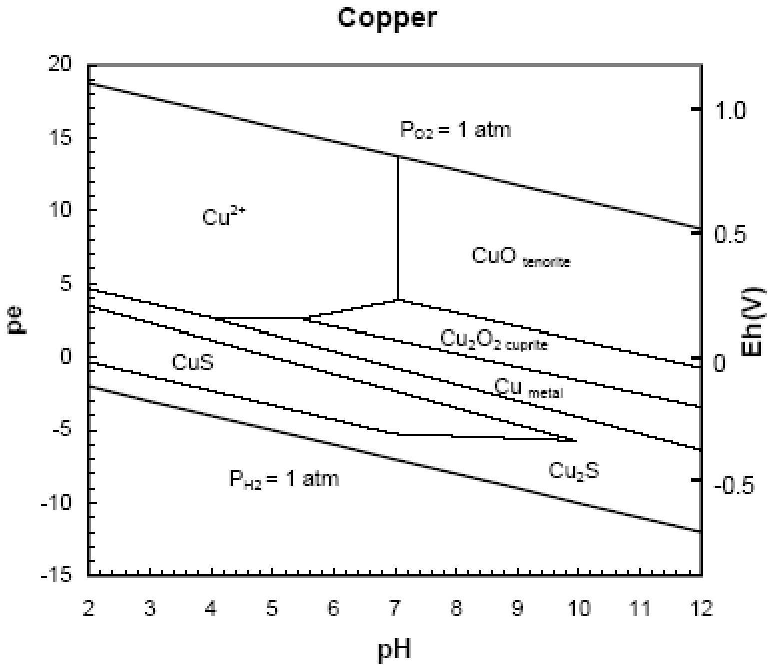
Soil Amendment Technology Evaluation

ERM evaluated several potential soil amendments based on two primary metal treatment mechanisms: 1) pH adjustment; and 2) stabilization by precipitation and/or adsorption. The evaluation considered the following factors:

- long-term effectiveness;
- implementability, including health and safety, and availability of the amendment material;
- limitations of the technology, including potential for copper resolubilization or mobilization of other metals; and
- relative cost.

ERM evaluated the use of lime (CaO) and magnesium hydroxide ($Mg[OH]_2$) as soil amendments that would raise the pH of the groundwater. Increasing the pH of the groundwater would affect the solubility of metal complexes and precipitate out metal hydroxides and carbonates. As shown on Figure 1, raising the pH of the groundwater from its current 5.7 measurement to greater than 7 would precipitate copper oxides (tenorite or cuprite). However, the pH adjustment mechanism was considered to be less permanent as pH levels will likely return to natural Site conditions over time and potentially allow resolubilization of the copper precipitants. Additionally, pH adjustment could result in dissolution of other metal complexes, thereby mobilizing other metals.

Figure 1 Graphical Representation of Redox Equilibria (pe-pH Diagram)



Source: Adventus, 2006

ERM also evaluated several soil amendments that would precipitate copper through other mechanisms such as peat (adsorption), EHC-M™ (reductive precipitation), ViroSoil™ (adsorption and pH adjustment), and kaolinite clay (adsorption and ion exchange). Of these amendments, ERM recommended EHC-M™ because of its anticipated long-term effectiveness, unlikely mobilization of other metals, availability, safe application and relative cost. EHC-M™ is an in-situ metals stabilization product developed by the Adventus Group. It consists of a controlled-release organic carbon source, a sulfate source, and zero-valent iron (ZVI) [Adventus, 2006]. EHC-M™ has been documented to produce removal rates of 92 to 99 percent for divalent (2+) metals, such as copper, in laboratory and field applications.

In-Situ Treatment of Copper Using EHC-M™

EHC-M™ treats heavy metals using the principles of:

1) **sulfate reduction/precipitation** by supplying a carbon source that fuels the sulfate-reducing bacteria in the groundwater to reduce the provided sulfate source to sulfide subsequently forming copper sulfide; a stable, insoluble precipitate; and

2) **adsorption** of copper by formation of iron oxide and iron oxyhydroxide metal complexes onto the ZVI surfaces. The sulfate reducing mechanism is represented by the following reaction:

