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1/10/11

ANALYSIS OF WATER QUALITY MEMO

Madison Water Utility
Madison, Wisconsin
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Madison, WI 53713

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B&V Project 169092.0100
B&V File 41.0800

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December 6, 2010

DRAFT

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Madison Water Utility mwu

Montgomery Associates
Resource Solutions, LLC

Memorandum

To:	Al Larson
From:	Steve Gaffield (Montgomery Associates) and Ken Quinn (RMT)
Date:	December 6, 2010
cc:	Paul Boersma, Black & Veatch
Re:	Analysis of water quality data for East Side Master Plan

Introduction

The purpose of this memorandum is to document compilation and evaluation of existing water quality data for Madison Water Utility (MWU) Unit Wells (UW) 7, 8 and 15 by Montgomery Associates: *Resource Solutions*, LLC (MARS) and RMT, Inc. This analysis is in support of the East Side Master Planning project and provides context for evaluation of options for water quality improvements at UW 7, 8 and 15.

This analysis entailed review of available information; no new data was collected. Data sources reviewed include the following:

- Pumping records for UW 7, 8 and 15 from the Madison Water Utility
- Water quality records for UW 7, 8 and 15 from the Madison Water Utility
- The City of Madison 2008-2009 Road Salt Report
- Wisconsin Geological and Natural History Survey (WGNHS) geologic logs and Wisconsin Department of Natural Resources high capacity well database records for UW 7, 8 and 15
- A compilation of Eau Claire Shale elevations compiled by Ken Bradbury of the Wisconsin Geological and Natural History Survey as part of the UW3 replacement search

Overview of Regional Geology

The Madison groundwater system includes two bedrock aquifers, the shallow sandstone and deep sandstone, which are separated in much of the City by the Eau Claire Shale (**Figure 1**). This thin shale layer has a very low permeability and helps protect the deep aquifer from contamination that originates near the land surface. This protection is incomplete, however, because the shale is not completely impermeable; it is missing in some locations, such as below the lakes; and some wells are open to both the shallow and deep sandstone aquifers, creating a conduit between the aquifers.

Well Construction and Hydro-Stratigraphy

The elevations of the open well interval and of the Eau Claire Shale were compiled from available data from the WGNHS and WDNR (**Table 1**). This data indicates that UW7 and UW8 are open only to the lower aquifer, although the UW7 casing appears to only partially penetrate the Eau Claire Shale. Although the Eau Claire Shale is present at UW7 and UW8, it is believed to be missing nearby under Lakes Mendota and Monona, where the bedrock surface has been eroded below the level of the shale (**Figure 1**).

The presence and depth of the shale in UW15 are uncertain. The geologic log prepared by the WGNHS shows the Eau Claire Formation, but no shale. In addition, the depth listed for the Eau Claire Formation corresponds to an elevation several hundred feet lower than in the other wells, suggesting a possible inconsistency in how bedrock units were logged at the different wells. Thus, it is uncertain whether or not the Eau Claire Shale is present at UW15 and, if so, whether the well is open above the shale.

Table 1. Well open interval and Eau Claire Shale elevations.

Well	Land Surface Elevation (ft) [1]	Open Interval Depth (ft) [2]	Open Interval Elevation (ft) [3]	Eau Claire Shale Elevation (ft)
UW7	890	238 – 736	652-154	674-639 [4]
UW8	876	280 – 774	596-102	628-614 [4]
UW15	888	172 - 753	716-135	Uncertain [5]

[1] Land surface elevations from Dane County 4 ft topographic contours.
[2] From WDNR high capacity well database.
[3] Calculated from land surface elevation and depth below ground surface.
[4] From WGNHS.
[5] WGNHS geologic log and WDNR high capacity well database show Eau Claire formation, but not shale. Elevation for Eau Claire formation at UW15 indicated by these sources is inconsistent with known elevation of Eau Claire formation in other east Madison locations.

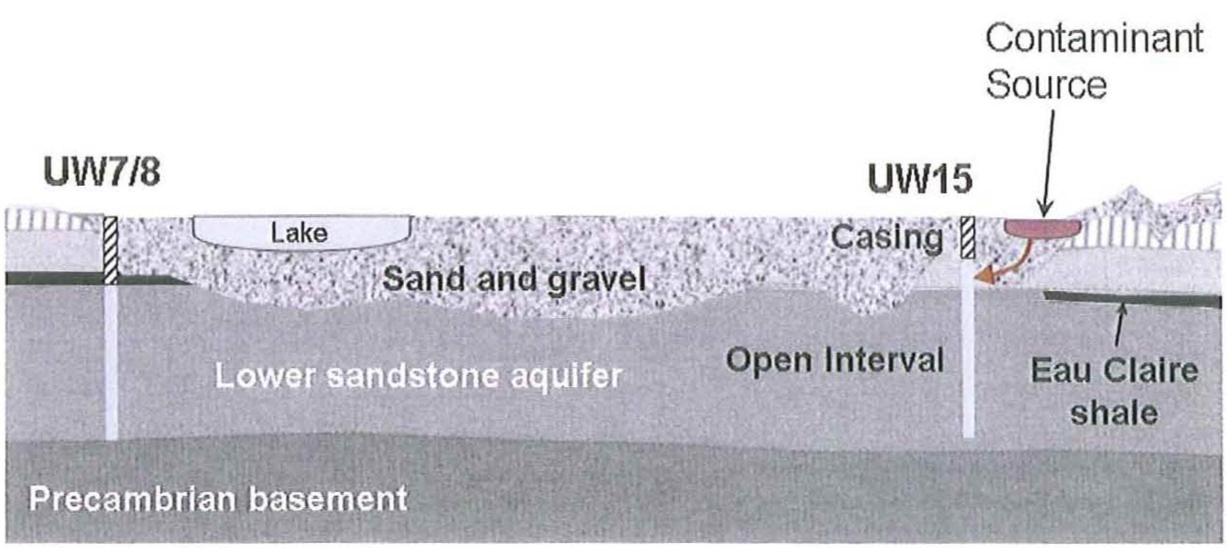

Figure 1. Conceptual geologic cross section showing construction of UW7, UW8 and UW15. Not to scale.

