# City of Colusa

# Water Well and Pump Station Evaluation Report

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## EXECUTIVE SUMMARY

The City of Colusa (City) water system is functional and meets current needs, but equipment is aging and maintenance has been deferred in many cases. The City should plan for increasing repair and replacement costs as equipment ages. Going forward, the City should plan to replace equipment and materials at a progressive interval of 50 years to reduce the risk of failure and promote system reliability.

### Wells

Wells Nos. 2 and 3 are probably at or beyond the normal reliable lifespan for similar structures. For Well No. 2, the City should spend as little time and money as possible to keep the well running until a replacement well is constructed. The Well No. 2 site would be suitable for a replacement well. The City should plan to phase out the use of Well No. 3 and ultimately abandon the site; its location and size will make future improvements and upgrades very difficult if not impossible. In the interim, the City's best option is probably to spend as little time and money as possible to keep Well No. 3 running.

Wells Nos. 4, 5, and 6 have some problems but are the City's lead wells and are within the normal reliable lifespan for similar structures. The City should plan to conduct regular (at least once per year) well testing to monitor the wells' performance and see if specific capacity declines or sand production increases over time. If changes in these parameters become problematic, or if other problems occur in any of the lead wells, the City should perform a video survey of the well structure to determine its condition and ability to withstand well repair or rehabilitation. The City should be prepared for some upcoming repair and rehabilitation, and ultimate replacement of the lead wells as the end of their normal reliable lifespan approaches.

The cost for engineering and construction to drill a test hole and construct a multiple-completion monitoring well to a depth of 1,000 feet, then construct a 16-inch production well to a depth of 500 feet, would be approximately $500,000.

### Pump Stations

Overall, the City's pump stations are functional and appear to meet service conditions. However, some of the equipment is outdated and near the end of its reliable service life. The City has deferred maintenance on some equipment. Although the age and condition of the equipment does not currently affect its functionality, it does affect reliability. With older equipment with deferred maintenance, the City should consider that a higher degree of redundancy may be needed to accommodate facilities that are off line for more frequent upcoming repairs/maintenance or during unexpected failures. The City should plan to replace equipment and materials at a progressive interval of 50 years to reduce the risk of failure and promote system reliability. An entirely new pump station, similar to Well No. 6, would cost approximately $750,000 for engineering and construction.

If the City wishes to continue to use Well No. 2 as an active permitted source, the well and discharge piping should be disinfected and flushed, then connected to the distribution system. The equipment should be exercised periodically to keep it operational. More frequent operation of the well should reduce the need for flushing.

For Well No. 3, the time delay relay setting on the soft start should be adjusted. If this does not significantly reduce motor noise on startup, the soft start should be replaced with a modern unit. Replacing the soft-start would cost approximately $15,000.

For Wells Nos. 3, 4, 5, and 6, the flowmeter calibration should be checked. If the flowmeters cannot be properly calibrated, modern flowmeter and pressure transmitter with digital output capability should be installed. Efficiency tests should be re-run once flowmeter have been confirmed accurate. Installation of new flowmeters would cost approximately $15,000 per site; rerunning efficiency test at all wells would cost approximately $5,000.

## Water Quality

The City has expressed that its primary concerns with regard to water quality are consumer complaints of dirty water and a rotten egg odor. Water quality in the City's wells generally meets all drinking water standards except for manganese, and occasionally iron. There is a secondary (aesthetic) maximum contaminant level (MCL) for manganese of 50 ug/L and for iron of 300 ug/L. Enforcement of secondary standards is somewhat discretionary, based on level of consumer complaints and cost of treatment, and the City has not been subject to enforcement.

Manganese and iron are the most likely causes of the "dirty water" complaint. The "rotten egg odor" is likely a result of the presence of hydrogen sulfide gas in water from the City's wells. Chlorination is the City's only treatment, and is helping reduce odor. The drawbacks with chlorination are that over-chlorination can contribute to dirty water, can leave a chlorine taste to the water, and can increase chlorine byproduct formation.

Oxidation and filtration is the standard treatment to remove iron and manganese, which should reduce the problem of "dirty water". Aeration removes odor and improves taste. Sequestering agents chemically bind iron and manganese to prevent them from reacting with chlorine, allowing them to remain soluble and pass undetected through the distribution system. The sequestering agents would help reduce the demand for chlorine so that it would be more effective in treating hydrogen sulfide without causing dirty water or other problems. Although sequestering agents would not reduce the amount of iron or manganese in the City's water, they would likely reduce the problems associated with their presence.

Oxidation and filtration could be considered for Wells Nos. 5 and 6, and aeration could be considered for Well No. 6. Well No. 4 has generally acceptable water quality according to the City. Because the lifecycle cost of sequestering agents is substantially lower than other recommended treatment options, we recommend that the City consider a pilot program to select and test whether sequestering agents would be a good option for the City.

A summary of the 25-year lifecycle costs, including capital and operating costs, for each recommended option for the City's lead wells is presented below. An annual inflation rate of 3% was assumed, and applied to yearly operations and maintenance costs, and to the cost of planned equipment replacement within the 25-year estimating period. Costs assume production of 110 MG/year for Well No. 4, 193 MG/year for Well No. 5, and 220 MG/year for Well No. 6.

| **Option** | **Lifecycle Costs (25 Years)** | | |
|---|---|---|---|
| | **Well No. 4** | **Well No. 5** | **Well No. 6** |
| Filtration | N/A | $822,400 | $1,214,000 |
| Aeration Only | N/A | N/A | $1,019,800 |
| Aeration + Filtration | N/A | N/A | $2,066,500 |
| Sequestering | $96,650 | $148,850 | $165,800 |

Because of the age, condition, and infrequent use of Wells Nos. 2 and 3, treatment is generally not recommended; however, sequestering could be considered as an option because its capital costs are much lower, and ongoing costs are proportional to production.

## DESCRIPTION OF WATER SYSTEM OPERATION

The City's water system consists of five wells, two storage tanks, and the distribution system. Three of the City's wells (Wells Nos. 4, 5, and 6) are "lead" wells, and two wells (Wells Nos. 2 and 3) are used for supplemental supply on an as-needed basis. The City serves water to approximately 2,400 service connections within and slightly outside of the City limits. The location of the City's wells, storage tanks, and distribution system are shown in Map 1; the location of the City's wells, storage tanks, and two new well sites are shown in Figure 1.

The City operates its wells to maintain pressure in the storage tanks between 48 to 54 psi, with a preferred range of 50 to 52 psi. Pressure is only monitored at the storage tanks, not in the distribution system. Wells Nos. 4, 5, and 6 are called on by a SCADA system at the City's master station located at the storage tank site. The master station is linked to the slave control panels at each well site via a landline telephone connection. The master station monitors pump station run status, pump failure, tank level, tank low and high level alarms, and loss of signal. The SCADA system was installed in 1992 and calls the well pumps to activate or deactivate to maintain pressure in the storage tanks according to a programmed sequence in the following order: First – Well No. 6, Second – Well No. 4, Third – Well No. 5. Well No. 3 can be called on using the SCADA system, but is not part of the automated routine; it must be called manually. Well No. 2 is not equipped with SCADA. Wells Nos. 2 and 3 must be flushed before water from the wells can be introduced into the distribution system, so they are typically operated manually.

## WELL FIELD PRODUCTION

The City's well field production averages about 575 million gallons (MG) per year. Average monthly production ranges from a low of about 25 MG in December, January, and February, to a high of about 75 to 80 MG in June, July, and August. Monthly and annual well field production are summarized in Figure 2 (no data was available for 2003).

During the period from 2002 through present (excluding 2003), Well No. 6 was off-line for a substantial period of time for rehabilitation. Well No. 6 is usually the City's lead well, but because it was off-line, from 2002 through present Well No. 5 had the highest average annual production, about 245 MG. Well No. 6 had an average annual production of about 200 MG and Well No. 4 had an average annual production of about 120 MG. Wells Nos. 2 and 3 produced less than 20 MG per year on average. Monthly and annual well production are summarized in Figure 3.

Daily well production for the City's lead wells from January through June 2007 (Figure 4) indicate that the City is meeting demands with one to three of its five wells operating each day. Wells Nos. 2 and 3 did not contribute significantly to the City's production during this period. Based on the approximate flow rates of the City's wells (Figure 4), the maximum total production with all three lead wells on line is 3,200 gpm. Well No. 6 is the largest contributor with an approximate flow rate of 1,450 gpm. If Well No. 6 were off line, both Wells Nos. 2 and 3 would be necessary to make up the 1,450 gpm capacity. The wells are theoretically capable of providing this backup capacity, but given the age and condition of the City's infrastructure (discussed further below), this may still not provide an optimal level of system redundancy.

# WELLS

## Wells – Evaluation of Construction

Well construction standards in California are established by the California Department of Water Resources (DWR) in Bulletins 74-81 and 74-90. Colusa County has also established standards for wells constructed within the County; these are set forth in Chapter 35 of the County Code and reference the DWR well construction standards. The California Department of Public Health (DPH) is the permitting agency for public water systems in the state, and generally requires conformance with DWR standards and also evaluates municipal well location with regard to offsets from additional potential contaminant sources. Key well construction standards as they relate to construction of the City's wells are outlined below. These standards are mainly applied to the construction of new wells; older existing permitted municipal wells may have been constructed prior to the establishment of some standards and may thus not comply with all current requirements.

Well Diameter, Depth, and Screened Interval

There are no established requirements for well diameter, depth, and screened interval. Information for the City's wells is provided below:

| Well | Year Constructed | Well Diameter (Inches) | Well Depth (Feet) | Screened Interval (Feet Below Ground Surface) |
|---|---|---|---|---|
| Well No. 2[i] | 1963 | 14 | 440 | 264 - 430 |

| Well | Year Constructed | Well Diameter (Inches) | Well Depth (Feet) | Screened Interval (Feet Below Ground Surface) |
|---|---|---|---|---|
| Well No. 3[i] | 1960 | 14 | 440 | 264 - 430 |
| Well No. 4[i] | 1975 | 14 | 500 | 254 - 294<br>360 – 370<br>394 – 444 |
| Well No. 5[ii] | 1981 | 16 | 328 | 250 - ? |
| Well No. 6[i] | 1990 | 16 | 440 | 275 – 300<br>320 – 340<br>400 - 420 |

Construction of the City's wells is very similar with regard to well depth and perforated interval. All of the City's wells are likely completed in the Tehama Formation, a massive water-bearing formation that generally extends from Tehama County to Solano County, and from the Coast Ranges to the Sacramento River.

Well Construction Materials

Records indicate that the City's wells are constructed of the following materials:

| Well | Well Casing Material / Thickness | Well Screen Material / Type | Gravel |
|---|---|---|---|
| Well No. 2[i] | Steel /<br>1/4" | Steel /<br>0.125" by 2 1/2" Machine Cut | Re-Run Pea Gravel |
| Well No. 3[i] | Steel /<br>1/4" | Steel /<br>0.125" by 2 1/2" Machine Cut | Re-Run Pea Gravel |
| Well No. 4[i] | Steel w/ 0.2% Copper /<br>1/4" | Steel /<br>0.50" Slotted | Size 21 |
| Well No. 5[ii] | Steel w/ 0.2% Copper /<br>5/16" | Steel /<br>0.100" Wire Wrapped XX Strong | 50% Size = 4 mm |
| Well No. 6[i,ii] | Steel /<br>1/4" | Steel /<br>0.60" Louvered | 1/4" x 8 |

Sanitary Seal

Sanitary seals for municipal wells must be a minimum of 50 feet deep and have an annular thickness of at least two inches (DWR Bulletin 74-81). The City's well seals are as follows:

| Well | Seal Depth (Feet) | Seal Thickness (Inches) | Complies with Current Standards |
|---|---|---|---|
| Well No. 2[i] | 90 | 3 | Yes |
| Well No. 3[i] | 50 | 3 | Yes |
| Well No. 4[i,ii] | 120 | 3 | Yes |
| Well No. 5[ii] | 50 | ~ 6.5 | Yes |
| Well No. 6[i,iii] | 50 | 3 | Yes |

Based on available records all of the City's wells meet the current minimum sanitary seal requirements.

Offset Requirements

The primary offset requirements for municipal wells are that they be located a minimum of 50 feet from sewer or storm drain mains or laterals. Offsets from the City's wells are as follows:

| Well | Offset from Sewer (Feet) | Complies with Current Standards |
|---|---|---|
| Well No. 2[IV] | 110 | Yes |
| Well No. 3[IV] | 23 | No |
| Well No. 4[V] | > 50 | Yes |
| Well No. 5[VI] | > 50 | Yes |
| Well No. 6[III] | > 100 | Yes |

Records indicate that Well No. 3 was located 23 feet from sewer lines when it was constructed. DPH instructed the City in 1973 to replace sewer lines within a 50-foot radius of Well No. 3 with "extra strength vitrified clay sewer with mechanical compression joints or Class 150 cast iron sewer with mechanical joints" and to relocate the sewer sections as far as possible from Well No. 3 within the existing roadway/alley. It is unclear from the City's well records whether these improvements were made. Based on available records, all of the other City wells meet the current sanitary sewer offset requirements.

## Wells – Evaluation of Condition

Evaluation of the condition of the City's wells has been based on available records, anecdotal information provided by the City, and well testing conducted by Wood Rodgers.

Water Level Measurements

It is difficult to measure water levels in the City's wells, and the City has not made any regular water level measurements. According to the City, all of the wells except for Well No. 6 had been equipped with air lines to measure water levels via pressure, but these systems are very prone to failure and are nonfunctional in the City's wells. Access for a water level sounder is poor at several of the wells that don't have dedicated sounding ports. In those wells, water levels have to be sounded through the casing vents, and the water level sounder is in the well with the column pipe when the well is pumping. In this situation, the water level sounder can get wrapped around the column pipe and must be left in the well. If water levels cannot be easily and reliably measured in the City's wells, it makes it difficult to monitor the well and pump station performance over time.

The City's well pumps are currently all oil-lubricated, and field measurements of water levels in the City's wells indicated that all of the wells have at least several feet of oil on the water surface. The presence of oil on the water surface makes sounding water levels messy, difficult, and prone to inaccuracy when using standard equipment. To accurately sound the oil thickness and water level in a well with oil in it, it is necessary to use an oil/water interface meter, which costs approximately $1,000 to $1,500 (at least twice as much as a standard water level meter). The oil/water interface meter cannot be run in a well alongside the pump column without serious risk of damage or destruction of the meter probe. An alternate method of quantifying the amount of oil in a well is to remove the well pump and bail out the oil. For this project, it was not possible to quantify the amount of oil in the City's wells; qualitatively, the amount of oil is enough to interfere with the accuracy of water level measurements and also to serve as a substrate for potential bacterial growth.

Pump Testing Results

With regards to evaluating the condition of the City's wells, the following information from well testing conducted by Wood Rodgers in August 2007 was used:

| **Well** | **Static Water Level (Feet)** | **Pumping Water Level (Feet)** | **Flow Rate (gpm)** | **Sand Production (ppm)** | **Specific Capacity (gpm/foot)** |
|---|---|---|---|---|---|
| Well No. 2* | 49 | 62 (20 min.) | 800 | ~ 60 (continuous) | ~ 60 (20 min.) |
| Well No. 3 | 46 | 53 (30 min.) | 800 | 4 (start-up only) | 115 (30 min.) |
| Well No. 4 | 47 | 68 (30 min.) | 850 | N/A (start-up only) | 40 (30 min.) |
| Well No. 5 | 47 | 70 (35 min.) | 750 | Trace (start-up only) | 30 (35 min.) |
| Well No. 6 | 53 | 116 (56 min.) | 1,400 | 1 (continuous) | 20 (56 min.) |

* Flowmeter data is highly unreliable, so results are rough estimates.

Ideally, sand production should be very small and only at start-up. Sand becomes problematic when it is produced in significant amounts whenever the well is being pumped. Specific capacity is the measure of gallons per minute produced per foot of drawdown; the higher the specific capacity, the more efficient the well and aquifer. Specific capacity varies by area and aquifer properties, but the City's wells are similar in this regard and can be evaluated in comparison to one another, and in comparison to historic measurements.

The 24-hour projected pumping water level in the City's wells was calculated by extrapolating drawdown data collected during short (20- to 56-minute-long) pumping tests. Because of difficulty in measuring water levels in the wells, only a limited number of water level measurements could be made during the pumping tests. The short test duration and limited number of measurements make the projection of 24-hour pumping water levels prone to error, so they should not be used for decision-making without other corroborating data. The 24-hour projected pumping water levels in the City's wells are as follows:

| Well | Duration of Test (Minutes) | Number of Measurements Made | 24-Hour Projected Pumping Water Level (Feet) |
|---|---|---|---|
| Well No. 2 | 20 | 3 | 66 |
| Well No. 3 | 30 | 2 | 56 |
| Well No. 4 | 30 | 13 | 69 |
| Well No. 5 | 35 | 2 | 103 |
| Well No. 6 | 56 | 3 | 125 |

Well No. 2

Well No. 2 was constructed in 1963 and is 44 years old. Well No. 2 is very rarely used because the water produced has a pronounced odor; the well must be manually operated. The thin mild steel materials used to construct Well No. 2 provide a low level of corrosion resistance. During pump testing, Well No. 2 produced approximately 60 ppm sand continuously throughout the 30 minute test. The reason for excessive sand production is unknown but could be from well screen openings that have worn and enlarged over time, or other holes in the well casing. A sand separator has been installed to prevent sand from entering the distribution system.

