IRON AND MANGANESE REMOVAL PILOT STUDY REPORT
JOB 31888

CONDUCTED BY LOPREST WATER TREATMENT COMPANY

FOR

RUBIDOUX COMMUNITY SERVICES DISTRICT
RUBIDOUX, CALIFORNIA
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LIST OF ACRONYMS AND ABBREVIATIONS

Iron	Fe
Manganese	Mn
Arsenic	As
Chlorine	Cl
California Department of Health Services	DHS
Maximum Contaminant Level	MCL
United States Environmental Protection Agency	USEPA
Milligrams per liter	mg/L
Parts per million (milligram per liter)	ppm
Micrograms per liter	µg /L
Parts per billion (microgram per liter)	ppb (=ug/L)
Gallons per minute	gpm
Loprest Water Treatment Company	LWTC
Community Services District	CSD

1.0 BACKGROUND

This report summarizes results and conclusions of a groundwater treatment pilot test program. This pilot test program was administered by Loprest for Rubidoux CSD under protocol detailed by Krieger & Stewart. This pilot test program was undertaken to demonstrate the ability of Loprest's equipment to remove manganese. Operating data collected during the study is used in the design of full-scale facilities for the enclosed bid.

The study goals are listed below.

- To verify the treatment process's capability to reduce the iron and manganese concentrations in the well water to the following levels:

  Manganese: $\leq$ 50 μg/L (MCL = 50 μg/L)

- Need for reaction vessel

- To determine chemical usage requirements including sodium hypochlorite and any other process specific chemicals used.

- To determine the most effective and economical filtration rate that will achieve the treatment goals.

- To verify theoretical filter runtime between backwashes.

- To confirm backwash rate and service duration for Loprest's filter equipment.

- To confirm solids settling time before recycle.

- To provide data necessary for Loprest to guarantee requirements of the bid documents.

1.1 INTRODUCTION

Water from Wells 17 and 18 in Rubidoux, California area are high in manganese. Due to the high levels, removal of manganese is required prior to supplying the District's existing distribution system. The facility is planned to initially produce and treat approximately 5500 gpm.

This pilot test program was conducted between September 14th and September 18th at Well 18 and September 28th and October 1st at Well 17.

1.2 EXECUTIVE SUMMARY

Loprest has been designing and fabricating manganese removal systems using manganese greensand for over forty years. Drawing on that experience; filtration rates, run times, backwash procedures, chemical dosage rates, etc. are all established by theoretical calculations and history. Therefore, Loprest's goal was to conduct uninterrupted operation per bid testing procedures (section 3.04) and document the results. The pilot test recommendations and our design criteria as requested are summarized below and presented in detail on the following report.

Loprest uses lower filtration rate with conventional media than some of our competitors with their proprietary medias. However, this approach has many advantages to it that overcomes the use of physically larger equipment. Replacement media costs less and is available from multiple sources. Service times between backwashes are very long, in this case over fifty hours. This reduces equipment wear and tear while prolonging media life. With the stainless steel internal components that we use, everything will last longer than the forty years typically used to depreciate the capital costs. On-going operational costs are minimal with only small amounts of chlorine required on a daily basis. Media life of greensand is typically in excess of ten years making manganese removal with manganese greensand the overwhelming technology used for the last forty years.

1.2.1 Recommended and Confirmed Design Criteria

a) Oxidation with chlorine only, at 0.8 ppm (Well 18) to 0.9 ppm (Well 17).

b) No reaction vessel required, chlorine added directly ahead of filter inlet.

c) Filtration rate of 9.0 gpm/SF at the levels of manganese encountered (<0.250 ppm) produced low (non-detect by lab testing) manganese in the product water for the entire fifty hour filter runs.

d) The greensand theoretical minimum capacity of 700 grains/SF was confirmed at fifty hour runs. Pilot operations were continued unattended overnight to get to fifty hours within the test period. Actual operations is expected to be longer than the minimum capacity of greensand.