Pumping Trends

Monthly pumping rates are plotted in **Figure 2** for January 2002 through mid-2010. Pumping rates are highly variable from month to month due to seasonal operation differences, down time for maintenance, and other factors. This variability makes long-term trends somewhat difficult to identify. Smoothing the data by computing the average of the previous 6 months of pumping (i.e. a 6-month moving average) more clearly shows these patterns (**Figure 3**). Note that pumping of UW7 has been relatively steady, except for a period of higher pumping in 2007 and 2008; pumping of UW8 has declined over the past 5 years; UW15 has typically been pumped at a higher rate than UW7, UW8 and UW29; UW15 had 2 periods of decreased pumping in 2005 and 2009; and pumping of UW29 has markedly increased since 2009 after its Fe and Mn filtration system went on-line.

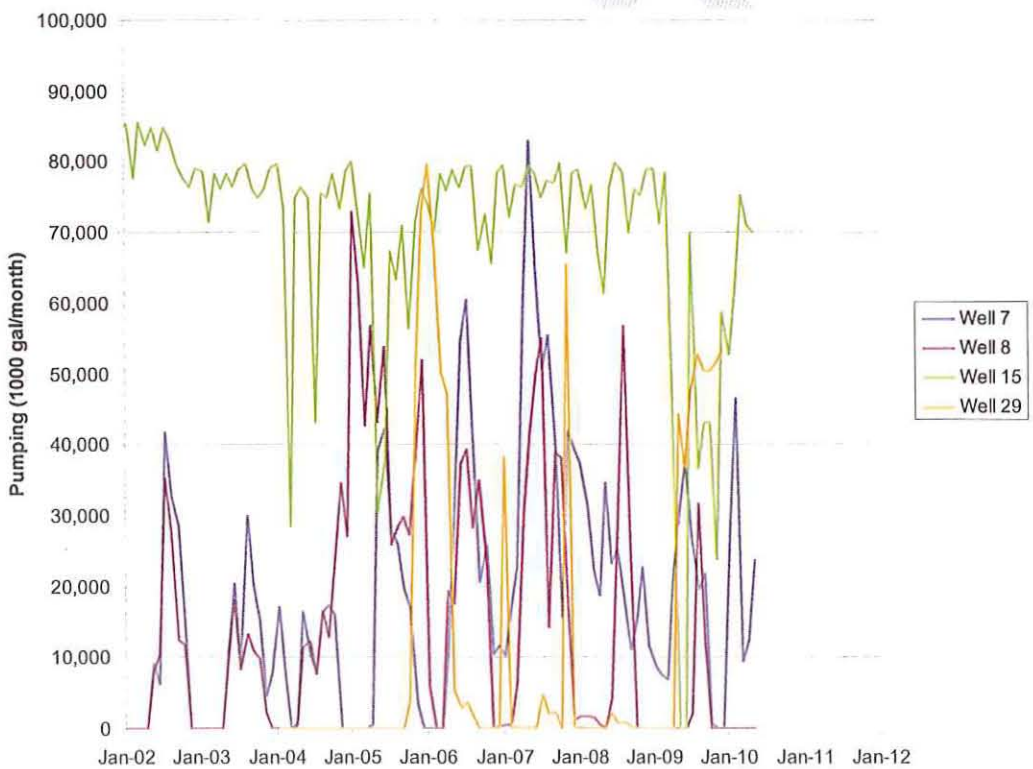

Figure 2. Monthly pumping rates for UW 7, 8, 15 and 29 for January 2002 through mid-2010.

