MEMORANDUM

Date: December 23, 2014

To: Water Utility Board

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Re: **Well 31 Energy Use and Upper Aquifer Well Alternative Evaluations**

Project: **Well 31 – Facility Design and Construction**

Introduction

At the November 2014 Water Utility Board Meeting we submitted a request for approval of the recommended Unit Well 31 design concept to allow the project team to proceed to final design of the proposed facility located at 4901 Tradewinds Pkwy. At that meeting the Board requested that we refer the request to allow for further energy and operational analysis to be completed. The requested analysis specifically included evaluation of the anticipated energy use of the proposed iron manganese filtration system and the consideration of potential operational savings that may be realized using a supplemental upper aquifer well. This report describes and summarizes these evaluations including our associated conclusions and recommendation.

Energy and Operational Analysis Scenarios

Four proposed operational scenarios were prepared to evaluate the amount of energy expected to be consumed by pumping and treatment operations. There is interest in determining if partially bypassing treatment or mixing water sources could reduce treatment requirements subsequently reducing energy costs. All proposed scenarios would meet or exceed Madison Water Utility's water quality goal for iron (0.10 mg/L) and manganese (20 ug/L). The four scenarios are described below:

- Scenario 1: Pump and treat from the lower aquifer at 2,200 gpm.
- Scenario 2: Pump from the lower aquifer at 2,200 gpm and treat only a portion of the water to meet the water quality goal of 0.10 mg/L for iron.

- Scenario 3: Drill a new upper aquifer well and pump at 640 gpm with no treatment. Pump and treat 1,560 gpm from the lower aquifer for a total supply of 2,200 gpm.
- Scenario 4: Drill a new upper aquifer well and pump at 640 gpm with no treatment. Pump from the lower aquifer well at 320 gpm with no treatment and blend to meet the water quality goal of 0.10 mg/L for iron.

Scenario Assumptions: The 2025 average day demand of Pressure Zone 4 is projected to be 1.4 million gallons per day (mgd). Of the 1.4 mgd, Well 31 is proposed to produce 0.7 mgd and Well 9 is proposed to produce 0.7 mgd for reliability within the zone. For the purposes of this analysis, for scenarios 1 through 3, the available supply pumping capacity is equal at 2,200 gpm with varying pump operation considerations in each scenario. Scenario 4 results in a limited supply capacity of 960 gpm or 1.38 mgd. The high lift pumps were assumed to also produce 0.7 mgd. At 2,200 gpm, the high lift pumps for unit well 31 would operate 5.3 hours per day. Pumping energy optimizations through variable frequency drive motor controls are described in greater detail within the attached 'Unit Well 31 – Energy Analysis Graduate Research Project' Memorandum.

Madison Gas and Electric provided information for peak electrical charges, and for this analysis peak occurrences were assumed during the time frame of 10 AM to 9 PM. Typically, water utilities operate to minimize pumping during peak electrical charge periods. For the purposes of this study, pumping will be considered evenly distributed throughout the day, and peak charges will be applied to 11 hours per day, or 46 percent of the total projected operating time of each pump.

Electrical power prices for both summer and winter were also provided by Madison Gas and Electric. The 2013 PCS Annual Report showed that 54 percent of water used during the year occurred during the months of April through September. Likewise, 46 percent of water use occurred during the months of October through March. Summer water rates were applied to 54 percent of the pumping, and winter rates were applied to 46 percent of the pumping.

Energy use is directly related to flow and vertical lift or pressure. The deep aquifer has a measured static water level of 35 feet below ground surface (bgs) with a specific capacity of 9.18 gpm/ft. The shallow aquifer was investigated in November and December 2012 and was found to have a static water level of 35 feet bgs with an estimated specific capacity of 4.0 gpm/ft. The drawdown for the deep aquifer was calculated with a pumping rate of 2,200 gpm for Scenarios 1 and 2 and 1,560 gpm for Scenario 3. The maximum potential drawdown for the shallow aquifer was estimated to be 160 feet. This calculates to an estimated maximum pumping rate of 640 gpm. It could be less.

