UNDERWOOD engineers

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TECHNICAL MEMORANDUM

To:	Sean Greig, Water & Sewer Superintendent	File: 2242.08
From:	Michael Metcalf, P.E.	
cc:	Keith Pratt, P.E.	
Date:	April 23, 2018	
Re:	**MacIntosh & Tucker Wells Treatment Evaluation**	

BACKGROUND

The Town of Newmarket has been dealing with limited water supply since a decision was reached in 2005 not to upgrade or replace their surface Water Treatment Plant to meet more stringent water quality regulations. With its two gravel packed wells, the Bennett and Sewell Wells, the Town was not in compliance with NHDES source water capacity criteria which require meeting average day demand with the largest well out of service. In 2006, the Town initiated a search for bedrock aquifer groundwater supplies which resulted in development and permitting of the MacIntosh and Tucker Wells. In response to a directive by NHDES, the Town completed a Corrective Action Plan (CAP) indicating how the Town would increase its source water capacity. The CAP, which was submitted and accepted by NHDES in May of 2012, provided a proposed schedule for placing the MacIntosh Well, into service.

The MacIntosh Well, which has been permitted at 300 gpm (432,000 gpd), has water with high sodium, chloride, TDS, and manganese concentrations that approach or exceed the secondary MCL's (SMCL's). In addition, arsenic is close to, and sometimes just at the primary MCL. The Town evaluated treatment with a membrane process known as Electrodialysis Reversal (EDR), putting the well on-line as is, and blending with the existing wells to try to reduce the concentrations of the previously mentioned contaminants to below the MCL's and SMCL's. Blending was the selected alternative and the Town completed a Blending Facility on Durell Drive. Water from the distribution system (i.e. Bennett and Sewell Well water) is directed into the Blending Facility where it is mixed with water pumped from the MacIntosh Well. The blend is then re-pumped into the system. Based on the results of a corrosion control analysis, NHDES provided startup conditions that dictated a maximum allowable percentage of 60% MacIntosh water in the blend. The blend was initiated at a ratio of about 30% MacIntosh water in the fall of 2016 and is currently at 60% MacIntosh water.

However, even with the MacIntosh well on line, there are still supply limitations. At 300 gpm, the MacIntosh Well is now the Town's largest well. If it is out of service, the Bennet and Sewell Wells can meet average day demand, but the Plains Aquifer, in which both wells are located, receives limited recharge and in the past has been drawn down to the extent that the pumping rates of the Bennett and Sewell Wells had to be cut back. To increase available water supply, the Town desires to: 1) bring the Tucker Well on line, and 2) use the MacIntosh Well as an independent source without the need to have the Bennett and/or Sewell Well on-line. The

Tucker Well has arsenic above the primary standard of 0.01 mg/L, manganese close to the secondary standard of 0.05 mg/L, and elevated sodium and chloride levels, although not as high as those in the MacIntosh Well. Due to the arsenic level, the Tucker Well would require either treatment or blending to reduce the concentration below the MCL. Similarly, the MacIntosh Well may require treatment in order to use it as a stand-alone source. To meet the goals for using these two wells, the Town required an evaluation of the following:

- The necessary treatment for the Tucker Well
- Whether blending this water with MacIntosh Well water will result in acceptable water quality
- Whether treatment should be installed to treat both MacIntosh and Tucker Well water at the site of the current blending facility
- The probable cost of the most advantageous blending or treatment scenario

SCOPE OF WORK

To meet the goals of the Town of Newmarket, a scope of work was developed which is summarized below:

- Review water quality of all wells and the current blend
- Determine the level of treatment required for:
  - Tucker Well alone
  - MacIntosh Well alone
  - Blend of Tucker and MacIntosh Wells
- Evaluate up to three treatment options and likely finished water quality
- Complete conceptual cost opinions for the options evaluated
- Recommend a treatment option
- Prepare a Technical Memorandum

WATER QUALITY REVIEW

When reviewing water quality, results are generally compared to the MCL or SMCL. In some cases, such as sodium, there is no SMCL, so the allowable concentration is up to the water purveyor. In terms of treatment, target treated water concentrations are usually at least the MCL or SMCL and typically lower. In the *Draft Pilot Study Report-MacIntosh Well Treatment Alternatives (Weston & Sampson, December 2012)* the following treatment target concentrations were established for the EDR and Blending alternatives.

- Total Dissolved Solids (TDS): <250 mg/L
- Sodium: <75 mg/L
- Chloride: <125 mg/L
- Total Manganese: <0.05 mg/L
- Total Arsenic: <0.005 mg/L

We have used these concentrations as a benchmark to assess water quality of the Tucker and MacIntosh Wells.

Tucker Well Water Quality

The only water quality data available for the Tucker Well was gathered during the 8-day pump test conducted from October 27, 2009 to November 4, 2009. That data is shown in **Table 1.**

Table 1 – Tucker Well Water Quality

Date	Na (mg/L)	Chl (mg/L)	Spec Cond (µS/cm	pH (S.U.)	Hard (mg/L)	As (mg/L)	Fe (mg/L)	Mn (mg/L)	Radon (pCi/L)
MCL/SMCL	**-**	**250**	**-**	**6.5-8.5**	**-**	**0.010**	**0.30**	**0.05**	**-**
10/27/09	140	180	930	8.0	91	0.009	BD	0.058	
10/29/09	113	172	-	-	-	-	-	-	
10/29/09	113	174	-	-	-	-	-	-	
10/30/09	112	170	-	-	-	-	-	-	
10/31/09	110	170	-	-	-	-	-	-	
11/1/09	110	140	770	8.0	72	0.012	BD	0.053	
11/2/09	105	165	-	-	-	-	-	-	
11/3/09	101	152	-	-	-	-	-	-	
11/4/09	115	160		7.7	82	0.012	BD	0.047	
11/4/09	90	140	730	8.1	68	0.013	BD	0.051	4,100
Average	**111**	**162**	**810**	**7.95**	**78**	**0.0115**	**BD**	**0.052**	**4,100**

It can be seen from **Table 1** that the raw Tucker Well water exceeds all of the target concentrations. However, it is also noted that even over this limited 8-day test, there is a very apparent downward trend in sodium, chloride, specific conductance and hardness (see **Figure 1**). In their report titled *Final Hydrogeologic Investigation for Newmarket Production Wells #3 (NGE-2B) and #4 (NGE-1A), (December 2010),* EGGI noted that the elevated sodium and chloride levels in both the Tucker and MacIntosh Wells is most likely due to paleo-seawater that was confined beneath or within glacial marine clays in the vicinity of the wells. It was also indicated that there was a relatively stagnant recharge condition under a non-pumping condition and it was theorized that as the wells are pumped, the paleo-seawater will be replaced by fresher, higher quality recharge and that sodium, chloride and related parameters will go down. The results in **Table 1** support this theory. The manganese concentration also has a slight downward trend but is staying close to or just above the SMCL. Arsenic, on the other hand, increased during the test so that even the average concentration exceeds the primary MCL. Plots for manganese and arsenic are shown in **Figure 2.**

As shown, Radon was detected in Tucker Well water at 4,100 pCi/L. There is currently no standard for Radon. The Radon Rule as originally proposed by EPA would have set an MCL of 300 pCi/L for radon in drinking water. This was never passed due in part to the financial impact this limit would have imposed on water systems. Since the primary health impact is due to inhalation of radon in air, an alternative proposal would have allowed the State (or the water system) to develop a Multi-Media Mitigation (MMM) program to address radon in indoor air, in which case an alternative MCL (AMCL) of 4,000 pCi/L could be applied. EPA was encouraging the MMM approach for smaller systems because it is the most cost-effective way to achieve the greatest radon risk reduction.