e) Clean filter head loss is less than 3 psi. The recommended maximum headloss prior to backwash is 8-10 psi and this value was not achieved prior to ending the test at the greensand minimum capacity.

f) The minimum backwash rate of 12 gpm/SF produced a clean filter bed, ready for the next service cycle.

g) The Loprest standard of a combined surface wash/backwash for four minutes, backwash only for four minutes and a two minute rinse produced a clean filter bed after backwash.

h) The recommended settle time for solids in the waste tank of eight hours can easily be achieved with fifty hour service runs.

i) State and Federal guidelines of a maximum 10% recycle rate will easily empty the settled waste tank prior to the next backwash.

j) Field results all showed manganese levels in the effluent of less than 50 ppb. Traditionally, field analysis reads higher than laboratory results and this was confirmed by Rubidoux CSD's lab analysis reporting non-detect for manganese in the effluent.

1.3 OVERVIEW OF IRON AND MANGANESE TREATMENT PROCESSES

A brief discussion of iron and manganese treatment processes follows.

1.3.1 Iron and Manganese Removal

Iron and manganese in water supplies can cause aesthetic problems such as discoloration of water, laundry, and plumbing fixtures, and taste problems. Secondary maximum contaminant levels (MCLs) of 0.3 and 0.05 mg/1, respectively, have been established for iron and manganese in drinking water by the USEPA and the California Department of Health Services.

The most common method of removing 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), and subsequent removal of the precipitates formed by filtration [1], When chlorine is employed as an oxidant, the following reactions occur.

Iron Removal	Manganese Removal
$2Fe^{+2} + Cl^{+0} \rightarrow 2Fe^{+3} + Cl^{-}$	$Mn^{+2} + 2Cl^{+0} \rightarrow Mn^{+4} + 2Cl^{-}$

One atom of iron reacts with one atom of chlorine, therefore the stoichiometric amount of chlorine required to oxidize 1 mg/1 of iron is equal to the atomic weight of chlorine divided by the atomic weight of iron, or (35.453/55.848) = 0.64 mg/1 of chlorine. At a pH of 5 and higher, Fe^{+2} that is not organically complexed is rapidly oxidized to insoluble $Fe+^{3}$ by free chlorine [1, 2]. (Organically complexed metal ions form covalent bonds with organic substances in water.)

One atom of manganese reacts with two atoms of chlorine, therefore the stoichiometric amount of chlorine required to oxidize 1 mg/1 of manganese is equal to twice the atomic weight of chlorine divided by the atomic weight of manganese, or [2(35.453)/54.938] = 1.29 mg/1 of chlorine. The rate at which soluble Mn^{+2} is oxidized to insoluble $Mn+^{4}$ is a function of pH, water temperature, chlorine concentration, and whether the manganese is organically complexed. The reaction is base catalyzed, with an increase in reaction rate as the pH increases. Free chlorine oxidizes $Mn+^{2}$ relatively slowly, unless the pH is above 9.0 and a large excess of free chlorine (400% of the stoichiometric requirement) is present [2].

Oxidized manganese-oxide (MnO_x) coated media enhances the oxidation and removal of manganese by adsorbing Mn^{+2} on the surface of the media, and by promoting the exchange of electrons to oxidize soluble Mn^{+2} to insoluble $Mn+^{4}$. The kinetics of Mn^{+2} uptake and oxidation on MnO_x coated media is a function of the specific concentration of adsorption sites on the media, the free-chlorine concentration, and the pH of the water. The reaction rate increases linearly with both increasing free chlorine concentration and increasing pH [2].

Manganese greensand is a commercially available manganese-oxide coated media. Manganese greensand is a zeolite mineral processed with manganese sulfide and potassium permanganate in alternating steps to produce a black precipitate of manganese dioxide on the granules. Other filter media, such as anthracite or uncoated silica sand, in iron/manganese removal systems naturally undergo an "aging" or "seasoning" process during which they become coated with manganese-oxide. This "naturally-occurring greensand effect" has been shown to be a viable functional removal mechanism [2].