While head losses are minor compared to vertical lift, head loss was still considered in the computations. For all scenarios, the process piping configuration for Scenario 1 was assumed. Horsepower requirements and associated energy used in treatment was applied separately as a pressure loss assumption within each pumping scenario. For these evaluations, water that passed through treatment had an assumed 8 psi average loss across the pressure filters. The pressure filters range in pressure loss from 2-5 psi when clean to 10-15 psi when fully saturated. Total dynamic head conditions are detailed in Appendix C of the Well 31 Design Basis Report.

Appendix R contains cost estimates for daily and annual energy consumption for each scenario. High lift pumping was considered to be the same in all scenarios. High lift pumping is estimated to cost $49 per day during summer months and $45 per day during winter months. The total energy cost for high lift pumping is estimated to be $9,600 during the summer months and $7,600 during the winter months, totaling $17,200 per year for high lift pumping.

Shallow Aquifer Well Considerations: The shallow aquifer is limited in its ability to provide water. A geologic cross section is shown in Appendix U. The existing deep well is cased just below the shaley sandstone confining layer to a depth of 316 feet. The shallow well would need to terminate a minimum of 15 feet above the top of this confining unit, at a depth of approximately 280 feet. A casing would be required to extend through the existing sand and gravel overburden into the top of rock formation at a depth of approximately 200 feet. The static water level in the upper aquifer is the same as the lower aquifer at 35 feet bgs. With a specific capacity of 4.0 gpm/ft, the aquifer could sustain a pumping capacity range from 400-640 gpm. Test pumping provided by the Utility and the geological cross section shown in Appendix U indicate the aquifer may not be capable of producing more than 640 gpm.

Wisconsin Administrative Codes do not require specific separation distances between water supply wells. In theory, the Eau Claire Shale confining layer should prevent well-to-well drawdown impacts and interactions, however in reality the Eau Claire shale layer is not perfectly confining. For that reason and potential well construction impacts, a well separation distance of less than 50-ft would not be considered for this concept and would require the supplementary well to be sited beyond the footprint of the main facility structure. A site plan indicating a potential location of a shallow aquifer well and well house is included in Appendix S.

Given that an upper aquifer well has greater risk for groundwater contamination compared to a lower aquifer well, and considering the proposed pumping rates and the known groundwater contamination plumes in the local area, installation of several monitoring wells would be certainly be required if the upper aquifer concept is pursued at this location.

Evaluation of Proposed Scenarios

Scenario 1: Pump and treat from the lower aquifer at 2,200 gpm: Scenario 1 involves pumping 2,200 gpm from Well 31 and treating 100 percent of flow to a finished iron concentration of approximately 0.02 mg/L. Figure Q-1 in Appendix Q shows a schematic of Scenario 1. The 340 HP rated motor on a VFD is expected to operate at a slightly lower speed with a typical electrical draw of 243 kW. To produce 0.7 mgd, the 2,200 gpm pump is expected to operate 5.3 hours per day, 2.4 hours on peak and 2.9 hours off peak.

The energy costs are summarized in Table R-1 in Appendix R. For all scenarios, about $17,200 per year is expected due to high lift pumping. The total estimated pumping cost for Scenario 1 is $53,000 per year with approximately $36,000 per year due to well pumping and pressure requirements in the water treatment processes.

The operations and maintenance costs are summarized in Table V-1 in Appendix V. The total estimated operational cost and maintenance cost is $44,000 per year.

