HARRISON HOT SPRINGS
Naturally Refreshed

VILLAGE OF HARRISON HOT SPRINGS

NOTICE OF MEETING
AND MEETING AGENDA

COMMITTEE OF THE WHOLE

DATE: Tuesday, October 11, 2011
TIME: 4:00 p.m.
LOCATION: Council Chambers, Harrison Hot Springs

1. CALL TO ORDER

Meeting called to order by the Mayor.

2. ITEMS FOR DISCUSSION

Water Supply and Treatment

3. REPORTS FROM MAYOR, REPORTS FROM COUNCILLORS

4. DELEGATIONS

5. STAFF REPORTS

6. PUBLIC QUESTIONS

7. ADJOURNMENT

13.3

HARRISON HOT SPRINGS
Naturally Refreshed

VILLAGE OF HARRISON HOT SPRINGS

REPORT TO COUNCIL

TO: Mayor and Council **DATE: September 12, 2011**

FROM: Ian Gardner, Operations Manager **FILE: 5340-03-01**

SUBJECT: Water System Supply and Treatment

ISSUE: For Council to consider the options of Lake Water Supply and Treatment or Ground Water Supply and Treatment to comply with the Operating Permit with the Ministry of Health.

BACKGROUND: Currently the Village's water is supplied from Harrison Lake through an intake, pumps, chlorination station to a reservoir and out to the distribution system.

In November 2009 The Ministry of Health sent the Village an amendment to the operating permit to include Treatment to have 4 log removal of viruses, 3 log removal of Giardia cysts and oocytes, and 3 log removal of Cryptosporidium cysts and oocytes. Commonly known as 4-3-3 removal. Research and costing for treatment was done. A Cartridge Filtration system with post Chlorination was recommended and a budget of $450,000.00 put into place. Since then, further investigation has revealed that, due to the high turbidity levels in the Lake source a Cartridge Filtration system cannot handle the turbidity levels we are experiencing. The need for a more complex Filtration Treatment System was required.

Civic Consultants provided the Village with a study to determine the needs to fully deal with the Treatment issues. Options were presented to Council in July 2011.

Lake Supply Option: Extension of the Intake line to deeper water, upgrading the 3 intake pumps and a Filtration Treatment Plant. An estimated cost of $1,715,000 was indicated.

Ground Water (Deep Well) Supply Option; To develop a Deep well pumping system and installation of a Green Sand Filtration Treatment Plant. An estimated cost of $1,148,927 was indicated.

The risk of contamination by outside influences is extremely higher in a Lake surface water source than in a Deep Well ground water source. The Ministry of Health has historically shown preference to a Deep Well Ground Source over a Surface Water Source. This was indicated by the Ministry of Health's Senior Engineer Tin Tun at a Council meeting of July 11, 2011.

Positives and Negatives of Lake Supply and Treatment vs. Ground Water Supply and Treatment;

Lake Water Supply (Surface) and Treatment

Positives (pros)	Negatives (cons)
○ Abundant supply of source water to meet demand ○ Will have excellent water quality after Treatment	○ High contamination risk of water source from outside influences ○ Treatment needed for removal of viruses, Giardia, Cryptosporidium and Turbidity. ○ Higher Operation and Maintenance costs ○ Interruption of water supply during construction ○ Higher project cost

Ground Water Supply (Deep Well) and Treatment

Positives (pros)	Negatives (cons)
○ Abundant supply of source water to meet demand ○ Will have excellent water quality after treatment ○ Very low contamination risk of water source from outside influences ○ Lower Operation and Maintenance costs ○ No interruption of water supply during construction ○ Lower project cost	○ Treatment needed for removal of Manganese and Sulfide

Since July it has been determined that, the operating costs for the Lake Source Treatment will exceed the operating costs for the Ground Water Source

Treatment by approximately 25% TO 35%. The life expectancy for each treatment plant option is 25 years.

The Hydrology report indicates that, the quality and quantity of water in the aquifer is acceptable as a source for water supply and will meet the requirements needed. If a second well is needed in the future to supplement the primary well for community growth needs, there is capacity in the aquifer to accommodate the requirement.

On Monday August 22, 2011 the Fraser Health Authority informed us, via email, they are taking extra Water Distribution samples to test for THMs. THM (Trihalomethane) is a byproduct produced from the combination of Chlorine and organic matter primarily found in Chlorinated water systems with high turbidity levels, such as our system is currently experiencing and has for several years. We also sent samples in for testing by our independent Laboratory for analysis. Chlorine dosage was increased to help offset the effects of higher Turbidity.

On Wednesday August 24, 2011, the Fraser Health Authority Inspector visited the Village to do an onsite system check. She requested we post a Water Quality Advisory, because of the continuous high turbidity levels in our Distribution system. This Advisory will remain in place until we have dealt with the turbidity issue.