2.0 DESCRIPTION OF PILOT TEST PROTOCOL

A description of the pilot test protocol follows, including a list of participants, a description of the test sites, characteristics of the feed water at both sites, raw water analytical data, and a description of the treated water and waste water handling facilities during the pilot study.

2.1 PILOT TEST PARTICIPANTS AND RESPONSIBILITIES

The names, contact information, title and responsibilities of each pilot test participant are provided in Table 1.

TABLE 1
PILOT TEST PARTICIPANTS AND RESPONSIBILITIES

Name and Contact Information	Title and Responsibilities
Randy Richey	President, Loprest Water Treatment Company Pilot Study Leader 510-799-3101 (phone) 510-799-7433 (fax) Randy@loprest.com
Lester Sanui	Engineer, Loprest Pilot Plant Process Engineer 510-799-3101 (phone) 510-799-7433 (fax) Lester@loprest.com

2.2 DESCRIPTION OF PILOT TEST SITE

Testing was conducted at Well 17 and Well 18 in Rubidoux, CA. The wells are located at 5245 34th Street, Rubidoux, California. There is a large open area around the well. Water was withdrawn from the well at approximately 10 gpm and $\geq$ 30 psi. while the production well was in operation.

A 3/4" hose bib was used to supply the pilot equipment. A treated water supply for backwash was available from a temporary tank used to collect pilot plant treated water effluent.

2.2.1 Raw Water Analytical Data

The well water analysis of Wells 17 and 18 were provided by the District and are shown in the attached lab results. See Appendix B.

3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION

The equipment used during the pilot test is described below, including the range of water quality that is treatable by the pilot equipment.

3.1 PILOT TEST EQUIPMENT DESCRIPTION

Loprest's pilot test equipment is installed in a trailer, which was parked onsite at the location. The pilot test components were constructed and installed in the trailer by Loprest at its manufacturing facility in Rodeo, California. The following equipment installed in the trailer was utilized during the pilot test:

- Two Walchem EZ-B10 chemical metering pumps, maximum flowrate of 0.6 GPH, and solution tanks.
- One vertical pressure filter constructed of clear acrylic tubing, 12" outside diameter (11.25" inside diameter) by 65 1/2" sideshell height, cross sectional area = 0.69 square feet, with internals, valves, controls and media as follows:
    - Slotted SS strainer underdrain laterals
    - Surface wash nozzle
    - 12 inches of anthracite coal, 0.6 to 0.8 mm effective size, uniformity coefficient = 1.65, 52 pounds per cubic foot
    - 18 inches of manganese greensand, 0.30 - 035mm effective size, uniformity coefficient = 1.60 or less, 85 pounds per cubic foot
    - 2 inches of 6 x 12 mesh barrier sand, 100 pounds per cubic foot
    - 5 inches of 1/8 x 1/4 inch pea gravel, 100 pounds per cubic foot
    - Automatically or manually operated valves to control filtration, rinse to waste, surface wash, and backwash
    - Allen-Bradley Micrologix 1500 PLC with touch screen interface.
    - Pressure gauges on inlet and outlet
    - Differential pressure gauge connected to inlet and outlet
    - Air release valve
    - Inlet and outlet sample ports
    - Rate of flow indicators for influent, backwash, and surface wash
    - Pressure regulator, 8 psi on filter discharge
- A 10.4 gallon capacity contact chamber for chemical mixing and detention time is installed in the trailer but was bypassed during the tests
- One pH adjustment system consisting of (but not used)
    - CO_2 cylinder,
    - pressure regulator/gauge
    - Rotameter, 475 cc/min max. at 100%, STP
    - Aquarium air stone, 14" x 3/4" with a 1/8" barb connector
    - Recirculation pump (also used for backwash)
    - 50 gallon open-top w/cover polyethylene mixing tank
    - Float-type water makeup valve for level control
    - Tygon tubing, 1/8"

- Test equipment as follows:
    - Quick II Arsenic test kit manufactured by Industrial Test Systems (part #481303), test range from <1 to 50 ppb.
    - Hach DR 890 Portable Colorimeter and associated reagents for iron and chlorine.
    - Hach portable handheld probes for pH and conductivity.