Scenario 2: Pump from the lower aquifer at 2,200 gpm and treat only a portion of the water to meet the water quality goal of 0.10 mg/L for iron: Scenario 2 involves pumping 2,200 gpm from Well 31 and treating approximately 73 percent of flow to a finished iron concentration of approximately 0.02 mg/L and bypassing 27 percent of the flow with no treatment. Figure Q-1 in Appendix Q shows a schematic of Scenario 2. The 340 HP rated motor on a VFD is expected to operate at a slightly lower speed with a typical electrical draw of 243 kW during treatment and at an even lower speed at 205 kW when bypassing treatment. To produce 0.7 mgd, the 2,200 gpm pump is expected to operate 5.3 hours per day, 2.4 hours on peak and 2.9 hours off peak. 1.4 of the hours are expected to bypass the plant, and 3.9 hours are expected to be treated.

The energy costs are summarized in Table R-2 in Appendix R. For all scenarios, $17,200 per year is expected due to high lift pumping. The total estimated pumping cost for Scenario 2 is $51,000 per year with approximately $34,000 per year due to well pumping and pressure requirements in the water treatment processes. Compared to Scenario 1, the reduction in annual pumping energy cost by not treating a portion of the flow was not substantial.

The operations and maintenance costs are summarized in Table V-2 in Appendix V. The total estimated operational cost and maintenance cost is $52,000 per year. Compared to Scenario 1, the operations and maintenance cost estimate assumes an additional 15 minutes of daily inspection and testing due to the blending process and an additional 96 hours per year for additional water main flushing efforts in the south half of Pressure Zone 4 because of increased iron concentrations. Also, because of the reduced treatment effort one less chlorine cylinder is anticipated per month. Compared to Scenario 1 the total estimated operational and maintenance costs were $8,000 more per year.

Estimated annual operating costs for Scenario 2 are approximately $6,000 more than for Scenario 1.

Scenario 3: Drill a new upper aquifer well and pump at 640 gpm with no treatment. Pump and treat 1,560 gpm from the lower aquifer for a total supply of 2,200 gpm: Scenario 3 involves drilling a new shallow well on site and mixing shallow aquifer water with treated deep aquifer water. The new shallow well would be pumped at approximately 640 gpm and Well 31 would be pumped at approximately 1,560 gpm. It was assumed that 50 percent of the 0.7 mgd volume would be provided by the new shallow well. Figure Q-3 in Appendix Q shows a schematic of Scenario 3. To produce 0.7 mgd, the deep well pump is expected to operate 3.7 hours per day and the shallow well pump is expected to operate 9.1 hours per day.

The energy costs are summarized in Table R-3 in Appendix R. For all scenarios, $17,200 per year is expected due to high lift pumping. The total estimated pumping cost for Scenario 3 is $41,000 per year with approximately $24,000 per year due to well pumping. Compared to Scenario 1, the reduction in annual pumping energy cost by not treating a portion of the flow was approximately $12,000.

A site plan indicating a potential location of a shallow aquifer well and well house is included in Appendix S.

The operations and maintenance costs are summarized in Table V-3 in Appendix V. The total estimated operational cost and maintenance cost is $54,000 per year. Compared to Scenario 1, the operations and maintenance cost estimate assumes an additional 30 minutes of daily inspection and testing due to the second supply well system and one additional equipment repair because of the additional equipment proposed in this scenario. Also, because of the reduced treatment effort 1.5 fewer chlorine cylinders are anticipated per month. Compared to Scenario 1 the total estimated operational and maintenance costs were $10,000 more per year.

Estimated annual operating costs for Scenario 3 are approximately $2,000 less than for Scenario 1.

Scenario 4: Drill a new upper aquifer well and pump at 640 gpm with no treatment. Pump from the lower aquifer well at 320 gpm with no treatment and blend to meet the water quality goal of 0.10 mg/L for iron: Scenario 4 involves drilling a new shallow well on site and mixing shallow aquifer water with deep aquifer water. The new shallow well would be pumped at approximately 640 gpm and

Well 31 would be pumped at approximately 320 gpm. Approximately 69 percent of the 0.7 mgd volume would be provided by the new shallow well to meet the finished iron concentration of 0.1 mg/L. Figure Q-4 in Appendix Q shows a schematic of Scenario 4. To produce 0.7 mgd, the deep well pump is expected to operate 11.3 hours per day and the shallow well pump is expected to operate 12.6 hours per day.