Figure 1
Tucker Well - Sodium, Chloride, Specific Conductivity, Hardness

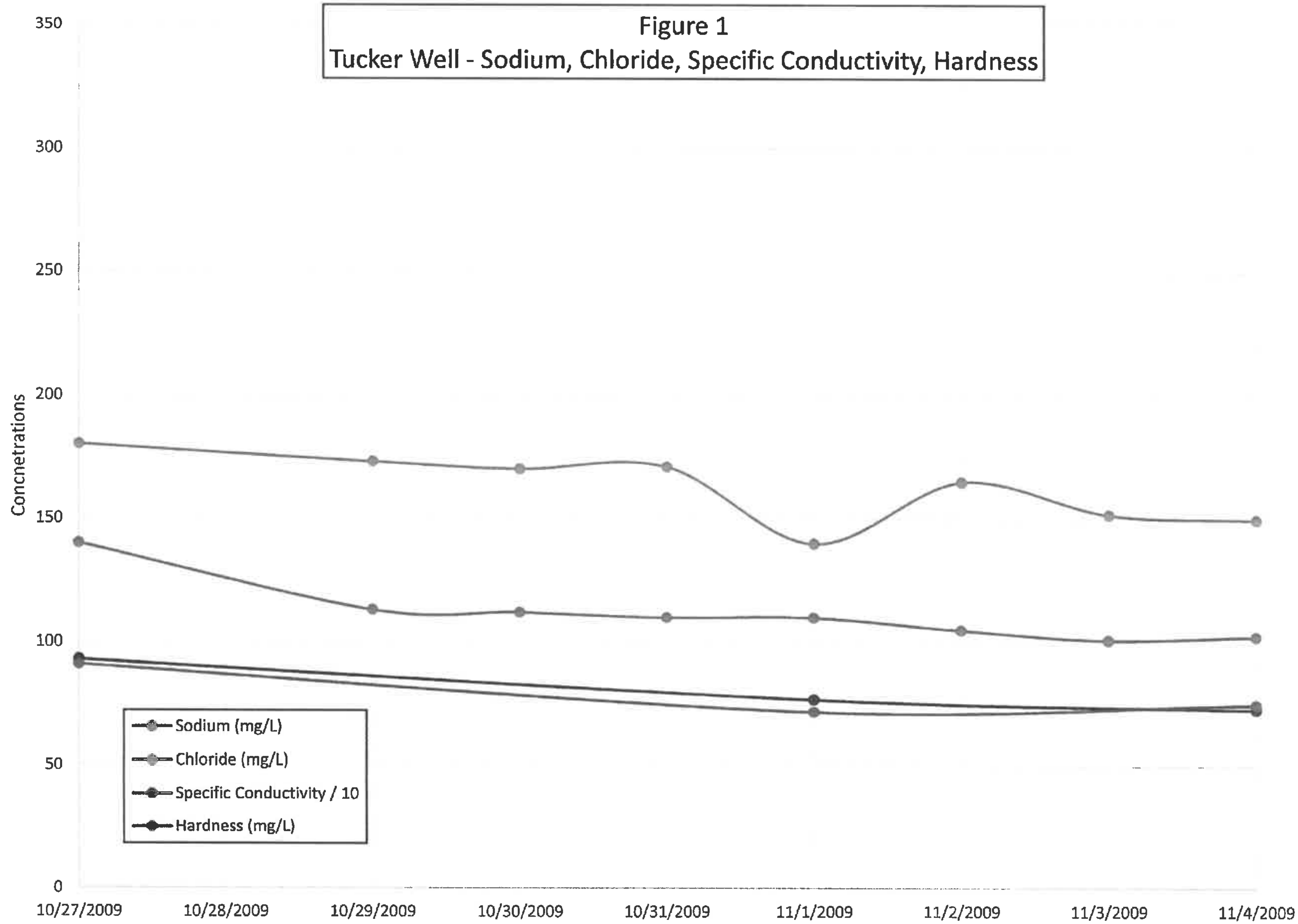
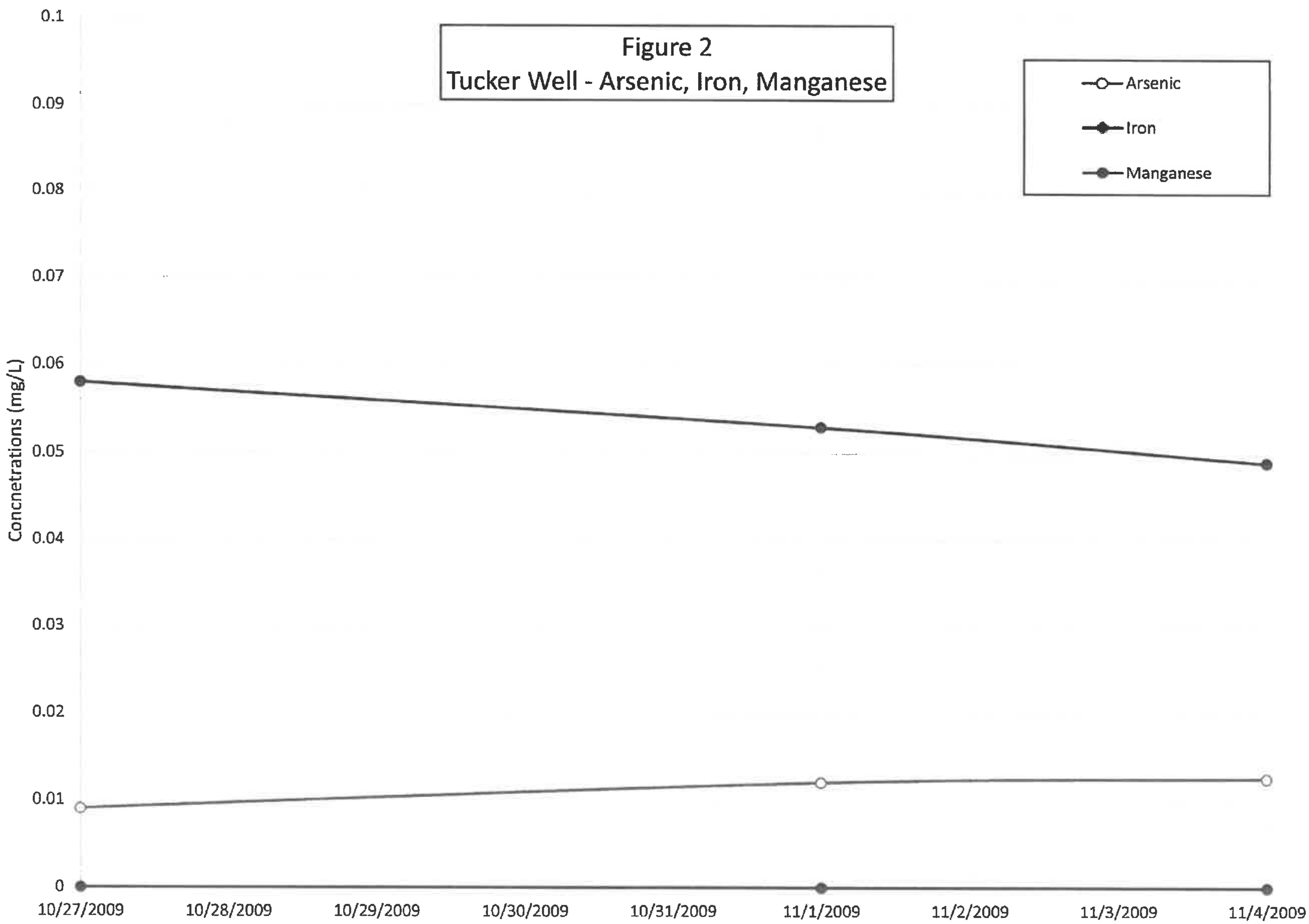


Figure 2
Tucker Well - Arsenic, Iron, Manganese



MacIntosh Well Water Quality

Water quality data taken on the MacIntosh Well, prior to blending, and starting about when the well was put on line, is shown in **Table 2**.

Table 2 – MacIntosh Well Water Quality (Before Blending)

Date	Na (mg/L)	Chl (mg/L)	Spec Cond (µS/cm)	pH (S.U.)	Alk (mg/L)	Hard (mg/L)	As (mg/L)	Fe (mg/L)	Mn (mg/L)
MCL/SMCL	-	**250**	-	**6.5-8.5**	-	-	**0.010**	**0.30**	**0.05**
9/16/16	185	302	-	7.9	-	103	<0.005	0.23	0.1
9/16/16	191	329	-	7.9	-	109	0.005	0.32	0.1
9/16/16	193	388	-	7.7	-	130	<0.005	-	0.37
9/19/16	178	312	-	7.8	-	99	0.006	-	0.12
9/19/16	168	280	-	7.9	-	93	0.006	0.11	0.1
9/20/16	168	270	-	7.7	-	86	<0.005	-	0.08
9/20/16	160	252	-	7.8	-	81	<0.005	-	0.06
9/21/16	160	220	-	8.3	-	77	0.007	0.27	0.05
9/23/16	148	244	-	7.6	-	80	<0.005	0.46	0.04
10/3/16	160	220	-	8.1	-	-	0.008	1.3	0.07
3/30/17	160	220	-	7.9	-	-	0.009	0.09	0.07
5/30/17	150	180	850	8.5	-	-	0.008	0.03	0.05
6/26/17	120	180	810	7.8	-	-	0.009	0.03	0.05
11/29/17	130	140	-	-	-	-	0.009	0.1	0.04
1/10/18	130	130	-	-	-	-	0.009	-	0.04
1/31/18	120	120	680	7.9	93	-	0.010	-	0.03
Average	**158**	**237**	**780**	**7.9**	**93**	**95**	**0.008**	**0.32**	**0.09**

The same trends seen in the 8-day pump test on the Tucker Well can be seen in the roughly 15 month pumping period for the MacIntosh Well, namely a significant downward trend in sodium, chloride, specific conductance, hardness and manganese and a slight upward trend in arsenic (see **Figures 3 and 4**). By the end of January of 2018, sodium and chloride had dropped about 35% and 60% respectively from the values in October of 2016. Using the values at the end of January 2018, MacIntosh Well water meets the treatment targets for chloride and manganese but not for sodium and arsenic. TDS has not been measured so the relation to the treatment target is unknown.

MacIntosh Blend Water Quality

Water quality data on the current Macintosh/Bennett/Sewell Blend, referred to herein as the MacIntosh Blend, is shown it **Table 3.** Based on the available data, the Blend over this time frame was in compliance with all MCL's and SMCL's and was meeting the treatment target concentrations for all parameters except sodium (93 vs 75 mg/L) and arsenic (0.007 mg/L vs 0.005 mg/L).

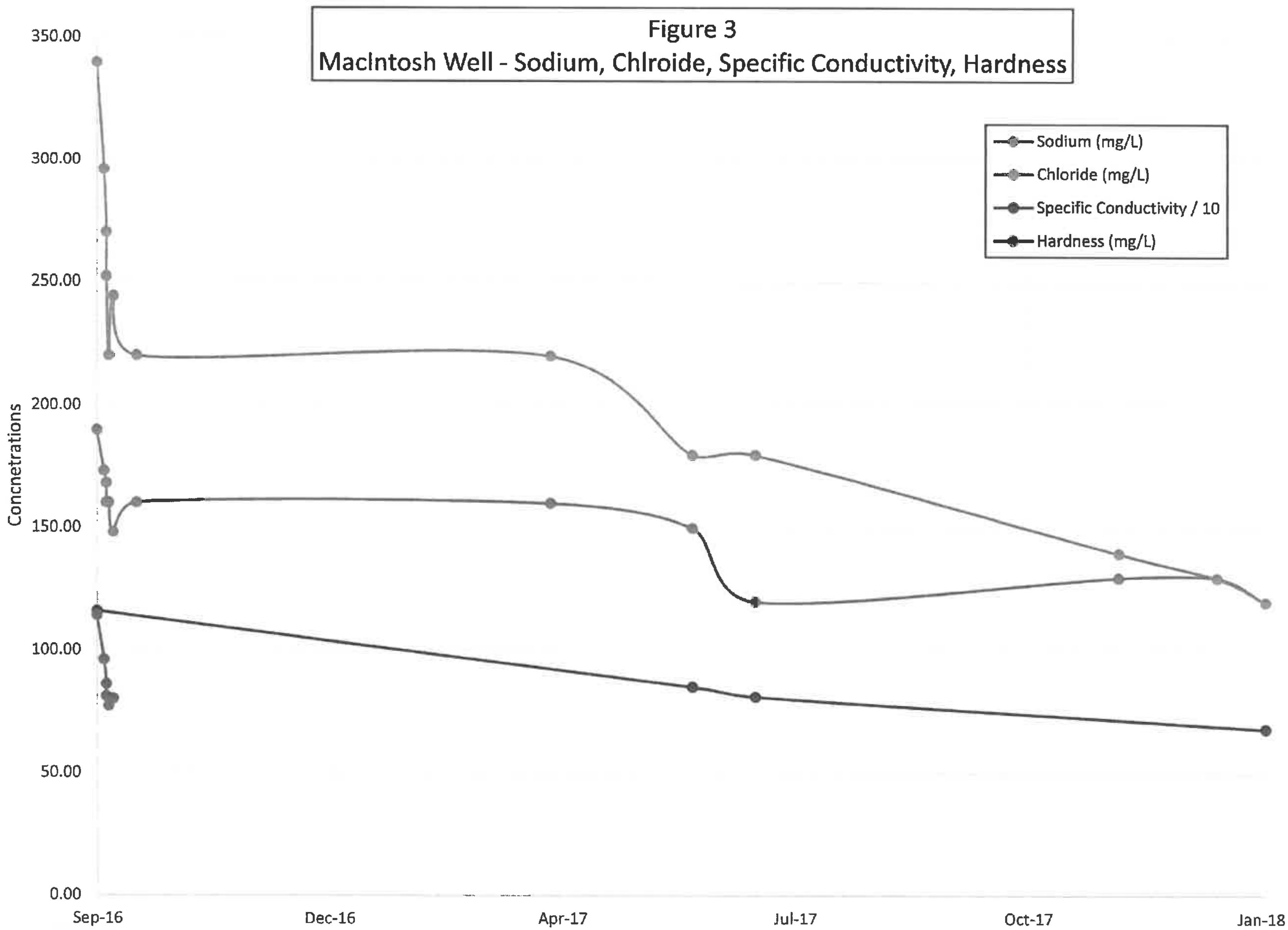


Figure 3
MacIntosh Well - Sodium, Chlroide, Specific Conductivity, Hardness
Sodium (mg/L)
Chloride (mg/L)
Specific Conductivity / 10
Hardness (mg/L)
Concnetrations
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Sep-16
Dec-16
Apr-17
Jul-17
Oct-17
Jan-18