During our discussion the Inspector was asked about Chlorination if we went to a Ground Water Deep Well Supply source. The Inspector indicated we would have to still Chlorinate the system until, the Village, could prove to the Ministry that, the Village has thoroughly cleaned the entire Water Distribution system due to the ongoing Turbidity issues and the fact the older distribution lines have never been cleaned properly by 'pigging' the lines. This would entail cleaning from the Reservoir through the entire Distribution system. During the Line cleaning process we would also install water sampling stations. These would be above ground stand-alone sampling pedestals at various locations throughout the water distribution system. This will eliminate obtaining samples from house taps and Fire Hydrants, both of which are undesirable sources. Approximately 10 units would be needed. The estimated cost to do this is $131,000.00 for Line and Reservoir cleaning and $15,000 for water sampling pedestals. These costs would apply to both Treatment options.

It was also learned from the Inspector that, if treatment of a Surface Water Supply does not meet the 4-3-3 log removal, Ultraviolet Light (UV) disinfection has to be installed as an addition to Chlorination. As stated in Civic Consultants report in July the Treatment option, A-C Water Treatment Plant, for the Lake Water Supply will only achieve 4-2.5-2.5 log removal. Therefore, a UV Disinfection system will have to be added to this option. Estimated cost is $50,000 - $70,000.

The following is to summarize the cost estimates of the two Supply and Treatment options, taking into consideration all the information provided.

Lake Water supply and Treatment

Intake extension	$850,000
Upgrade of Pumps	$150,000
Treatment Plant	$702,000
UV Disinfection	$ 70,000
Cleaning of Reservoir and Lines	$ 131,000
Water sampling Pedestals	$ 15,000
Total	$1,918,000

Ground Water supply and Treatment

Well and Pumping system	$ 130,000
Treatment Plant	$ 931,000
Cleaning of Reservoir and Lines	$ 131,000
Water sampling Pedestals	$ 15,000
Total	$1,207,000

POLICY CONSIDERATIONS: (if any)

RECOMMENDATION: THAT Council approves proceeding with the Ground Water Supply and Treatment option.

Respectfully submitted for your consideration;

Ian Gardner
Operations Manager

DIRECTOR OF FINANCE COMMENTS:
Either option will involve a significant portion of the costs to be funded by borrowing.

Dale Courtice
Director of Finance

CHIEF ADMINISTRATIVE OFFICER COMMENTS:
I concur with the recommendation.

Ted Tisdale
Chief Administrative Officer

Village of Harrison Hot Springs
Water Treatment Plant Report

Project Description

The Ministry of Health has directed the Village of Harrison Hot Springs to provide treatment to the Village water system. This directive was issued in a letter dated Nov. 6th, 2009, from Ms. Jeniene Lutz, C.P.H.I. stating;

> As a follow up to the Village of Harrison Hot Springs Council resolution of April 19, 2007 regarding the treatment of the Village's water supply, the following terms and conditions were added to the operating permit:
>
> On or before December 31, 2010, the finished water supplied by the Village of Harrison Hot Springs water system must have undergone treatment that achieves the following:
>
> - At least a 4-log (99.9 9%) reduction and/or inactivation of viruses
> - At least a 3-log (99.9 %) reduction and/or inactivation of Giardia cysts and oocysts
> - At least a 3-log (99.9 %) reduction and/or inactivation of Cryptosporidium cysts and oocysts
>
> Please advise Fraser Health in writing as to how the Village of Harrison Hot Springs intends to meet the above terms and conditions.

Village staff was unaware of the extent of the works and the cost that this would entail until they tried to implement the objectives. The deadline to have this work done has passed and the Village and the Ministry are anxious to have the works completed.

The removal and/or inactivation of *Giardia* cysts and *Cryptosporidium* oocysts from raw water are complicated by their small size and resistance to commonly used oxidants such as chlorine. *Cryptosporidium* oocysts are harder to eliminate but are fortunately much less common in Canadian surface waters.

It is possible to reduce the viability of *Giardia* cysts by 99.9% using chlorination alone but long contact times are required. Ozone and chlorine dioxide are much better disinfectants but both are expensive and result in the formation of unwanted by-products (particularly chlorite formation in the case of chlorine dioxide). Ozone is a better choice but is unreliable when turbidity is high (as can be the case for the Village's Lake supply) or variable because cysts are protected in flocculated particles.

Inactivation of Cryptosporidium oocysts by chlorination alone is impractical but ozonation can be effective when used properly.

Filtration followed by chlorination is a practical and cost effective answer to solve the problem. The estimate for this solution is in the range of $450,000 (BI Purewater). Based on this estimate, the Village set a budget for this solution at $450,000.

However, upon further investigation, it was determined that the TSS (total suspended solids) of the Lake supply runs from 3 - 5 mg/l (during normal periods) to 15 mg/l (or higher) during storms or periods when the Lake turns over. The filtration of water with a TSS of 4 - 5 mg/l and above, is complicated by the need to backwash and/or replace filters too often. The higher levels of TSS result in a large increase in the operations and maintenance costs which negates the cost advantages for this solution.

The next choice is filtration with the aid of coagulation/flocculation. This is the most practical method to achieve high removal/inactivation rates of cysts and oocysts in turbid water to meet the requirements of the Ministry of Health and the Canadian Drinking Water Guidelines.