Records indicate that in 1964[iv], Well No. 2 produced 915 gpm with a specific capacity of 133 gpm/foot. The well has lost approximately 50% of its specific capacity over the last 43 years. Specific capacity can often be partially restored through well rehabilitation, but the age of the structure and the materials used to construct Well No. 2, combined with its sand production, make well rehabilitation inadvisable. Well No. 2 is probably at or beyond the normal reliable lifespan for similar structures.

Well No. 3

Well No. 3 was constructed in 1960 and is 47 years old. Well No. 3 is typically used as supplemental supply when one of the City's lead wells (Nos. 4, 5, and 6) is offline. The thin mild steel materials used to construct Well No. 3 provide a low level of corrosion resistance. During pump testing, Well No. 3 produced a small amount of sand, and only on startup; however, Well No. 3 is equipped with a sand separator, indicating that sand production has been problematic. Well No. 3 is located near abandoned underground fuel storage tanks, and has been subject to an increased sampling frequency for MTBE. The well is also located within close proximity of sewer lines. Additionally, the Well No. 3 site is very small and would not accommodate a replacement well or wellhead treatment.

Records indicate that in 1964[iv], Well No. 3 produced 1305 gpm with a specific capacity of 156 gpm/foot. The well has lost approximately 35% of its specific capacity over the last 43 years. Specific capacity can often be partially restored through well rehabilitation, but the age of the structure and the materials used to construct Well No. 3, along with its problematic sand production, may make well rehabilitation inadvisable.  Well No. 3 is probably at or beyond the normal reliable lifespan for similar structures.

Well No. 4

Well No. 4 was constructed in 1975 and is 32 years old.  Well No. 4 is one of the City's lead wells, and the second most frequently used (after Well No. 6).  The copper-bearing steel casing material used to construct Well No. 4 provides a good level of corrosion resistance, and the well appears to be well-designed.  During pump testing, Well No. 4 produced a small amount of sand on start-up only.

Recent testing of Well No. 4 indicates that the specific capacity is 40 gpm/foot, which is better than the City's newer wells.  Because historic data is not available, it is unknown whether this value is lower than when the well was first constructed.  If a video survey of Well No. 4 indicated that the structure was in good condition, the well could probably be rehabilitated without significant risk of damage to the well structure.  Well No. 4 is probably at least 75% through the normal reliable lifespan for similar structures.

Well No. 5

Well No. 5 was constructed in 1981 and is 26 years old.  Well No. 5 is one of the City's lead wells, and the third most frequently used (after Wells Nos. 4 and 6).  The thicker copper-bearing steel casing material used to construct Well No. 5 provides a preferred level of corrosion resistance.  Unfortunately, the mild steel wire-wrapped well screen is prone to failure.  During pump testing, Well No. 5 produced a trace of sand on start-up only.  Well 5 produces entrained gas, which will be discussed in subsequent sections and is not considered a problem with the well structure.

Recent testing of Well No. 5 indicates that the specific capacity is 30 gpm/foot, which is average for the City's newer wells.  Because historic data is not available, it is unknown whether this value is lower than when the well was first constructed.  Even if a video survey of Well No. 5 indicated that the structure was in good condition, any well rehabilitation should be extremely gently and carefully performed to avoid damaging the mild steel wire-wrapped well screen.  Well No. 5 is probably about 60% through the normal reliable lifespan for similar structures.

Well No. 6

Well No. 6 was constructed in 1990 and is 17 years old.  Well No. 6 is the City's lead well.  The type of steel casing material used to construct Well No. 6 is not known, but it is likely copper-bearing, which provides a preferred level of corrosion resistance, and the louvered well screen is generally durable.  During pump testing, Well No. 6 produced a small amount of sand continuously throughout the test.  Well No. 6 also has problems with odor, but these are not considered well structure problems and are discussed separately.

Recent testing of Well No. 6 indicates that the specific capacity is 20 gpm/foot, which is low for the City's newer wells.  Historic data indicates that when the well was new, the specific capacity was about 36 gpm/foot, which means that it has declined nearly 50% in

17 years. According to the City, a decline in specific capacity led the City to rehabilitate Well No. 6 with swabbing. After the well rehabilitation, Well No. 6 produced pea gravel. The pump setting depth was lowered, which remedied the problem. Recent video surveys of Well No. 6 indicate that the well casing is damaged, and this may make future well rehabilitation inadvisable. The cause of the damage is unknown and could date back to when the well was constructed. Well No. 6 is probably about 40% through the normal reliable lifespan for similar structures, but its problems to date may make it less reliable.

## Wells – Recommendations for Repairs or Rehabilitation

Water Level Measurements

When the City replaces well pumps, they should consider switching to product- (water) lubricated pumps and also remove the oil in the well at that time. Future City wells should be designed with dedicated sounding ports that run parallel to the well casing and enter the well below the lowest pumping water level; this will allow for water level measurements to be made without potential interference with the pump column. The City should also consider equipping the wells with pressure transducers and tying them into an updated SCADA system to monitor water levels on a regular basis. When the City replaces wells, it should consider installing multiple-completion monitoring wells as a first step to evaluate water quality in different aquifer zones before designing a production well. This could provide better water quality in future production wells.

Well No. 2

The City rarely uses Well No. 2, and is meeting demands with its other wells. This fact, along with the age and condition of Well No. 2, means that it is probably not worthwhile to invest significant resources into improving Well No. 2. If the City wishes to continue to maintain Well No. 2 as supplemental supply, its best option is probably to spend as little time and money as possible to keep the well running. Alternately, if the City wishes to have a more reliable and frequently-used well at this site, we would recommend constructing a replacement well at the site. This replacement well could become one of the City's lead wells.

Well No. 3

The City relies on Well No. 3 for supplemental supply on a regular basis, but the age and condition of Well No. 3 make it less than ideal in terms of reliability. Because the City can also call Well No. 2 if Well No. 3 is off line, the reliability of Well No. 3 has not been an issue. Over the long term, the City should plan to phase out the use of Well No. 3 and ultimately abandon the site; its location and size will make future improvements and upgrades very difficult if not impossible. In the interim, the City's best option is probably to spend as little time and money as possible to keep the well running. In conjunction with phasing out the use of Well No. 3, the City should replace Well No. 2.

Well No. 4

Well No. 4 is one of the City's lead wells, is operating reliably, has a good specific capacity when compared with the City's newer wells, and produces only a small amount of sand. At this time, there is no reason for the City to make any repairs or rehabilitation to Well No. 4. However, the City should plan to conduct regular (at least once per year) well testing to monitor the well's performance and see if specific capacity declines or sand production increases over time. If changes in these parameters become problematic, or if other problems occur, the City should perform a video survey of the well structure to determine its condition and ability to withstand well repair or rehabilitation. Well No. 4 will reach the end of the normal reliable lifespan for similar well structures within about ten years, so the City should be prepared for some upcoming repair and rehabilitation, and ultimate replacement of the well.

Well No. 5

Well No. 5 is one of the City's lead wells, is operating reliably, has a good specific capacity when compared with the City's newer wells, and produces only a trace amount of sand. At this time, there is no reason for the City to make any repairs or rehabilitation to Well No. 5. However, the City should plan to conduct regular (at least once per year) well testing to monitor the well's performance and see if specific capacity declines or sand production increases over time. If changes in these parameters become problematic, or if other problems occur, the City should perform a video survey of the well structure to determine its condition and ability to withstand well repair or rehabilitation. Well No. 5 will reach the end of the normal reliable lifespan for similar well structures within about 15 years, so the City should be prepared for some upcoming repair and rehabilitation, and ultimate replacement of the well.

Well No. 6

Well No. 6 is the City's lead well, is operating fairly reliably but continually produces a very small amount of sand, has a low specific capacity when compared with the City's newer wells, and has damage to the well structure. Because the well is meeting the City's needs at this time, there is no reason for the City to make any repairs or rehabilitation to Well No. 6. However, the City should plan to conduct regular (at least once per year) well testing to monitor the well's performance and see if specific capacity declines or sand production increases over time. If changes in these parameters become problematic, or if other problems occur, the City should perform another video survey of the well structure to determine any changes to its condition and its ability to withstand well repair or rehabilitation. If future work is performed, the City should consider repairing damage to the well structure. Well No. 6 will reach the end of the normal reliable lifespan for similar well structures within about 25 years, but its reliable lifespan may be shorter because of damage to the structure. The City should be prepared for some upcoming repair and rehabilitation, and ultimate replacement of the well.

## Wells – Cost Estimates

Cost estimates for engineering and construction of new production wells are as follows:

| | |
|---|---|
| Test hole and multiple-completion monitoring well to 1,000 feet | $150,000 |
| Construction of new 500-foot 16-inch production well with estimated 75-year service life | $350,000 |

# PUMP STATIONS

## Pump Stations – Evaluation of Construction

To evaluate the construction and condition of the City's pump stations and related equipment, Wood Rodgers visited each of the City's five well sites on August 24, 2007 with the City's chief operations technician, Mr. Jessee Cain. During the site visit, each well pump was operated as needed to record flow, pressure, and other readings.

All of the City's wells are located inside either metal buildings or stud-frame construction with metal or wood siding and include standing-seam or corrugated metal roofs. The pump, motor, discharge valve, switchgear, and motor control center for each well is contained within the main compartment of each building; the chlorine gas disinfection equipment is housed in a separate interior compartment of each building. The wells are each equipped with multi-stage vertical turbine pumps with an intake depth of 150 feet. The pumps have solenoid-operated oil lubrication systems, vertical lineshaft constant-speed alternating current motors, conventional discharge circuits, and chlorine gas-feed disinfection systems. A more detailed description of equipment at each facility, along with recorded measurements and conditions, is provided below.

<u>Well No. 2</u>

The Well No. 2 site was constructed in 1963 and is located in the southeast corner of Davison Park on Webster Street between 8th and 9th Streets. The site has room for a replacement well and/or water treatment equipment. The facility consists of a small pump building and fenced area containing an approximate 5,000-gallon vessel-type sand separator. Well No. 2 is operated infrequently and must be flushed before water can be introduced in to the City's distribution system. The well is reported to produce approximately 600 gpm; however, during the site visit, this could not be verified because the output was discharged to atmosphere upstream of the flowmeter. The following information was documented from the site visit:

| | |
|---|---|
| **Pump Manufacturer and Model** | Byron Jackson 2KM-4 (4-stage) |
| **Pump BEP** | 800 gpm @ 205 feet TDH |
| **Maximum Pump Bowl Efficiency** | 81% |
| **Maximum Pump BHP** | 50 hp |
| **Motor** | 50 hp, 480 volts AC, 3φ, 4-Pole, 1,750 rpm |
| **Motor Current** | Phase A – 45.5 amps<br>Phase B – 43.0 amps<br>Phase C – 44.0 amps<br>FLA – 61 amps |
| **Measured Flow and Pressure** | N/A |

The Well No. 2 site is shown in Figure 6, and the pump characteristic curve for single-stage performance is shown in Figure 7.

Well No. 3

The Well No. 3 site was constructed in 1960 and is located in a parking lot on 6th Street between Fremont and Carson Streets. The site does not have room for a replacement well or water treatment equipment. The facility consists of a small metal-sided pump building and fenced area containing a hydrocyclone-type sand separator. Well No. 3 is typically used as supplemental supply when one of the City's lead wells (Nos. 4, 5, and 6) is offline, and must be flushed before water can be introduced in to the City's distribution system. The following information was documented from the site visit:

| | |
|---|---|
| **Pump Manufacturer and Model** | Byron Jackson 12GH-3 (3-stage) |
| **Pump BEP** | 1,150 gpm @ 225 feet TDH |
| **Maximum Pump Bowl Efficiency** | 83% |
| **Maximum Pump BHP** | 85 hp |
| **Motor** | 75 hp, 480 volts AC, 3φ, 4-Pole, 1,760 rpm |
| **Motor Current** | Phase A – 80 amps<br>Phase B – 78 amps<br>Phase C – 82 amps<br>FLA – 86 amps |
| **Measured Flow and Pressure** | 830 gpm (Signet meter)<br>@ 67 psi (gauged downstream of swing check valve) |

The Well No. 3 site is shown in Figure 8, and the pump characteristic curve for three-stage performance is shown in Figure 9.

Well No. 4

The Well No. 4 site was constructed in 1975 and is located in the City's corporation yard near the Colusa County Fairgrounds on Colusa Avenue between Will S. Green Avenue and 8th Street. The site has room for a replacement well and/or water treatment equipment. The facility consists of a small metal-sided pump house with all-indoor pumping equipment. Well No. 4 is one of the City's lead wells, and is called based on the pressure in the City's water tanks once Well No. 6 cannot maintain the pressure on its own. The following information was documented from the site visit:

| | |
|---|---|
| **Pump Manufacturer and Model** | Byron Jackson 12GH-3 (3-stage) |
| **Pump BEP** | 1,200 gpm @ 280 feet TDH |
| **Maximum Pump Bowl Efficiency** | 82% |
| **Maximum Pump BHP** | 85 hp |
| **Motor** | 75 hp, 480 volts AC, 3φ, 4-Pole, 1,775 rpm |
| **Motor Current** | Phase A – 86 amps<br>Phase B – 84 amps<br>Phase C – 79 amps<br>FLA – 90 amps |

| | |
|---|---|
| **Measured Flow and Pressure** | 1,000 gpm (Rockwell meter)<br>@ 59 psi (gauged upstream of silent check valve) |

The Well No. 4 site is shown in Figure 10, and the pump characteristic curve for single-stage performance is shown in Figure 11.

Well No. 5

The Well No. 5 site was constructed in 1982 and is located in the southwest corner of C.D. Semple Park at the intersection of Larsen Lane and 3rd Street. The site has room for a replacement well and/or water treatment equipment. The facility consists of a small metal-sided pump house and a fenced area containing a Bell & Gosset Model RL-8 air separator that was installed in 1997. The City indicated that the Well No. 5 pump was rebuilt roughly 20 years ago and that the motor was rewound approximately ten years ago. Well No. 5 is one of the City's lead wells, and is called based on the pressure in the City's water tanks once Wells Nos. 6 and 4 cannot maintain the pressure on their own. The following information was documented from the site visit:

| | |
|---|---|
| **Pump Manufacturer and Model** | Byron Jackson 2KH-9 (9-stage) |
| **Pump BEP** | 670 gpm @ 225 feet TDH |
| **Maximum Pump Bowl Efficiency** | 81% |
| **Maximum Pump BHP** | 50 hp |
| **Motor** | 50 hp, 480 volts AC, 3φ, 4-Pole, 1,150 rpm |
| **Motor Current** | Phase A – 54 amps<br>Phase B – 65 amps<br>Phase C – 58 amps<br>FLA – 65 amps |
| **Measured Flow and Pressure** | 750 gpm (Signet meter)<br>@ 66 psi (gauged upstream of swing check valve) |

The Well No. 5 site is shown in Figure 12, and the pump characteristic curve for single-stage performance is shown in Figure 13.

Well No. 6

The Well No. 6 site was constructed in 1990 and is located on the south side of Memorial Park on Jay Street between 9th and 10th Streets. The site has room for a replacement well and/or water treatment equipment. The facility consists of a small wood frame pump house with indoor pumping equipment. Well No. 6 is the City's lead well, and is called first based on the pressure in the City's water tanks. The following information was documented from the site visit:

| | |
|---|---|
| **Pump Manufacturer and Model** | Peerless 12MB-4 (4-stage) |
| **Pump BEP** | 1,300 gpm @ 245 feet TDH |
| **Maximum Pump Bowl** | 83% |

| | |
|---|---|
| **Efficiency** | |
| **Maximum Pump BHP** | 104 hp |
| **Motor** | 100 hp, 480 volts AC, 3φ, 4-Pole, 1,790 rpm |
| **Motor Current** | Phase A – 100 amps<br>Phase B – 110 amps<br>Phase C – 114 amps<br>FLA – 115 amps |
| **Measured Flow and Pressure** | 1,450 gpm (Signet MK 586 meter)<br>@ 62 psi (gauged downstream of swing check valve) |

The Well No. 6 site is shown in Figure 14, and the pump characteristic curve for single-stage performance is shown in Figure 15.

## Pump Stations – Chlorination System

The City's wells are chlorinated using gas chlorine injection. Chemical dosing is monitored and recorded daily by hand at each well site. The gas chlorine feed system at each well site is hard-wired to operate whenever the well pump is in the run mode. Dosage pacing is preset to achieve a desired chlorine residual, which is measured in the distribution system about 100 feet downstream of each well site. The chlorine residual is measured about five times per month and is hand recorded. The chlorination system consists of twin gas cylinders that are connected to a vacuum regulator and Wallace-Tiernan V75 V-notch Chlorinator, used to produce vacuum pressure and a controllable feed rate to the injector valve. The injector valve mixes the chlorine gas with a feed water supply provided by an approximately 2-hp end-suction centrifugal pump. The resultant solution is injected under pressure into the discharge main through a diffuser. The 150-pound bottles of liquefied chlorine gas are automatically switched over and changed out in proportion to the feed rate at the given station when indicated by the preset scale set point. Gas sensors and a display console are used to monitor for and alarm of the presence of chlorine gas.