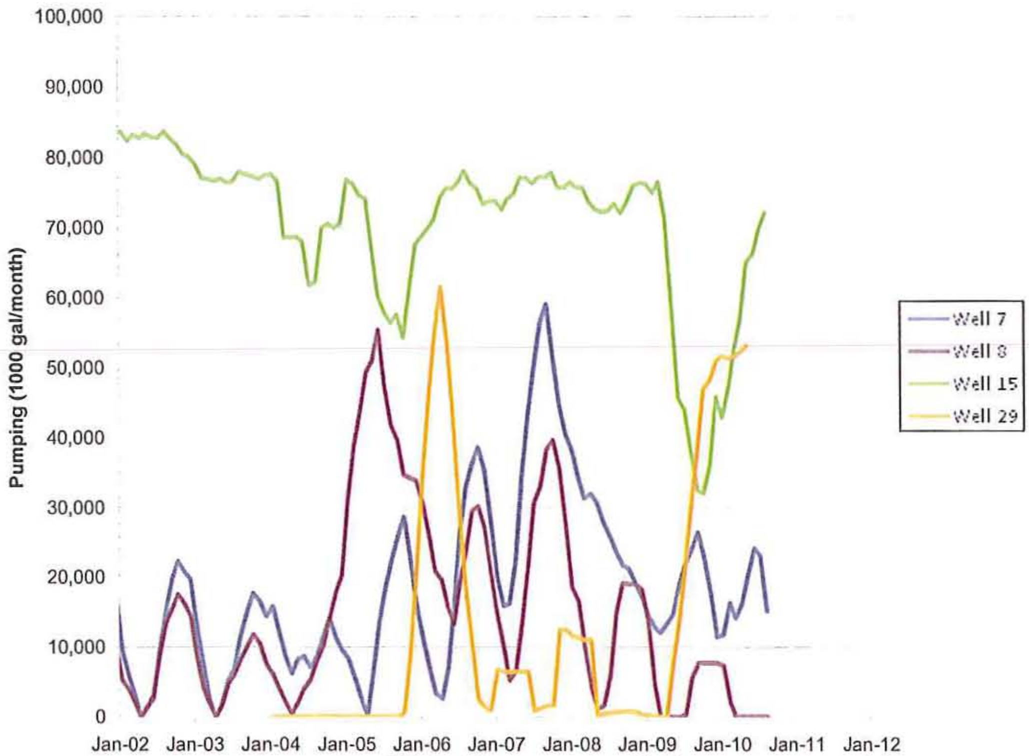

Figure 3. 12-month moving average pumping rate for January 2002 through mid-2010.

Water Quality Assessment for UW7, UW8, and UW15

Chloride as an Indicator of Groundwater Sources

Winter use of road salt has led to an increasing trend in chloride levels in Madison-area lakes for the past several decades (**Figure 4**). This trend has also been observed in the groundwater in some of the MWU's unit wells. This effect of road salt on the groundwater demonstrates the interaction between the surface and Madison's aquifers. Road salt can reach the aquifer through either direct recharge of water containing road salt, rainfall percolation through soil that contains residual road salt, or recharge of surface water containing road salt. **Figure 5** shows chloride trends in Unit Wells 7, 8 15 and 29 since the 1990s. Unit Well 29 is open only to the deep aquifer and has very low chloride concentrations. In contrast, UW15 has experienced a persistent increase in chlorides since at least 1993. The concentration is currently about 50 mg/L and increasing at a rate of about 2 mg/L per year. If it maintains this trend, it would require many years to exceed chloride's secondary drinking water standard (250 mg/L). However, the increasing chloride trend indicates that UW15 is susceptible to contaminants in the shallow aquifer, consistent with the increasing trend in PCE concentrations discussed later in this report.

Changes in sodium in groundwater are also associated with road salt affects on Madison's aquifers. While there is no MCL for sodium, the United States Environmental Protection Agency has issued a health-based drinking water guideline of 20 mg/l or less for individuals with a restricted sodium diet, and a concentrations exceeding 30 to 60 mg/L can create a taste issue[1]. The sodium concentration in UW15 is approaching this EPA guideline of 20 mg/L (**Figure 6**).

[1] City of Madison, 2009. Road Salt Report.

Chloride levels in UW7 and UW8 are slightly elevated, but lower than the current concentrations in the Madison lakes. Concentrations have fluctuated during the past decade with no clear trend. It appears likely that UW7 and UW8 are pumping some water from the shallow aquifer and/or lakes, with dilution by groundwater with lower chloride levels from the deep aquifer.

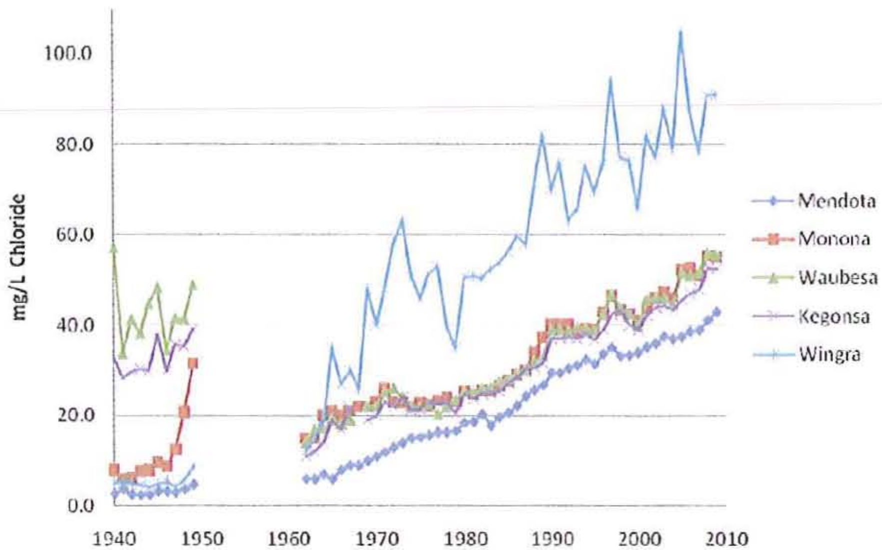

Figure 4. Chloride levels in Madison lakes (City of Madison 2008-2009 Road Salt Report)