A picture of the interior of the trailer is shown.

FIGURE 1
INTERIOR VIEW OF TRAILER

3.2 CONTAMINANT REMOVAL PERFORMANCE CAPABILITIES

This system is capable of achieving contaminant removal to the study level goals without pH adjustment. This statement of performance is based on the results obtained in the pilot tests conducted for this study, and on results obtained from previous pilot tests. The statement of performance is also based on treating waters of similar characteristics to the water treated in this study. See executive summary and bid proposal for final design criteria.

4.0 FIELD OPERATIONS PROCEDURES

This section describes the operating procedures for the equipment and performance testing used during the test.

4.1 TIME AND DURATION OF TESTS

The tests at Well 18 were conducted between September 14 and September 17, 2009. The tests at Well 17 were conducted between September 28 and October 1, 2009. The filter was backwashed after each wellsite. Runs were conducted round the clock to complete total service run hours. The table below details the test runs.

TABLE 2
SUMMARY OF TEST RUNS AND DURATIONS

Start Date	Run ID	Location	Duration	Reason for Termination
09/14/09	Breakpoint 18	Well 18	1 hour 20 min.	Breakpt. achieved
09/15/09	Run 1	Well 18	50 hours	Test complete
09/28/09	Breakpoint 17	Well 17	1 hour 20 min.	Breakpt. achieved
09/29/09	Run 2	Well 17	50 hours	Test complete

4.2 OPERATING PROCEDURES AND PERFORMANCE TESTING

This section describes the operating procedures for the pilot testing equipment and the field testing procedures. Pilot test runs were conducted at a flow rate of 6.2 gpm (9 gpm/square foot).

4.2.1 CHEMICAL SOLUTION PREPARATION AND FEEDING

Commercially available, six percent sodium hypochlorite (household bleach) was used to prepare the chlorine treatment solution. Four hundred sixty-two (462) ml of bleach was added per five gallons of potable water. The feed rate of this solution for each filter flow rate was calculated to provide the desired chlorine dosage in ppm. The calculated feed rate was established by timing the rate of drawdown from a 250 ml calibration cylinder. To confirm the desired chlorine dosage, the chlorine residual was measured on filter effluent during each test run. The chlorine residuals for each run are shown in the attached results.

4.2.2 PILOT TEST EQUIPMENT OPERATING PROCEDURE

The initial run was to determine chlorine demand of the raw water (chlorine breakpoint) as required in the Pilot Test specifications. The chlorine breakpoint is achieved when an amount of additional chlorine dose to a source (filter influent) results in the equivalent increases in both free and total chlorine residuals. In all cases, the chlorine feed rates selected was far greater than the corresponding breakpoint value thus eliminating the possibility for less than total chlorination.

Each run was conducted to demonstrate contaminate removal capability for a set period without adjustments/changes between backwashes. Chlorine feed rates were adjusted to achieve a targeted free/total residual between 0.4 and 0.6 ppm in the filter effluent. Once the run was started, only minor adjustments were made to the system for the purpose of maintaining the process parameters at their targeted values.

Prior to startup and at the end of each run, the filter was backwashed. The backwash cycle was completed in three steps: 1) surface wash plus backwash for 4 minutes with a surface wash flow rate of 2 gpm/square foot, and a backwash rate of flow of 12 gpm/square foot; 2) backwash only for 4 minutes at a flow rate of 12 gpm/square foot, and filter to waste for 2 minutes at a flow rate of 6.2 gpm. Filtered and chlorinated effluent water was accumulated for use as backwash supply water.

During each filter run, the filter inlet and outlet pressure, and pressure loss was recorded. No excessive pressure loss was observed for any of the runs.