Chlorine dosage and residual was evaluated for the City's lead wells (Wells Nos. 4, 5, and 6). Data was insufficient to evaluate chlorine dosage and residual for Wells Nos. 2 and 3. Chlorine dosage averages about 0.75 mg/L in Well No. 4, 1.0 mg/L in Well No. 5, and 2.25 mg/L in Well No. 6. The City doses chlorine in Well No. 6 at a higher rate to help treat hydrogen sulfide odor, which is more prominent in Well No. 6 than in the other lead wells. The chlorine residual from all of the lead wells averages about 0.5 mg/L. The fact that the chlorine residual in Well No. 6 is about the same as in the other lead wells, despite more than twice the dosing, indicates that the additional chlorine is reacting with some chemical(s) in water from Well No. 6, likely hydrogen sulfide. The chlorine dosage and measured residual in the City's lead wells are shown in Figure 5.

## Pump Stations – Evaluation of Condition

Evaluation of pump station condition was based on visual inspections of the sites and data collected during site visits. Some anecdotal information from the City was used in our evaluation when records were not available.

Overall, the City's pump stations are functional and appear to meet service conditions. However, some of the equipment is outdated and near the end of its reliable service life. The City has deferred maintenance on some equipment. Although the age and condition of the equipment does not currently affect its functionality, it does affect reliability. With older equipment with deferred maintenance, the City should consider that a higher degree of redundancy may be needed to accommodate facilities that are off line for more frequent upcoming repairs/maintenance or during unexpected failures.

In order to assess overall plant operating efficiency, Wood Rodgers worked with Kirby Pump and Mechanical to conduct tests at each pumping station and record measurements at various instruments at each site. It should be noted the correctness of the calculations described below is contingent on the accuracy of these instruments. Data collected for each site included: flow (instantaneous and totalized), discharge pressure, water level below discharge centerline, and motor current. Since supplemental loads at the site (e.g. chase water pump, disinfection system, exhaust fans, and incidental electrical items) would distort the estimate of overall plant efficiency, amperage data was collected at the motor terminal leads of the respective motor starter. This enabled us to more accurately calculate energy consumed by the well pump only, as opposed to using direct readings from the electrical meter. The calculated energy can be compared against the electrical meter readings to validate measurements taken during operational testing. The electrical loads, flow meter readings, pumping water levels, and pressure at the proximity of pump discharge are all used to qualify plant performance.

Water levels were measured from centerline of pump discharge to average water surface during pump testing. Total dynamic head was calculated from addition of discharge pressure, static lift, and friction/minor losses attributed to 150-feet of pump column (C=130), discharge elbow, check valve, fitting losses. The method for calculating overall plant, or wire-to-water, efficiency (OPE) is to divide water horsepower by input horsepower. This means dividing the rate of useful work performed by the pump by the rate of energy used by the motor. OPE was calculated at the discharge head, conservatively assuming a constant voltage of 480-VAC and a power factor of 0.8. The following equations are applied to calculate overall plant efficiency.

Water horsepower (hp) = (gpm x TDH) / 3,960
Input horsepower (hp) = 0.89 x average amperage

OPE = Water horsepower / Input horsepower
OPE = (gpm x TDH) / (3,960 x 0.89 x average amperage)
OPE = (gpm x TDH) / (3,524 x average amperage)

The OPE is the combination of motor efficiency and pump efficiency. Motor efficiency is about 92% for a normal motor, and maximum pump efficiency is about 83%, so the maximum possible OPE is about 76%. In practice, an OPE of 70-75% is excellent.

The data collected during the Wood Rodgers/Kirby testing, and the calculated TDH and OPE, is presented below:

| Well | Flow Reading (gpm) | Calculated TDH (feet) | Average Amperage (amps) | OPE | Discharge Pressure (psi) | Pumping Water Level (feet) |
|---|---|---|---|---|---|---|
| Well No. 2 | N/A | N/A | 44 | N/A | N/A | 60 |
| Well No. 3 | 830 | 211 | 80 | 62% | 67 | 52 |
| Well No. 4 | 1,000 | 207 | 83 | 71% | 59 | 68 |
| Well No. 5 | 750 | 219 | 59 | 79% | 66 | 65 |
| Well No. 6 | 1,450 | 262 | 108 | 100% | 62 | 115 |

During the Wood Rodgers/Kirby pump testing, water levels were measured from centerline of pump discharge to average pumping water surface. Total dynamic head (TDH) was calculated by adding the head from discharge pressure, static lift, and friction/minor losses attributed to 150 feet of pump column (C=130), discharge elbow, check valve, and fittings. OPE was calculated at the discharge head, assuming a constant voltage of 480-VAC and a power factor of 0.8.

The results of the Wood Rodgers/Kirby testing are compared against the results of similar tests conducted in 2004 by Layne in the table below:

| Well | Flow (gpm) | | TDH (feet) | | Amperage (amps) | | OPE (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2004* | 2007** | 2004 | 2007 | 2004 | 2007 | 2004 | 2007 |
| Well No. 2 | N/A | N/A | N/A | N/A | N/A | 44 | N/A | N/A |
| Well No. 3 | 1,365 | 830 | 205 | 211 | 106 | 80 | 73 | 62 |
| Well No. 4 | 1,025 | 1,000 | 180 | 207 | 86 | 83 | 59 | 71 |
| Well No. 5 | 930 | 750 | 170 | 219 | 59 | 59 | 71 | 79 |
| Well No. 6 | 1,240 | 1,450 | N/A | 262 | 115 | 108 | N/A | 100 |

* Testing conducted by Layne in 2004.
** Testing conducted by Wood Rodgers/Kirby Pump and Mechanical in 2007.

The OPE for Wells Nos. 5 and 6 are unrealistic since they exceed the theoretical maximum OPE. It is likely that results are a consequence of measurement inaccuracies of the existing flowmeters. In contrast with the Layne pump efficiency testing results published March 8, 2004, there are several areas of agreement and discrepancy with the Wood Rodgers/Kirby test results.

The Layne test data and results feature one questionable item. Well No. 3 has a motor with a full-load amp rating of 86 amps. It would not have been possible for the existing well equipment to have produced the flow stated during the 2004 test as the capacity of the motor would not have allowed for 106 hp, a 23% overrun of the rated full-load amperage. The motor would have had to produce 85 hp per the manufacturer's performance curve to push the said flow rate. However, the pumping head versus flow appears consistent with the manufacturer performance curve. According to Wood Rodgers' test data, the flow is about 25% lower, but the electrical demand of 80 amps is much more consistent with the nameplate rating of the motor.

General Evaluation

- The well sites and buildings are locked for security, but are (with the exception of Well No. 4) located in easily accessible public areas. This may make them more vulnerable to vandalism, fire, and other threats. Redundancy of the well sites reduces this risk.

- The City uses gas chlorine for disinfection. The City's well buildings are not well-sealed, and three of the City's five well sites are located in community parks. Gas detectors and alarms are present within the control buildings, and the gas cylinders are equipped with an auto-shutoff system that close actuators on the cylinders if a gas leak is detected. Despite this precaution, the location of the wells in parks presents a risk of serious emergency if a chlorine leak occurs and the auto-shutoff system does not function as designed.

  Additionally, the use of gas chlorination requires substantial administration. Users of gas chlorine must have a Risk Management Plan (RMP) and a Process Management Plan (PMP) in place for each gas location. The plans are extensive and detailed, and must be regularly updated. Facilities with RMPs are routinely inspected by Cal OSHA for compliance with permitting requirements, and to verify that required leak repair kits and breathing apparatus kits, etc. are onsite. Noncompliance can result in fines up to $250,000.

- Points of connection at chlorine injection diffusers are badly corroded at all well sites. Saddle clamping tees, tapped connections, and piping in the vicinity all show signs of significant corrosion but do not appear to be in danger of immediate failure.

- Based on field observations, the City's existing flowmeters and totalizers appear to provide unstable readings and may be inaccurate. The location of the flowmeters within the discharge piping, and the dated technologies used in the flowmeters, are both factors that are likely to decrease accuracy and prevent them from being comparable to more modern flow measurement technologies. Accurate flowmeters are considered critical for calculating chlorine doses, monitoring operating conditions, tracking equipment performance, and alerting to critical maintenance needs.

- Based on field observations, the City's piping and valving are functional but aging. They are not in need of immediate replacement.

- None of the City's wells are equipped with automatic discharge to waste. Many municipal systems operate their wells to discharge to waste on startup, so that stagnant water and entrained sand are discharged before introducing flow to the system. Additionally, several of the City's well sites have significant limitations in discharge capacity because of a lack of drainage.

- The City's wells are all equipped with oil-lubricated pumps. This type of pump is very reliable and has a long lifespan, but also constantly discharges oil through the top case or stator bearing of the bowl assembly, which accumulates within the well casing. Since oil is less dense than water, a significant quantity of oil builds up making water level monitoring difficult. Oil also can serve as a substrate for bacterial growth, which can negatively affect water quality and well performance.

- The City's pump motors, with the exception of Well No. 6, are normal efficiency. A significant reduction in annual energy use, as well as utility service rebates, can be realized by switching to premium-efficiency motors, which are about 2-3% more efficient.

- The switchgear and motor control centers reportedly require no maintenance. The electrical equipment is contained within sealed panels in buildings. No apparent problems or imminent failures were observed. All panels feature across-the-line starters/motor contactors, with the exception of Well No. 3, which is equipped with a reduced-voltage soft starter. This is unusual because electrical utilities typically won't allow across-the-line full voltage motor starters for motors over 40 hp because they draw too much amperage on startup. [See below for discussion of problem with Well No. 3 soft starter.]

- The City currently uses its elevated storage tanks as equalizing reservoirs for the wells, which are operated sequentially. There does not appear to be any need for variable-frequency drives unless the City would like more operational flexibility. Dynamic losses within the system as a result of operating pumps at full speeds versus partial speeds would not likely provide considerable operating cost savings.

- The City has two backup generators that are stored at the Well No. 4 site. They will reportedly "barely" start a 100 hp motor, which would make them barely able to start Well No. 6.

- The City's SCADA system is very outdated and limited in terms of its functions.

<u>Well No. 2</u>
Well No. 2 is not currently connected to the sand separator or distribution system. The well must be flushed prior to water being introduced into the distribution system. There is no flowmeter on the discharge-to-waste.

<u>Well No. 3</u>
Excess motor noise was observed during reduced voltage start-up of Well No. 3. The well must be flushed prior to water being introduced into the distribution system. The facility reportedly has an old electrical panel for which parts are no longer available, and the panel has grounding problems and the "mag" chatters.

<u>Well No. 4</u>
Well No. 4 has no significant observed problems; however, the previous electrical meter at the site did "blow up" for unknown reasons.

Well No. 5
Well No. 5 was reportedly at least partially equipped with older salvaged equipment. The Well No. 5 motor exhibited a noticeable degree of phase imbalance, roughly 15-20% between the highest and lowest phase currents. Phase imbalance is typically an indicator of gradual motor degradation, generally caused by a decay in the motor winding insulation or resin. It can also be caused by voltage imbalance from the electrical service provider. Finally, the imbalance could be caused by corroded or dirty leads and motor contactors or poor terminations affecting resistance of the conductors. The Well No. 5 flowmeter produces an instantaneous flow reading that is about 40% higher than the totalizer reading divided by the elapsed time. According to our calculations, the totalizer reading is correct and the analog gauge readings are artificially high. The meter is either dysfunctional or is calibrated to an improper scale.

Well No. 6
The Well No. 6 motor exhibited a noticeable degree of phase imbalance, roughly 15-20% between the highest and lowest phase currents. Phase imbalance is typically an indicator of gradual motor degradation, generally caused by a decay in the motor winding insulation or resin. It can also be caused by voltage imbalance from the electrical service provider. Finally, the imbalance could be caused by corroded or dirty leads and motor contactors or poor terminations affecting resistance of the conductors. The Well No. 6 flowmeter operation is questionable.

## Pump Station – Recommendations for Repairs or Rehabilitation

General Recommendations

- Consider removing signs that indicate the type of facility, for example "Well #3". During regular site visits, note any incidences of vandalism or attempts at entry into the well sites. Improve site security if necessary. Consider integrating site entry alarms into updated SCADA system.

- Ensure compliance with RMP and PMP requirements. Inspect each location frequently for signs of problems or malfunctions. Maintain required repair and emergency equipment at each site. Conduct required staff training and ensure that staff understand emergency procedures and are prepared to respond appropriately in an emergency situation. Consider advance coordination with first responders to plan for possible emergencies. In long-range planning, consider converting to sodium hypochlorite for disinfection. Include sodium hypochlorite disinfection rather than gas chlorine disinfection in new well facilities. Incorporate an auto-dialer for transmitting alarm notification if it does not already exist.

- Consider incremental replacement of corroded equipment. For existing facilities, consider using materials with higher corrosion-resistance for replacement. For new wells, provide better isolation between chlorination chemicals and other components of the pump station, for example by locating chlorination chemicals in a separate room that is accessible only from the outside of the building.

- Check calibration of existing flowmeters. Consider replacing flowmeters with relatively low-cost modern V-cone or electromagnetic flowmeters. Consider equipment with digital output and real-time recording capability for tracking facility performance. Consider integrating flowmeter data into updated SCADA system.

- Consider replacing equipment and materials at a progressive interval of 50 years to reduce the risk of failure and promote system reliability.

- Consider equipping new facilities with discharge to waste on startup. If adequate drainage does not exist to allow for significant discharge to waste, consider incorporating discharge basins at new well sites to allow for waste discharge during pump testing and/or well rehabilitation.

- When pump replacement is necessary or desired, consider replacing pumps with product- (water) lubricated pumps. Remove oil from wells when pumps are pulled.

- When motor replacement is necessary or desired, consider replacing motors with premium efficiency units. For lead wells, consider motor replacement for cost savings; initial costs could be fully recouped in savings over 5-6 years.

- Plan for possible future requirements to install soft starters on existing and/or new facilities.

- Continue to use constant-speed drives unless more operational flexibility is desired.

- Consider whether larger capacity and/or more backup generators are necessary to maintain a desired level of emergency capacity. Consider equipping at least some new well sites with auto-transfer capability and providing adequate secured space so that generators can be at the sites and ready to be called on in the event of a power outage emergency.

- Consider updating the SCADA system by replacing it with newer equipment with expanded capabilities. RTU panels capable of transmitting real-time data, alarms, and operating conditions may be useful. Monitored items incorporated could include: entry alarms, water levels, discharge pressure/flow, chlorine dosage, chlorine alarm, etc.

- Metal doors and exhaust fans at the City's well sites should be replaced with fiberglass equivalents when eventual replacement is required. New well sites should incorporate fiberglass doors and exhaust fans.

Well No. 2

If the City wishes to continue to use Well No. 2 as an active permitted source, the well and discharge piping should be disinfected and flushed, then connected to the distribution system. If the site is to be maintained as supplemental supply, the equipment should be exercised periodically to keep it operational. More frequent operation of the well should reduce the need for flushing. If the well is not going to be more frequently operated, consider constructing a replacement well at the Well No. 2 site, or dismantling and salvaging components.

Well No. 3
Reduce the time delay relay setting on the soft start from 2-3 seconds to 1 second. If this does not significantly reduce motor noise on startup, replace the soft start with a modern unit. The pump and motor at this site could use an overhaul/rewind or replacement; however, since Well No. 3 is not frequently used, this may not be a worthwhile expense. Consider installing a modern flowmeter and pressure transmitter with digital output capability. Consider re-running efficiency test with more reliable flowmeter in place.

Well No. 4
Consider installing a modern flowmeter and pressure transmitter with digital output capability. Consider re-running efficiency tests with more reliable flowmeter in place and then evaluating whether pump overhaul and motor upgrade to premium efficiency would be warranted.

Well No. 5
Check flowmeter calibration and if still questionable install a modern flowmeter and pressure transmitter with digital output capability. Consider rerunning efficiency tests with more reliable flowmeter in place and then evaluating whether pump overhaul and motor upgrade to premium efficiency would be warranted.

Well No. 6
Check flowmeter calibration and if still questionable install a modern flowmeter and pressure transmitter with digital output capability.