The energy costs are summarized in Table R-4 in Appendix R. For all scenarios, $17,200 per year is expected due to high lift pumping. The total estimated pumping cost for Scenario 3 is $34,000 per year with approximately $17,000 per year due to well pumping. Compared to Scenario 1, the reduction in annual pumping energy cost by not treating was approximately $19,000.

A site plan indicating a potential location of a shallow aquifer well and well house is included in Appendix S.

The operations and maintenance costs are summarized in Table V-4 in Appendix V. The total estimated operational cost and maintenance cost is $53,000 per year. Compared to Scenario 1, the operations and maintenance cost estimate assumes an additional 30 minutes of daily inspection and testing due to the second supply well system and one fewer equipment repair because of the elimination of the treatment equipment proposed in this scenario. Because of the reduced treatment effort two fewer chlorine cylinders are anticipated per month. Also, an additional 96 hours per year for water main flushing efforts are anticipated in the south half of Pressure Zone 4 because of increased iron concentrations. Compared to Scenario 1 the total estimated operational and maintenance costs were $9,000 more per year.

Estimated annual operating costs for Scenario 4 are approximately $10,000 less than for Scenario 1.

Maximum summer water supply demands for Pressure Zone 4 are projected to range from 2.3 to 2.7 mgd. Water supply requirements for PZ 4 are to provide adequate supply capacity for maximum demand with one source out of service. With Well 9 out of service, a two well configuration at Tradewinds Parkway would not be able to meet maximum demands. Therefore Scenario 4 does not meet the basic reliability and redundancy objective of this project. Scenario 4 was developed to consider the feasibility of utilizing the upper aquifer water supply to blend with lower aquifer water at a ratio that would meet project water quality requirements while simultaneously reducing pumping costs. Based on the water quality of the lower aquifer, the required 2:1 blending ratio to attain a 0.1 mg/l iron concentration restricts the total available supply capacity of this scenario to below 1,000 gpm. With the two wells located at Tradewinds Parkway limited to less than 1.4 mgd, Scenario 4 will not be considered further. Capacity limitation is considered to be a fatal flaw.

Unit Well 31 Facility Design Considerations

As presented at the November 2014 Water Utility Board Meeting, two concepts for Unit Well 31 had been developed and presented for final design consideration. The concepts are primarily based on a detached potable water ground storage facility and an attached potable water ground storage facility. Only the arrangement of the facilities and the style of the tanks vary between the options and not the fundamental design constraints. To recap, the preliminary design concepts presented were as follows:

Option 1: Option 1 is comprised of a pumping/filtration facility, separate backwash room with steel tanks and chemical feed rooms all located within one building shell. Treated ground water is pumped to a detached 1.5 million gallon wire wound cylindrical concrete potable water ground storage tank. This facility also includes an attached storage building of a minimum size of 2400 sf. The exterior work would include a dual drive way, paved driveway entrance, two 20-foot sliding gates into a storage yard facility. The storage yard facility will be used to store yard piping such as ductile iron pipe, hydrants, and valves used by the utility. Surrounding the 1.5 million gallon reservoir would be a drivable landscape surface for maintenance type access and security.

Option 1A: Option 1A is generally the same as Option 1 but with a smaller square footage building, comprised of pumping/filtration facility room, and chemical feed rooms, and would consist of a concrete back wash tank all accessible from the pumping/filtration room and located within one building shell.

Option 2: Option 2 would be comprised of a pumping/filtration facility, chemical feed rooms, and a concrete back wash tank all accessible from the pumping/filtration room and located within one building shell. The treated water would be pumped to an attached rectangular 1.5 million gallon storage tank which would be cast in place with a concrete sloped cover. This facility also includes an attached storage building of a minimum size of 2,400 sf facing west. The exterior work would include a dual drive way, paved driveway entrance, a 20-foot sliding gate entrance and one 16-foot sliding gate exit within yard facility. The storage yard facility will be used to store yard piping such as ductile iron, hydrants, and valves used by the utility. Surrounding the entire complex would be an asphaltic surface driveway for building security and maintenance type access.