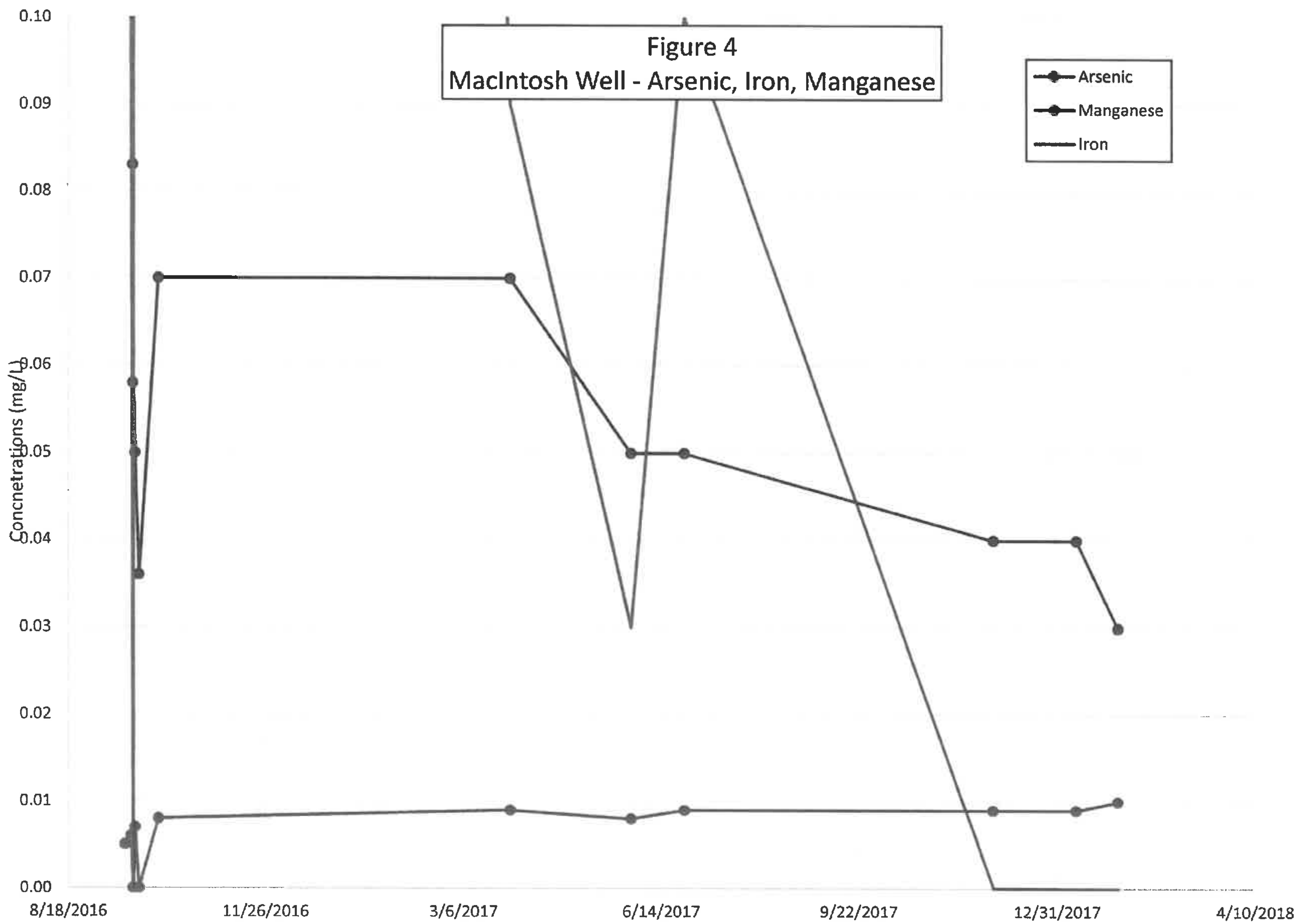


Figure 4
MacIntosh Well - Arsenic, Iron, Manganese
Arsenic
Manganese
Iron
Concnetrations (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
8/18/2016
11/26/2016
3/6/2017
6/14/2017
9/22/2017
12/31/2017
4/10/2018

Table 3 – MacIntosh Blend Water Quality[1]

Date	Na (mg/L)	Chl (mg/L)	Spec Cond (µS/cm)	pH (S.U.)	Alk (mg/L)	As (mg/L)	Fe (mg/L)	Mn (mg/L)
MCL/SMCL	**-**	**250**	**-**	**6.5-8.5**	**-**	**0.010**	**0.30**	**0.05**
2/1/17	-	-	595	7.95	72	-	0.03	0.036
2/15/17	-	-	605	7.96	68	-	0.03	0.039
3/2/17	-	-	602	8.04	73	-	0.02	0.034
3/9/17	-	-	590	8.09	76	-	0.03	0.032
4/11/17	-	-	587	8.45	78	-	0.02	0.027
4/18/17	-	-	587	8.29	75	-	0.02	0.029
5/10/17	-	-	574	8.53	73	-	0.03	0.026
5/25/17	-	-	578	8.37	75	-	-	-
6/7/17	-	-	549	8.29	76	-	-	-
6/14/17	-	-	549	8.31	74	-	-	-
6/26/17	92	130	-	7.8		0.007	0.15	0.03
7/13/17	-	-	534	8.29	84	-	-	-
7/21/17	-	-	526	8.4	82	-	-	-
8/2/17	-	-	532	8.42	80	-	-	-
8/23/17	-	-	529	8.39	80	-	-	-
9/6/17	-	-	511	8.14	70	-	-	-
9/13/17	-	-	503	8.28	79	-	-	-
1/10/18	93	100[2]	560	8.3	-	0.006	-	0.02
Average	**93**	**115**	**559**	**8.24**	**76**	**0.007**	**0.04**	**0.03**

[1]Blend during this timeframe was 40% - 50% MacIntosh
[2]Lab report indicated 83% for matrix spike. Acceptance criteria is 90-110%.

Since Tucker Well water quality is slightly better than MacIntosh water quality (except for arsenic), it could be blended with Bennett and/or Sewell water to produce water meeting the MCL's and SMCL's and all treatment targets except for arsenic which would most likely be between the MCL and target value. However, since a goal is to be able to use the Tucker and MacIntosh wells independently without having to run the Bennett or Sewell Wells, this blending option has not been evaluated any further.

MacIntosh & Tucker Blend Water Quality

The simplest and least expensive way of using the MacIntosh and Tucker Wells would be to blend them in the existing blending facility without the Bennett and Sewell Well contribution, if the blend allowed the target treatment concentrations to be met. We have estimated the water quality of such a blend assuming the MacIntosh Well is run at 300 gpm and the Tucker Well is run at 275 gpm. **Table 4** shows the expected blended water quality using the average concentrations from Tables 1 and 2. **Table 5** shows the expected blended water quality using the most recent concentrations from Tables 1 and 2.

Table 4 – MacIntosh & Tucker Blend Expected Water Quality Using Average Concentrations

Parameter	Units	MacIntosh Well	Tucker Well	MacIntosh & Tucker Blend
Sodium	mg/L	158	111	136
Chloride	mg/L	237	162	201
Specific Cond	μS/cm	780	810	794
pH	S.U.	7.9	7.95	7.92
Hardness	mg/L	95	78	87
Arsenic	mg/L	.008	0.0115	0.0975
Iron	Mg/L	.32	0.005[1]	0.16
Manganese	mg/L	.09	0.052	0.07
Radon	pCi/L	1077	4100	2523

[1]Assumed at 50% of the reporting limit of 0.01 mg/L since result was BD.

Table 5 – MacIntosh & Tucker Blend Expected Water Quality Using Most Recent Concentrations

Parameter	Units	MacIntosh Well	Tucker Well	MacIntosh & Tucker Blend
Sodium	mg/L	120	90	106
Chloride	mg/L	120	140	130
Specific Cond	μS/cm	680	730	704
pH	S.U.	7.9	8.1	8.0
Hardness	mg/L	80	68	74
Arsenic	mg/L	0.01	0.013	0.011
Iron	Mg/L	0.1	0.005[1]	0.055
Manganese	mg/L	0.03	0.051	0.04
Radon	pCi/L	1077	4100	2523

[1]Assumed at 50% of the reporting limit of 0.01 mg/L since result was BD

Using the average concentrations as shown in **Table 4**, none of the treatment targets are met. Arsenic is just below the MCL and manganese is above the SMCL. Using the most recent data, the sodium and chloride target concentrations are still exceeded, but by much less. The manganese concentration is below the SMCL and therefore the target. Arsenic however, not only exceeds the target, but also the MCL due to the slight increase in arsenic in both wells with pumping.