## Pump Station – Cost Estimates

Cost estimates for engineering and construction of the recommended pump station improvements are as follows:

| | |
|---|---|
| Entirely new pump station, similar to Well No. 6 | $750,000 |
| Installation of new soft start unit with new panel, for 75-hp motor | $15,000 |
| Installation of new flowmeter and pressure transmitter with digital output capability, per facility | $15,000 |
| Rerunning efficiency tests | $5,000 |
| Pump overhaul | ~$10,000 |
| Pump removal and disposal | $5,000 |
| Installation of new water-lube pump | $25,000 |
| Motor replacement with premium efficiency (100-hp) | $10,000 |

| | |
|---|---|
| Replacement of SCADA system with newer equipment and expanded capabilities, including RTU panels capable of transmitting real-time data, alarms, and operating conditions. Monitored items to include entry alarms, water levels, discharge pressure/flow, chlorine dosage, chlorine alarm, etc. Installation including PLC cabinet, radio, antenna, per site. | $60,000 |
| SCADA programming and testing, per site. | $10,000 |

# WATER QUALITY

## Evaluation of Water Quality

The City has expressed that its primary concerns with regard to water quality are consumer complaints of dirty water and a rotten egg odor. Gilmore Engineering evaluated water quality in the City's wells, along with treatment options and recommendations, and prepared a technical memorandum that is attached as an Appendix. This discussion is general; more detail on water quality as it relates to water treatment can be found in the Gilmore Engineering report.

Water quality in the City's wells generally meets all drinking water standards except for manganese and occasionally iron. There is a secondary (aesthetic) maximum contaminant level (MCL) for manganese of 50 ug/L and for iron of 300 ug/L. Compliance with secondary MCLs for manganese and iron is determined by the running annual average of four quarterly samples, if quarterly samples are taken. The California Department of Public Health (DPH) enforces drinking water standards. Enforcement of secondary standards is somewhat discretionary, based on level of consumer complaints and cost of treatment. Manganese and iron are the most likely causes of the "dirty water" complaint. The "rotten egg odor" is likely a result of the presence of hydrogen sulfide gas in water from the City's wells. There is no drinking water standard for hydrogen sulfide, but there is a secondary standard for threshold odor of 3 TON.

General water quality for the City's wells is summarized below:

| Date | Specific Conductance (umhos/cm) | Hardness (mg/L) | Turbidity (NTU) | Iron (ug/L) | Manganese (ug/L) | Odor (TON) |
|---|---|---|---|---|---|---|
| **Well No. 2** | | | | | | |
| 5/22/1986 | 408 | 44 | | <30 | <30 | |
| 7/19/1989 | 441 | 43 | 0.3 | <33 | **52** | <1 |
| 3/12/1992 | 652 | 98 | 1.3 | <100 | 30 | 1 |
| 7/19/2001 | 478 | 77 | | **2000** | **99** | |
| 8/5/2005 | | | 0.82 | 106.1 | **89.3** | 2 |
| 8/23/2007 | 570 | | 0.65 | **420** | **63** | |
| **Well No. 3** | | | | | | |
| 5/22/1986 | 450 | 67 | | <30 | **60** | |
| 8/29/1989 | 509 | 55 | <0.1 | <30 | **65** | **3** |
| 3/12/1992 | 509 | 56 | 0.6 | <30 | **70** | 1 |

| Date | Specific Conductance (umhos/cm) | Hardness (mg/L) | Turbidity (NTU) | Iron (ug/L) | Manganese (ug/L) | Odor (TON) |
|---|---|---|---|---|---|---|
| 7/19/2001 | 447 | 68 | | 0 | **82** | |
| 8/4/2005 | | | 0.65 | 0 | **75.1** | 2 |
| 8/24/2007 | 450 | | 1.4 | <100 | **89** | |
| **Well No. 4** | | | | | | |
| 5/15/1984 | 580 | 86 | | 140 | 40 | |
| 12/8/1988 | 710 | 107 | 0.33 | 110 | **130** | <1 |
| 7/18/1989 | 702 | 96 | 0.6 | <37 | **100** | <1 |
| 3/12/1992 | 679 | 100 | 0.6 | 140 | **110** | <1 |
| 7/19/2001 | 575 | 95 | | 0 | **97** | |
| 8/4/2005 | | | 0.24 | 0 | **83.9** | 0 |
| 8/23/2007 | 790 | | <0.5 | <100 | **150** | |
| **Well No. 5** | | | | | | |
| 5/22/1986 | 550 | 100 | | <30 | 40 | |
| 7/19/1989 | 534 | 75 | 0.2 | <54 | 42 | <1 |
| 8/29/1989 | 509 | 55 | <0.1 | <30 | <5 | **3** |
| 3/12/1992 | 517 | 72 | 0.2 | 94 | 49 | <1 |
| 7/19/2001 | 479 | 70 | | 0 | 48 | |
| 8/4/2005 | | | 0.21 | 0 | 43.3 | 0 |
| 8/24/2007 | 500 | | <0.5 | <100 | **53** | |
| **Well No. 6** | | | | | | |
| 7/6/1990 | 412 | 52 | <0.1 | <30 | **57** | <1 |
| 3/12/1992 | 410 | 48 | 0.1 | <30 | 43 | <1 |
| 4/15/1998 | 425 | | | 38 | 46 | |
| 7/19/2001 | 378 | 48 | | 0 | 44 | |
| 8/5/2005 | | | 0.97 | 0 | **63.6** | **3** |
| 8/24/2007 | 370 | | <0.5 | <100 | 44 | |

All of the City's wells have exceeded the MCL for manganese at some point, and Well No. 2 has also exceeded the MCL for iron. Wells Nos. 5 and 6 have the lowest concentrations of manganese, averaging slightly below the MCL. Water quality results from Well No. 2 are questionable because of their variability, extremely high iron results, and the fact that Well No. 2 is not operated frequently; they may not be representative of groundwater quality. Even though Well No. 4 has the highest manganese of the City's wells, it is reportedly the "best" well, has "no" odor and can be run into the system without generating complaints; odor data confirm that Well No. 4 has had the least odor of any of the City's wells. This indicates that the odor is likely caused by hydrogen sulfide, not manganese.

Manganese concentrations do not appear to be increasing or decreasing with time. Recent samples with low field turbidity had similar manganese concentrations to historic samples with unmeasured field turbidity, indicating that historic results appear to be representative. Samples for Wells Nos. 2 and 3 had higher turbidity because these wells are not operated as frequently.

Concentrations of hydrogen sulfide and other gases in the City's wells are as follows:

| Well | Hydrogen Sulfide (ppm) | Dissolved Oxygen (mg/L) | Methane (ug/mL) | Carbon Dioxide (ug/mL) |
|---|---|---|---|---|
| Well No. 2 | N/A | 0.7-1.0 | N/A | N/A |
| Well No. 3 | ~ 0.2 | 1.4-3.4 | N/A | N/A |
| Well No. 4 | N/A | 0.1-0.6 | 0.092 | N/A |
| Well No. 5 | <0.05 | 0-0.4 | 0.30 | 14 |
| Well No. 6 | 0.1-0.2 | 0-1.8 | N/A | N/A |

Well No. 6 had the worst odor problems, and the City has to dose it with approximately twice as much chlorine as the other lead City wells to achieve the same residual. Well No. 3 reportedly takes a long time to exhibit chlorine residual. Wells Nos. 3 and 6 had the highest concentrations of hydrogen sulfide, which is likely increasing chlorine demand in these wells. Well No. 5, which has an air separator installed, has significant concentrations of carbon dioxide. This is likely present in groundwater at the Well No. 5 site, rather than being a well or pump problem. Typically, in a well or pump problem, dissolved oxygen will be present in higher concentrations as a result of cascading water or holes in the pump column pipe. Methane was present in small concentrations in Wells Nos. 4 and 5.

## Treatment Options and Recommendations

Gilmore Engineering evaluated treatment options and recommendations, and prepared a technical memorandum that is attached as an Appendix. This discussion is a general summary of Gilmore Engineering's findings; more detail can be found in the Gilmore Engineering report.

The options considered for water treatment for the City of Colusa are presented below:

| Treatment Type | Removes Manganese | Removes Iron | Reduces Color | Reduces Odor | Improves Taste |
|---|---|---|---|---|---|
| Chlorination | | | | X | X |
| Oxidation and Filtration | X | X | X | | |
| Proprietary Filtration | X | X | X | | |
| Aeration + Oxidation and Filtration | X | X | X | X | X |
| Aeration + Oxidation | | | | X | X |
| Sequestering Agent + Chlorine | | | X | X | X |

Chlorination is the City's only treatment, and is helping reduce odor. The drawbacks with chlorination are that over-chlorination can contribute to dirty water, can leave a chlorine taste to the water, and can increase chlorine byproduct formation. Oxidation and filtration is the standard treatment to remove iron and manganese. Aeration removes odor and improves taste.

Sequestering agents chemically bind iron and manganese to prevent them from reacting with chlorine, allowing them to remain soluble and pass undetected through the distribution system. The sequestering agents will also bind calcium and magnesium to help prevent hard water scale. The sequestering agents would help reduce the demand for chlorine so that it would be more effective in treating hydrogen sulfide without causing dirty water or other problems. Although sequestering agents would not reduce the amount of iron or manganese in the City's water, they would likely reduce the problems associated with them. One negative aspect of using sequestering agents is that they may contribute to additional flushing needs for the distribution system, as the sequestering agents can break down and degrade over long periods of time. This may be problematic in areas of the distribution system with long residence times, or that are difficult to flush.

## Treatment – Cost Estimates

A summary of the 25-year lifecycle costs, including capital and operating costs, for each recommended option for the City's lead wells is presented below. An annual inflation rate of 3% was assumed, and applied to yearly operations and maintenance costs, and to the cost of planned equipment replacement within the 25-year estimating period. The life expectation of filtration and aeration is 25 years, and the life expectance of a sequestering agent metering pump is 5 years. The lifecycle costs presented below include replacement of the metering pumps 4 times during the 25-year period. Costs assume production of 110 MG/year for Well No. 4, 193 MG/year for Well No. 5, and 220 MG/year for Well No. 6.

| **Option** | **Lifecycle Costs (25 Years)** | | |
|---|---|---|---|
| | **Well No. 4** | **Well No. 5** | **Well No. 6** |
| Filtration | N/A | $822,400 | $1,214,000 |
| Aeration Only | N/A | N/A | $1,019,800 |
| Aeration + Filtration | N/A | N/A | $2,066,500 |
| Sequestering | $96,650 | $148,850 | $165,800 |

The City may wish to consider a pilot program to select and test whether sequestering agents would be a good option for the City. Gilmore Engineering's technical memorandum provides recommendations for such a program.

Because of the age, condition, and infrequent use of Wells Nos. 2 and 3, treatment is generally not recommended. Sequestering could be considered as an option because its capital costs are much lower, and ongoing costs are proportional to production.

## ABBREVIATIONS

| | |
|---|---|
| AC | Alternating Current |
| BEP | Best Efficiency Point |
| BHP | Brake Horsepower |
| FLA | Full Load Amperage |
| hp | Horsepower |
| psi | Pounds per Square Inch |
| rpm | Revolutions per Minute |
| TDH | Total Dynamic Head |

[i] DWR Well Completion Report
[ii] City Records
[iii] DPH, *Permit Amendment,* 1990
[iv] DPH, *Sanitary Engineering Investigation of Domestic Water Supply*, 1964
[v] Site visit
[vi] DPH, *Permit Amendment*, 1981


**LEGEND**

- Proposed Well Site
- Water Tower
- Well Location

**SOURCES:** ESRI Street Map/USA Imagery

0 500 1,000 Feet

# CITY OF COLUSA

## CITY WELL EVALUATION

### WELL AND WATER TANK LOCATIONS

AUGUST, 2007

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

**FIGURE 1**

Project Path: J:\Jobs\8307 Colusa, City of\8307.003\GIS\Figure 1 Well Location Map

| | 2002 | 2004 | 2005 | 2006 | 2007 | AVERAGE |
|---|---|---|---|---|---|---|
| January | 28.328 | 21.262 | 23.387 | 24.972 | 31.312 | 25.852 |
| February | 26.693 | 20.543 | 21.863 | 28.073 | 25.187 | 24.472 |
| March | 31.59 | 30.308 | 26.996 | 23.335 | 40.769 | 30.600 |
| April | 44.476 | 50.66 | 47.0568 | 35.299 | 49.421 | 45.383 |
| May | 63.554 | 71.814 | 47.2788 | 49.678 | 70.787 | 60.622 |
| June | 82.82 | 74.948 | 59.7357 | 79.451 | 79.069 | 75.205 |
| July | 91.146 | 78.533 | 65.3196 | 76.376 | 89.364 | 80.148 |
| August | 84.419 | 77.309 | 78.4442 | 66.482 | - | 76.664 |
| September | 71.821 | 66.113 | 65.3196 | 59.205 | - | 65.615 |
| October | 55.248 | 42.498 | 53.8385 | 51.664 | - | 50.812 |
| November | 31.426 | 22.896 | 29.863 | 28.808 | - | 28.248 |
| December | 25.385 | 23.105 | 25.304 | 22.48 | - | 24.069 |
| **TOTAL** | **636.906** | **579.989** | **544.4062** | **545.823** | | **576.781** |
| **Month** | **Production (MG)** | | | | | |

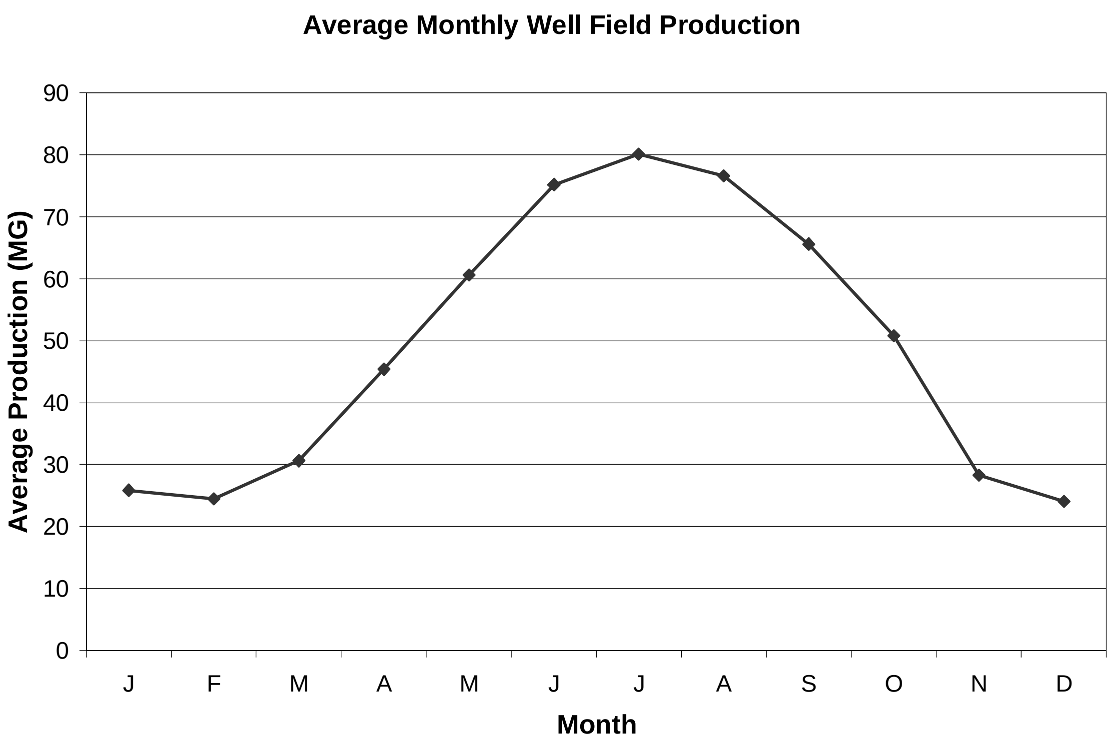



Figure 2. Average Monthly Well Field Production

| Month | Production (MG) | | | | |
|---|---|---|---|---|---|
| | Well No. 2 | Well No. 3 | Well No. 4 | Well No. 5 | Well No. 6 |
| January | 0 | 0.002 | 1.586 | 24.167 | 0.097 |
| February | 0 | 0.006 | 1.820 | 16.881 | 5.765 |
| March | 0 | 0.287 | 5.661 | 20.761 | 3.891 |
| April | 0.044 | 4.512 | 7.891 | 23.465 | 9.471 |
| May | 0.044 | 1.023 | 6.655 | 23.560 | 29.341 |
| June | 1.346 | 2.855 | 16.281 | 23.606 | 31.116 |
| July | 0 | 4.455 | 20.547 | 24.295 | 30.851 |
| August | 0.008 | 5.106 | 20.309 | 25.983 | 25.258 |
| September | 0 | 1.244 | 18.380 | 23.521 | 22.469 |
| October | 0 | 0.125 | 12.098 | 20.892 | 17.697 |
| November | 0 | 0.015 | 6.051 | 8.923 | 13.260 |
| December | 0 | 0.015 | 5.005 | 10.190 | 8.859 |
| **TOTAL** | **1.441** | **19.645** | **122.2833** | **246.2451** | **198.075** |