Reverse osmosis (RO) plants are the high end solution. Not only do they remove cysts and oocysts, they also remove a wide variety of impurities and bacteria. However, the cost for this solution is too exorbitant for a small community.

The Village therefore continued on with the investigation of the mid priced treatment systems.

Project Details

Civic Consultants provided the Village with a study to determine their present and future water requirements. The present maximum daily water demand (MDD) is 30 l/sec at 565 kPa and is borne out by the Village records. This is without any effort at water conservation. With water conservation policies in place, it is estimated that the current capacity could be maintained to the year 2018.

The Village asked three manufactures (BI Purewater, Corix and Timbro) to provide concept and Class C budgets for solutions to the problem.

BI Purewater, the company that provided the initial estimates, did not provide a proposal. Their primary treatment product is cartridge filtration plants. Once they were informed of the level of TSS in the Lake, they decided not to submit a quote. The problem with TSS was discussed previously in this Brief.

The proposals received were as follows;

1. A-C (Absorbent Clarifier) Water Treatment Plant by Corix Water Systems.
   The AC water treatment plants use a combination of hydraulic "tortuous path" flocculation/clarification filtration and rapid rate filtration to produce a superior quality of potable water. They are suitable for stable, well or surface waters where turbidity levels seldom exceed 50 NTU.

   The final water quality is
   - less than 0.1 NTU final turbidity.
   - 2.5 log, multi-barrier protection against Giardia and Cryptosporidium.

   Enclosed are conceptual design drawings for the AC System. For more information go to www.keywin.mb.ca/files/CWS_AC%20Water%20Treatment%20Plant.pdf

2. Trident Model TR-210 A by Siemens Water Technologies

3. Culligan Hi-Flo 50 Series Industrial Water Filter System

4. Z-Box S-18 Ultrafiltration Water Treatment System by GE

Estimate of Costs (including breakdown)

Optional Treatment Plants

1	A-C Water Treatment Plant by Corix Water Systems	$518,000
	Miscellaneous 10%	$51,800
	Engineering 10 %	$56,980
	HST 12%	$75,214
		$701,994
2	Trident Model TR-210 A by Siemens Water Technologies	$1,089,717
	Miscellaneous 10%	$108,972
	Engineering 10%	$119,869
	HST 12%	$158,227
		$1,476,784
3	Culligan Hi-Flo 50 Series Industrial Water Filter System	$656,880
	Miscellaneous 10%	$65,688
	Engineering 10%	$72,257
	HST 12%	$95,379
		$890,204
4	Z-Box S-18 Ultrafiltration Water Treatment System by GE	$1,092,063
	Miscellaneous 10%	$109,206
	Engineering 10%	$120,127
	HST 12%	$158,568
		$1,479,964

Based on the above, the cost to provide treatment of the Lake supplied water should be $700,000. which includes HST.

The initial quote from IDL of $483,415 included exceptions. I have gone back to them to get them to remove the exceptions.

The new estimate is $518,000.
The changes to the previous proposal include

a) Added dry chlorination system
b) location of plant moved to flat area next to old reservoir up steep access road.
c) 3 phase power is located at the site and no additional power pole is required to connect power to building
d) cut into raw water forcemain to new reservoir and connect raw water line from lake pumps to raw water intake
e) connect plant treated water line and back wash line to the forcemain section going to the new reservoir
f) connect plant backwash waste line to existing reservoir overflow line to rock pit.

The above works assumes that no rock blasting or removal is required and the existing forceman and overflow pipe are within 50ft of the location of the plant

As well as the requirements for treatment by the Ministry of Health, the Village water supply intake is also a concern. The intake is located approximately 1 km off shore in about 3.5 meters of water at low levels. It poses a risk for purposeful or accidental contamination. However, to date, no problems have occurred.

The two solutions to reduce or eliminate the risk are;

- to move the inlet further out into deeper water (more than 18 meters) which will reduce the risk, or
- change the supply of water from the Lake to a protected groundwater source which will eliminate the risk.

1. Civic Consultants provided the Village with a report entitled "Harrison Hot Springs Water Study Nov 2007". This Report looked at relocating the inlet out to deeper water to reduce the risk of contamination. The cost was estimated to be about $850,000 for the relocation of the inlet and an additional $150,000 to change the pumps to obtain the same capacity. As well, the water would still require treatment to achieve the Ministry of Health requirements.

To reduce the risk of Lake Water contamination and to meet the Ministry of Health requirements the estimated cost would be approximately $1,715,000 (relocated inlet plus treatment).

2. Providing a ground water supply and incorporating a ground water protection plan, the risk of purposeful or accidental contamination is virtually eliminated.

The new requirements from the Ministry of Health apply to surface water or groundwater under the direct influence of surface water (GUDI). If the source of supply was changed from Harrison Lake to a ground water supply that was not under the direct influence of surface water, these new requirements would not apply. GUDI wells are generally less than 18 meters deep.