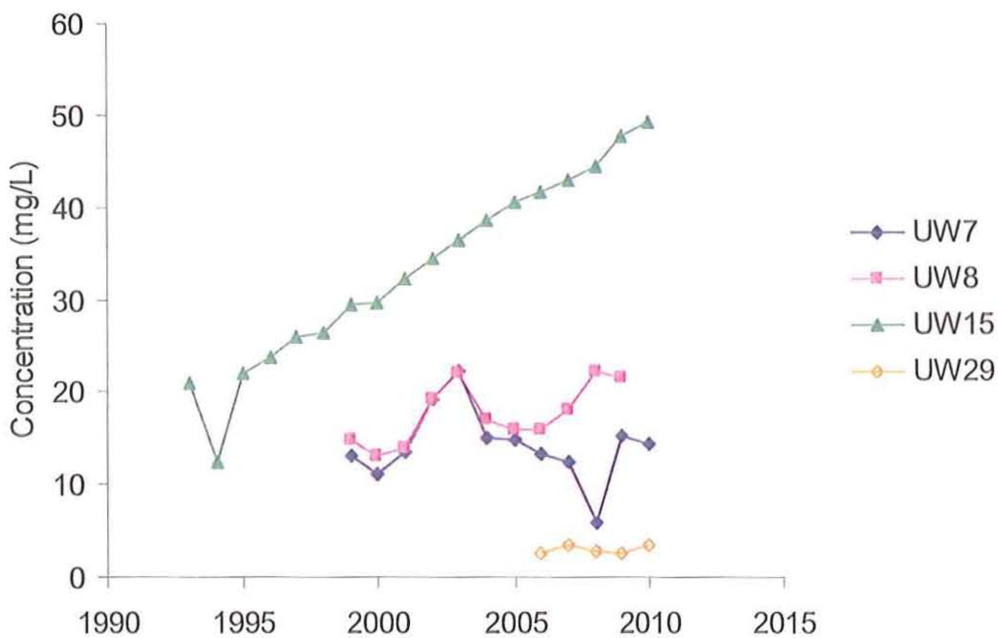

Figure 5. Chloride trends in UW7, 8, 15 and 29

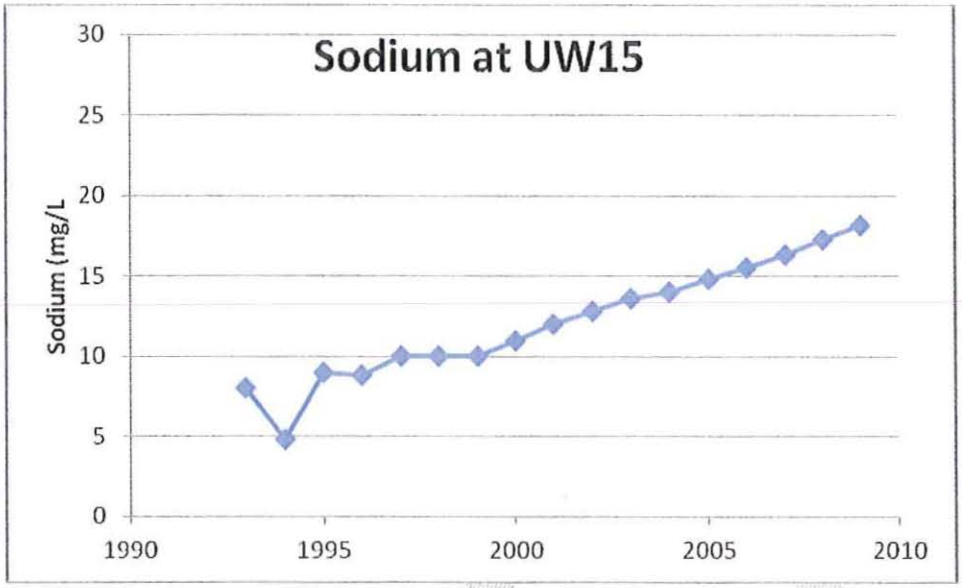

Figure 6. Sodium trend in UW15.

Iron and Manganese in UW7 and UW8

The Madison Water Utility collects water quality samples at least annually from each of its unit wells. Annual data for iron (Fe) and manganese (Mn) in Unit Wells 7, 8 and 15 are plotted in **Figures 7** and **8**. In addition, samples were collected each month for four years from 2006 – 2009; these results are plotted in **Figures 9** and **10**. Since 1999, a weak upward trend in Fe and Mn concentrations is apparent at UW8. No obvious trend is visible for UW7 or UW15. Unit Well 15 has much lower Fe and Mn than UW7 and UW8.

The probable cause of the difference in Fe and Mn between UW7/UW8 and UW15 is differences in the groundwater chemistry. Specifically, reducing conditions are present in the aquifer near UW7/UW8 and not at UW15. Under reducing conditions, Fe and Mn dissolve from the bedrock of the aquifer. The MWU does not routinely test for redox potential, however the MWU's sampling for nitrate, Mn, Fe, and SO_4 provides a very good indication of redox conditions. For example, nitrate has consistently not been detected in UW7 and UW8, where reducing conditions presumably have converted this aerobic species to a reduced species (e.g., ammonia or nitrogen gas). The nitrate concentrations at UW15 reflect surficial conditions, with a concentration of around 2 mg/L.

The reason for the difference in chemical (redox) conditions at UW7/UW8 and UW15 is likely caused by degradation of a carbon source near UW7 and UW8. Given the proximity of UW7 and UW8 to Lakes Mendota and Monona, and the likelihood that the Eau Claire Shale is missing below the lakes, one possible carbon source is induced flow of lake water through organic-rich lake bottom sediment. However, if UW7 and UW8 were strongly influenced by lake water, an upward trend in chloride in these wells would be expected. It is possible that the period of monitoring is not sufficient to detect such a trend, that lake water is being diluted in the wells by deeper groundwater, or that there is a different source of reducing conditions such as organic-rich glacial sediment deeper in the subsurface. In the future, stable or slightly increasing Fe and Mn concentrations are expected to persist at UW7 and UW8.