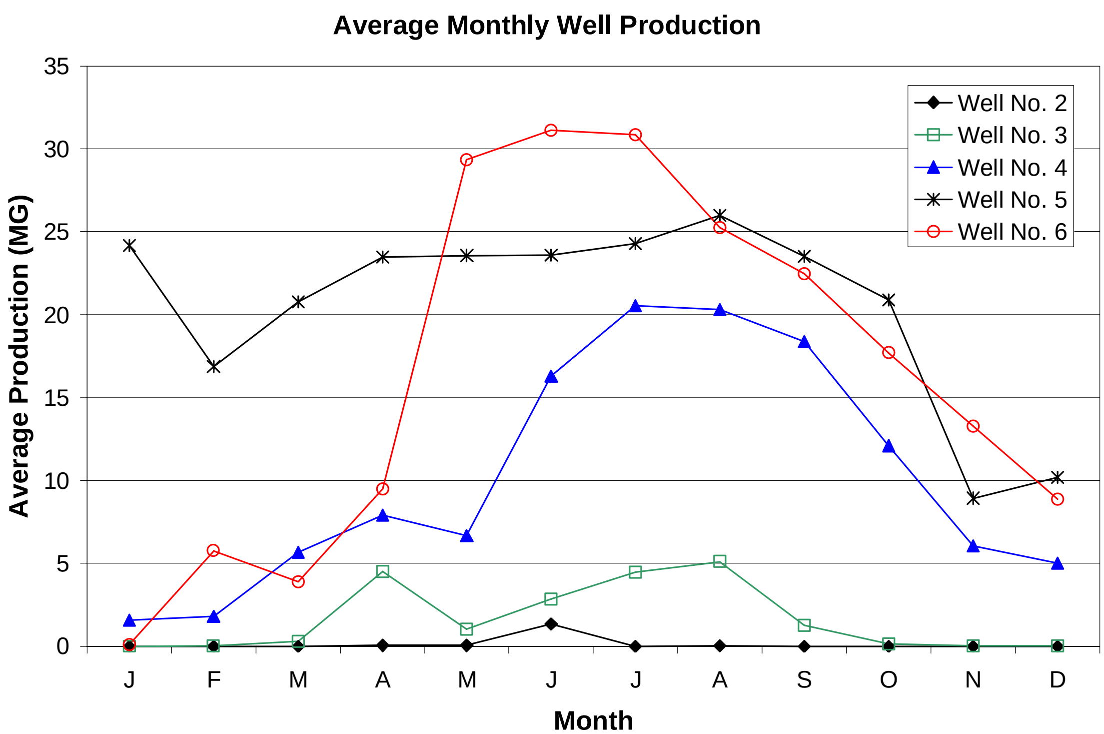
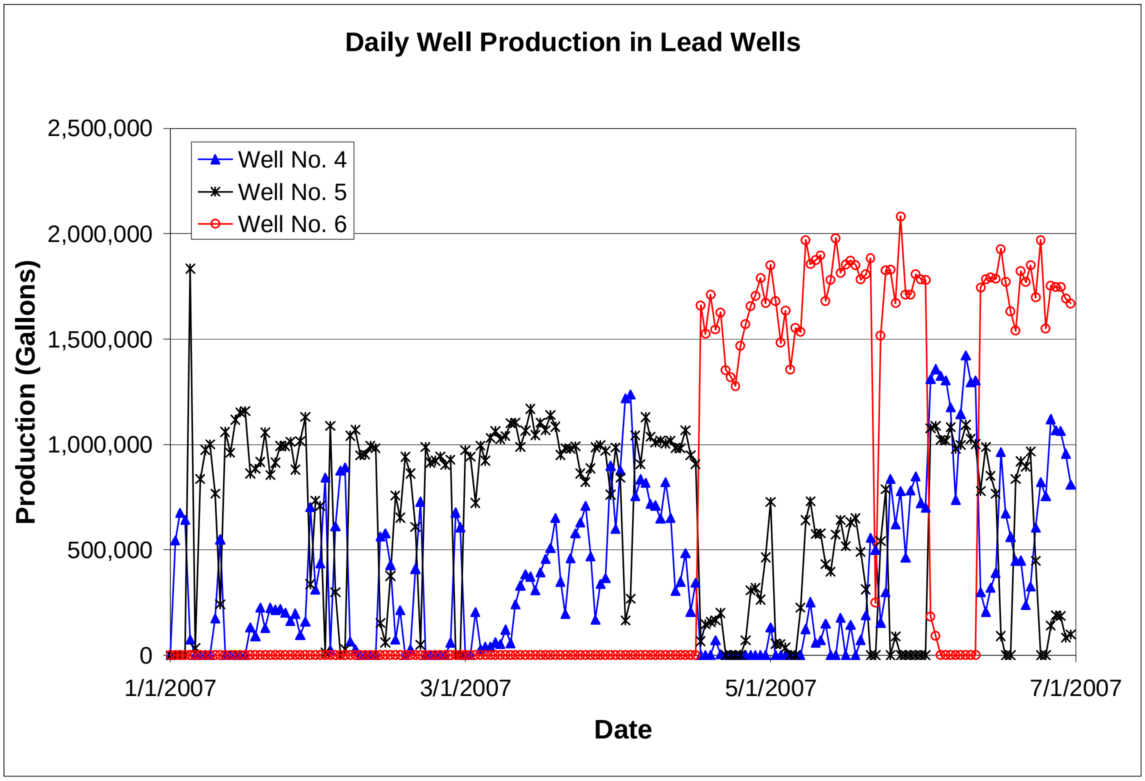


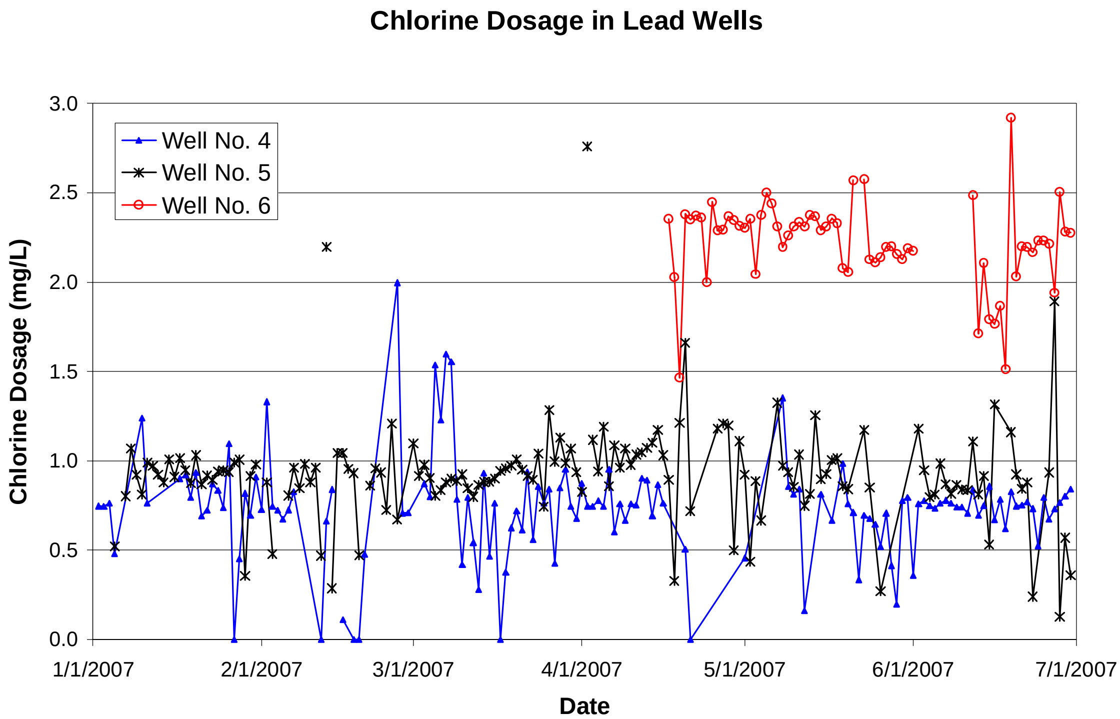

Figure 3. Average Monthly Well Production




| Well | Approximate Flow Rate (gpm) |
|---|---|
| Well No. 2* | 800 |
| Well No. 3 | 800 – 830 |
| Well No. 4 | 850 – 1,000 |
| Well No. 5 | 750 |
| Well No. 6 | 1,400 – 1,450 |

* Flowmeter data is highly unreliable.

Figure 4. Daily Production and Approximate Flow Rates in Lead Wells



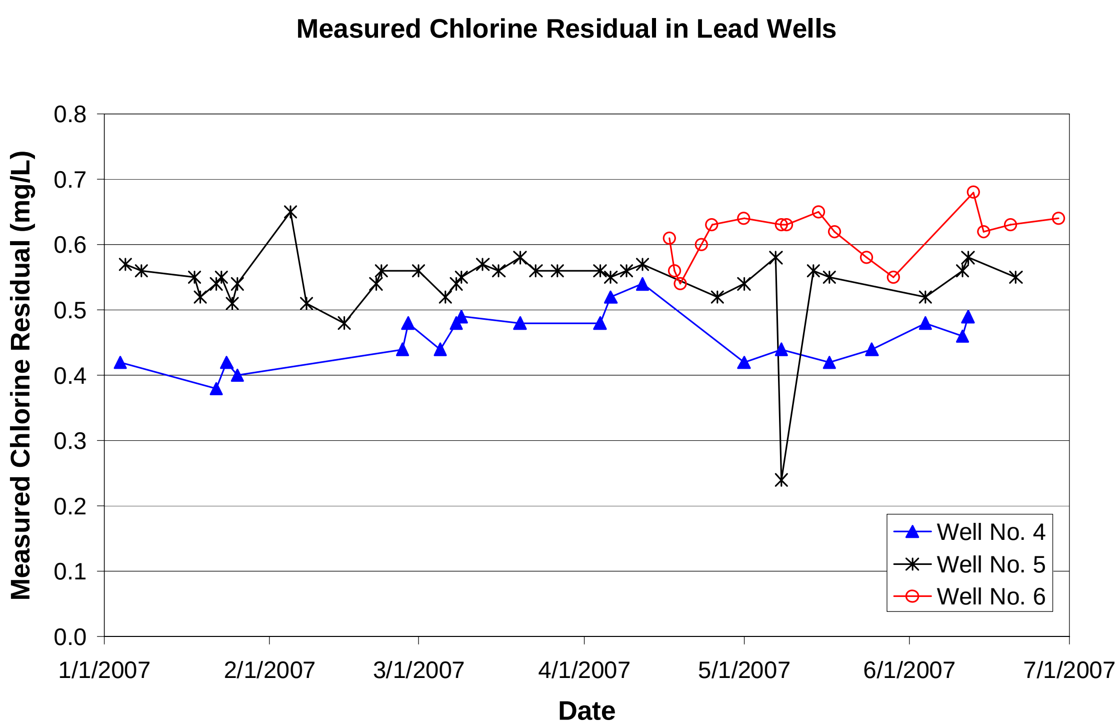




Figure 5. Chlorine Dosage and Residual in Lead Wells


Figure 6. Well No. 2 Site

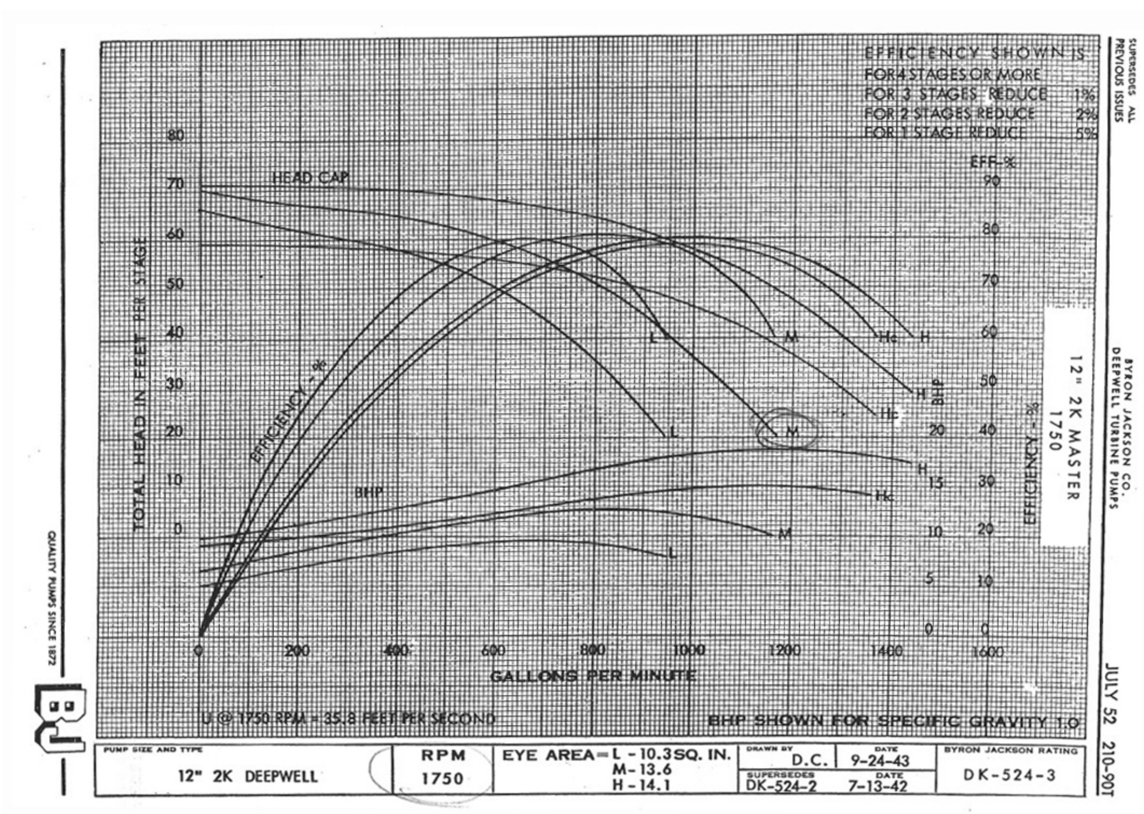



Figure 7. Well No. 2 Pump Curve (Single-Stage)

Figure 8. Well No. 3 Site

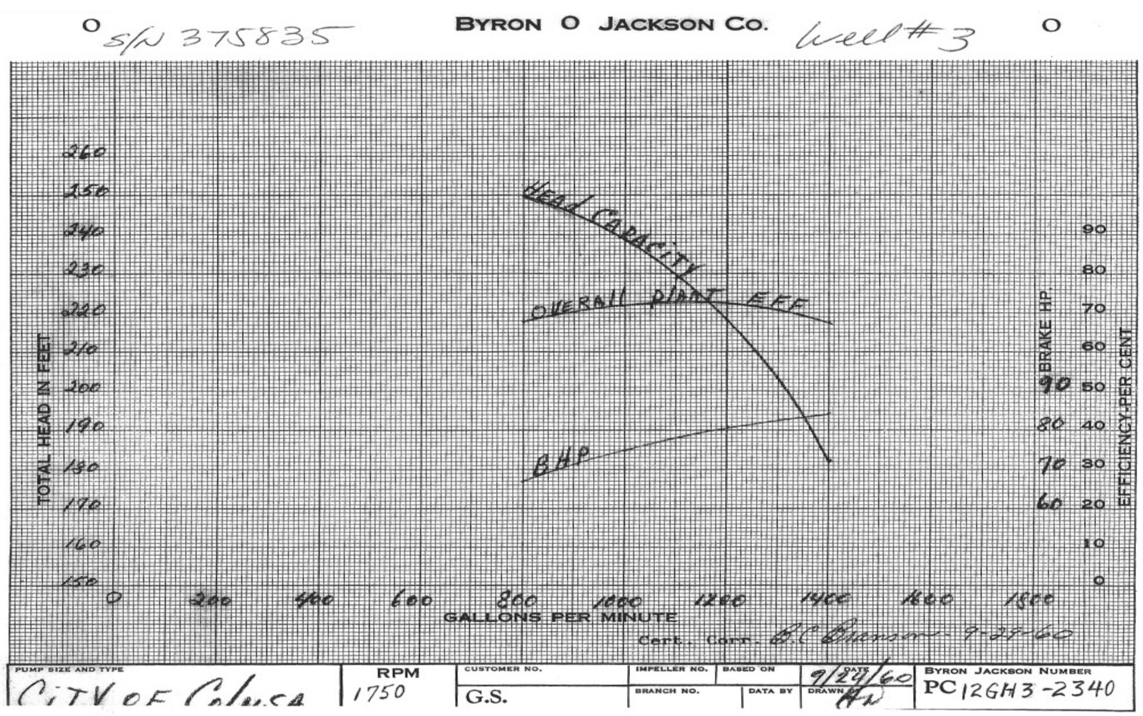



Figure 9. Well No. 3 Pump Curve (3-Stage)