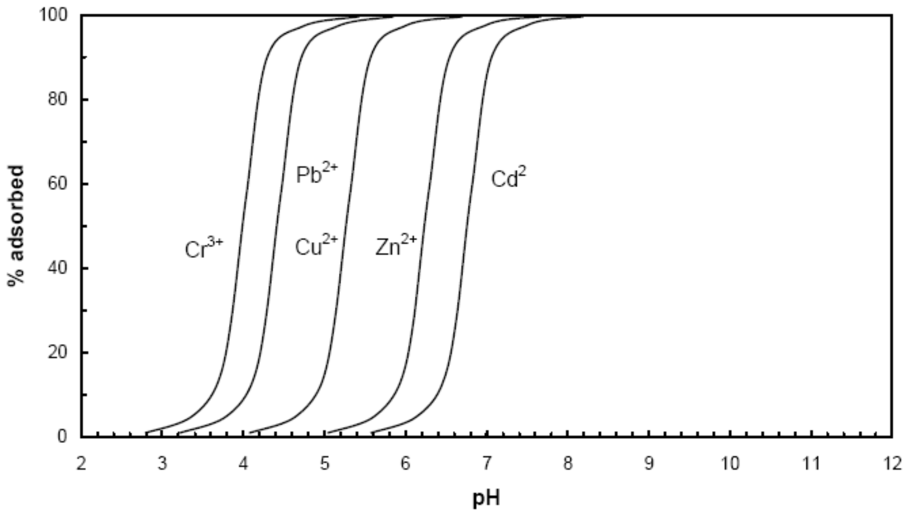
$$2CH_2O_{(s)} + SO_4^{2-} + 2H^+_{(aq)} \rightarrow H_2S + 2CO_{2(aq)} + H_2O$$
$$Me^{2+}_{(aq)} + H_2S_{(aq)} \rightarrow MeS_{(s)} + 2H^+_{(aq)}$$

where: CH_2O represents organic carbon and Me^{2+} represents a divalent metal cation.

Source: Adventus, 2006

The potential for generating reducing conditions for effective metal sulfide precipitation is favorable based on recently measured Site groundwater quality parameters, including redox potential (approximately 200 millivolts [mV]) and pH (approximately 5.7). Additionally, effective copper adsorption is anticipated with ZVI when the pH is above 5, see Figure 2 below.

Figure 2 Metals Adsorption on Hydrous Ferric Oxide as a Function of pH (Ionic Strength of 0.1M)



Source: Adventus, 2006

Additionally, the concentrations of competing electron acceptors (oxygen and nitrate vs. sulfate) for bacteria are low, therefore the sulfate-reducing reaction is anticipated to be effective.

Technical Considerations of EHC-M™ Application in Groundwater

The products generated by EHC-M™ treatment include precipitated metal sulfides, dissolved iron, hydrogen gas, volatile fatty acids, dissolved organic carbon, methane, and carbon dioxide gas [Adventus, *2]. Concentrations of dissolved iron (< 4 milligrams per liter [mg/L]) and total sulfur (<5 mg/L) are expected to increase only in the areas directly influenced by the EHC-M™ and are not anticipated to occur further downgradient due to chemical and biological attenuation [Adventus, *2].

None of the constituents or potential by-products of EHC-M™ are listed under the United States Environmental Protection Agency's (USEPA's) National Primary Drinking Water Regulations. Three parameters potentially affected by the use of EHC-M™, including iron, sulfate, and total dissolved solids, appear on the list of National Secondary Drinking Water Standards, the non-enforceable drinking water guidelines set by the USEPA for potential cosmetic and aesthetic effects (see Table 1).

Table 1 Maximum Current Site Concentrations and Secondary Drinking Water Standards

Constituent	Maximum Current Site Concentrations (mg/L)	Secondary Drinking Water Standard (mg/L)
Iron	1.14	0.3
pH[1]	6.09	6.5-8.5
Sulfate	9.35	250
Total Dissolved Solids	123[2]	500

[1] pH measured in Standard Units (S.U.).

[2] Calculated from specific conductance field measurements.

It is anticipated that the current sulfate and total dissolved solid concentrations in Site groundwater are low enough that they will remain below the Secondary Drinking Water Standards with the addition of EHC-M™. Iron concentrations may temporarily increase, though it is expected that the extent of the potentially elevated iron concentrations will not exceed the direct area of influence of EHC-M™ and will not remain over the long term as iron will be co-precipitated with metal compounds, as described previously. The pH level is anticipated to decrease slightly due to the formation of hydrogen from the metal sulfide reaction, though the change in pH is expected to be minimal and short-term as the hydrogen will further react and diffuse. The addition of EHC-M™ is therefore not anticipated to pose a risk to human health or the environment.

Based on the reaction chemistry of the material and verified by the manufacturer, EHC-M™ will not mobilize other metal solutions (Mueller, 2009b). The low concentrations of other metals present in Site groundwater (e.g. magnesium, manganese) may decrease further by the same treatment mechanisms as the expected copper treatment.