Insights from Unit Well 29

A study of UW29 completed in 2007 by MARS and RMT indicated that elevated Mn and Fe can be caused by naturally occurring conditions in the aquifer. Both Mn and Fe were found to be abundant in the rock solids of the aquifer at UW29, and the redox conditions leading to dissolution of Mn and Fe into the groundwater did not appear to be related to near-surface contaminants or interaction with surface water. New information is available from a sentry well installed between the landfill and UW29 [2], and review of this data suggests a similar conclusion as the 2007 work regarding the source of Mn and Fe. Note that the ratio of Mn to Fe at UW29 (before installation of the treatment system) was much higher than for either UW7 or UW8, suggesting that different chemical processes may be operating at UW7 and UW8, and that influence by near-surface conditions is possible.

The work at UW29 also evaluated the potential to capture contaminants from the nearby Sycamore Landfill. Although UW29 is open only below the Eau Claire Shale, there has been some concern about drawing in contaminants from shallow groundwater below the landfill. A 2007 pumping test at UW29 indicated some potential for movement of contaminants downward from the landfill and through the shale, although very limited data were available to evaluate this possibility. Based on this conclusion, the MWU decided to operate UW29 at approximately 50% of its average capacity to minimize its potential to capture contaminated groundwater from the landfill.

The new sentry well provides additional data to evaluate this risk. Data available to date indicate that the Eau Claire Shale may offer more protection to UW29 than suggested by the 2007 work. If true, the pumping rate of UW29 may be able to be increased while maintaining a low risk of capturing contaminants from Sycamore Landfill. Additional data from pumping UW29 and monitoring the effect on the sentry well would be needed to evaluate this possibility.

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[2] Gotkowitz, MB, JL Demorett, KR Bradbury, K Quinn and NR Zolidis, 2010. Depth-discrete groundwater monitoring near a water-supply well. American Water Resources Association Wisconsin Section poster presentation.

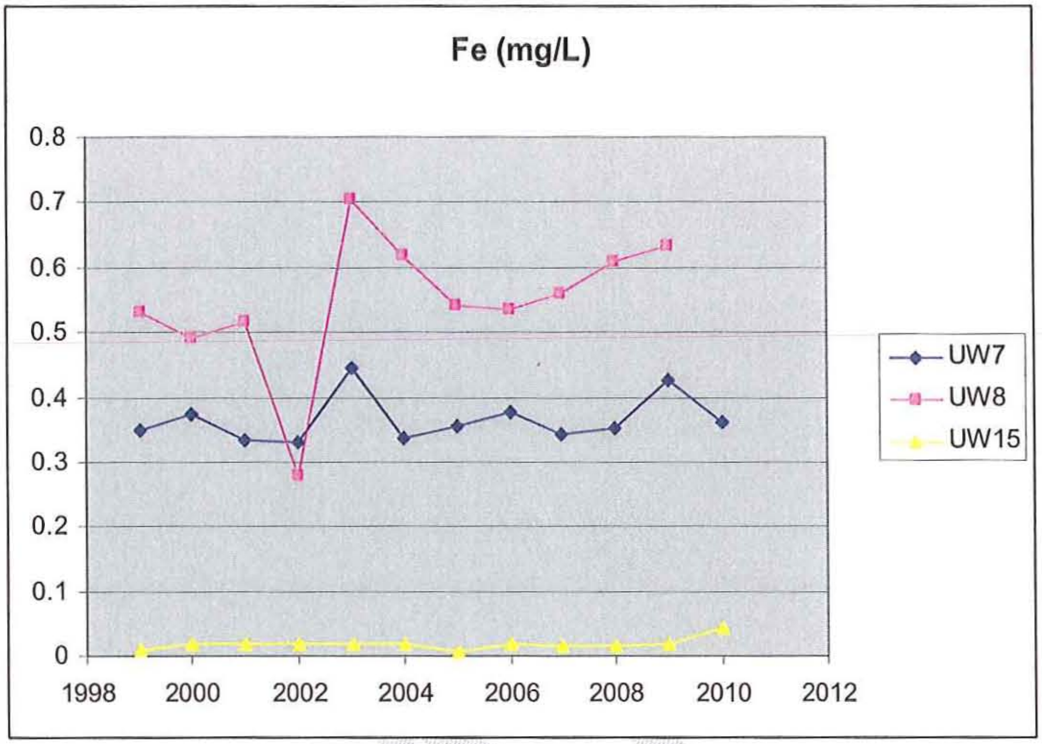

Figure 7. Annual iron concentrations in UW7, UW8 and UW15.