Figure 10. Well No. 4 Site

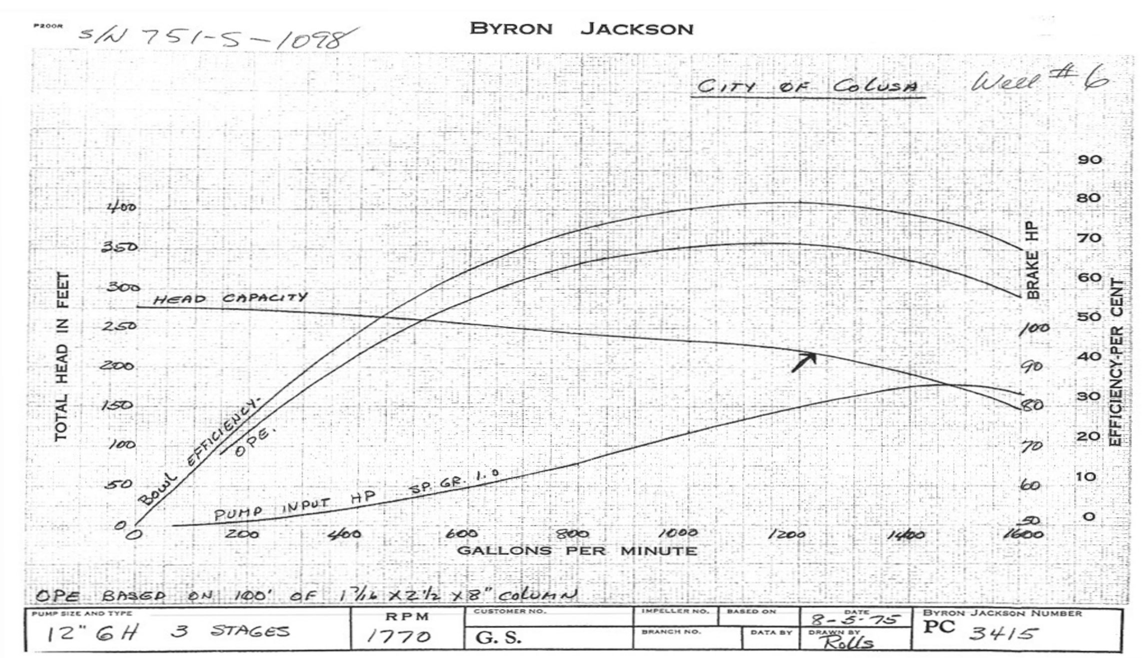



Figure 11. Well No. 4 Pump Curve (Single-Stage)


Figure 12. Well No. 5 Site

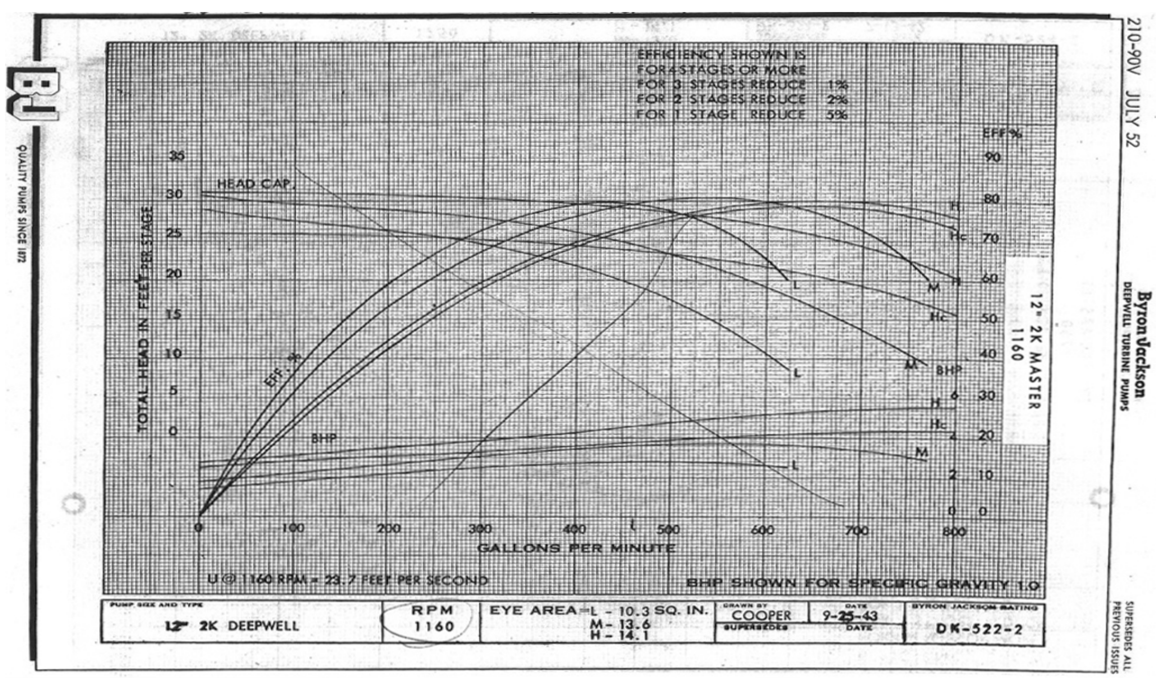



Figure 13. Well No. 5 Pump Curve (Single-Stage)


Figure 14. Well No. 6 Site

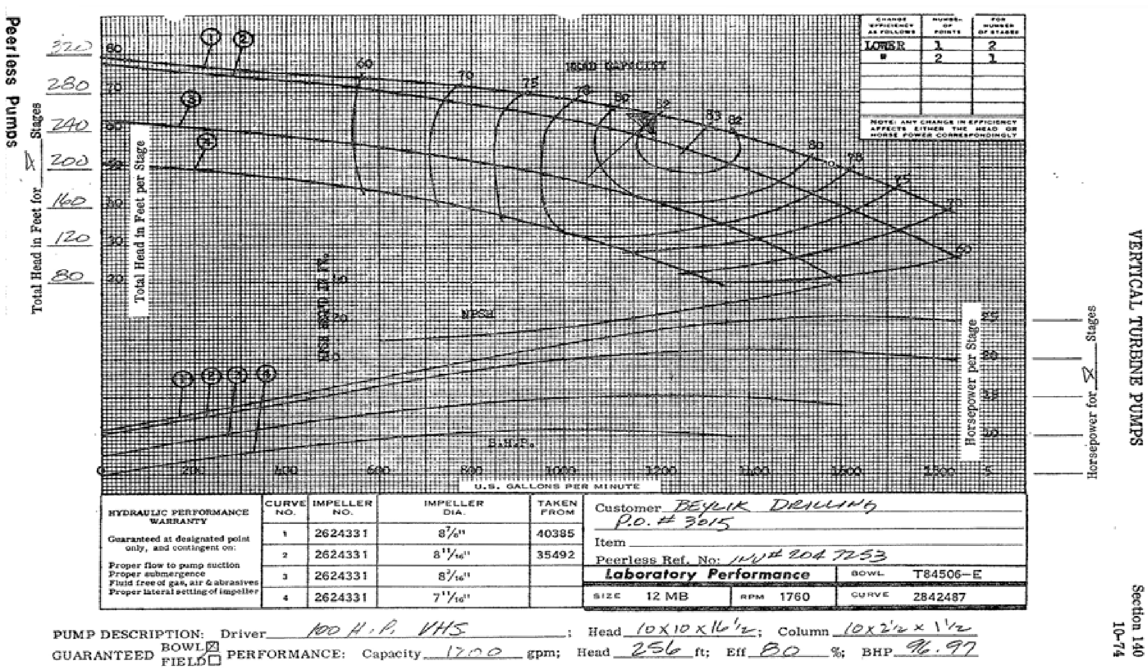



Figure 15. Well No. 6 Pump Curve (Single-Stage)

437 East Walnut St.
Lodi, CA 95240
209-339-1290
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Gilmore Engineering
Specialists in Water Treatment

# Technical Memorandum

To: Kim Venton

From: Roger Gilmore

CC: Larry Ernst, Tim Buller

Date: November 14, 2007

Re: City of Colusa Domestic Well Field– Water Quality Evaluation – Technical Memorandum

---

## BACKGROUND

As summarized in the Wood Rodgers Draft Technical Engineering Memorandum – Facility Assessment and Proposed Upgrades, dated October 5, 2007, the City operates five municipal wells and two elevated storage tanks to serve approximately 2,400 customers. Wells 4, 5, and 6 are designated as active wells, with well 2 and 3 used on an as-needed basis. The City typically operates one or two wells in the winter and spring months, and two or three wells in the summer and fall months. All well heads are located inside buildings, with vertical turbine pumps set at 150 feet, constant speed motors, and gas chlorine disinfection systems.

A summary of key data on the wells is provided in Table 1 on the following page. The data was compiled from the Draft TM referenced above, from City of Colusa records, from the California Department of Public Health records, and from Wood Rodgers' spreadsheets.

## WATER QUALITY

The City's customer's main complaints are dirty water, and a rotten egg odor, which is more of a problem in the summertime.

As indicated in Table 1, wells 4, 5, and 6 supply approximately 90% of the City's annual demand, with well 6 producing approximately 40% by itself. Well 6 also contains hydrogen sulfide at significant levels, which causes the rotten egg odor. To control the odor, the City feeds chlorine. However, chlorine will also oxidize iron and manganese, and if too much chlorine is fed, brown or dirty water will result. Warmer water temperatures will exacerbate the odor problem, which is why the complaints are higher in the summertime. Feeding chlorine to control hydrogen sulfide when iron or

TABLE 1
CITY OF COLUSA DOMESTIC WELLS
SUMMARY OF WELL DATA AND QUALITY

| PARAMETER | WELL 2 | WELL 3 | WELL 4 | WELL 5 | WELL 6 |
|---|---|---|---|---|---|
| Production, gpm | 600[1] | 830 | 1,000 | 750 | 1,450 |
| Discharge pressure, psi | ? | 67 | 59 | 66 | 62 |
| Entrained air or gas | | high | no | yes | yes |
| Taste and Odor | | high | none | minimal | high |
| Turbidity, NTU | ~0.40 | ~0.40 | ~0.5 | ~0.3 | ~0.5 |
| pH | ~8.5 | ~8.1 | ~8.1 | ~8.3 | ~8.5 |
| TDS, ppm | ~410 | ~340 | ~560 | ~370 | ~280 |
| Iron, ppb | 30-2000 | 0-100 | 0 -140 | 30-90 | 0-38 |
| Manganese, ppb | 30-99 | 60-89 | 40 - 150 | 40-49 | 43-63 |
| Arsenic, ppb[2] | 6 | 7 | 4.5 | 0 | 5-6 |
| $H_2S$, ppm | 0 | ~0.2 | 0 | <0.05 | 0.1-0.2 |
| Sand, ppm | 60 | 4 | ~10 | 0.15 | 1.5 |
| Hardness, mg/L | 44-98 | | ~100 | ~70 | ~50 |
| Sand separator | yes | yes | no | no | no |
| Motor HP | 50 | 75 | 75 | 50 | 100 |
| Percent contributed to annual water supply | 0 | less than 10 | ~20 | ~35 | ~40 |
| Chlorine demand[3], pounds/month | | ~900 | ~150 | ~150 | ~900 |

[1] Estimated flow rate
[2] From Reese Crenshaw on Oct. 10, 2007
[3] When operated continuously

or manganese is present in significant amounts is essentially a balancing act, in other words.

## DRINKING WATER STANDARDS

Drinking water standards are published in Title 22 of the California Code of Regulations. Standards are expressed as maximum contaminant levels (MCLs). Primary MCLs address health concerns, and Secondary MCLs address esthetics, such as taste and odor, iron and manganese. Arsenic is one of the Primary MCLs, and is addressed in the Arsenic Rule.

The Secondary MCL for iron is 0.30 mg/L (300 µg/L or ppb), and 0.05 mg/L (50 ppb) for manganese. The MCL for arsenic is 10 ppb.

The standard for compliance with the Secondary Standards is based on the average of four quarterly reports submitted to the California Department of Public Health (CDPH), so that one high quarterly report above the MCL, by itself, does not trigger a notice of non-compliance from the CDPH.

The level of iron is well below the MCL, although present at levels that are noticeable, especially when combined with manganese. Manganese exists at levels that are slightly higher than the MCL, although no notices for non-compliance have been issued by the CDPH to date. However, the CDPH has not received quarterly reports for iron or manganese since the summer of 2005.

Manganese, when oxidized with chlorine or other oxidant, will be visible as dark brown to black particles or deposits on plumbing fixtures, or on laundered clothing, and can cause the water to have a cloudy or dirty appearance. Manganese also can cause an unpleasant, somewhat metallic taste.

To date, arsenic has not been detected at or above the MCL, except for one instance for well 2 in October 2006, when it was measured at 11.4 ppb. Arsenic has not been detected above 6 ppb in wells 4, 5, and 6.

## TREATMENT OPTIONS

Treatment for manganese and hydrogen sulfide would significantly improve the esthetic quality of the water. Treatment to remove manganese would also remove iron.

Several technologies for manganese removal are available, and have been widely used for many years by municipal water systems. These technologies include oxidation with chlorine or other oxidant, followed by filtration to remove the oxidized manganese.

## FILTRATION

Filters may be either gravity or pressure filters, although pressure filters are more widely used with wellhead treatment. Filter media may be manganese greensand, pyrolucite, silica sand, anthracite coal, or other proprietary media. Oxidation with chlorine or other oxidant is required to oxidize the iron or manganese to produce a solid (an oxide of iron or manganese) that is filterable.

For higher levels of manganese, manganese greensand is normally used. Manganese greensand is a proprietary media that has undergone a conditioning process using potassium permanganate and manganese sulfide to produce a black precipitate of manganese dioxide on the filter granules. Other filter media, such as silica sand and anthracite coal, naturally undergo an aging process during which they become coated with manganese oxide over a period of a few days to a few weeks. Numerous full scale plants and pilot studies have shown that higher filtration rates can be used with manganese greensand than can be used with the other media, however. Iron and manganese removal with greensand and other oxide coated media is very common, with dozens of operating plants in California.

For levels of manganese near those present in Colusa, silica sand and anthracite would be effective, and also costs much less than manganese greensand.

The most common method of filtration of iron and manganese from water involves the oxidation of soluble iron ($Fe^{+2}$, or ferrous ion) and manganese ($Mn^{+2}$, or manganous ion) to insoluble forms ($Fe^{+3}$, ferric ion, and $Mn^{+4}$, tetravalent manganese ion), followed by removal of the precipitates by filtration. Chlorine is most commonly used as an oxidant. Ozone, potassium permanganate, and other oxidants may also be used.

One atom of iron reacts with one atom of chlorine; therefore a stoichiometric calculation determines that 0.64 mg/l of chlorine is required to oxidize 1.0 mg/l of iron. For manganese, stoichiometric calculations establish that 1.29 mg/l of chlorine is required to oxidize 1.0 mg/l of manganese, since one atom of manganese reacts with two atoms of chlorine.

Iron reacts with chlorine in minutes, whereas manganese reacts much more slowly, up to several hours. The rate of $Mn^{+2}$ oxidation is a function of pH, water temperature, chlorine concentration, and whether or not the manganese is organically complexed.

Oxidized manganese oxide ($MnO_x$) coated media enhances the oxidation and removal of manganese by adsorption of the $Mn^{+2}$ on the surface of the media, which allows time for the oxidation process to complete over a period of hours.

This type of treatment is commonly called “catalytic oxidation” because the oxide coating essentially acts as a catalyst in the removal process.

Filtration would remove the elemental sulfur resulting from oxidizing the hydrogen sulfide, plus any iron and manganese and a small percentage of the arsenic, if arsenic is present along with iron. Filtration a viable treatment option for wells 4, 5, and 6. However, because of the capital cost and because well 4 produces 20% of the total annual production (on average), filtration is not recommended for well 4.

With this option, a pressure filter system would be installed near the well head, and the well pump would deliver water through the filters to the distribution system. The pressure filter system will cause a pressure drop of approximately 8 psi, which would cause a small reduction in flow, as the well pump would be operating at a different point on the pump curve. For example, at well 6, the reduction in flow would be approximately 200 gpm.