4.2.3 PILOT TEST RESULTS

Actual pilot data is presented in Appendix A.

4.2.4 SAMPLING AND TEST RECORDS

Lab samples for Rubidoux CSD were collected during all runs by Rubidoux personnel.

The lab samples were drawn directly into an acidified sample bottle provided by the lab. Hourly field samples were taken and analyzed immediately by Loprest. Chain of Custody forms were used in the collection of the lab samples.

It was observed that the results from the lab were consistently lower than field results. This was expected. In fact, the lab results showed in all cases the manganese level out of the pilot column was consistently below the 10 ppb detection limit (MCL is 50 ppb). The lab results are attached in Appendix B.

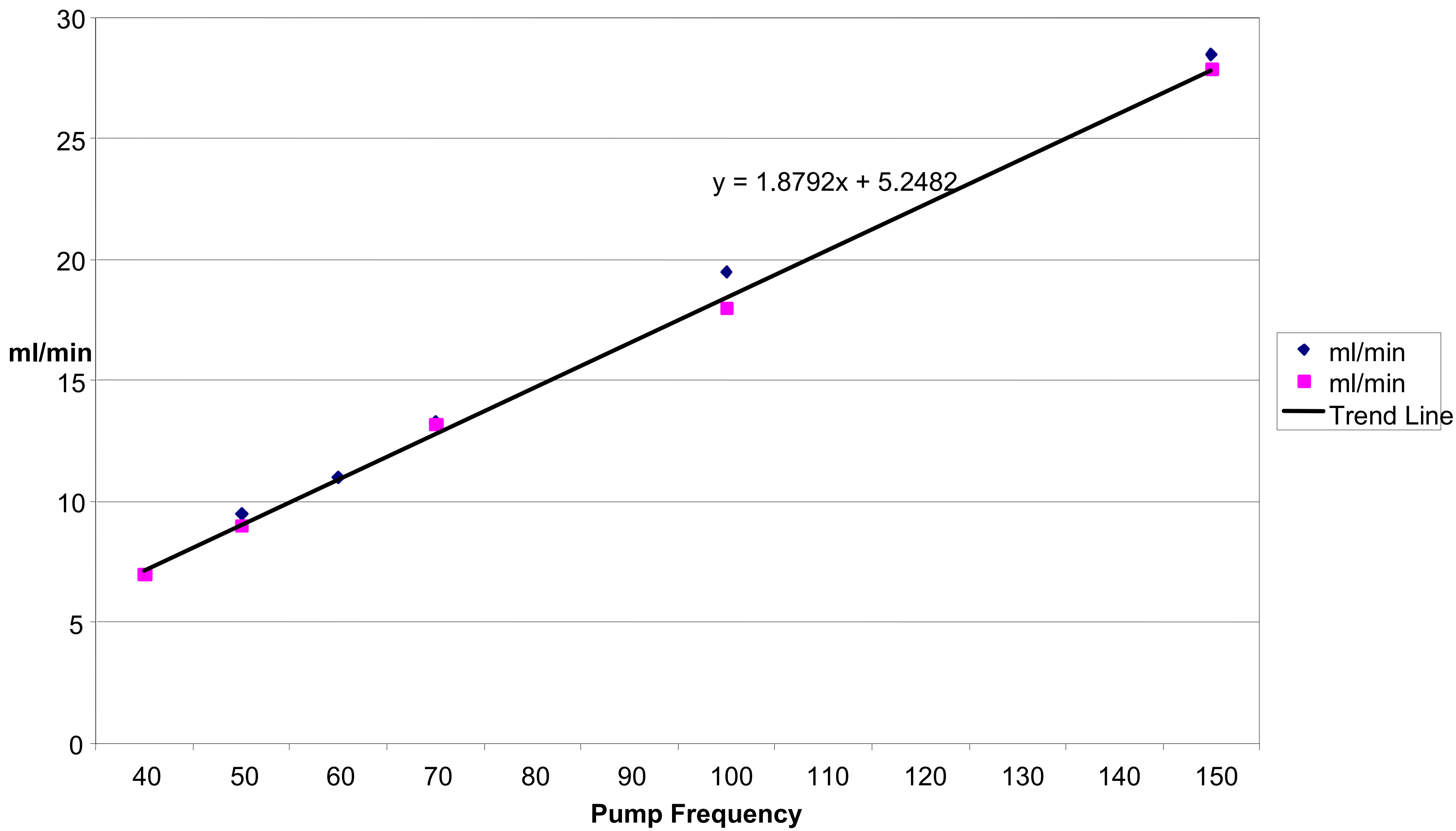
4.2.5 FIELD TESTING EQUIPMENT AND PROCEDURES