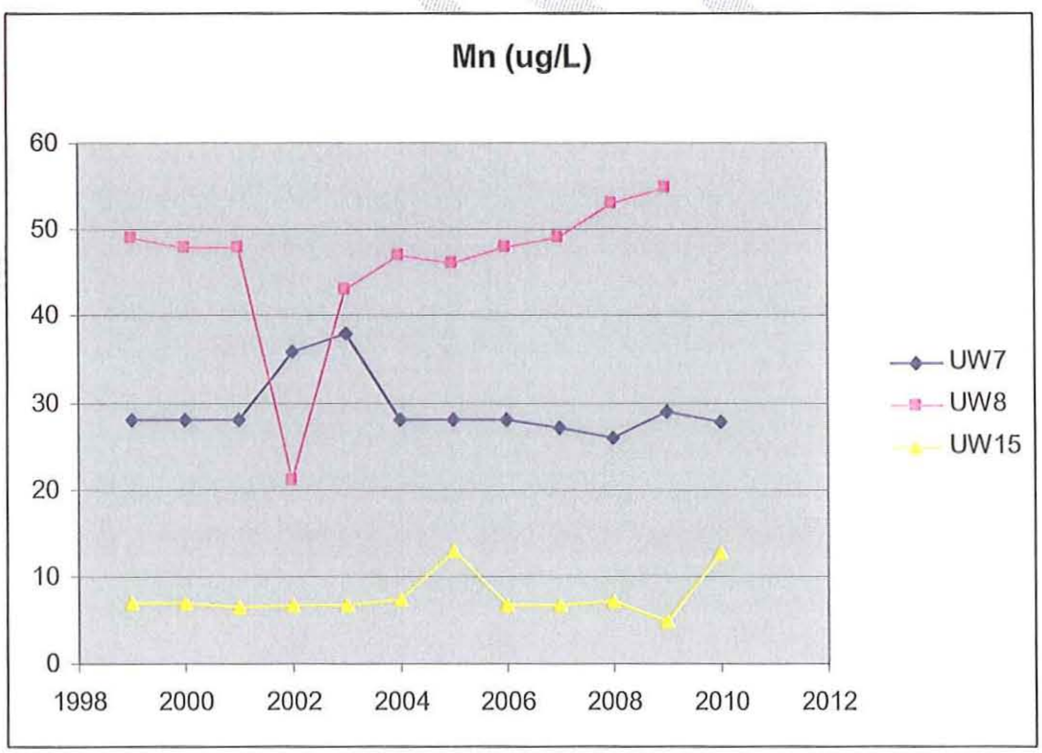

Figure 8. Annual manganese concentrations in UW7, UW8 and UW15.

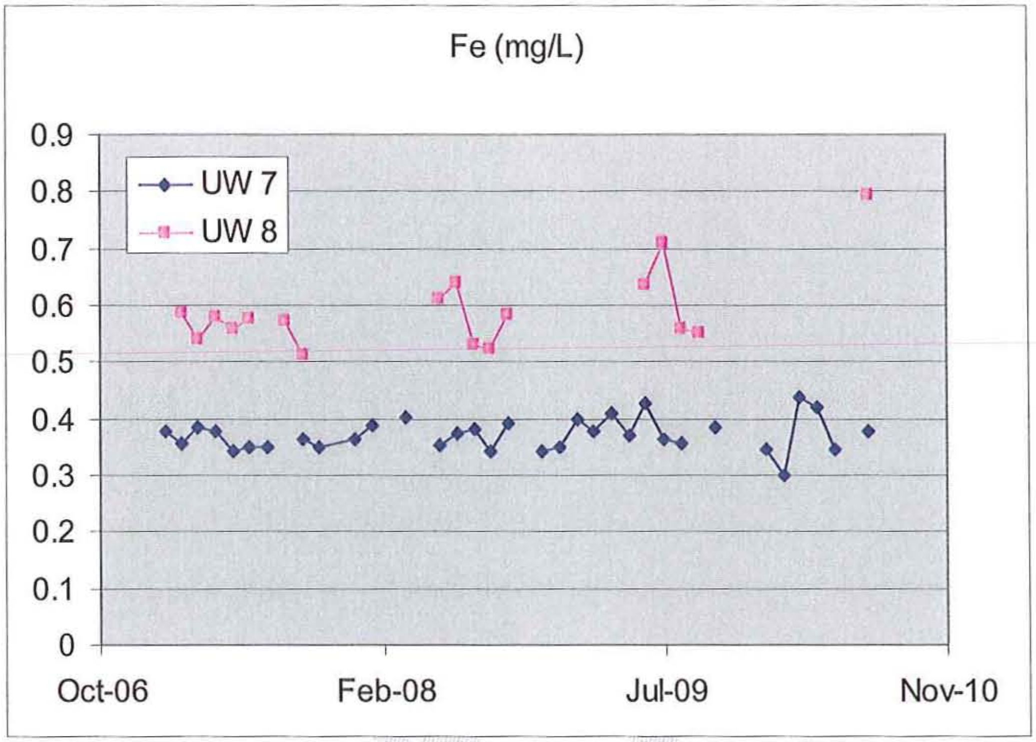

Figure 9. Monthly iron concentrations in UW7 and UW8.