## FILTER LOADING RATES AND FEATURES

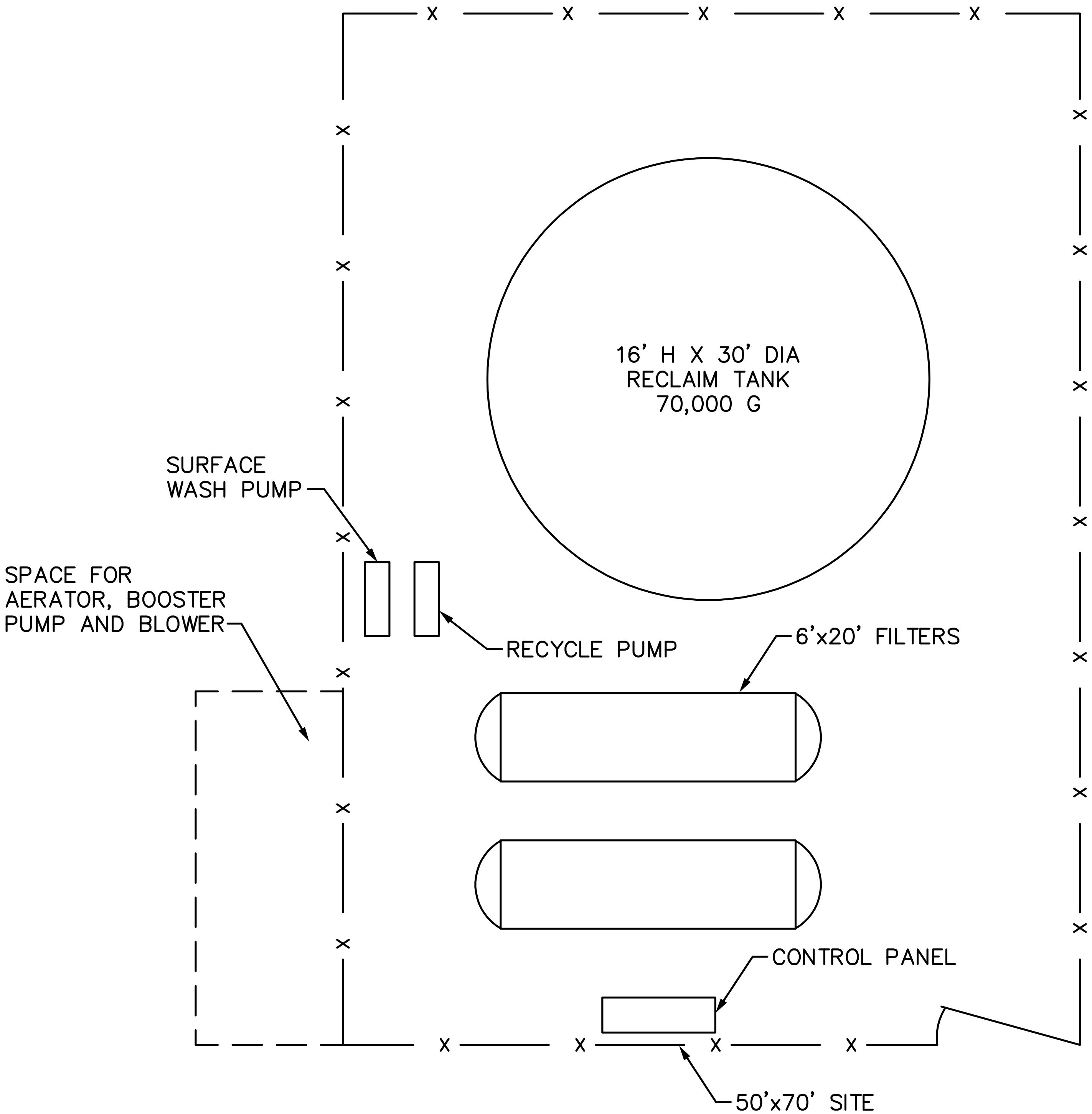
For manganese greensand filters, filter flow rates up to 8 gpm per square foot are typically used. For the naturally coated media, lower filter flow rates are used, usually around 5 to 6 gpm per square foot. Manganese greensand filters are more effective in removing manganese at the higher filter flow rates. Iron is easily removed in either type of filter.

For any iron or manganese removal filter, either air scour or surface wash equipment is required to adequately clean the filter media during backwash. Surface wash is much simpler to implement for pressure filters than air scour. A booster pump is required for surface wash, along with a grid of spray nozzles inside the tank, suspended just above the surface of the media. For well 5, a 5 hp pump is required, and for well 6, a 10 hp pump is required.

Typical site plans of a pressure filtration system for well 5 and for well 6, with and without aeration, are provided in Figure 1.

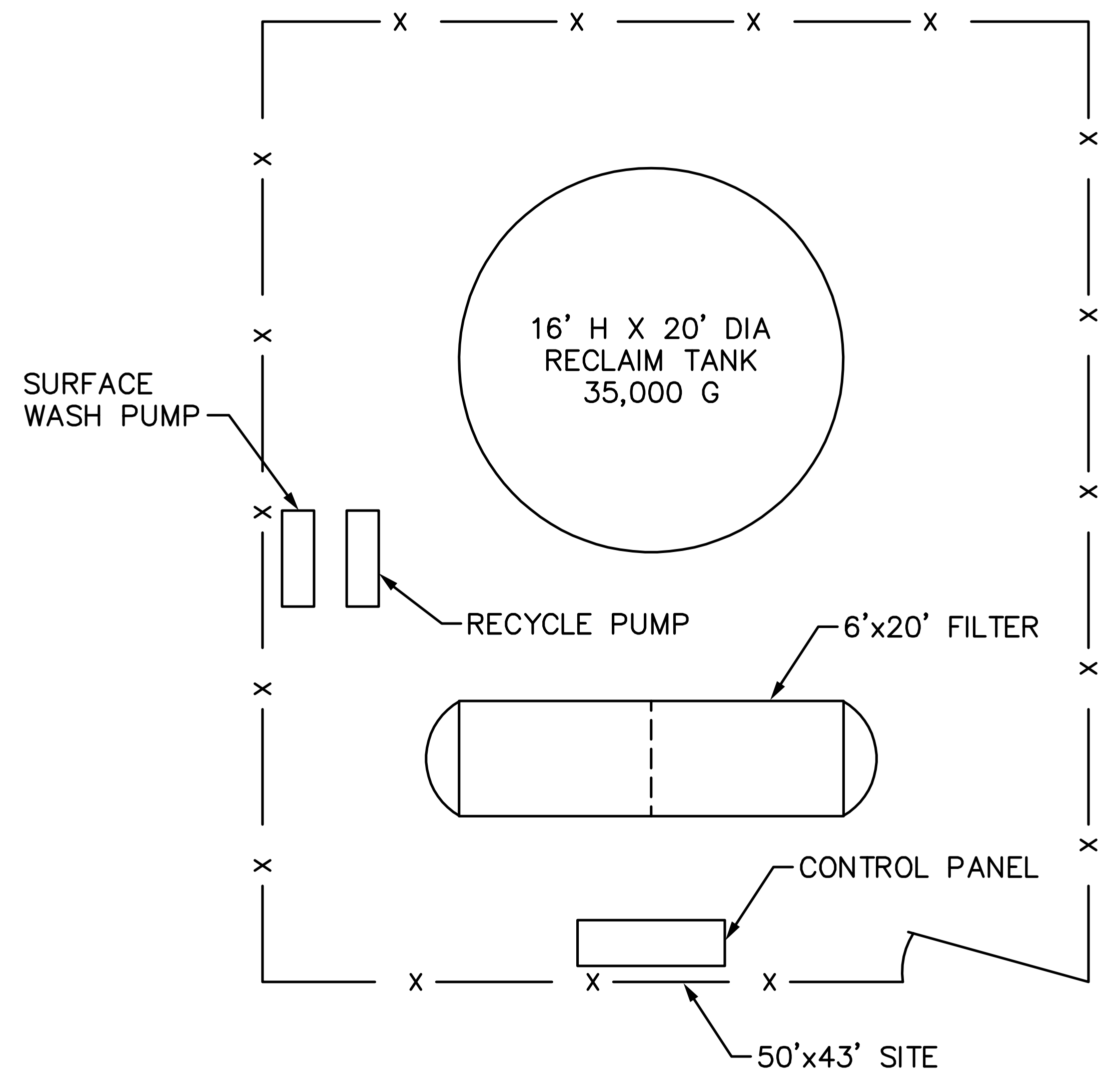
## ALTERNATIVE FILTRATION PROCESSES

The process described above is utilized by several manufacturers including the Loprest Water Treatment Company, Rescue Engineers, and Hungerford & Terry. A competing process offered by Filtronics and Pureflow is similar. With these two companies’ process, higher filter rates are used, up to 12 gpm per square foot. This process uses chlorine in higher doses than the greensand filter process (up to the breakpoint) and subsequent dechlorination with sulfur dioxide or other reducing agent, followed by filtration through proprietary filter media.




# 1450 GPM FILTER PLANT

SCALE: 1"=10'




# 700 GPM FILTER PLANT

SCALE: 1"=10'

| FIGURE 1 |
| --- |
| PRELIMINARY SITE PLANS<br>700 AND 1,450 GPM |
| *GILMORE ENGINEERING* |

The catalytic oxidation and greensand processes have several advantages over the Filtronics/Pureflow process. First of all, the capital cost and the operational cost are lower. The Filtronics/Pureflow equipment also uses more backwash water since the filters require backwashing each time the plant is shut down, whereas the greensand filters do not. The Filtronics/Pureflow media is more delicate, costs much more than greensand, and does not last as long as greensand, which typically will last 20 years or more if properly backwashed.

**ARSENIC REMOVAL WITH CATALYTIC OXIDATION**

Arsenic removal does not appear to be necessary at this time, since none of the well water exceeds the MCL for arsenic. However, if the levels increase (or if the CDPH sets the MCL lower than the Federal standard) and arsenic removal becomes necessary, it can also be removed with the catalytic oxidation process along with iron and manganese, with minor modifications. In fact, a small percentage of the arsenic will be removed along with any natural iron that is present in the water, as a side effect of the catalytic oxidation process. If a higher percentage of arsenic removal is necessary, and sufficient natural iron is not present in the raw water, iron can be added in the form of iron salts such as ferric chloride or ferric sulfate. In most water sources, the amount of arsenic removed is simply a function of the amount of iron present, either natural or added.

The addition of iron salts does create a significant amount of solids which must be removed by filtration, and places an added load on the filters compared to iron and manganese removal. Consequently, arsenic removal filters will typically be operated at lower filter rates than iron and manganese removal filters. A reduction in the arsenic concentration of 5 to 10% is anticipated with the relatively low iron levels present in well 4 and 6 water.

**HYDROGEN SULFIDE TREATMENT**

Hydrogen sulfide may be treated with oxidation, aeration, aeration followed by filtration, or oxidation followed by filtration. When oxidizing with chlorine, elemental sulfur is produced, which remains in the water unless filtration is implemented. Oxidation with chlorine is the process the City currently uses.

**AERATION**

Aeration with forced draft aerators (sometimes called air strippers) will replace the hydrogen sulfide with oxygen. The oxygenation of the water in the aerator also normally oxidizes iron, depending on the pH. Aeration will not oxidize manganese to any significant degree. Aerators are commonly employed for treatment where hydrogen sulfide and iron are present. Aeration will improve the taste and odor of the finished water more than oxidation and filtration, as the hydrogen sulfide is removed before oxidation to sulfur. Aeration also drives off any volatile organics and carbon dioxide, if present.

A typical installation for hydrogen sulfide and iron removal is to pump well water to the inlet of the aerator, with chlorine injected at the outlet of the aerator, followed by filtration. Both iron and manganese will be removed in the filter as described previously.

Aeration followed by filtration of well 3 and well 6 water would be a good treatment scheme for these well waters. However, since well 3 operates only a small percentage of the time, only well 6 deserves further evaluation.

One drawback to aeration is that repumping is required. At well 6, a 100 hp pump delivers water at 62 psi at the wellhead. The existing pump is a four stage pump, and the water level during testing averaged 115 feet from the surface. Removing two of the four stages from the pump would deliver water to a point approximately 20 feet above the wellhead, which is ample to deliver water to the aerator inlet. The 100 hp pump would then operate with the approximate power consumption of a 50 hp pump. To deliver water from the aerator sump, through a pressure filter, and then directly into the distribution system would require a new 75 hp booster pump, for a total pumping requirement of 125 hp.

Aerators are available in several configurations, including low profile and tower type aerators. One advantage of the low profile type aerator is they are easily hidden from view with a low fence. Tower type aerators are approximately 15 feet tall or more, plus the height of the collector sump. Both types of aerators are equally efficient. A low profile aerator is suggested to improve the appearance of the treatment system.

One manufacturer, Lowry Systems, offers stainless steel, low profile aerators which utilize an air blower/bubbler system. A simplified cross section of a Lowry aerator is provided in Figure 2, and a picture in Figure 3.

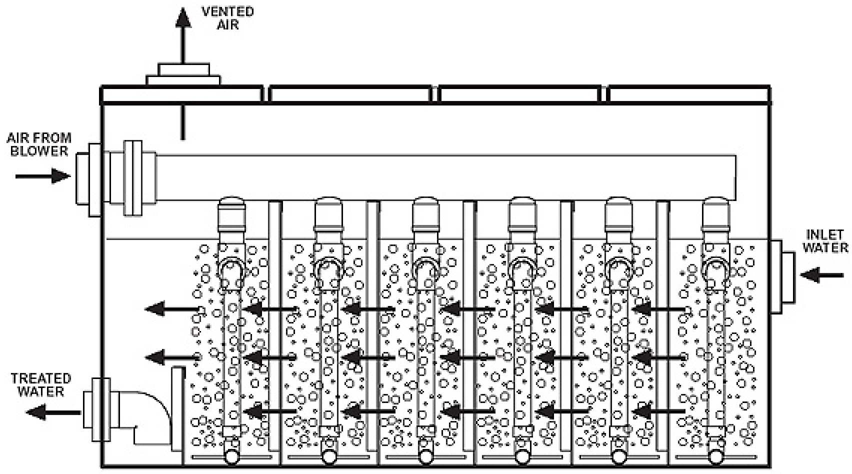



**FIGURE 2**
**CROSS SECTION OF LOW PROFILE LOWRY AERATOR**

**FIGURE 3**
**LOW PROFILE LOWRY AERATOR**

Aeration, followed by chlorination and filtration would remove hydrogen sulfide, iron, manganese, and up to 10% of the arsenic. This option would produce the highest quality water from a taste and odor perspective.

Aeration followed by chlorination, without filtration, would also remove hydrogen sulfide, and would improve the taste and odor from current levels. However, the iron and manganese would not be reduced from current levels, and cloudy or dirty water could result.

## BACKWASH WATER HANDLING

A backwash water recycling system would be required for any filter system, unless the water could be discharged to a sewer. The instantaneous rate of backwash flow could be as high as the well flow rate, i.e. 1,450 gpm at well 6. If discharged to a sewer, a holding tank would be required to allow discharging at a rate of flow the sewer could handle.

The recycling system would consist of a grade level storage tank sized to contain up to two times the volume of one backwash and rinse cycle, a recycle pump, and controls. For well 6, a tank with a volume of 70,000 gallons below the overflow is suggested. A 30' diameter by 16' high welded steel tank with a cone roof is recommended. An aggregate base contained by a steel grade ring is suitable for this tank. For well 5, a 35,000 gallon tank is suggested, 20' diameter by 16' high. For this tank, a concrete ringwall foundation with anchor bolts is required for seismic restraint due to the low diameter to height ratio. Typically, if the diameter to height ratio is less than about 2, anchor bolts are required.

The backwash water is allowed to settle for an hour or two before recycling the supernatant through the filters at a rate of flow equal to approximately 10% of the filter flow rate. A recycle pump adjacent to the tank would pump water from the tank through a floating intake, and pump to the filter inlet when the well pump is running. A 10 hp pump would be required for well 6, and a 5 hp for well 5.

The solids that settle and remain can be removed by vacuum truck for disposal offsite, or can be discharged to a sewer by gravity. In most treatment plants, removal by vacuum truck is completed one to four times per year. Where this method of solids disposal is used, the solids volume typically represents less than 0.1% of the plant production. If the solids are discharged to the sewer, discharges can be as frequently as daily, or as necessary.

## SEQUESTERING

Sequestering agents can be used to chemically bind the iron ($Fe^{+}2$) and manganese ($Mn^{+}2$), to prevent these constituents from reacting with chlorine, and allow them to remain in their soluble form and pass undetected through the distribution system. Calcium (Ca+2) and magnesium (Mg+2) also remain soluble under most conditions, but they do react with soap to form insoluble salts (soap scum). When heated, as in a hot water heater, calcium and magnesium also form insoluble hard water scale. A sequestering agent will also bind the calcium and magnesium.

One type of sequestering agent is offered by the Carus Corporation.  Carus supplies their AQUA MAG® TK and AQUA MAG® C-10 polyphosphates to maintain iron, manganese, calcium and magnesium as colorless soluble molecules that resist oxidation caused by aeration, disinfection, storage, and transmission of finished water.

A further benefit of sequestering is that by sequestering raw water minerals at the source, the demand for chlorine is reduced, resulting in less chlorine consumption and improved water quality.

All phosphate ions are negatively charged particles (anions) with an electronic attraction for oppositely charged positive ions (cations) in the water or on a pipe surface. When soluble cations such as Fe+2, Mn+2, Ca+2, or Mg+2 come in contact with the polyphosphate anions, they react in various degrees to form a coordinated molecular structure that remains soluble in the water. As a result of this chemistry, application of polyphosphates into water will delay or prevent the oxidation, color formation, and precipitation of metallic cations in a water system.

Sequestering agents are typically injected via a chemical metering pump at the wellhead prior to other chemical additives such as chlorine. If possible, these agents should be injected down the well casing to mix with groundwater at the pump intake, to allow the chemical reaction to occur prior to injection of chlorine. Carus suggests that a dosage between 2 and 3 mg/L would be required.

This treatment option would improve the clarity of the water delivered to consumers, as the iron and manganese would remain soluble.  Sequestering the calcium and magnesium would also be beneficial, as the water is moderately hard. Taste and odor would also be improved as less chlorine would be used.  Only the amount of chlorine required to oxidize the hydrogen sulfide would be required, as the iron and manganese would be sequestered before the chlorine is injected.