It is concluded that simply blending the MacIntosh and Tucker wells may result in acceptable sodium, chloride and manganese levels, especially if these parameters continue to decrease in the raw water. However, blending will not reliably reduce the arsenic below the MCL and treatment will be required unless these wells continue to be blended with Bennett and Sewell Well water. Since the Town's goal is to be able to use the Tucker and MacIntosh Wells independently, our treatment assumptions assume that blending with Bennett and Sewell will not continue

REQUIRED LEVEL OF TREATMENT

The parameters which have been identified as potentially requiring treatment in the MacIntosh and Tucker Wells are arsenic, sodium, chloride, manganese and radon. These are addressed below:

- Arsenic
  - Arsenic has a slight upward trend in both wells with the most recent samples from both wells either at or above the MCL. Therefore, treatment for arsenic reduction or removal is required for both wells.
- Sodium & Chloride
  - Initial concentrations of sodium and chloride in both wells, and especially the MacIntosh Well, warranted consideration of reduction through removal or blending for reasons of both taste and corrosivity. However, as predicted by EGGI, the concentrations of these parameters appear to be declining with increased pumping. While treatment for reduction of sodium and chloride is addressed in this report in accordance with our scope, it is our opinion that if the current trend of decreasing sodium and chloride in both wells continues, and if concentrations close to the treatment targets established in the 2012 Weston and Sampson report are acceptable to the Town, this treatment will not be required.
- Manganese
  - Manganese was above the SMCL in the MacIntosh Well at startup but has been steadily declining such that the last three samples have been below the SMCL In the Tucker Well, manganese continues to stay just above or below the SMCL These levels do not require removal and can be addressed by the sequestering action provided by the current blended phosphate feed. However, as will be discussed, there may be concomitant reduction of manganese due to the treatment to reduce arsenic.
- Radon
  - In their December 2010 Final Hydrogeological Report on the Tucker Well, EGGI indicated that NHDES recommends removal of radon at concentrations above 2,000 pCi/L. We believe this is a misinterpretation of NHDES guidance in a Fact Sheet on Radon for homeowners which states that "for private wells with radon concentrations between 2,000 and 10,000 pCi/L, the treatment of water may be advisable if air concentrations in the home exceed 4 pCi/L." We checked with the NHDES Drinking and Groundwater Bureau and they do not have a blanket recommendation that radon should be removed above 2,000 pCi/L. Furthermore, they have contacted EPA and have been informed that there is no plan to regulate radon in the foreseeable future. Given the radon level in the Tucker Well only 100 pCi/L above the one-time proposed AMCL of 4,000 pCi/L, the lack of any actual standard, and the fact that there is unlikely to be a standard, we do not believe treatment for radon removal is necessary. Additionally, there has been only one test for radon in 2009 and as shown in **Table 1**, the water quality was changing with only 8 days of pumping. Additional sampling is necessary to determine the current radon level.

TREATMENT EVALUATION

Based on our review of the water quality, we have evaluated treatment for the following two scenarios:

- Arsenic and manganese only
- Arsenic, manganese, sodium and chloride

Arsenic and Manganese Treatment

As the primary, health related contaminant, arsenic is the controlling factor when looking at these two parameters. Arsenic can exist in four valence (oxidation) states but the most prevalent form in water is As^{5+} (arsenate) or As(V). Arsenite (As^{3+} or As(III)) may also be present. This can be readily oxidized to As(V) in aerobic waters above a pH of 7.0, or with a chemical oxidant such as sodium or calcium hypochlorite. As(V) has a high affinity to be adsorbed to iron-based media or an iron hydroxide precipitate. This is an important aspect of the available treatment techniques. Removal efficiency for the treatment techniques noted herein is improved when As(III) is oxidized to As(V).

At the relatively low concentrations in the MacIntosh and Tucker Wells, the available treatment technologies include blending with another supply source, adsorption, ion exchange, and co-precipitation.

<u>Blending</u>
The current process of blending MacIntosh Well water with Bennett and Sewell Well water is successfully maintaining the arsenic level below the 0.010 mg/L standard. Blending could achieve the same result with Tucker Well water. However, since the goal is to meet drinking water quality standards without the need to run the Bennett and Sewell Wells in conjunction with either the MacIntosh or Tucker Well, this is not an acceptable solution. Additionally, it was shown in the Water Quality section of this report that blending MacIntosh and Tucker Well water will not maintain the arsenic level below the MCL.

<u>Adsorption</u>
Adsorption involves the use of a non-regenerable, disposable media designed for the removal of arsenic. This is generally an iron-based media such as granular ferric hydroxide (GFH) or granular ferric oxide (GFO) although there are also titanium-based medias. Raw water is fed into a pressure filter with the adsorptive media and when all the adsorptive capacity of the media is exhausted, the media must be replaced. Media life is determined by raw water pH and the concentration of other parameters that compete with arsenic for adsorption sites. The media is relatively expensive. In a Water Online (2014) article it was estimated that 80% of utilities that remove arsenic from their water, do so with adsorptive media, and 80% of the operating cost is due to media replacement. Given the high mineral content of both MacIntosh and Tucker Well water and the concern about media life, we met with a representative of Secondwind Water Systems who have a great deal of experience with arsenic removal in small systems (<100 gpm) using adsorptive media. It was their opinion that with the water quality and a total flow rate of up to 575 gpm, adsorptive media would be a cost prohibitive alternative for the MacIntosh and Tucker Wells.

Ion Exchange

This is a physical-chemical process where ions are exchanged between the solution phase and the solid phase on a resin with a selectivity for arsenic. These resins have a stronger affinity for As(V) so it would be necessary to feed sodium or calcium hypochlorite to oxidize any As(III) if it is present to As(V). Arsenic ions are exchanged for chloride ions on the resin. When the ion exchange capacity of the media has been used up, it must be regenerated by feeding a brine solution which replaces the arsenic ions on the resin with chloride ions and the concentrated arsenic/brine waste must be disposed of. It is not permissible to discharge arsenic at concentrations exceeding the ambient groundwater concentration to the ground so it would be necessary to direct this waste to the sewer. An issue with this treatment technique is that it adds chloride to the water as part of the exchange process. Additionally, this process removes alkalinity and makes the water more corrosive. In our opinion this is not an appropriate treatment process for the MacIntosh and Tucker Wells.

Co-Precipitation

Co-precipitation, which may also be referred to as coagulation-filtration, utilizes the affinity of arsenic for iron hydroxide to precipitate arsenic out along with iron. This is essentially the same process used to remove iron and manganese from drinking water. The process involves feed of an oxidant (usually sodium or calcium hypochlorite) to oxidize any As(III) to As(V) since only about 50% of As(III) is removed by iron coagulants. This will also oxidize any dissolved (ferrous) iron to particulate (ferric) iron. Experience has shown that for effective co-precipitation of arsenic, a ratio of at least 20 parts of iron to 1 part of arsenic is necessary. If there is not enough naturally occurring iron, it can be added in the form of an iron-based coagulant such as ferric chloride or ferric sulfate. The oxidized water is then fed into a pressure filter where the combined iron and arsenic is filtered out. Various media can be used including but not limited to, silica sand, garnet sand, manganese greensand, greensand plus, anthrasand, and pyrolusite (manganese dioxide) media. The choice of media depends primarily on raw water quality and what one wants to remove. As the media filters out more arsenic/iron precipitate, it reaches a point, based on headloss, gallons processed, or time, where it must be backwashed to remove the accumulated precipitate. This arsenic bearing backwash must be directed to either the sewer or onsite backwash/residuals basins. As noted above, a discharge to the ground that results in arsenic levels greater than the ambient level is not permitted. In order for this to be permissible, the solids would have to undergo a Toxic Characteristic Leaching Procedure (TCLP) to ensure that arsenic is not leaching into the groundwater.

In EPA guidance (*Arsenic Removal Treatment Technologies, November 2005)* it is indicated that co-precipitation is often less expensive than other arsenic removal technologies, especially if there is naturally occurring iron. While there is very little iron in the Tucker Well, concentrations in the MacIntosh Well have varied between 0.03 mg/L and 1.3 mg/L with an average of 0.32 mg/L. This would allow removal of arsenic up to 0.016 mg/L in the MacIntosh Well with no ferric feed. With iron below detection in the Tucker Well, a ferric feed equivalent to about 0.26 mg/L of iron would be required to remove the highest arsenic concentration of 0.013 mg/L.

In a document entitled *The Removal of Arsenic from Drinking Water Supplies* by Pureflow© Filtrations Systems with many AWWA, JAWWA and EPA references; arsenic removal technologies were reviewed including adsorption onto iron or titanium-based media, ion exchange, activated alumina, lime softening, coagulation-filtration (co-precipitation), electrodialysis, and nano-filtration. It was concluded that of all these technologies, "iron coagulation, whether practiced primarily for the removal of arsenic, or also of iron/manganese, appears to be the most promising, cost effective and proven process available."

Based on our review of treatment technologies, we have selected co-precipitation to evaluate further for the removal of both arsenic and manganese from MacIntosh and Tucker Well water.

Co-Precipitation Alternative

The Water Treatment Plant (WTP) would be constructed at the site of the existing Blending Facility (BF) and would most likely be added on to the BF. In terms of connecting the Tucker Well, the intent is to run a raw water main cross country to Ash Swamp Road and then along the access road to the MacIntosh Well site where it would be tied into the pipeline which conveys MacIntosh Well water to the BF. Therefore, a WTP at the BF location would be able to treat either or both wells. The WTP would utilize the cleared area behind the building on the side opposite Durell Drive. The raw water main from the MacIntosh Well runs behind the building so this would need to be taken into account and most likely relocated. There is only about 50 feet between the back wall of the BF and the property line and the Town would prefer not to have to purchase additional land so this will have to be taken into account when laying out the building in the Preliminary Design phase. Due to the limited space behind the building, an addition may need to wrap around the south (uphill) side of the building. Based on the topography, it is assumed that at minimum a construction easement would be required to construct the WTP and a permanent slope easement is possible as well.

Given the need to remove manganese as well as arsenic, we have assumed the use of Greensand Plus media for this option. The system would be designed for a capacity of 575 gpm so that it has capacity to treat either well singly or both wells if pumped together. Based on an equipment proposal from Tonka Water, this would require three 9'-6" diameter Greensand Plus vertical pressure filters assuming a filter loading rate of 2.7 gpm/ft^2. The pH range for co-precipitation is between 5.5 and 8 (EPA, 2005). Given average pH's of 7.9 and 7.95 respectively for the MacIntosh and Tucker Wells, pH adjustment is not required. Chemical feed systems would be required for, 1) sodium or calcium hypochlorite (or an alternative oxidant) to oxidize any As(III) to As(V) as well as to oxidize dissolved iron and manganese, and 2) ferric chloride or sulfate in case there is not sufficient naturally occurring iron for co-precipitation. It is assumed that the existing blended phosphate feed system will be utilized for the treated water discharge from the WTP.