Potential for Hydrogen Sulfide Gas Generation from EHC-M™

As indicated in the reaction chemistry, hydrogen sulfide (H_2S) is generated in an aqueous form from the sulfate reducing reaction. However, there is little potential for generating unsafe levels of H_2S gas over time because this is a controlled-release reaction and the H_2S is primarily converted to metal sulfide or otherwise diffused before it accumulates as a gas. According to the manufacturer, the use of EHC-M™ in direct soil applications, such as the one proposed for the Site, is reported to produce odors from the anaerobic degradation process (methane and H_2S) during initial mixing activities, but air monitoring results are reported to remain below levels that may cause unacceptable risk to human health and the environment (Mueller, 2009a).

EHC-M™ Implementation

A manufacturer-recommended treatment ratio of 1 percent by weight of EHC-M™ to saturated soils has been proposed for this Site. Table 2 (attached) summarizes the Site parameters, assumptions and calculations used to evaluate the EHC-M™ mass required for copper treatment at the Site.

The estimated mass of EHC-M™ required for copper removal is 850 pounds. A safety factor of 1.5 is applied to ensure sufficient material distribution is achieved for reaction with the copper in the saturated soil matrix. The material must come in contact with the dissolved copper for the precipitation and adsorption reactions to occur. This results in an application of approximately 1,300 pounds of EHC-M™.

EHC-M™ is reported to influence the aquifer from 10 to 60 feet downgradient of the excavation location when mixed directly with soils. Therefore, any impacts to the groundwater beyond the TTM property boundary are anticipated to be negligible. Further, it will not influence the groundwater quality at the nearest drinking water supply well, which is 2,800 feet to the northeast (upgradient) of the Site.

The application of EHC-M™ presents no major health and safety concerns during application (though odors will likely occur) with the use of proper personal protective equipment (protective clothing, gloves, and safety glasses). The material will likely be mixed at the proper ratio in a backhoe bucket, then lowered into the excavation and mixed with the upper 2 feet of the saturated soils in the floor of the excavation.

No registration is required with the Washington State Department of Ecology's Underground Injection Control (UIC) Program because the excavation is wider than it is deep (maximum anticipated dimensions are 20 feet x 20 feet x 11 feet deep) and does not meet the definition of a UIC well.

Summary

Based on the evaluation described in this Technical Memorandum, ERM recommends EHC-M™ as the preferred soil amendment to treat the copper-impacted groundwater at the Site because of its anticipated long-term effectiveness, ease of implementability, low risk of health and safety issues, and low cost.

References

Adventus, 2006. Adventus Americas Inc. (Adventus). *Immobilization Process for Dissolved Trace Metal Treatment Using EHC-M.* Technical Note. June 2006.

Adventus, *2. Adventus. *Information Needed to do Risk Assessments for Products Applied to Groundwater or Soil Containing No Microorganisms.* State of North Carolina Underground Injection Control (UIC) Program Form GW/UIC-3. Date Unknown.

USEPA, 1992. U.S. Environmental Protection Agency. *National Primary and Secondary Drinking Water Standards.* USEPA 816-F-03-0016. June 2003.

Mueller, 2009a. Mueller, Jim Ph.D. Adventus. Telephone conversation. 13 May 2009.

Mueller, 2009a. Mueller, Jim Ph.D. Adventus. E-mail communication. 11 May 2009.

Przepiora, 2009. Przepiora, Andrzej M.Sc. Adventus. E-mail communication. 19 May 2009.

Table

Table 2
EHC-M™ Mass Requirement Calculations
TTM Technologies, Inc.
Redmond, Washington

Assumptions	**Value**	**Unit**
Treatment Area Dimensions		
Length of treatment zone	56	ft
Width of treatment zone	10	ft
Depth to top of treatment zone	8	ft
Depth to bottom of treatment zone	10	ft
Treatment zone thickness	2	ft
Soil/Groundwater Properties		
Estimated porosity	40%	
Groundwater velocity (max.)	0.5	ft3
Average copper concentration	5	mg/L
EHC-M™ Properties		
Copper removal ratio	15	mg Cu / g EHC-M™
Treatment life	5.0	years
Unit Conversions		
Liters per cubic foot	28.3	L/ft^3
Grams per pound	453.59	g/lb
Calculations		
56 ft x 2 ft x (0.5 ft/day) x 0.4	22.4	ft^3/day
22.4 ft^3/day x (28.3 L/ft^3) x 5 (mg/L Cu)	3,170	mg Cu/day
3,170 mg Cu/day / (15 mg Cu/g EHC-M™)	211	g EHC-M™/day
211 g EHC-M™/day x (365 days/yr) x 5 yrs x (1 lb/453.59 g)	**850**	**lbs EHC-M™**
850 lbs EHC-M™ x 1.5 (Safety Factor)	**1,275**	**lbs EHC-M™**