Prior to use, the inlet rotameter and the chlorine metering pump were calibrated. The inlet rotameter was calibrated by filling a known volume (5 gallons) at a constant rate and measuring the time required.

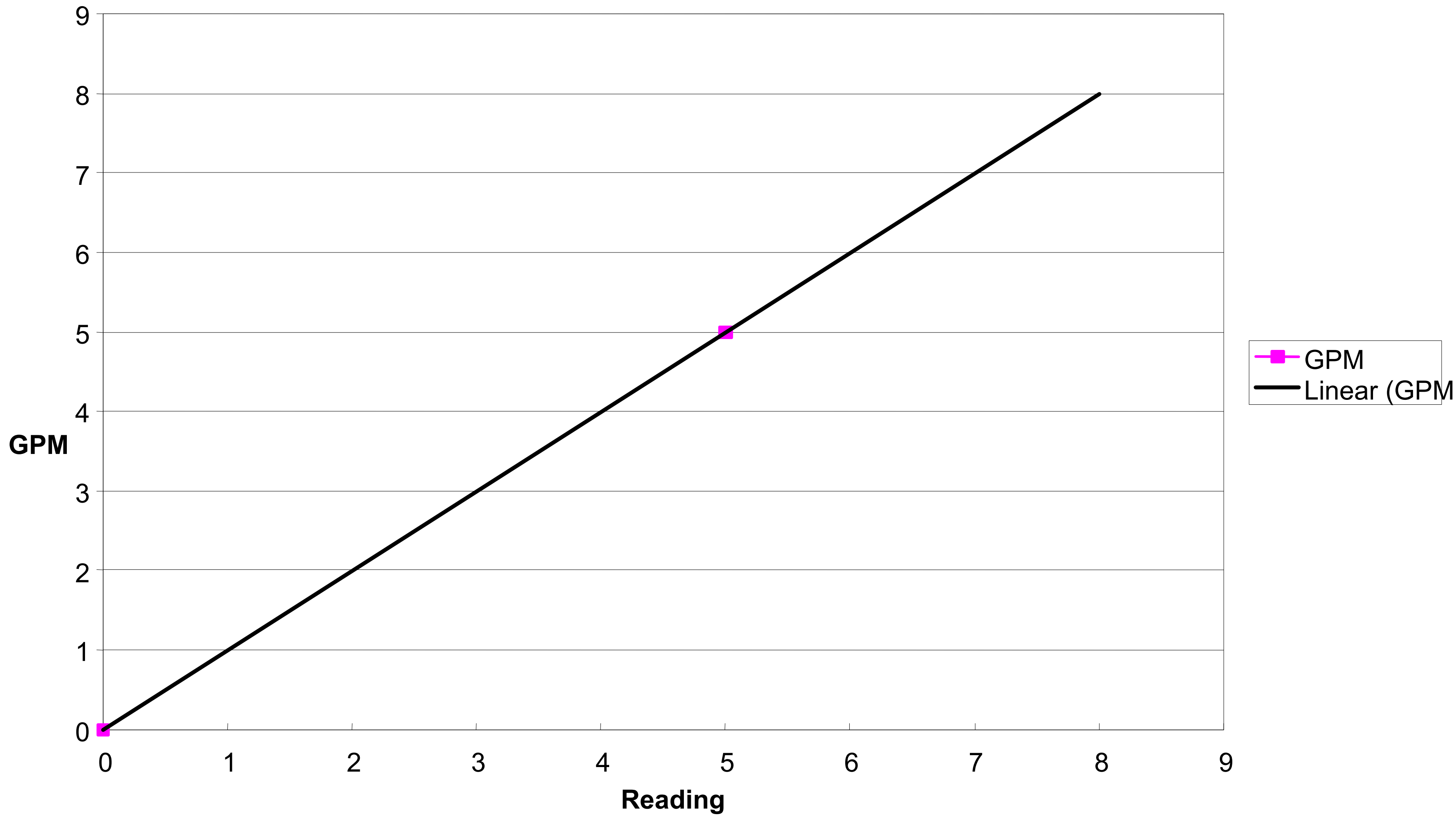
The metering pump is a fixed-stroke, variable frequency diaphragm pump. A calibration buret is installed on the inlet of the pump. The pump is operated for a known period of time at several frequencies and the volume pumped is recorded. The calibration chart for the chlorine metering pump is shown in Figure 2. The calibration chart for the inlet rotameter is detailed in Figure 3.