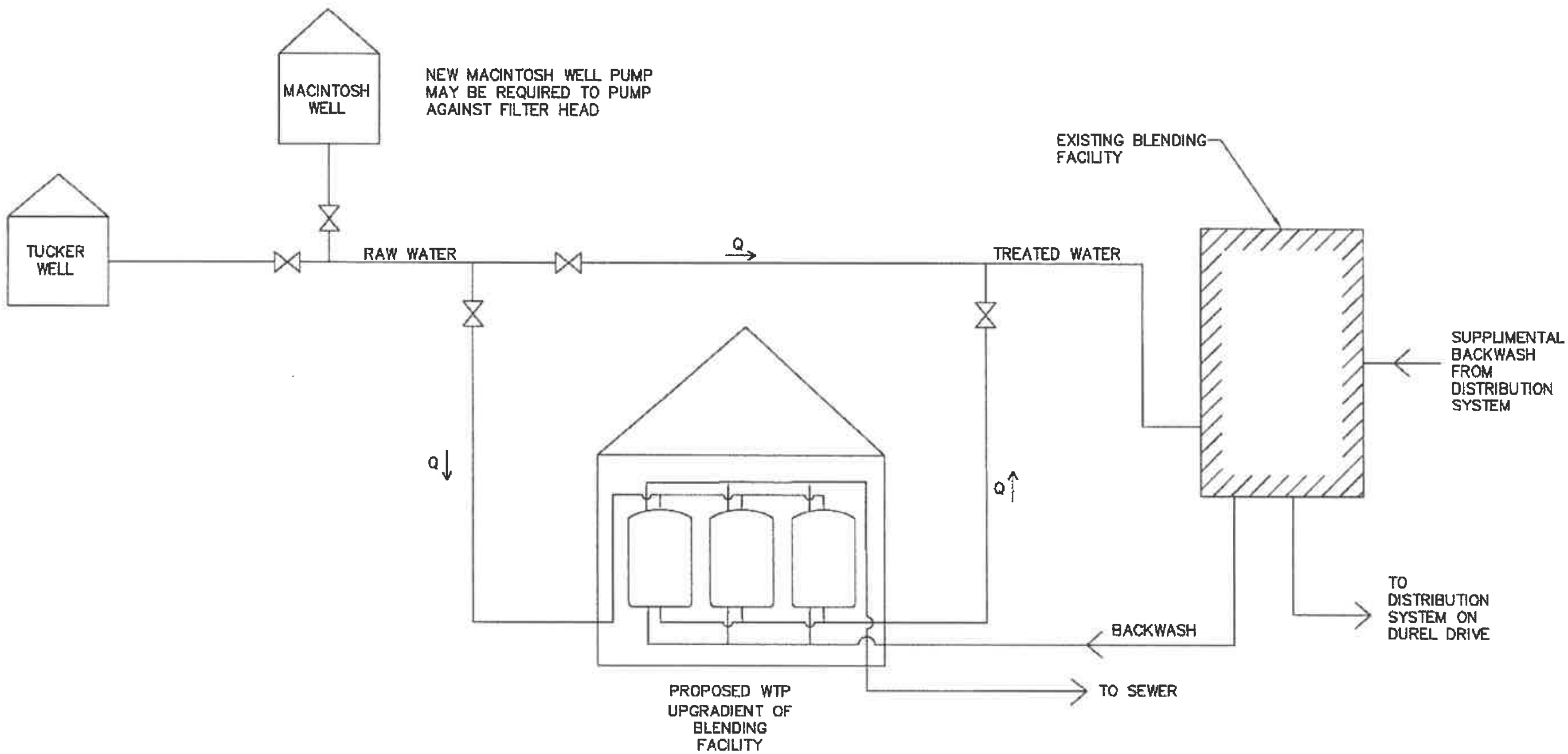
The goal would be to utilize the existing BF and infrastructure to the extent possible. The WTP could be constructed hydraulically upgradient (before) or downgradient (after) of the BF. If constructed before the BF (**Figure 5**) raw water would be pumped from the Tucker and/or MacIntosh Well directly to the WTP where an oxidant and ferric (if required) would be fed before the water enters the filters. The pump in the MacIntosh Well may need to be replaced due to the added head of the pressure filters. Treated water would flow to the existing blending tank which would be repurposed as a clearwell to be used for both treated water storage and backwashing of the filters. The existing blended phosphate feed system and injection point would remain unchanged. At least one of the three 25 Hp pumps that currently pump to the system would either be re-purposed or replaced with a pump for backwashing the filters with corresponding piping changes. An issue is the size of the blending tank for backwashing purposes. The tank has a total volume of about 7,600 gallons and Tonka indicates that 6,827 gallons are required to backwash each filter with a system requirement of 20,481 gallons to backwash all three filters. It is noted that Tonka uses a combined air-water backwash entitled

Simul-Wash™ which they claim saves 15,727 gallons per system backwash over their competitor's systems of equal capacity. If this is assumed to be true, then a competing system would require about 12,000 gallons per backwash with a total system requirement of about 36,000 gallons. There are two options for providing the necessary backwash volume; 1) construct additional clearwell storage hydraulically linked to the blending tank, or 2) use the existing inlet and control valve which currently regulates the amount of distribution system (Bennett and Sewell Wells) water going to the blend with MacIntosh Well water. The latter option would require instrumentation and controls to ensure that there is sufficient volume in the tank for each backwash. This raises the question of continuing dependence on having the Bennett and/or Sewell Well on line for backwashing of the filters. However, even if close to 30,000 gallons was necessary to augment the blending tank volume, this amounts to a drop of 2.4 feet in the Great Hill Storage Tank. The normal operating band is 6 feet (50 to 56 feet) so depending on where the tank is in the cycle, this would not be enough to activate the Bennet or Sewell Well. Typically, this would happen about once every other day. It is assumed this is an acceptable and less expensive method of providing the required backwash volume.

The other option is to construct the WTP hydraulically downgradient of the BF (**Figure 6**). In this case, the MacIntosh Well would continue to pump directly to the blending tank so there would be no need to change the well pump. Water would be pumped from the blending tank, through the pressure filters and into the system. This may require replacement of the pumps due to the added head of the pressure filters. Since the blending tank would now hold raw water it could not be used for backwashing, necessitating either construction of a clearwell or obtaining all backwash water directly from the distribution system. The treated water discharge would either need to run back to the BF for the blended phosphate feed, or a new injection location would have to be established.

Based on the evaluation above, it is our opinion that constructing the WTP hydraulically upgradient of the BF, as shown in **Figure 5,** provides the greatest advantage and re-use of existing infrastructure.

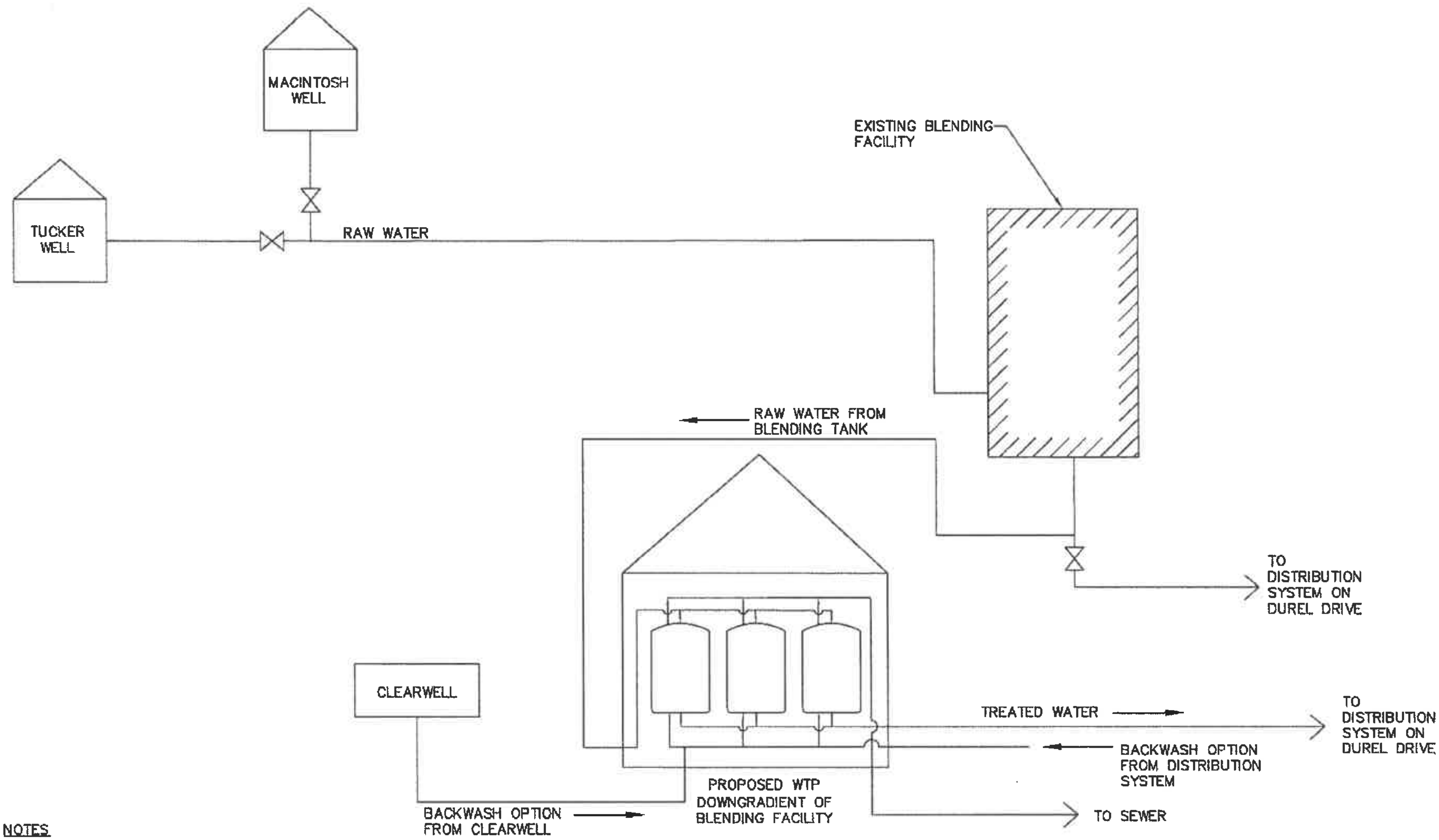
There is not sufficient room for residual infiltration basins without purchasing additional land and given potential issues with discharging backwash with arsenic above the ambient concentration, it is our opinion that backwash discharge to the sewer is the best method of handling the waste stream. In order to minimize the flow to the sewer the design would include one or more recycle tanks located in the basement level of the WTP. Filter backwash would be directed to the recycle tank(s) and after an appropriate settling time, the supernatant would be pumped back to the influent line to the pressure filters. This would be limited to no more than 10% of the raw water flow. Solids handling pumps would pump the settled solids to the sewer.