The cost to switch over to a ground water supply, if an adequate supply of ground water meeting the Guidelines for Canadian Drinking Water Quality were found, would be approximately;

Well Drilling	$15,000
Hydrology Report	$7,000
Capacity Testing	$5,000
Chemical Testing	$500
Well Construction	$60,000
Pipe Work	$50,000
Well Protection Plan	$25,000
	$162,500
Contingencies 20%	$32,500
HST 12%	$23,400
	$218,400

This solution would obviously be the least expensive solution if an adequate supply of ground water meeting the Guidelines for Canadian Drinking Water Quality could be found. The Village explored this option by drilling a 200 mm test well. Sufficient water was found but unfortunately, the water did not meet the Canadian Guidelines. The water is high in manganese and hydrogen sulphide (H_2S).

The Village conducted a demonstration treatment project to determine if there was an adequate solution for the parameters not meeting the Guidelines. A "green sand" filtration plant was provided by Corix and a three day testing program undertaken. The manganese and the H_2S were successfully removed to acceptable limits.

The Village obtained conceptual estimates for a "green sand" treatment plant with the following results.

1 Corix PF-485-3 WTP	$629,415
Miscellaneous 20%	$125,883
Engineering 10 %	$75,530
HST 12%	$99,699
	$930,527
2 Aeralater Type II Plant by Siemens	$878,577
Miscellaneous 10%	$87,858
Engineering 10%	$96,643
HST 12%	$127,569
	$1,190,648
3 Hi-Flo 50 Cullsorb Filter System by Culligan	$998,589
Miscellaneous 10%	$199,718
Engineering 10%	$119,831
HST 12%	$158,176
	$1,476,314

In total, the cost to convert the Lake Supply to a Ground Water Supply would be approximately $1,148,927. This would meet the Ministry of Health requirements and eliminate the risk of contamination.

I have enclosed a copy of the estimate for the PF - 485-3. As with the AC Plant, there are exceptions with the quotation. I have made allowance for these by adding a 20% miscellaneous amount.

Another major factor that will affect the decision is the cost of operations and maintenance. As can be seen from the initial concept of applying a straight forward filtering system, the costs for labour and filters would be excessive. BI Purewater's primary treatment plants are cartridge filter plants. Due to the high levels of turbidity, they decided not to provide a quote for their plants.

The effect of the turbidity problem is demonstrated in the existing water lines. When the public works crews flush the lines, the mains run extremely dirty until most of the settled solids are flushed out. The muck in the lines also causes problems with the chlorine residual values and can lead to failing test results in the water system.

Alum is the coagulant that is generally added to the raw water to precipitate dissolved contaminants and encourage suspended particles to group together in the form of "floccs". As the water passes upward through the upflow clarifier filter, these grow and are removed by the coarse media. The clarified water then passes on to the downflow rapid gravity filter for final polishing. Solids that accumulate within both the upflow and downflow filters are periodically removed by automatically controlled air/water backwashing.

The more turbid the water is, the more frequent the backwashing program will be. Manual operation of the backwashing process may be required due to fluctuating levels of TSS. Manual operations require labour which can be expensive. As well, backwashing also requires energy demand and is a negative for water conservation. .

The ground water supply does not have the TSS or turbidity problem that the Lake supply does. What is being filtered out is the excessive manganese. This is in much lower concentrations than the TSS and therefore requires much less backwashing than the AC plants does. The backwashing can generally be done on an automatic schedule to reduce operational labour costs.

The regeneration of the potassium permanganate does add costs but it mostly done on an automatic basis.

To this point, we have not done a detailed analysis of the labour costs for each process.

Village of Harrison Hot Springs
Water Treatment Plant Report
Supplemental Information

There are other works that will be required for water supply that will be necessary either for a Lake Supply or a Ground Water Supply. The existing water mains have an excess of sands/silts built up over the years due to the use of the turbid Lake Supply. These mains need to be cleaned. Treating the water at the source will not protect the users from the sands or silts already in the system.

To clean out the lines properly requires a process known as "pigging" the lines. A series of small polyethylene foam cleaning devices are put into the pipe line through a fire hydrant barrel. They are also retrieved from another fire hydrant barrel down the line. A short video of this process can be seen at *www.youtube.com/watch?v=alij-Ts61Tw* .

We have contacted ABC Pipe Cleaning for a rough budget estimate. Their response was that it would be in the range of $____/m. The Village has __________ m of mains for an estimate of *$80,000* (temporary guesstimate) for this work. A contingency amount of 35% should be added for a total estimate of $121,000 (which includes HST) . The total should be added to either the Lake Supply Grant application or the Groundwater Supply Grant application.

Before an application for a Grant is made, a more detailed estimate for the pigging process should be obtained.

If the lines are cleaned, the Ministry of Health has stated that they would consider not requiring chlorination of the groundwater supply. The Lake Water Supply would need chlorination in either case.

As well, the Ministry of Health would like to see proper sampling ports on the water system. Currently samples are being taken from individual home taps and or fire hydrants. This methodology is not acceptable.

The proposed sampling ports would be similar to those used in the District of Kent. For budgetary purposes, I have estimated that 10 sampling ports should be installed at a cost of $1,000 each for a total of $10,000 plus contingencies plus HST.