Carus claims these additional benefits for their sequestering agents:

- Prevents color formation from Fe/Mn and water deterioration in the system
- Over 1.0 mg/L combined Fe/Mn treated
- Prevents carbonate scale formation from Ca/Mg hard water
- Effectively lower chlorine demand and stabilize system residual
- Gradually remove surface deposits and corrosion by-products in the system
- Remove protective environment of bacterial regrowth
- Increase C-Factor and fire hydrant flow rates and improve valve operations
- Inhibit general surface corrosion, microbial corrosion, and pitting

Implementing the feeding of sequestering agents would require the installation of a metering pump, which could be mounted on a shelf above the top of a drum of sequestering agent. Injection of the sequestering agent prior to chlorination is required. Injection at the inlet of the turbine pump is ideal, and would require the installation of a ½ to ¾ inch injection line through the well head, terminating at the pump inlet screen. If injecting at the pump intake is not feasible, the chemical may be injected a minimum of 6 feet upstream of the point of chlorine injection.

Drums are available in 30 gallon or 55 gallon sizes, and in 275 gallon totes. The weight of the chemical is 11.6 pounds per gallon, so a 55 gallon drum would weigh 638 pounds plus the drum tare weight. For ease of handling, a 30 gallon drum may be the best option. A 30 gallon drum, at a dosage of 2 mg/L, would last for 11 days at well 6 if the well was operated continuously at a flow rate of 1,450 gpm. An alternative method of delivering the product to the well sites would be to purchase the product in 275 gallon totes, and then pump the product from the tote (on a truck or pickup) into the drum or solution container at the well sites.

The cost of the Carus product is approximately $10 per gallon, plus sales tax and freight from Los Angeles. NTU Technologies, Inc. also offers sequestering agents that are very similar to the above described products.

One negative with the use of sequestering agents is that flushing of the distribution system may be required more frequently, especially where distribution system residence times are longest. Flushing is sometimes necessary as the sequestering agents can break down or degrade over a long period of time.

Additional research and testing is suggested to select competing products for testing. Testing is suggested to confirm the effectiveness on well water samples. Samples of well water from wells 3 through 6 should be dosed with sequestering agent at two to three doses, and then dosed with chlorine to achieve the chlorine residual normally maintained in the distribution system. These samples should then be kept at the temperatures normally encountered in the distribution system in the summertime, for a period of time equaling the longest distribution system residence time. The samples should then be visually inspected for clarity, and sampled by a panel of individuals to assess the taste and odor.

## OPERATOR REQUIREMENTS FOR TREATMENT

The CDPH determines the operator certification requirements based on up to 13 parameters including whether surface water or groundwater is being treated, the coliform density, turbidity, whether nitrate is present, the type of filters, the flow rate of the treatment plant, etc. Points are assigned for each variable and the total determines the operator certification required. For any of the Colusa wells, after addition of filtration, aeration, or sequestering, a T1 certificate would be required.

A summary of the key parameters, advantages and disadvantages of each treatment option is provided in Table 2.

**TABLE 2**
**CITY OF COLUSA DOMESTIC WELLS**
**SUMMARY OF TREATMENT OPTIONS**

| TREATMENT TYPE | REMOVES MANGANESE | REMOVES IRON | REDUCES COLOR | REDUCES ODOR | IMPROVES TASTE | ADVANTAGES | DRAWBACKS |
|---|---|---|---|---|---|---|---|
| Chlorination | | | | X | X | Already used for disinfection. | Excessive chlorination can cause problems with color. |
| Oxidation and Filtration – greensand | X | X | X | | | More effective for manganese removal | Higher cost than silica sand/anthracite |
| Oxidation and Filtration – silica sand/anthracite | X | X | X | | | Lower cost than greensand. | |
| Filtration – proprietary, with chlorination/ dechlorination | X | X | X | | | Smaller footprint, less space required | More expensive and problematic than greensand or silica sand/anthracite. |
| Aeration + Oxidation and Filtration | X | X | X | X | X | Would most improve taste/odor. | Requires boosting. Highest capital costs. |
| Aeration + oxidation | | | | X | X | Would improve taste/odor. | Could result in cloudy or dirty water. |
| Sequestering Agent + Chlorination | | | X | X | X | Lower capital costs. Would reduce chlorine demand. Would resist oxidation of iron and manganese and improve color. Would improve color, odor and taste. | Would not remove iron or manganese. |

## CAPITAL AND OPERATING COSTS OF TREATMENT OPTIONS

Capital and operating costs are provided in the following sections. In each case, the operating cost presented is the increased cost of treatment above the current costs of operation. Capital cost includes the cost of construction only. Design costs, administration costs, and construction management costs are not included, and typically average 30% of the construction cost.

## FILTRATION

For well 6, two each 6' diameter by 20' sideshell filters are suggested, for a total filter surface area of 240 square feet. At the well flow rate of 1,450 gpm, the service flow rate would be 6 gpm/sf. To avoid drawing backwash water from the distribution system, backwash water would be supplied by the well, at the normal well flow rate of 1,450 gpm. One filter at a time would be backwashed, followed by a short filter to waste period (2 to 5 minutes long).

For well 5, one 6' diameter by 20' sideshell filter is suggested. This filter would be furnished with two cells or compartments, which would backwash independently, one at a time. This would allow backwashing at approximately the normal well flow rate of 700 gpm. A recycle pump and a pump to supply water for surface washing during backwash are included for both well 5 and 6.

Filter controls and the pump starter(s), and disconnect switches would be installed in an air conditioned enclosure outdoors, inside the fenced enclosure.

Capital cost estimates for installing filtration equipment at wells 5 and 6 are provided in tables 3 and 4.

## TABLE 3
## CAPITAL COST ESTIMATE
## 700 GPM FILTER SYSTEM – WELL 5

| Item | Unit | Quantity | Unit Cost, $ | Total Cost, $ |
|---|---|---|---|---|
| Mobilization and demobilization | LS | 1 | 10,000 | 10,000 |
| Site preparation | LS | 1 | 5,000 | 5,000 |
| AB base for entire site 3" deep | SF | 2,150 | 3 | 6,500 |
| Pressure filter – 1 ea 6'x20' 2 cell | LS | 1 | 200,000 | 200,000 |
| Filter foundations and filter installation cost | LS | 1 | 12,000 | 12,000 |
| Backwash reclaim tank including painting inside & outside | LS | 1 | 75,000 | 75,000 |
| Concrete ringwall tank foundation | CY | 15 | 600 | 9,000 |
| Recycle pump, 5 hp, installed | EA | 1 | $5,000 | $5,000 |
| Surface wash pump, 5 hp, installed | EA | 1 | $5,000 | $5,000 |
| Yard piping | LS | 1 | $30,000 | $30,000 |
| Fence | LF | 186 | $12 | 2,200 |
| Electrical and controls, installed[4] | LS | 1 | 87,500 | 87,500 |
| Subtotal | | | | 447,200 |
| 20% contingency | | | | 89,500 |
| **Subtotal** | | | | 536,700 |
| 30% Engineering design, construction management, and City administration costs | | | | 161,000 |
| **Total Cost** | | | | 697,700 |

[4] Does not include the cost of upgrading the electrical service to the site, if necessary

**TABLE 4**
**CAPITAL COST ESTIMATE**
**1,450 GPM FILTER SYSTEM – WELL 6**

| Item | Unit | Quantity | Unit Cost, $ | Total Cost, $ |
|---|---|---|---|---|
| Mobilization and demobilization | LS | 1 | 12,000 | 12,000 |
| Site preparation | LS | 1 | 7,500 | 7,500 |
| AB base for entire site 3" deep | SF | 3,500 | 3 | 10,500 |
| Pressure filters – 2 ea 6'x20' | LS | 1 | 300,000 | 300,000 |
| Filter foundations and filter installation cost | LS | 1 | 20,000 | 20,000 |
| Backwash reclaim tank including painting inside & outside | LS | 1 | 130,000 | 130,000 |
| Steel grade ring and aggregate base for tank | LS | 1 | 3,500 | 3,500 |
| Recycle pump, 10 hp, installed | EA | 1 | $5,000 | $5,000 |
| Surface wash pump, 10 hp, installed | EA | 1 | $5,000 | $5,000 |
| Yard piping | LS | 1 | $35,000 | $35,000 |
| Fence | LF | 240 | $12 | 2,900 |
| Electrical and controls, installed[5] | LS | 1 | 133,000 | 133,000 |
| Subtotal | | | | 664,500 |
| 20% contingency | | | | 133,000 |
| **Subtotal** | | | | 797,500 |
| 30% Engineering design, construction management, and City administration costs | | | | 239,300 |
| **Total Cost** | | | | 1,036,800 |

Operating costs include only the increased cost of treatment above the current cost of operating each well. For wells 5 and 6, the increased costs include the maintenance costs of the filter system, the additional pumps, and maintenance of the storage tank. Operating costs are estimated to average 2% of the capital cost annually. For well 5, the operating cost is estimated at $11,000, and for well 6, $16,000.

## AERATION

A cost estimate is provided only for well 6, as discussed previously in the Aeration section. Aeration would include continued use of chlorination for residual disinfection.

[5] Does not include the cost of upgrading the electrical service to the site, if necessary

**TABLE 5**
**CAPITAL COST ESTIMATE**
**1,450 GPM AERATION SYSTEM – WELL 6**

| Item | Unit | Quantity | Unit Cost, $ | Total Cost, $ |
|---|---|---|---|---|
| Mobilization and demobilization | LS | 1 | | 5,000 |
| Site preparation | LS | 1 | 2,500 | 2,500 |
| AB base around aerator | SF | 250 | 3 | 750 |
| Aerator, installed, including blower | LS | 1 | 30,000 | 30,000 |
| Foundation | LS | 1 | 2,000 | 2,000 |
| Booster pump, 60 hp, installed | EA | 1 | $15,000 | $15,000 |
| Yard piping | LS | 1 | $5,000 | $5,000 |
| Fence | LF | 75 | $12 | 900 |
| Electrical and controls, installed[6] | LS | | | $75,000 |
| Subtotal | | | | 136,500 |
| 20% contingency | | | | 27,300 |
| **Subtotal** | | | | 238,800 |
| 30% Engineering design, construction management, and City administration costs | | | | 71,600 |
| **Total Cost** | | | | 310,400 |

The cost of operating the aeration system includes the cost of operating the booster pump and a small amount of maintenance work on the aerator. Maintenance of the aerator includes only annual cleaning, which can be completed in one workday.

At 15 cents per kwH for electrical power cost, the annual cost of operation is $0.10 per thousand gallons pumped, including power cost for the 10 hp air blower and 60 hp booster pumps. Assuming 300 million gallons annual production, the increased cost of operation for aeration only at well 6 would be $30,000.

## AERATION AND FILTRATION

Cost estimates are provided only for well 6, as discussed previously in the Aeration section.

[6] Does not include the cost of upgrading the electrical service to the site, if necessary

**TABLE 6**
**CAPITAL COST ESTIMATE**
**1,450 GPM AERATION PLUS FILTER SYSTEM – WELL 6**

| Item | Unit | Quantity | Unit Cost, $ | Total Cost, $ |
|---|---|---|---|---|
| Mobilization and demobilization | LS | 1 | 14,000 | 14,000 |
| Site preparation | LS | 1 | 7,500 | 7,500 |
| AB base for entire site 3" deep | SF | 4,000 | 3 | 12,500 |
| Pressure filters – 2 ea 6'x20' | LS | 1 | 300,000 | 300,000 |
| Filter foundations and filter installation cost | LS | 1 | 20,000 | 20,000 |
| Backwash reclaim tank including painting inside & outside | LS | 1 | 130,000 | 130,000 |
| Steel grade ring and aggregate base for tank | LS | 1 | 3,500 | 3,500 |
| Aerator, installed, including blower | LS | 1 | 30,000 | 30,000 |
| Foundation | LS | 1 | 2,000 | 2,000 |
| Booster pump, 60 hp, installed | EA | 1 | $15,000 | $15,000 |
| Recycle pump, 10 hp, installed | EA | 1 | $5,000 | $5,000 |
| Surface wash pump, 10 hp, installed | EA | 1 | $5,000 | $5,000 |
| Yard piping | LS | 1 | $40,000 | $40,000 |
| Fence | LF | 240 | $12 | 2,900 |
| Electrical and controls, installed | LS | | | 146,900 |
| Subtotal | | | | 734,300 |
| 20% contingency | | | | 146,900 |
| **Subtotal** | | | | 881,300 |
| 30% Engineering design, construction management, and City administration costs | | | | 264,400 |
| **Total Cost** | | | | 1,145,700 |

Operating and maintenance cost for the aeration plus filtration option includes the estimated 2% of capital cost annually for routine maintenance, plus the cost of electrical power for the additional pumps and blower. Assuming 300 million gallons annual production for well 6, the increased cost of operation for aeration plus filtration would be $30,000 for electrical power and $17,600 for maintenance, for a total of $47,600 annually.

## SEQUESTERING

The cost of a metering pump, installed and connected to operate when the well pump is operating, is estimated to be $2,500. Installation cost of a chemical feed line through the wellhead to the pump intake is estimated to be $1,000. Engineering, construction management and administration costs are estimated at $5,500 per well site.

The operating cost of injecting a sequestering agent is estimated at approximately $17.25 per million gallons treated, based on a dose of 2 mg/L and a cost per gallon of $12.00. Assuming total yearly production at 600 million gallons, the annual cost of the sequestering agent would be approximately $10,000.

## SUMMARY OF CAPITAL AND ANNUAL OPERATING AND MAINTENANCE COSTS

Capital, operating and maintenance costs are summarized in table 7.

**TABLE 7**
**SUMMARY OF CAPITAL AND ANNUAL OPERATING AND MAINTENANCE COSTS, $**

| | WELL NUMBER | | | | | |
|---|---|---|---|---|---|---|
| | 4 | | 5 | | 6 | |
| Option | Capital | O&M[7] | Capital | O&M[8] | Capital | O&M[9] |
| Filtration | n/a | n/a | 697,700 | 11,000 | 797,500 | 16,000 |
| Aeration only (includes continued use of chlorination) | n/a | n/a | n/a | n/a | 310,400 | 30,000 |
| Aeration plus filtration | n/a | n/a | n/a | n/a | 1,145,700 | 47,600 |
| Sequestering | 9,500 | 1,900 | 9,500 | 3,330 | 9,500 | 3,800 |

A summary of the life cycle costs is presented in table 8, which includes capital and operating costs for the estimated life of the equipment. The life expectancy of filtration and aeration equipment is 25 years, and the life expectancy of a sequestering agent metering pump is 5 years. The life cycle costs presented in table 8 include replacement of the metering pumps 4 times during the 25 year period.

Table 8 assumes an annual inflation rate of 3%, which was applied to yearly operations and maintenance costs, and to the cost of planned equipment replacement within the 25-year estimating period.

[7] Based on production of 110 million gallons annually (20% of total well production)
[8] Based on production of 193 million gallons annually (35% of total well production)
[9] Based on production of 220 million gallons annually (40% of total well production)

**TABLE 8**
**SUMMARY OF 25 YEAR LIFE CYCLE COSTS, $**

| OPTION | WELL NUMBER | | |
|---|---|---|---|
| | 4 | 5 | 6 |
| Filtration | n/a | 822,400 | 1,214,000 |
| Aeration only | n/a | n/a | 1,019,800 |
| Aeration plus filtration | n/a | n/a | 2,066,500 |
| Sequestering | 96,650 | 148,850 | 165,800 |

## OTHER ISSUES

The City uses gas chlorination at the well sites. Most water agencies have switched from gas chlorination to liquid sodium hypochlorite or to onsite generation in recent years due to the burden of compliance with EPA regulations, Risk Management Plans, updating permits, and the increasing cost of insurance for gas facilities. The City may want to review the issues involved in the use of chlorine gas and consider other options for chlorination.

## LIST OF CONTRACTORS OR VENDORS

A list of contractors and/or vendors for each treatment option are provided below.

Filtration equipment manufacturers: Loprest Water Treatment Company, Rodeo, CA; Rescue Engineers, Diamond Springs, CA; Hungerford & Terry, Clayton, NJ.

Aeration equipment manufacturers: Lowry Systems, Inc., Blue Hill, ME; Delta Cooling Towers, Rockaway, NJ, US Filter, General Filter Division, Ames, IA.

Sequestering equipment suppliers: Carus Corporation, Peru, IL; NTU Technologies, Inc., Napa, CA.

Installation contractors: Auburn Constructors, Sacramento, CA; K.G. Walters Construction, Inc., Santa Rosa, CA; Cushman Contracting Co., Goleta, CA.

## SUMMARY AND RECOMMENDATIONS

Each of the evaluated treatment options would improve the taste and odor of the water. Filtration would also remove the iron and manganese to non-detect levels, and improve the clarity of the water. Sequestering would not remove any iron or manganese, but it would prevent or retard the oxidation of these constituents by chlorine, which would prevent the formation of oxides that cause water to become cloudy. Due to the substantially lower capital and operating costs of sequestering vs. any other option, the use of a sequestering agent is the recommended option, pending further study and testing.