NOTES

1. PROPOSED WTP INCLUDES THREE GREENSAND PLUS TREATMENT VESSELS

DATE	UNDERWOOD engineers	TUCKER AND MACINTOSH WELL TREATMENT UPGRADIENT CO-PRECIPITATION ALT.	FIG.
FEB 2018	25 Vaughan Mall, Portsmouth, N.H. 03801 Tel. 603-436-6192 Fax. 603-431-4733	TOWN OF NEWMARKET NEWMARKET, NH	5
PROJECT 2242			



NOTES

1. PROPOSED WTP INCLUDES THREE GREENSAND PLUS TREATMENT VESSELS
2. FINAL BACKWASH OPTION TBD

DATE	UNDERWOOD engineers	TUCKER AND MACINTOSH WELL TREATMENT	FIG.
FEB 2018	25 Vaughan Mall, Portsmouth, N.H. 03801	DOWNGRADIENT CO-PRECIPITATION ALT.	6
PROJECT 2242	Tel. 603-436-6192 Fax. 603-431-4733	TOWN OF NEWMARKET NEWMARKET, NH	

There is currently no sewer line in Durell Drive at the BF location. Sewer exists both at the top of the hill at Ledgeview and the bottom of the hill at the intersection of Durell Drive and Huckins Drive. If possible, gravity flow to the bottom of the hill is preferable to pumping the backwash waste up the hill. However, there is a low spot between the BF and Huckins Drive where Durell Drive crosses Moonlight Brook, so we checked on elevations and note the following:

- BF Finish Floor El - 116 ft MSL
- MH (#5-54) Rim - 81.2 ft MSL
- MH (#5-54) Invert out - 71.45 ft MSL
- Road El. @ Moonlight Brook - 74 ft MSL

It is about 400 feet from MH #5-54 to the low point over Moonlight Brook. A 12-inch sewer laid at minimum slope (0.0022ft/ft) would have an invert El of 72.33 at the low point. Given that the top of the pipe would nearly be at the road surface, gravity flow from the BF to MH #5-54 is not possible. We have therefore assumed that the pumps drawing settled solids from the recycle tank would connect directly to a force main which would convey these solids directly to MH #5-54.

Our preliminary opinion of the probable total cost for a 575 gpm Co-Precipitation process for removing arsenic and manganese is $3,870,000. A detailed opinion is contained in **Appendix A.**

Arsenic, Manganese, Sodium & Chloride Treatment

Removing sodium and chloride is a challenge. None of the treatment techniques discussed above for arsenic and manganese removal will reduce sodium or chloride, and at least one, ion exchange, would increase the chloride level. To remove sodium and chloride, it is necessary to turn to desalination treatment techniques. Two processes, Electrodialysis Reversal (EDR) and Reverse Osmosis (RO) were considered.

Electrodialysis Reversal

EDR was evaluated by Weston & Sampson Engineers (WSE) for treating MacIntosh Well water and is discussed in their *December 2012 Draft Report – Newmarket, NH, Pilot Study Report, MacIntosh Well Treatment Alternatives*. This report compared EDR to Blending with Bennett and Sewell Well water. It was noted that EDR would provide the best water quality and allow the MacIntosh Well to be used as an independent source. However, since the blending option was nearly $1 million less than EDR, the Town opted to move ahead with blending which lead to the current Blending Facility.

EDR is an electrochemical process that applies an electrical charge between electrodes which causes positively charged ions (cations) such as sodium to flow toward the negatively charged cathode while negatively charged ions (anions) such as chloride flow toward the positively charged anode. Alternating layers of membranes permeable respectively to cations and anions are placed between the electrodes. Flow spacers are placed between the membranes to support them and create channels for flow. The ions travel through the membranes as water travels tangentially to the membranes so that one stream is demineralized (product water) while the other is concentrated (concentrate water). An EDR cell pair consists of an anion exchange membrane, a concentrating spacer, a cation exchange membrane and a diluting spacer. The actual treatment unit is known as a membrane stack which can contain up to 600 cell pairs placed between identical electrodes. The electrical polarity of the electrodes is automatically reversed two to four times an hour. This reverses the direction of ion movement and causes an "electrical flushing" of the membranes which reduces scaling and membrane fouling. This also causes switching of the product and concentrate flow streams. At reversal, automatically operated valves switch the inlet and outlet streams so that incoming feed water flows to the new product channels and recycled concentrate flows to the new concentrating channels. The effect of the reversal is that there is a brief period where the product water would have higher sodium and chloride than specified. Conductivity controlled valves send this stream to waste until the water is back within specification. The typical water recovery of an EDR system is reportedly about 85%.

On a daily basis the electrodes are cleaned with hydrochloric acid, typically for about 45 minutes, to control carbonate scale formation. Periodically (about every 4 – 6 weeks) the membrane stacks require a chemical clean in place to remove fouling by circulating a chemical cleaning solution through the stacks.

When WSE was evaluating EDR in 2012 the process was owned and manufactured by General Electric Water & Process Technologies (GE Water). Since that time, GE Water has been purchased by Suez Water Technologies (Suez). When UE contacted Suez relative to the water quality to be treated and the use of EDR, we were informed that Reverse Osmosis (RO) would be a more economical and better treatment choice. Given this recommendation and the fact that the decreasing trend of sodium and chloride makes treatment for removal of these parameters unnecessary as long as concentrations close to the treatment level targets established by WSE in 2012 are acceptable to the Town, we did not pursue further evaluation of EDR and requested a proposal on RO only.

<u>Reverse Osmosis Alternative</u>

RO involves using a high-pressure pump to force raw (feed) water with dissolved solids through a semi-permeable membrane. The high pressure is necessary to overcome the osmotic pressure which increases with higher concentrations of dissolved solids in the feed water. The membranes have microscopic pores which will allow water molecules to pass through the membrane (permeate) while larger, heavier dissolved solids such as arsenic, sodium and chloride cannot and they become the reject stream (concentrate). The reported nominal membrane rejection rate is 97% to 99% meaning that only 1% to 3% of dissolved solids will pass through the membrane. The high rejection rate results in a lower recovery rate for RO which is increased by adding RO stages in which the concentrate from one stage becomes the feed water for the next stage and/or concentrate recycle where some portion of the concentrate is directed back to the feed water stream. The proposed recovery rate for this RO system is 77.5%

Since the membranes will reject a number of contaminants, pretreatment is critical to prevent fouling, scaling, and premature RO membrane failure. Based on the MacIntosh and Tucker Wells water quality, Suez recommends two pretreatment steps, manganese greensand filtration for iron and manganese reduction and water softening to remove calcium and magnesium.

The main components of the Suez RO proposal for treating 500 to 600 gpm are noted below:

- Greensand Filtration System
    - 12 – 4'diameter pressure filters arranged in 3 quadplex banks
    - 25 cubic feet of Greensand Plus media per filter
- Water Softener System
    - 8 – 4' diameter pressure vessels arranged in 2 quadplex banks
    - 40 cubic feet of ResinTech CG8 cationic resin per vessel

- RO System
  - 2 PRO-FLEX 72-3 RO skids with 100 Hp pumps
  - Performance data (per skid)
    - Design permeate flow - 300 gpm
    - Feed flow - 387 gpm
    - Concentrate feed flow - 87 gpm
    - Recovery - 77.5%
    - Design temperature - 50°F
    - Design pH - 5.5 – 8.5
    - System inlet pressure - 40 psi
    - System operating pressure - 268 psi

It is noted that due to the recovery of 77.5%, Suez has indicated that the feed flow would need to be 387 gpm to produce a permeate flow of 300 gpm. This is obviously not possible if only the MacIntosh Well, with a permitted production volume of 300 gpm is being treated. Given this recovery, and a feed of 300 gpm from the MacIntosh Well, an RO system would only provide about 233 gpm flowing to the system.

As with the co-precipitation alternative, the RO and pretreatment facilities would be incorporated in a WTP built behind and hydraulically upgradient of the BF which may require replacement of the MacIntosh Well pump and motor due to the additional head, and the blending tank would be used for finished water and backwash storage. Backwash for the greensand filters would be supplied both from the blending tank and the distribution system as described for co-precipitation. The existing blended phosphate storage and feed facilities would be reused. Given the footprint required for RO and pretreatment facilities, fitting the WTP on the existing BF lot will be more of a challenge than the co-precipitation alternative. This layout would be determined in Preliminary Design.

The pretreatment and RO steps would result in three waste streams; 1) greensand filter backwash, 2) softener regeneration brine waste, and 3) RO concentrate. Similar to the co-precipitation alternative, these streams would discharge to a recycle tank or tanks with supernatant returned to the influent line to the greensand filters and the settled solids would be pumped to the sewer system via a force main to manhole #5-54.

Suez's proposal did not contain any chemical feed systems. Based on the design pH and the raw water pH of both MacIntosh and Tucker Well water, pH adjustment is not required. Typically, chlorine is fed ahead of a Greensand Plus filter to oxidize iron and manganese, and as discussed in the co-precipitation alternative, to oxidize As(III) to As(V). Suez indicates that arsenic will be removed in the RO stage so neither oxidation nor a ferric feed for co-precipitation are required. They also noted that with the relatively low concentrations of iron and manganese, and the adsorbent properties of the Greensand Plus media, chlorine should not be required to oxidize iron and manganese. If levels increased however, feed of chlorine might become necessary. This could be problematic since modern thin composite membranes are not very tolerant to chlorine which can "burn" holes in the membrane pores causing irreparable damage. Therefore, if oxidation of iron or manganese is necessary, the chlorine dose would have to be carefully managed to avoid membrane damage. Any other chemical feeds would be related to maintaining and cleaning the membranes. Suez indicates that an anti-scaling chemical may be recommended before the RO units depending on how the Town wants to service them. Cleaning in place with both a low pH chemical for scaling, and a high pH chemical for organics, colloidal and biofouling would be required about four times a year, or alternatively, membranes can be cleaned offsite by a specialty service company.

Our preliminary opinion of the probable total cost for a 500 – 600 gpm RO and pretreatment WTP for removing arsenic, manganese, sodium and chloride is $4,996,000. A detailed opinion is contained in **Appendix A.**

TUCKER WELL CONNECTION

In a Technical Memorandum dated October 31, 2016, UE reported on an evaluation of options to connect the Tucker Well to the Newmarket Water System with the proposed connection point at the MacIntosh Well. Five options were evaluated to provide power and access to the Tucker Well along with a water main connection between the two well locations. The selected option was a common corridor for water main, power and access which starts from the Tucker Well and proceeds southeast through the Tucker Well property (Parcel R4-50), then northeast along a private drive (Parcel R4-41) to Ash Swamp Road where three phase power is available and the access road would start (see **Appendix B**). Water main would continue northwest on Ash Swamp Road to the access road to the MacIntosh Well, and then along that where it would be connected to the discharge main leaving the MacIntosh Well Pump Station.

UE's cost opinion for all five alternatives carried a well pump house at $100,000, which is fine for comparison purposes since this was common to each alternative. However, in discussion with Town staff, they would like to see a pump station at the Tucker Well similar to the facility at the MacIntosh Well. This is a 12' x 22' precast concrete building which houses the well head and all electrical, instrumentation and control equipment. The reported cost of this station including equipment was about $500,000. Substituting this pump station cost into the cost opinion from the October 31, 3016 Technical Memorandum results in a total project cost of $2,600,000. The revised detailed cost opinion is contained in **Appendix A.**

SUMMARY

Following is a summary of our evaluation.