Comments from Corix on the comparison between an AC plant and Cartridge filter plants.

To meet GCDWQ guidelines a 1 micron cartridge filter must be installed. We know of one plant up north in which the owners specified and ordered a cartridge filter plant. The data they presented indicated the turbidity was <2 NTU. However there were incidences this spring in which the turbidity went much higher. The town was changing filters every day at great expense. It is our experience that anything over 2 NTU for a 1 micron filter will greatly increase cartridge filter replacement.

The AC plant on the other hand will handle turbidity up to 25 with normal operation. Higher turbidities are possible however backwashing will increase considerable as will operator attention. This gives the Village a significant safety factor from turbidity increases. Under 25 NTU, one essentially pays only for extra chemicals as the turbidity increases. It is difficult to predict how much the chemical use will increase with higher turbidity, but it's probably in the neighborhood of 20%.

Tin Tun, the Ministry of Health Regional Engineer stated at the last meeting that the Harrison Hotel had provided a cartridge filtration system for their treatment. It became so plugged up that they had to disconnect it.

Civic is aware of a cartridge plant that was supplied for a small water system on Shuswap Lake. The filters had to be changed two or three times a day. The Owners had to purchase a different type of plant to cope with the turbidity.

The estimate for the groundwater supply included an estimate for the construction of a well and the installation of a well pump. We have since obtained a more detailed estimate from Corix. Their estimate is as follows;

The scope for the well pump equipment includes:
- Well pump and cables, c/w leak detection and overload protection
- low water level detector
- Well pipe
- pitless adaptor
- Pump controls and starter added to WTP PLC
- Local well disconnect (equipment will be in the WTP building)
- 60m power and instrumentation cable (WTP to well)

Grundfos Pump information
Pump to handle 486 usgpm water at (149.8 psig) 346 ft TDH at the worst case scenario (i.e. filter is plugged); pump will deliver 550 usgpm water at (125 psig) 289 ft TDH when filter is completely clean.
The system will require a modulating valve at discharge to keep flow rate constant at 400 usgpm. (More is available if needed in the future)

One only Grundfos model 475S600-6 all stainless steel submersible well pump end, 8" dia. pump
with 6" FNPT connection; ship wt. 107 lbs

One only Grundfos 6" dia. 60 hp, 304SS motor for above pump, 3450rpm, 575v, 3ph, 60hz, 13000 lbs maxi.
thrust capable, std. 312" long motor lead; ship wt. 390 lbs

Note 1: TWU6-4 pump cable good for 550 ft continuous run on 60hp, 575 volt application;
Nema 4 starter required, A/B J45 heater for overload relays or equal, overload
relay amp sets at 67.0 to maxi. of 72.8 (60hp, 575v motor rated at 64.4 amps)

Note 2: Pumps specs to be fine tuned upon detail design

Installation scope:
- Install force main from well to WTP 50m
- Install well pump, cable and sensors
- Install 50m of u/g cable and local disconnect
- install well head protection 1m deep, 5 meter radius, plastic sheet, bentonite seal

Total cost of well pump, cables, installation, well head protection, etc. is $45,000

The cost for a well would be;

Well drilling	$12,000	complete
Hydrology Report	$ 3,000	underway
Capacity testing	$ 5,000	complete
Chemical Testing	$ 500	complete
3 phase power to well head	$20,000	
Well Construction	$45,000	
	$85,500	
Contingencies 20%	$30,200	
HST 12%	$13,884	
	$129,584	

Previous estimate was	$218,400

In Summary the Lake Supply Treatment System should cost approximately;

Treatment Plant (including contingencies and HST)		$702,000
Cleaning the lines (including contingencies and HST)		$121,000
Sampling Ports (including contingencies and HST)		$ 15,000
	Total	$838,000

The Groundwater Supply and Treatment System should cost approximately

Treatment Plant (including contingencies and HST)		$931,000
Well and pumping system (including contingencies and HST)		$130,000
Cleaning the lines (including contingencies and HST)		$121,000
Sampling Ports (including contingencies and HST)		$ 15,000
	Total	$1,197,000

Operating Costs

1. Cartridge Filtration System was not estimated due to the unknown number of filter changes.

2. AC PLANT (assumes 10 NTU lake water)

Chemicals: Polymer, Alum, Soda Ash.	Total $538.30/week
Power: Mostly due to pumping to WTP from primary pumps	Total $381.92/week
Power: Due to pumping from WTP to reservoir	Total $124.33/week
Operating Labour 2 hours/day. 4 hours/week for chemical replenishment.	
Total 14 hours/week Assume labour costs @ $40/hour	Total $560.00/week
	$1,604.55/week
Total cost / m^3 (based on a MDD of 2,242 m^3/day)	$0.10/$m^3$

3. PRESSURE FILTER

Chemicals: KmnO4	Total $164.50/week
Power: Mostly due to well pump	Total $556.50/week
Labour hour/week 14 Assume labour costs @ $40/hour	Total $560.00/week
	$1,281.00/week
Total cost / m^3 (based on a MDD of 2,242 m^3/day)	$0.08/$m^3$

Life Expectancy.