Field testing for chlorine and manganese was performed with a Hach DR 890. With this instrument, packets of reagents specific for each constituent tested are added to a sample cylinder, which is then inserted into the test instrument. The colorimetric test results are compared to a "zero" standard and displayed on the digital readout. For manganese, the PAN method was used. For chlorine, the Free Chlorine DPD Method 8021 was used.

CHLORINE PUMP CALIBRATION
FIGURE 2



ROTAMETER CALIBRATION
FIGURE 3



5.0 BACKWASH WATER AND SLUDGE PRODUCTION

Data from other pilot tests [3, 4] and from full scale plants [5] using Loprest equipment suggest waste collection and recycling is imminently feasible. Waste collection into a separate tank with settling period of 8 hours allows > 99.9% of the waste water to be decanted and returned to the front of the filter system. This recycle process eliminates the need for a sewer connection at the treatment site. The settled sludge accumulates in the bottom of the waste tank and is removed via vacuum services on a periodic basis. The frequency and amount for off site disposal depends on the raw water characteristics. Most installations [5] clean their waste tanks 2-3 times per year.

5.1 BACKWASH WASTE SLUDGE ESTIMATES

The sludge that will be generated and have to be hauled off can be estimated from calculations. These are shown below.

Basis:
5000 gpm and 24/7 operation
Raw water manganese (no iron) is 0.170 ppm and complete removal
1 lb Mn^{2+} = 1.6 lb MnO_2 solid sludge (from chemical equation of oxidation of manganese with sodium hypochlorite)

Then:
5000 gal/min x 60 min/hr x 24 hr/day x 8.33 lb/gal = 60 M lbs/day of raw water
@0.170 lbs Mn^{2+} /M lbs water x 60 M lbs water/day = 10.2 lbs Mn^{2+}/day
10.2 lbs M^{2+} x 1.6 = 16.3 lbs/day sludge

For Cleanout of waste tank every 120 days
120 x 16.3 = 1956 lbs of sludge

This sludge is typically concentrated in a volume of waste water approximately 15% of one total backwash waste volume or (.15) (35,000) = 5250 gals (see enclosed full scale equipment bid).

6.0 TREATMENT EQUIPMENT PERFORMANCE EVALUATION

This section provides a summary of the performance of the equipment during the pilot test. Refer to Section 3.0 for a complete description and specification of the pilot test equipment and field analysis test equipment.

Chlorine was injected at an injection point approximately ten feet upstream of the filter inlet line. From the injection point to the entrance into the filter, less than thirty seconds of contact time is provided. No special mixing was used.

6.1 CONTAMINANT REMOVAL SUMMARY

The pilot plant manganese removal performance was detailed in section 4.0. Field data and offsite laboratory data confirm that raw water manganese can be reduced from incoming levels to well below the MCL. Iron was not present in the raw water and iron removal is not a concern.