Background

- The Town has had limited water supply since a 2005 decision not to upgrade the surface WTP to meet more stringent water quality regulations,
- The MacIntosh Well at 300 gpm adds to the water supply but due to water quality, it can only be used in conjunction with the Bennett & Sewell Wells with a maximum of 60% MacIntosh Water in the blend.
- The MacIntosh Well is now the largest source and if it is offline, the Bennett & Sewell Wells can meet average day demand and therefore NHDES supply criteria, but;
  - Plains Aquifer in which Bennett and Sewell are located receives limited recharge.
  - In past dry periods, the aquifer has been dewatered to the point where pumping rates had to be cut back.
- To increase water supply, the Town wants to;
  - Bring the Tucker Well online, and,
  - Use the MacIntosh Well as an independent source.
- To meet these goals, a treatment evaluation of the MacIntosh and Tucker Wells was conducted.

Water Quality Review

- The following treatment targets established in the *Draft Pilot Study Report-MacIntosh Well Treatment Alternatives* (WSE, December 2012) were used to evaluate MacIntosh and Tucker Well water quality.
  - Total Dissolved Solids (TDS): <250 mg/L
  - Sodium: <75 mg/L
  - Chloride: <125 mg/L
  - Total Manganese: <0.05 mg/L
  - Total Arsenic: <0.005 mg/L
- Tucker Well
  - Water quality from 8-day pump test in 2009
  - Exceeds all of target concentrations
  - However, sodium, chloride, and specific conductance all declined over 8 days.
    - Supports EGGI theory that high sodium and chloride are due to paleo-seawater confined beneath or within marine clays under a stagnant recharge condition and that with increased pumping, this paleo-seawater will be replaced with fresher higher quality recharge
  - Manganese declined slightly but stayed close to SMCL of 0.05 mg/L
  - Arsenic increased over course of 8-day test and exceeds MCL of 0.01 mg/L
  - Radon measured at 4,100 pCi/L, but there is no standard for radon.
- MacIntosh Well
  - Water quality from 15 months of operation of Blending Facility
  - Same downward trend in sodium, chloride, specific conductance, hardness and manganese and slight upward trend in arsenic
    - Sodium has dropped by 35% since October 2106
    - Chloride has dropped by 60% since October 2016
  - Average values for 15 month period exceed all treatment targets
  - Using the concentrations at the end of January 2018
    - Chloride and manganese treatment targets met

        - Arsenic and sodium treatment targets exceeded
- Existing MacIntosh/Bennet/Sewell Blend
    - Meets all MCL's and SMCL's
    - Treatment targets met except for:
        - Sodium (93 mg/L vs 75 mg/L)
        - Arsenic (0.007 mg/L vs 0/005 mg/L)
    - Tucker Well could be blended with Bennett/Sewell and meet MCL's/SMCL's but this does not meet goal of an independent source.
- MacIntosh/Tucker Blend
    - Simplest, least expensive option if water quality acceptable.
    - Using average values for MacIntosh water quality, none of treatment targets are met, arsenic is just below MCL and manganese exceeds MCL
    - Using values for MacIntosh from the end of January 2018, sodium and chloride are close to, but exceed the targets, manganese is below the target, but arsenic exceeds the target.
    - Due to arsenic levels, a simple blend of MacIntosh and Tucker will not meet the MCL and treatment is required.

Required Level of Treatment

- Arsenic
    - Upward trend in both wells and concentration either at or exceeds MCL.
    - Treatment for arsenic reduction or removal is required
- Sodium & Chloride
    - Initial high levels are decreasing with pumping of MacIntosh Well and same trend was seen with Tucker Well over 8-day test.
    - If this trend continues, the concentrations will drop below treatment targets of <75 mg/L for sodium and <125 mg/L for chloride
    - If these levels are acceptable to Town, treatment for removal or reduction of sodium and chloride is not required.
- Manganese
    - Concentrations have slight downward trends in both wells and remain at or just below the SMCL of 0.05 mg/L.
    - Sequestering with current blended phosphate is adequate for these concentrations.
    - Treatment for arsenic may cause reduction of manganese
- Radon
    - There is no standard and both EPA and NHDES indicate there is no plan to regulate radon
    - Tucker radon concentration at 4,100 pCi/L just exceeds one time proposed AMCL of 4,000 pCi/L
    - There may be opportunity for radon reduction with other process changes for treatment of arsenic
    - Adding a unit process for radon reduction is not required.

Treatment Evaluation

- Arsenic and Manganese Treatment
    - Blending
        - Blending MacIntosh and Tucker Well does not meet arsenic MCL
        - Blending either well with Bennett or Sewell will meet arsenic MCL but not the goal of independent use of supply sources
        - Blending is not recommended

- Adsorption
    - Uses non-regenerable, disposable iron based media to adsorb arsenic.
    - Media is relatively expensive and life would be impacted by high mineral content of water
    - Adsorption would be cost prohibitive and is not recommended.
- Ion Exchange
    - Uses resin with a selectivity for arsenic where arsenic ions are exchanged for chloride ions. Increases chloride concentration,
    - Process reduces/removes alkalinity and makes water more corrosive
    - Ion Exchange is not recommended
- Co-Precipitation
    - Uses affinity of arsenic for iron hydroxide precipitate so both constituents can be oxidized and filtered out together
    - Same process used for iron and manganese removal with various media types
    - Need 20 parts of iron for 1 part of arsenic so have to add it if there is not enough naturally occurring iron
    - EPA guidance and industry treatment evaluations indicate that co-precipitation is often less expensive than other arsenic removal technologies and is the most cost effective and proven process available.
    - Co-precipitation was selected for further evaluation.
- Co-Precipitation Alternative
    - Three 9'-6" diameter vertical pressure filters with Greensand Plus media
    - No pH adjustment required
    - Chemical feed systems
        - Sodium or calcium hypochlorite to oxidize arsenic, iron and manganese
        - Ferric chloride or sulfate if not enough naturally occurring iron
        - Use existing blended phosphate storage and feed facilities
    - Construct WTP as addition to Blending Facility (BF) using cleared area behind the building and potentially on south (uphill) side as well.
    - WTP to be hydraulically upgradient of BF. This may require replacement of MacIntosh Well pump and motor due to additional head of pressure filters.
    - Existing blending tank to be repurposed as a clearwell for treated water and backwash storage.
        - Backwash to be supplemented from distribution system using existing infrastructure.
    - Backwash to flow to recycle tank(s) with supernatant recycled to head of process at no more than 10% of raw water flow and settled solids to be pumped to sewer with the connection being made to MH #5-54 at the intersection of Durell Drive and Huckins Drive
    - Low point of Durell Road where it crosses Moonlight Brook eliminates option of gravity flow to MH #5-54 so a force main will be required.
    - Preliminary opinion of probable cost for this option is $3,870,000.

- Arsenic, Manganese, Sodium & Chloride Treatment
    - Desalination techniques are required for sodium and chloride removal. Two processes considered.
    - Electrodialysis Reversal (EDR)

        - Uses electric potential to move dissolved inorganic ions through a membrane stack consisting of alternating cationic and anionic flat sheet membranes. Periodic reversing of the polarity of the electrodes creates "electrical flushing" which reduces fouling and scaling.
        - Evaluated by WSE in 2012 but was about $1 million more than blending so blending was implemented.
        - Suez Water Technologies manufactures the EDR process. When contacted relative to use in Newmarket, Suez indicated that Reverse Osmosis would be a more economical choice of treatment for the water quality so EDR was not evaluated further.
    - Reverse Osmosis (RO) Alternative
        - Uses high pressure pump to force raw water through a semi-permeable membrane. Water molecules pass through the membrane but larger heavier molecules such as dissolved arsenic, sodium and chloride are rejected by the membrane.
        - Recovery rate is, at best, 77.5% meaning that 22.5% of the feed water flows to waste.
        - Pretreatment is critical to prevent fouling, scaling and premature membrane failure. Based on water quality, Suez recommends Greensand Plus filtration and Water Softening prior to the RO units.
        - Proposed system includes:
            - Greensand Filtration System
                - 12 – 4'diameter pressure filters
                - 25 cubic feet of Greensand Plus media per filter
            - Water Softener System
                - 8 – 4' diameter pressure vessels
                - 40 cubic feet of ResinTech CG8 cationic resin per vessel
            - RO System
                - 2 PRO-FLEX 72-3 RO skids with 100 Hp pumps
        - Due to 77.5% recovery, starting with 300 gpm feed from the MacIntosh Well would result in about 233 gpm flowing to the system.
        - Location and configuration of an RO WTP would be similar to the Co-Precipitation alternative:
            - Hydraulically upgradient of BF which may require replacement of MacIntosh Well pump and motor
            - Use cleared area behind BF
            - Existing blending tank to become finished and backwash water storage. Backwash would be supplemented with water from the distribution system.
            - Backwash would flow to recycle tank(s) with supernatant pumped to head of process and settled solids pumped to sewer system (MH #5-54) via a force main installed along Durell Drive.
        - Preliminary opinion of probable cost for this option is $4,996,000.

Tucker Well Connection

- A pump station at the Tucker Well and a connecting water main to the MacIntosh Well location will allow either or both wells to be treated at the Durell Drive location
- Utilizing a pump station similar to the MacIntosh Well Pump Station results in a probable cost of $2,600,000 for the station and connecting water main.

CONCLUSIONS

Based on our evaluation we have the following conclusions.

- To use either the MacIntosh or Tucker Wells individually requires treatment for the removal or reduction of arsenic.
- The most cost effective, proven treatment technique for arsenic reduction in municipal wells of this size is Co-Precipitation using Greensand Plus media in pressure filters. This will also reduce manganese.
- Sodium and chloride levels have been steadily decreasing in the MacIntosh Well over a 15 month operating period and the same trend was evident in the 8-day pump test on the Tucker Well. The levels are approaching or have dropped below the treatment targets set in the *December 2012 Draft Report – Newmarket, NH, Pilot Study Report, MacIntosh Well Treatment Alternatives.* Assuming these levels are acceptable to the Town, treatment for reduction or removal of sodium and chloride is not required.
- Manganese remains at about the SMCL concentration of 0.05 mg/L in both wells. This can be adequately addressed through the sequestering ability of the current blended poly/orthophosphate feed but the recommended treatment for arsenic will also reduce manganese.
- Radon removal is not required.
- A WTP for removal of arsenic and manganese can be constructed as an addition to the existing Blending Facility on Durell Drive
    - This should be conducted hydraulically upgradient (before) the Blending Facility,
    - The layout and configuration of the WTP will need to take into account the relatively small lot to avoid purchasing additional land. A construction easement and/or a permanent slope easement may be necessary.
    - The existing Blending Facility tank can be repurposed as a clearwell for finished water and backwash water storage. Due to the size of this tank, water would be drawn from the distribution system as well during backwashing.
    - For backwash waste disposal, a force main will be required from the WTP location to MN #5-54 at the Durell/Huckins Drive intersection.
- Connection of the Tucker Well to the MacIntosh Well discharge piping will allow either well to be treated at the Durell Drive location.