The life expectancy of the two systems is an average of 25 years. The tanks themselves should last for about 40 years.

We have asked Corix to provide some assurance that H2S and Manganese will be removed

Their response;

The pilot test is our best assurance that sulphides (and Manganese will be removed)
The reported values and observations from the April pilot test were:

"Manganese Tests
GCDWQ aesthetic objective: <0.05 mg/l
Raw water average: 0.12 mg/l
Treated water average 0.008 mg/l
Average removal efficiency 93%

Sulphide Tests
GCDWQ aesthetic objective: <0.05 mg/l
Raw water average: 0.023 mg/l 400 gpm value 0.027 mg/l
Treated water average 0.007 mg/l
Average removal efficiency 70%

The results indicate that all measured treated water parameters were within GCDWQ by a safe margin. This result is indicative that the manganese green sand filter system would safely and economically meet VHHS's potable water objectives.

The pilot test operator also indicated that the water taste quality was good with only very faint odours before treatment and no odours following treatment. "

PITEAU ASSOCIATES
GEOTECHNICAL AND
HYDROGEOLOGICAL CONSULTANTS

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Our file: 3127

September 2, 2011

Civic Consultants Ltd.
410 – 3rd Street
New Westminster, B.C.
V3L 2S2

Attention: Lorne Davidson, P.Eng.

Dear Sirs:

Re: Groundwater Supply Test Well, Harrison Hot Springs

In response to your recent request for comment on the groundwater supply test well installed in 2010 in the Village of Harrison Hot Springs, Piteau Associates Engineering Ltd. (Piteau) is pleased to provide the following letter to outline our opinions on well efficacy, water quality and development risks associated with use of this site for converting the communities water supply to a local groundwater source.

BACKGROUND

In March 2010, A & H Drilling Ltd. under contract to Corix Water Systems (Corix), completed installation and pump testing of a 31.7m (104') test well within a 41m (135') borehole on community property in the Village of Harrison Hot Springs (Fig. 1). Piteau understands that the objective was to test for local potential to convert the community water supply from a surface water source to a groundwater source to mitigate drinking water quality problems experienced by the community, including issues with turbidity and the potential for microbiological contamination associated with a surface water supply. The future water demand is 25 L/s (400 USgpm).

Based on apparent sulphide odours noted during drilling and subsequent exceedance of Canadian Drinking Water Guidelines aesthetic objectives for manganese from water quality testing, a field filtration test was conducted by Corix in 2011 (Corix, 2011) to test the effectiveness of Greensand and activated carbon filter media for removing these ions. They reported that manganese tests showed 93% average removal efficiency and 70% average removal efficiency for sulphide, reducing concentrations of the respective ions to well below water quality guidelines at a pilot plant scale.

WELL HYDROGEOLOGY AND CONSTRUCTION

A test well was drilled to 41m (135') depth into an unconfined sand and gravel aquifer. This composition is consistent with the highly productive Agassiz – Seabird Island Aquifer which has been mapped to extend from below the Fraser River, through Agassiz and below Harrison Hot Springs and Harrison Lake (Fig. 1). This aquifer comprises generally coarse-grained alluvial sediments and overbank deposits associated with the Quaternary path of the Fraser River and its local tributaries extending as far north as Harrison Lake.

The driller's log for the test well is included as Appendix A. The well consists of 200mm (8") casing with a 4.9m (16'2") length of stainless steel well wire-wound screen exposed to sand and gravel between depths of 26.8 and 31.7m (87.8 and 104'). The screen slot size used was 0.5mm (0.020"). The static water level at the time of well construction was 3.4m (11') below ground.

REVIEW OF PUMP TEST DATA

Corix Water Systems conducted a variable-rate aquifer pumping test on the test well on April 13 and 14, 2010. According to the well test record (Appendix B), the well was pumped at rates of 5.0, 8.3, 13.6, 17.9, and 25.5 L/s (80, 131, 216, 284, and 404 USgpm) for intervals each lasting 20 minutes, and the final interval was extended provide a total test duration of 1,180 minutes (19.7 hours). Although not indicated in the well test record, it is understood that the pumping rate was increased to 31.5 L/s (500 USgpm) during the initial "constant-rate" portion step of the test, between about 90 and 200 minutes after pumping began.

The pumping test results are illustrated on Fig. 2. Drawdown is plotted versus the logarithm of time from the beginning of the test. The aquifer transmissivity estimated from the portion of the drawdown curve between 90 and 200 minutes using the Cooper-Jacob (1946) method is estimated at 5.3×10^{-3} m^2/s. This was calculated using the recorded flow rate of 25.5 L/s. The actual rate recorded during this portion of the test may have been greater, which would result in a higher value of transmissivity. Water level recovery data was insufficient to provide a reliable estimate of transmissivity.

Extrapolating the portion of the drawdown curve between 90 and 200 minutes to 100 days yields a projected drawdown of 12.9m (42.3'). Using this value in a calculation of safe yield based on an allowable drawdown after 100 days equivalent to 70% of the available drawdown (Table I) results in a value of 28.4 L/s (450 USgpm).