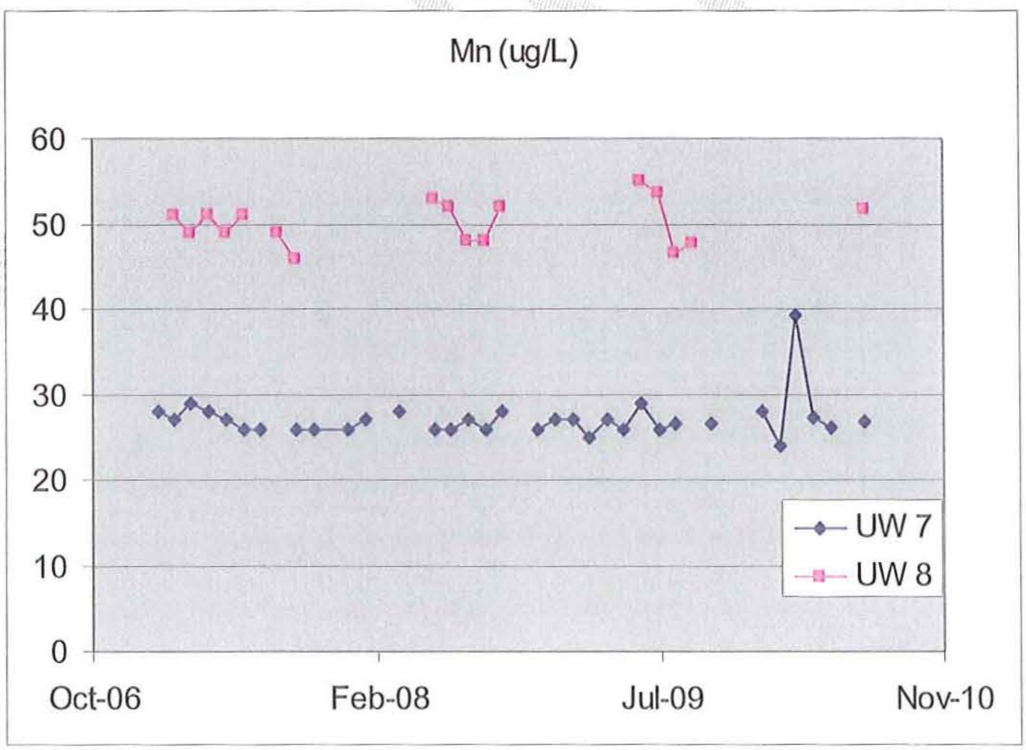

Figure 10. Monthly manganese concentrations in UW7 and UW8.

Volatile Organic Compounds in UW15

Volatile Organic Compounds (VOCs) are a class of contaminants that include petroleum compounds and industrial solvents, several of which are known carcinogens. The purpose for assessing VOCs at UW15 is to determine whether there are any changes in the construction or operation of Well UW15 or changes in the vicinity of well UW15 that could eliminate or significantly delay the potential for exceeding the Maximum Contaminant Level (MCL) at UW15. This assessment considers the UW15's water quality, pumping rates, and hydrogeologic setting.

Based on the well construction, hydrostratigraphic and chloride data discussed above, UW15 does not appear to be protected by a confining unit between the shallow and deep sandstone aquifers. This creates a direct connection to shallow groundwater and susceptibility to contaminates that originate near the land surface (**Figure 1**).

VOCs have been present since monitoring began in the late 1980s, as shown in **Figure 11**. Initial VOCs detected were PCE, TCE, and 1,1,1 TCA. In 1996, the TCE concentration started to decline and has leveled off at 0.33 ug/L in the last several years. This concentration is a small fraction of the 5 ug/l Maximum Contaminant Level (MCL), which is the concentration considered by the EPA acceptable for drinking water. . The 1,1,1-TCA has always been low relative to its MCL (200 ug/L) and has very generally followed the TCE trend, in that it has decreased over the last decade.

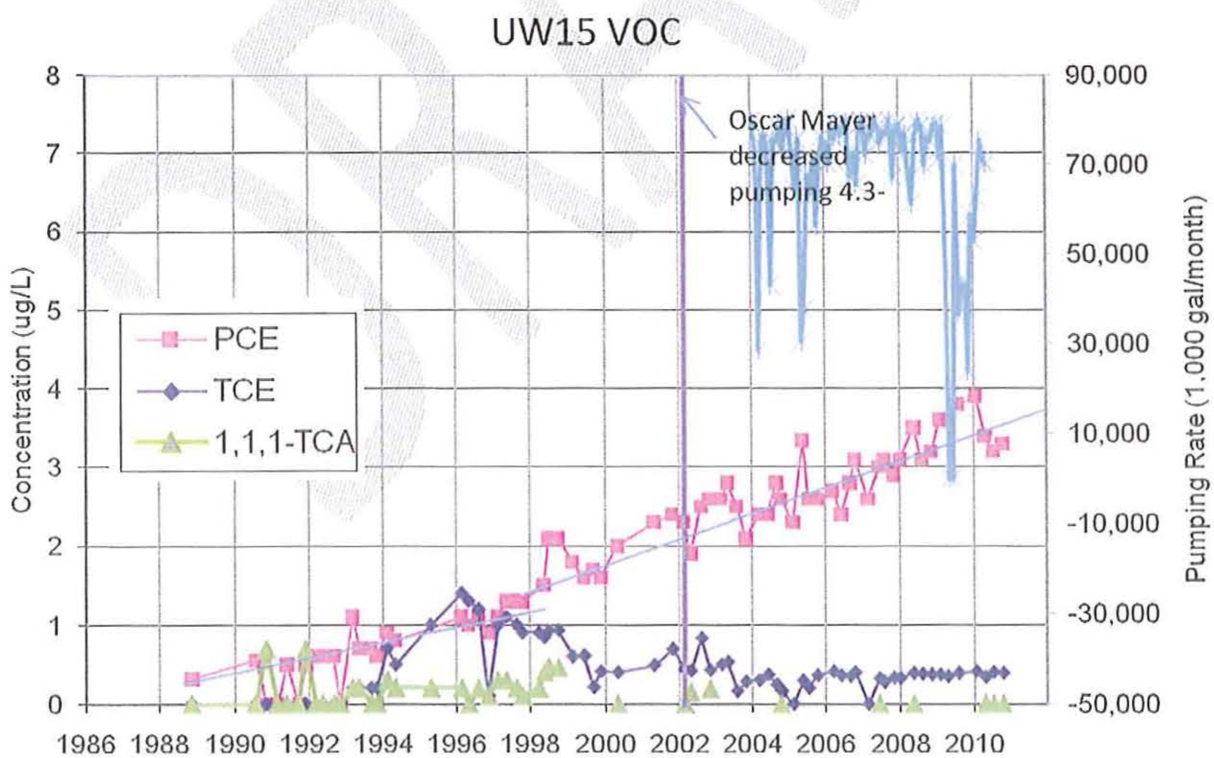

Figure 11. Volatile Organic Compound concentrations in UW15. Pumping rate shown in light blue.