RECOMMENDATIONS

To increase the Town of Newmarket's water supply and make the MacIntosh and Tucker Wells independent sources, we recommend the following:

- Construct a 575 gpm capacity WTP using pressure filters with Greensand Plus media to co-precipitate arsenic as an addition to the existing Blending Facility on Durell Drive.
- Reconfigure piping and equipment to re-purpose the current blending tank as a clearwell for finished water and backwash water storage.
- Continue to use the existing blended phosphate storage and feed system for corrosion control.
- Construct a force main from the WTP to the sewer system at the intersection of Durell and Huckins Drives to discharge backwash waste.
- Construct a pump station at the Tucker Well and a pipeline from the Tucker Well to the MacIntosh Well discharge pipe so that either well can be treated at the Durell Drive location.
- The probable total project costs for the recommendations above is shown below:

575 gpm Co-Precipitation WTP at Durell Drive	-	$3,870,000
Tucker Well Pump Station & Connecting Water Main	-	$2,600,000
TOTAL	-	$6,570,000

APPENDIX A

ENGINEER'S OPINION OF PROBABLE COST

Engineer's Opinion of Probable Cost
MacIntosh and Tucker Well Treatment
Co-Precipitation Alternative for Arsenic & Manganese Treatment
Newmarket, NH
OPINION OF PROBABLE COST - 2018 Dollars

4/25/2018

ITEM	QTY	UNIT	UNIT PRICE	PROBABLE COST	SUBTOTAL
Final Design Phase					
Final Design (WTP only)	1	LS	$214,000	$214,000	
Piloting	1	LS	$25,000	$25,000	
SUBTOTAL					**$239,000**
Construction Phase					
General Requirements (11.5% of Construction Cost)	1	LS	$276,000	$276,000	
Site Work (incl. foundation excavation & backfill, gravel drive, fence/gates, tree clearing)	1	LS	$125,000	$125,000	
Replace MacIntosh Well Pump and Motor	1	LS	$40,000	$40,000	
Construct 40 x 60 CMU building (incl. concrete foundation and slab)	2400	SF	$150	$360,000	
SCADA and controls	1	LS	$100,000	$100,000	
Generator	1	LS	$75,000	$75,000	
Electrical work	1	LS	$140,000	$140,000	
HVAC	2400	SF	$20	$48,000	
Sewer Pumping Station	1	LS	$50,000	$50,000	
Sewer Force Main	1200	LF	$350	$420,000	
Treatment Unit					
Furnish packaged GSP filtration equipment	1	LS	$441,000	$441,000	
Install packaged iron/manganese filtration equipment (35%)	1	LS	$154,350	$154,350	
Overhead and profit (15% of F&I)	1	LS	$23,153	$23,153	
Backwash reclaim tank	2	LS	$45,000	$90,000	
Backwash pumps	2	LS	$20,000	$40,000	
Waste residuals (sludge) pump	2	LS	$20,000	$40,000	
Chemical feeds	1	LS	$100,000	$100,000	
F&I interior piping (incl. static mixer, flow meters)	1	LS	$150,000	$150,000	
Construction Phase Engineering (~15%)	1	LS	$400,000	$400,000	
Contingency (~20%)	1	LS	$535,000	$535,000	
Other costs: Legal, Administration	1	LS	$20,000	$20,000	
SUBTOTAL					**$3,630,000**
TOTAL PROBABLE CONSTRUCTION COST					***$3,870,000***

Notes:

Engineer's Opinion of Probable Cost
MacIntosh and Tucker Well Treatment
Reverse Osmosis Alternative for Arsenic, Manganese, Sodium & Chloride Treatment
Newmarket, NH
OPINION OF PROBABLE COST - 2018 Dollars

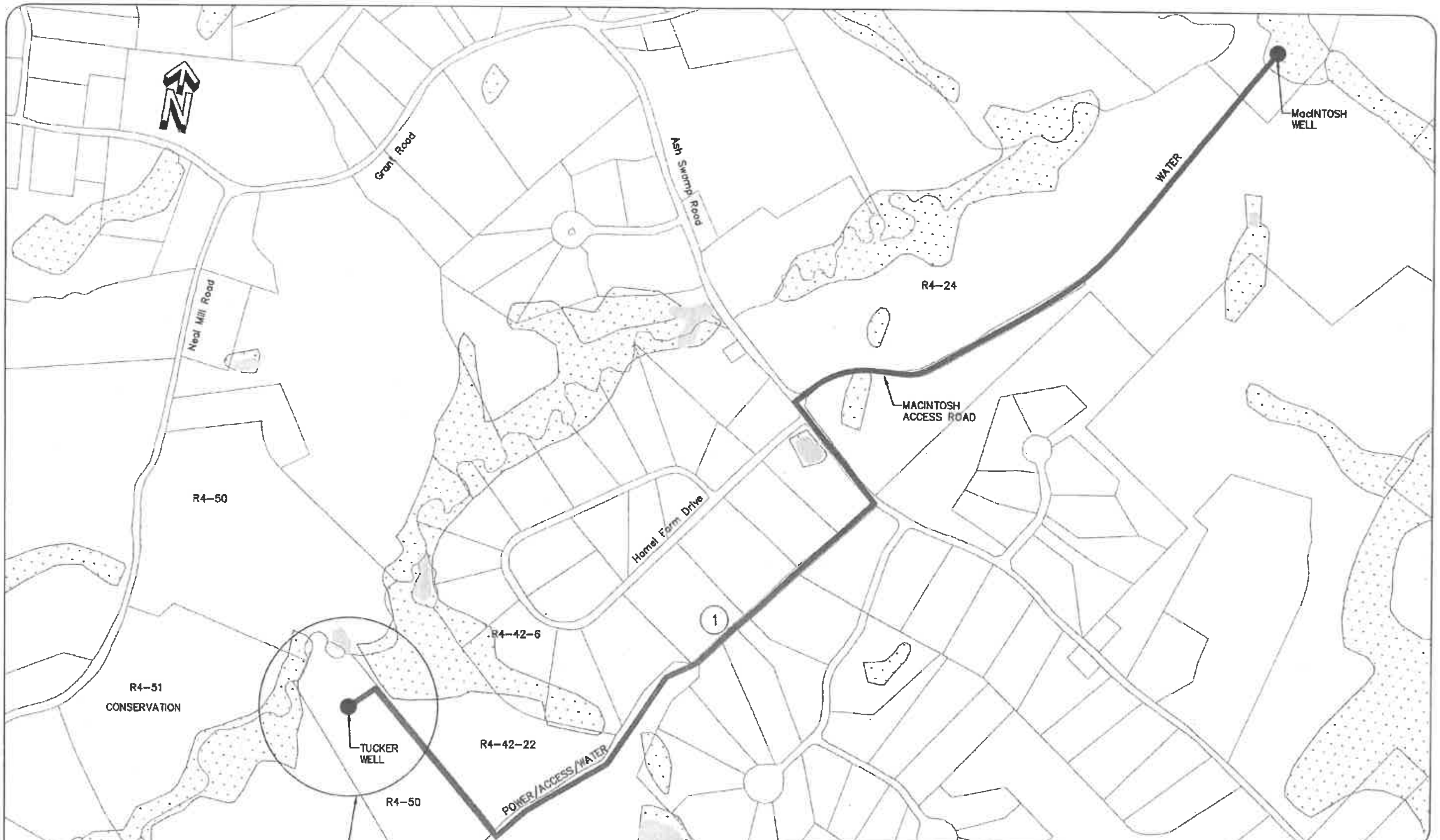
4/25/2018

ITEM	QTY	UNIT	UNIT PRICE	PROBABLE COST	SUBTOTAL
Final Design Phase					
Final Design (WTP only)	1	LS	$275,000	$275,000	
Piloting	1	LS	$25,000	$25,000	
SUBTOTAL					$300,000
Construction Phase					
General Requirements (11.5% of Construction Cost)	1	LS	$355,000	$355,000	
Site Work (incl. foundation excavation & backfill, gravel drive, fence/gates, tree clearing)	1	LS	$125,000	$125,000	
Replace MacIntosh Well Pump and Motor	1	LS	$40,000	$40,000	
Construct 45 x 65 CMU building (incl. concrete foundation and slab)	2925	SF	$150	$438,750	
SCADA and controls	1	LS	$100,000	$100,000	
Generator	1	LS	$75,000	$75,000	
Electrical work	1	LS	$150,000	$150,000	
HVAC	2925	SF	$20	$58,500	
Sewer Pumping Station	1	LS	$50,000	$50,000	
Sewer Force Main	1200	LF	$350	$420,000	
Treatment Unit					
Furnish packaged GSP filtration equipment	1	LS	$278,000	$278,000	
Furnish packaged water softener system	1	LS	$149,000	$149,000	
Furshish packaged RO system	1	LS	$370,000	$370,000	
System Startup	1	LS	$35,000	$35,000	
Install packaged equipment (GSP, water softener and RO)(35%)	1	LS	$278,950	$278,950	
Overhead and profit (15% of F&I)	1	LS	$119,550	$119,550	
Backwash reclaim tank	2	LS	$45,000	$90,000	
Backwash pumps	2	LS	$20,000	$40,000	
Waste residuals (sludge) pump	2	LS	$20,000	$40,000	
Chemical feeds	1	LS	$50,000	$50,000	
F&I Interior piping (incl. static mixers, flow meters)	1	LS	$175,000	$175,000	
Construction Phase Engineering (~15%)	1	LS	$520,000	$520,000	
Contingency (~25%)	1	LS	$690,000	$690,000	
Other costs: Legal, Administration	1	LS	$50,000	$50,000	
SUBTOTAL					$4,698,000
TOTAL PROBABLE CONSTRUCTION COST					***$4,998,000***

Notes:

APPENDIX B

TUCKER WELL RECOMMENDED CONNECTION ROUTE (Figure 2)



DATE			FIG.
10/28/16	**UNDERWOOD** engineers 25 Vaughan Mall, Portsmouth, N.H. 03801 Tel. 603-436-6192 Fax. 603-431-4733	TUCKER WELL RECOMMENDED CONNECTION ROUTE NEWMARKET, NH	2
PROJECT 2096			

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