A commonly accepted design concept is that water wells should be constructed with sufficient open area within the well screen so that during pumping the calculated entrance velocity will not exceed 0.1 feet per second (ft/second). The basis for this is that it is believed to maintain friction losses to a minimum, and to minimize potential for chemical encrustation and/or corrosion of the screens. The maximum capacity of the test well based on this limiting criteria (Table I) would be 15 L/s (241 USgpm). However, as the scientific basis for this 0.1 ft/second threshold is unclear, and it is judged that pumping the test well at rates up to 25 L/s (400 USgpm) is unlikely to result in any noticeable decrease in long-term well performance. Nevertheless, it is recommended that any new production wells should be designed to achieve a 0.1 ft/second screen entrance velocity.

REVIEW OF WATER QUALITY ANALYSIS

A summary of all available water quality analyses is provided in Table II, including two water quality samples taken in 2010 following well construction, and one during the filtration test in 2011. All analyte concentrations were found to be below Canadian Drinking Water Guideline maximum acceptable concentrations and aesthetic objectives, except for manganese, which ranged from 0.112 to 0.115 mg/L, versus the aesthetic objective of 0.05 mg/L. Sulphurous smells noted from water samples and the high total sulphur content suggests that dissolved sulphide (H_2S) may exceed aesthetic guidelines. Corix (2011) indicated that sulphide concentrations were elevated, but the average concentration of 0.023 mg/L does not exceed the 0.05 mg/L. The source of this analysis was not available at the time of this report. Olfactory indications of the presence of sulphide dissolved in the well water observed during drilling and filtration tests indicate the water is chemically reduced.

CONCLUSIONS AND RECOMMENDATIONS

Piteau has completed a review of available data from the Harrison Hot Springs test well program including a review of pump test and water quality data and offers the following conclusions:

1. The relatively high transmissivity and calculated sustainable yield indicate that the local aquifer below the test site will likely sustain a groundwater flow sufficient to meet a demand of 25 L/s (400 USgpm).
2. Preliminary water quality analyses of samples from the test well indicate most major element concentrations are below detectable limits or at concentrations well below the maximum allowable concentrations and aesthetic objectives outlined by the Canadian Drinking Water Quality Guidelines. Corix (2011) demonstrated that concentrations of those elements which exceed, or potentially exceed, the guidelines (manganese and sulphide, respectively) can be reduced to achieve levels below the water quality guidelines.
3. The test well is situated within a region utilized for residential and agricultural purposes, and is in close proximity to natural mineral springs. Groundwater quality analyses should therefore be expanded to include potential contaminants from these sources, which could include bacteria, nutrients (ammonia, nitrite, & nitrate), pesticides and herbicides, and radionuclides.
4. An analysis of the potential for groundwater to be under the direct influence of surface water should be undertaken before the groundwater is utilized for drinking water purposes. Providing that the well is more than 100m (330') from the nearest surface watercourse, and that there are no E.Coli or coliform bacteria present in the groundwater from the well, it is likely that a determination that the well is not under the direct influence of surface water can be made.

5. It is recommended that the capture zone(s) for all new supply wells should be estimated to enable definition of a wellhead protection zone, and development of an aquifer protection plan.
6. Due to the apparent heavy utilization of the aquifer illustrated by the density of reported groundwater wells in the aquifer (Fig. 1), and the anticipated stress this well will apply to the aquifer, an analysis of the potential for local well interference in the vicinity of the test well is advisable to ensure that the abilities of other wells in the vicinity are not affected.

LIMITATIONS

This letter of opinion has been prepared using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in B.C. No warranty is expressed or implied.

This letter of opinion is prepared for the sole use of Civic Consultants Ltd. and their client, the Village of Harrison Hot Springs. Any use, interpretation, or reliance on this information by any third party, is at the sole risk of that party, and Piteau accepts no liability for such unauthorized use.

CLOSURE

We trust these comments are sufficient for your present needs. Please contact the either of the undersigned if you require further assistance.

Yours truly,

PITEAU ASSOCIATES ENGINEERING LTD.

M. L. STEWART
#31068
02/09/11

Martin L. Stewart, P.Geo.
Hydrogeologist

D. J. TIPLADY
#16053
Sept 1 2011

David J. Tiplady, P.Eng.
Principal Hydrogeologist
Vice President – Groundwater

MLS/DJT/slc
Att.

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Cooper, H.H. and Jacob, C.E., 1946. A generalized graphical method for evaluating formation constants and summarizing well field history. In American Geophysical Union transactions, V. 27, pp526-534.