The PCE concentration has an upward trend since monitoring started in November 1988. The trend is shown as two separate trend lines on **Figure 11**. From November 1988 through about May 1996, the PCE trend was similar to that for TCE, increasing at a relatively slow rate. From about May 1996 through October 2010, the rate of concentration increase has been slightly higher. If the recent trend continues, PCE will exceed the 5 mg/L standard within the next year or two.

The source of the VOCs and the pumping rates at well UW15 are important considerations in whether there is an opportunity to control the water quality at well UW15. The presence of a group of VOCs (PCE, TCE, and 1,1,1-TCA) in the late 1980s would suggest one type of source (e.g., a metals operation that used and released various solvents) or multiple sources (e.g., a metals operation that used and released TCE and 1,1,1-TCA, and a dry cleaner that used and released PCE). The fact that the TCE has not tracked with the PCE concentrations demonstrates that at least some of the TCE is from a source other than biodegradation of the PCE.

The drop in TCE and 1,1,1-TCA, while PCE concentrations increase indicate that:

- The source of some or all of the TCE and 1,1,1-TCA has been depleted or remediated; or
- The pumping rates of wells in the area have changed to shift the capture zone of well UW15 away from the source of TCE and 1,1,1-TCA.

The acceleration in rate of PCE increase at about the same time that TCE and 1,1,1-TCA started to decline suggests that a change in pumping rate of UW15 or a nearby well may have had an effect. The principal recent change in pumping on the east side was in 2002 when Oscar Meyer stopped pumping their wells. However, given this timing it cannot be the cause of the change in VOC trends at UW15 in 1996.

Between 2004 and 2010, UW15 has had two periods of time of decreased pumping rate[3] of more than one month duration, in approximately May through June 2005 and April 2009 through February 2010. During both of these periods, it appears that the PCE concentration at UW15 increased above the trend line. These increases have been small (less than 1 ug/L), but they are significant with respect to the change that would exceed the MCL (i.e., from about 3 ug/L to 5 ug/L). These small increases appear to be temporary, potentially because of the short-term reduction in pumping rate. A correlation between lower pumping rate and increased PCE concentration at UW15 would suggest that the PCE:

- Has a source relatively close to UW15;
- Would flow into or close to UW15 regardless of the pumping rate;
- Is entering the well from the shallow portion of the aquifer; and
- Can be diluted by pumping water from deeper zones of the aquifer.

Water quality in UW15 reflects shallow groundwater quality (i.e., road salt and probable dry cleaner solvent), presumably due to the short casing and likely lack of Eau Claire Shale. The relatively low iron and manganese concentrations at UW15 probably reflect shallow groundwater that is relatively aerobic (i.e., contains dissolved oxygen or nitrates) and is not sufficiently reducing to dissolve iron and manganese from the aquifer solids.

[3] Pumping rates that effect on groundwater flow directions and flow rates must be average rates over at least a month due to the slow rate of groundwater flow. Therefore, when talking about changing pumping rates, it is not the rate the well pump is pumping, it is the total volume pumped on a monthly basis (i.e., the well's average pumping rate and the duration it was run).

Preliminary Conclusions & Recommendations

UW7 and UW8

- Both wells are cased to the Eau Claire Shale, however the shale is has been mapped[4] as missing under the nearby lakes (**Figure 1**).
- No strong trend in Fe or Mn concentrations has been observed in either well.
- The absence of detectible nitrate in UW7 and UW8 support the conclusion that the elevated Fe and Mn are caused by reducing conditions in the aquifer.
- Reducing conditions are typically caused by degradation of a carbon source.
- The source of reducing conditions at UW7 and UW8 is unknown. One possibility is induced recharge through organic-rich lakebed sediment, however the lack of an obvious increasing trend in chloride at either well calls this possibility into question.
- Extending either well's casing deeper would probably not significantly improve the Fe and Mn concentrations, because the wells are already cased through the Eau Claire Shale. If the Fe and Mn concentrations are related to induced flow from the lakes, however, there could be some benefit to extending the casing and creating a longer flow path from the lakes to the well.
- Wellhead sampling for stable isotopes could provide additional insight into the degree of lake water influence on UW7 and UW8 and provide additional information on possible causes of the elevated Fe and Mn, as well as potential solutions.

UW15

- It is unclear whether the Eau Claire Shale is present.
- The source of PCE is probably from a dry cleaner or other sole use of PCE.
- The source of PCE appears to be relatively close to UW15.
- The increasing PCE and chloride concentrations indicate a strong connection with the shallow groundwater system (**Figure 1**). This underscores the need for wellhead protection and watershed management to protect source water quality.
- If the recent trend continues, PCE may exceed the 5 mg/L standard within the next year or two.
- The rise in PCE concentration is expected to continue, at least in the near future, regardless of the pumping rate. Eventually the source of PCE will be depleted, but this could take many years.
- It may be possible to manage PCE concentrations by:
    - Maintaining a relatively high average monthly pumping rate to dilute the PCE; or
    - Extending the casing deeper to draw less shallow groundwater and more water from deeper parts of the aquifer.

[4] Based on bedrock topography in Cline (1965), Groundwater Resources of Dane County, Wisconsin. USGS Water Supply Paper 1779-U.