Option 2A: Option 2A is generally the same as Option 2, comprised of pumping/filtration and would consists of separate backwash room with two steel tanks and chemical feed rooms all located within one building shell with only interior process piping necessary to fill the potable water tank. The attached storage building would be rotated 90 degrees and now faces north maintaining a minimum size of 2,400 sf storage facility.

Facility Concept Recommendation: As a result of MWU staff comments, Public Informational Meeting comments and current budgets Option 1A and Options 2 were further modified to include a smaller footprint and to provide two interior concrete backwash tanks. The rectangular concrete backwash water ground storage tanks typically have a higher volume versus foot print and the slightly lower maintenance costs as describe in Appendix O of the previously submitted Well 31 Design Basis Report. Concrete backwash tanks typically require minimal routine maintenance, and may only require localized repairs with pitting in the concrete as the years pass. See Appendix P of the Well 31 Design Basis Report for the revised Option 1A and Option 2 building foot print, isometric views, cost estimates.

The estimated costs of the water treatment facility and storage facility are equal in Options 1A and Option 2, $3,764,000 and $390,000 respectively. The detached wire wound cylindrical concrete ground storage tank in Option 1A has an estimated cost of $1,315,000. The attached rectangular concrete tank in Option 2 has an estimated cost of $2,579,000. The total estimated capital cost of Option 1A is $5,469,000 and the total estimated capital cost of Option 2 is $6,733,000, which is a difference of $1,264,000. MWU currently has $5.7 Million budgeted for the project.

Pumping Facility Decision Matrix (Scale 1 – 3: 1 = Least Desirable, 3 = Most Desirable)				
Scenario	**Option 1**	**Option 1A**	**Option 2**	**Option 2A**
Aesthetics	**2**	**2**	**2**	**2**
Operation and Maintenance	**1**	**2**	**2**	**1**
Capital & Construction Costs	**3**	**3**	**1**	**1**
1.5 MG Life Cycle Cost	**2**	**3**	**1**	**1**
Total Score	**8**	**10**	**6**	**5**

(Most Desirable Facility)

Based on a review of these revisions and the facility matrix evaluation it is recommended that Option 1A be constructed with a unit well building square footage of 4,052, a 3,900 square foot storage building two rectangular concrete backwash tanks above grade and one 1.5 MG wire wound cylindrical concrete potable water ground storage tank due to the lower capital and life cycle costs compared to

Option 2. The Option 1A facility configuration recommendation remains regardless of the operational/pumping scenario recommended for the project.

Operational Impacts on Capital Costs

The cost implications of the four operational scenarios were incorporated into the capital cost estimates for the recommended facility Option 1A.

Scenario 1: Pump 2,200 gpm from Deep Aquifer in Existing Well 31: The total estimated capital cost for facility Option 1A, operating with Scenario 1 pumping conditions is $5,470,000 as shown in Table T-1 in Appendix T.

Scenario 2: Pump 2,200 gpm from Deep Aquifer in Existing Well 31 and Treat a Portion to meet 0.1 mg/L Iron: The total estimated capital cost for facility Option 1A, operating with Scenario 2 pumping conditions is also $5,470,000 as shown in Table T-2 in Appendix T. Scenario 2 is equivalent to Scenario 1 except small amount of additional water main and controls would be required to bypass the facility. Only about one-fourth of the flow could be bypassed while maintaining 0.1 mg/L iron. Scenario 2 assumes 100 percent of flow passes through the plant for approximately 75 percent of pumping time, and then 100 percent of the flow is diverted around the plant for approximately one-fourth of the time.