6.2 PERFORMANCE EVALUATION SUMMARY

The pilot tests demonstrate that Loprest's equipment can successfully and reliably remove incoming manganese that is present to the required less than 50 ppb level. Further, this removal can be done with a minimum of chemical treatment and equipment. Results indicate run times are greater than the minimum capacity calculations for manganese greensand. These estimates are shown in Table 3.

6.3 FULL SCALE PLANT DESIGN CRITERIA

The specific design parameters can be scaled from the equipment used during the pilot study evaluation. These design parameters are itemized below. Bid documents contain a proposal for full scale design.

- Chlorine (sodium hypochlorite) is the chemical (oxidant) required. No permanganate is required.

- Chlorine is added to the raw water at the rate of 1 ppm of each ppm of iron and 2 ppm for each ppm of manganese. The calculated value to achieve a 0.50 ppm effluent free chlorine value is 0.84 ppm.

- No Chlorine Contact tank is required, chemical addition may be added at the filter inlet.

- No pH reduction is required.

- Filtration can be successfully accomplished at treatment rates of up to 9 gpm/sq. ft. of filter area.

- Filter cycle times are dependent on the raw water composition. See Table 3.

- Loprest filters using manganese greensand and anthracite media can be operated to a maximum pressure drop of 8-10 psi [5].

- The pilot unit and full scale plants require a minimum backwash water supply rate of 12 gpm/sq. ft. to 15 gpm/sq. ft. maximum supply rate.

- The recommended backwash cycle duration for full scale systems is similar to the pilot plant. The backwash cycle is detailed below.

    - Backwash @ 10 gpm/sq. ft.(min) and surface wash @ 2 gpm/sq. ft. simultaneously for 4 minutes
    - Backwash only @ 12 gpm/sq. ft.(min) for 4 minutes
    - Rinse to waste (purge) for 2 minutes at service rate
    - Return to service

- A rinse cycle as detailed above is part of the complete backwash cleaning process. It is required as part of the total filter backwash. A separate rinse to waste or purge step is not required after the filter operation is momentarily stopped or a complete shutdown/start-up operation.

- Backwash waste water recycling can be achieved. The recommended backwash waste settling period prior to recycling is an 8-hour minimum time [3]. Settling should be as long as feasible and still be able to decant the waste tank prior to the next cycle.

- The backwash waste recycle rate is a maximum 10% of the filtration influent flow as set by ODW guidelines.

- Loprest can guaranty its equipment will produce water at these wells to well levels below the state MCL level of manganese. This guaranty is subject to operation of equipment per manufacturer's guidelines including the addition of chlorine.

TABLE 3

RUN TIME ESTIMATES (MAXIMUM Mn LEVEL)

Basis: 2000 gpm 313.5 SF of filter area 700 grains capacity of greensand per SF 0.23 ppm Mn, no iron
Then: 313.5 SF x 700 gr = 219,450 grains capacity (2)(0.23 ppm Mn) / 17 ppm/gr/gal = 0.027 grs/gal (219,450 grains) / (0.027 grains/gal) = 8,200,000 gals @ 2750 gpm then 3000 min or 50 hrs between backwash

7.0 REFERENCES

1. American Water Works Association; *Water Quality and Treatment, a Handbook of Community Water Supplies, Fourh Edition; 1990.*

2. Knock, William; Van Benschoten, John; Kearny, Maureen; Soborski, Andrew; and Rechow, David; *Alternative Oxidants for the Removal of Soluble Iron and Manganese*; American Water Works Research Foundation; March 1990.

3. Gilmore Engineering; *Arsenic Removal Pilot Study Report;* California American Water Company; June 2005.

4. Loprest; Arsenic Removal pilot study report; Loprest Job 31297, Indian Wells Valley Water District, August 2007

5. Loprest Quote Q09-104; Rubidoux.

APPENDIX A

Loprest Field Results

APPENDIX B

ES Babcock Lab Results