Technically, MWU could potentially construct three-fourths of the filters and bypass one-fourth of the flow continuously. However, the relative cost of 12 filters versus 16 filters and the future cost to install the remaining four filters would make constructing 12 filters now and potentially 4 later more costly in the long run. Pressure filters are more cost effective when installed during the construction of the plant and not as cost-effective when being installed in a finished and operating facility. Also, a final treated water iron concentration of 0.02 mg/L was assumed, based on the pilot study, but actual treated concentrations could vary from 0.01 to 0.04 mg/L and would change allowable the bypass volume, changing the number of required filters.

Scenario 3: Pump and Treat 1,560 gpm from Deep Aquifer in Existing Well 31 and Mix with New Shallow Well: The total estimated capital cost for facility Option 1A, operating with Scenario 3 pumping conditions is $5,802,000 as shown in Table T-3 in Appendix T. The treatment facility cost estimate for Scenario 3 is approximately $350,000 lower than Scenarios 1 and 2 due to the reduction in treatment equipment and process piping. Scenario 3 would require 12 filters (totaling 143 ft^2) rather than the 16 filters (totaling 201 ft^2 in Scenarios 1 and 2). However, that reduction is offset by the need to construct a new well at a cost of approximately $680,000. The total capital cost of this option is estimated to be approximately $330,000 greater than Scenarios 1 and 2. The estimated operational and maintenance savings under this Scenario were approximately $2,000 per year as stated earlier.

Scenario 4: Pump 320 gpm from Deep Aquifer in Existing Well 31 and Mix with New Shallow Well to meet 0.1 mg/L Iron: The estimated capital costs for Scenario 4 were not prepared because this Scenario did not meet project objectives due to supply capacity limitations. Operational Scenario 4 is not being considered for the proposed Well 31 project.

Conclusion & Recommendation

An evaluation matrix is presented below for Deep Well and Shallow Well Scenarios 1 through 3. The matrix ranks each alternative based upon energy use, operation and maintenance, costs, and reliability.

Well 31 Operational Scenario Decision Matrix (Scale 1 – 3: 1 = Least Desirable, 3 = Most Desirable)			
Alternative	**Scenario 1:** **Pump 2,200 gpm from Deep Aquifer in Unit Well 31**	**Scenario 2:** **Pump 2,200 gpm from Deep Aquifer in Unit Well 31 and Treat a Portion to meet MWU standards of 0.1 mg/L Iron**	**Scenario 3:** **Pump and Treat 1,560 gpm from Deep Aquifer in Existing Well 31 and Mix with New Shallow Well**
Energy Use	2	2	3
Operation & Maintenance	3	1	2
Capital Costs	3	3	1
Reliability	3	2	2
Water Quality	3	2	3
Operational Complexity	3	2	1
Distribution System Impacts	3	2	3
Totals	**20**	**14**	**15**

(Most Desirable Pumping Scenario)

Based on a review of the Well 31 Operational Scenario Decision Matrix evaluation it is recommended that pumping Scenario 1 be recommended for facility design concept 1A.

Further energy optimization measures will be evaluated and implemented to maximize operational efficiency of the proposed facility. Efforts such as optimizing the proposed VFDs, off-peak pumping and seasonal use of Well 31 will be incorporated into the overall facility operation plan. Additional information regarding Well 31 and Pressure Zone 4 pumping optimization through VFDs is described within the attached 'Unit Well 31 – Energy Analysis Graduate Research Project' Memorandum.

Attached:

- Appendix Q – Schematic Diagrams of Proposed Operational Scenarios
- Appendix R – Anticipated Energy Costs by Operational Scenario
- Appendix S – Proposed Upper Aquifer Well Location on Well 31 Site Plan
- Appendix T – Estimated Capital Costs by Operational Scenario
- Appendix U – Geologic Cross Section of Proposed Well 31 Site
- Appendix V – Estimated Operational & Maintenance Costs by Operational Scenario
- Unit Well 31 – Energy Analysis Graduate Research Project Memorandum