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TABLES

TABLE I
TEST WELL YIELD CALCULATION

LEVELS AND RATES	UNIT	TEST WELL
CASING ELEVATION (ESTIMATE)	m-geod	10.97
STATIC WATER DEPTH [1]	m-bgl	4.27
STATIC WATER ELEVATION [2]	m-geod	6.71
ESTIMATED INTERFERENCE FROM OTHER WELLS [2]	m	
ALLOWANCE FOR SEASONAL WATER LEVEL REDUCTION	m	2.00
ESTIMATED MINIMUM STATIC DEPTH [3]	m-bgl	6.27
DEPTH TO TOP OF WELL SCREEN	m-bgl	26.77
DEPTH TO PUMP INTAKE [4]	m-bgl	24.77
RECOMMENDED LOWEST PUMPING DEPTH [5]	m-bgl	22.77
AVAILABLE DRAWDOWN [6]	m	20.50
FACTOR OF SAFETY	m	0.30
MAXIMUM ALLOWABLE DRAWDOWN [7]	m	14.35
PUMP TEST LENGTH	min	1180
FINAL WATER DEPTH	m	13.87
DRAWDOWN AT END OF TEST	m	9.60
PROJECTED 100-DAY DRAWDOWN	m	12.90
PROJECTED 100-DAY SPECIFIC CAPACITY [8]	L/s/m	1.98
TEST PUMPING RATE	L/s	25.5
	m^3/day	2202
	USGPM	404
	IGPM	337
CALCULATED LINEAR YIELD [9]	L/s	28.36
ESTIMATED SUSTAINABLE SAFE YIELD [10]	L/s	>25.5
	m^3/day	>2203
	USGPM	>404
	IGPM	>337
SCREEN LENGTH	m	4.9
OPEN AREA	cm^2 / m	1016
TOTAL AREA	m^2	0.5
MAXIMUM SCREEN CAPACITY [11]	L/s	15
	m^3/day	1311
	USGPM	241
	IGPM	200

H:\Project\3127\2011\[Safe well yield Mar2010 production well-v2.xls]Well yield

1 Static water elevation at time of test.
2 No known well interference
3 Estimated minimum static depth is taken as measured static depth
4 Assumes pump intake is 2m above the base of lowest screen (i.e., motor 1m above bottom of screen and motor 1m in length).
5 Calculated as 2m above the pump intake
6 Difference between recommended lowest pumping level and estimated static elevation.
7 Allowable drawdown equals available times(1-factor of safety). No factor of safety used for dewatering design.
8 Specific capacity is pump test rate divided by drawdown at end of pump test.
9 Calculated linear yield is the allowable drawdown times the 100-day specific capacity.
10 Estimated sustainable yield is the calculated linear yield where this is less than the test pumping rate. For linear yields greater than the pump test flow rate, the sustainable yield may be nonlinear and therefore the pump test rate provides a minimum guideline sustainable safe yield.
11 Maximum screen capacity is calculated as screen opening area times recommended maximum entrance velocity of 0.1 ft/s.

TABLE II
WATER QUALITY ANALYSES 2010/2011 AND DRINKING WATER GUIDELINES

Sample ID Date Sampled	UNITS	WELL SAMPLE #1[1] 14-APR-10	WELL SAMPLE #2[1] 14-APR-10	SAMPLE AJ2988[2] 27-Apr-11	CDWQ[3] GUIDELINES MAC	CDWQ[4] GUIDELINES AO
Physical Tests						
Hardness[5] (as CaCO3)	mg/L	127	126		see below	see below
Total Metals						
Aluminum (Al)-Total	mg/L	<0.010	<0.010	<0.003		0.1
Antimony (Sb)-Total	mg/L	<0.00050	<0.00050	<0.0005	0.006	
Arsenic (As)-Total	mg/L	0.00453	0.00446	0.00570	0.01	
Barium (Ba)-Total	mg/L	0.033	0.032	0.036	1	
Boron (B)-Total	mg/L	<0.10	<0.10	<0.05	5	
Cadmium (Cd)-Total	mg/L	<0.00020	<0.00020	<0.0001	0.005	
Calcium (Ca)-Total	mg/L	36.9	36.7	39.1		
Chromium (Cr)-Total	mg/L	<0.0020	<0.0020	<0.001	0.05	
Copper (Cu)-Total	mg/L	<0.0010	0.0019	<0.0002		1
Iron (Fe)-Total	mg/L	0.062	0.103	0.076		0.3
Lead (Pb)-Total	mg/L	<0.00050	<0.00050	<0.0002	0.01	
Magnesium (Mg)-Total	mg/L	8.40	8.35	8.98		
Manganese (Mn)-Total	mg/L	**0.112**	**0.115**	**0.115**		0.05
Mercury (Hg)-Total	mg/L	<0.00020	<0.00020	<0.00005	0.001	
Molybdenum (Mo)-Total	mg/L			0.001		
Nickel (Ni)-Total	mg/L			0.001		
Potassium (K)-Total	mg/L	1.90	1.89	2.15		
Selenium (Se)-Total	mg/L	<0.0010	<0.0010	<0.0001	0.01	
Silver (Ag)-Total	mg/L			<0.00002		
Sodium (Na)-Total	mg/L	2.9	2.9	3.1		200
Sulfur (S)-Total[6]	mg/L	**0.97**	**0.96**	<3		
Uranium (U)-Total	mg/L	<0.00010	<0.00010	<0.0001	0.02	
Vanadium (U)-Total	mg/L			<0.005		
Zinc (Zn)-Total	mg/L	<0.050	<0.050	<0.005		5

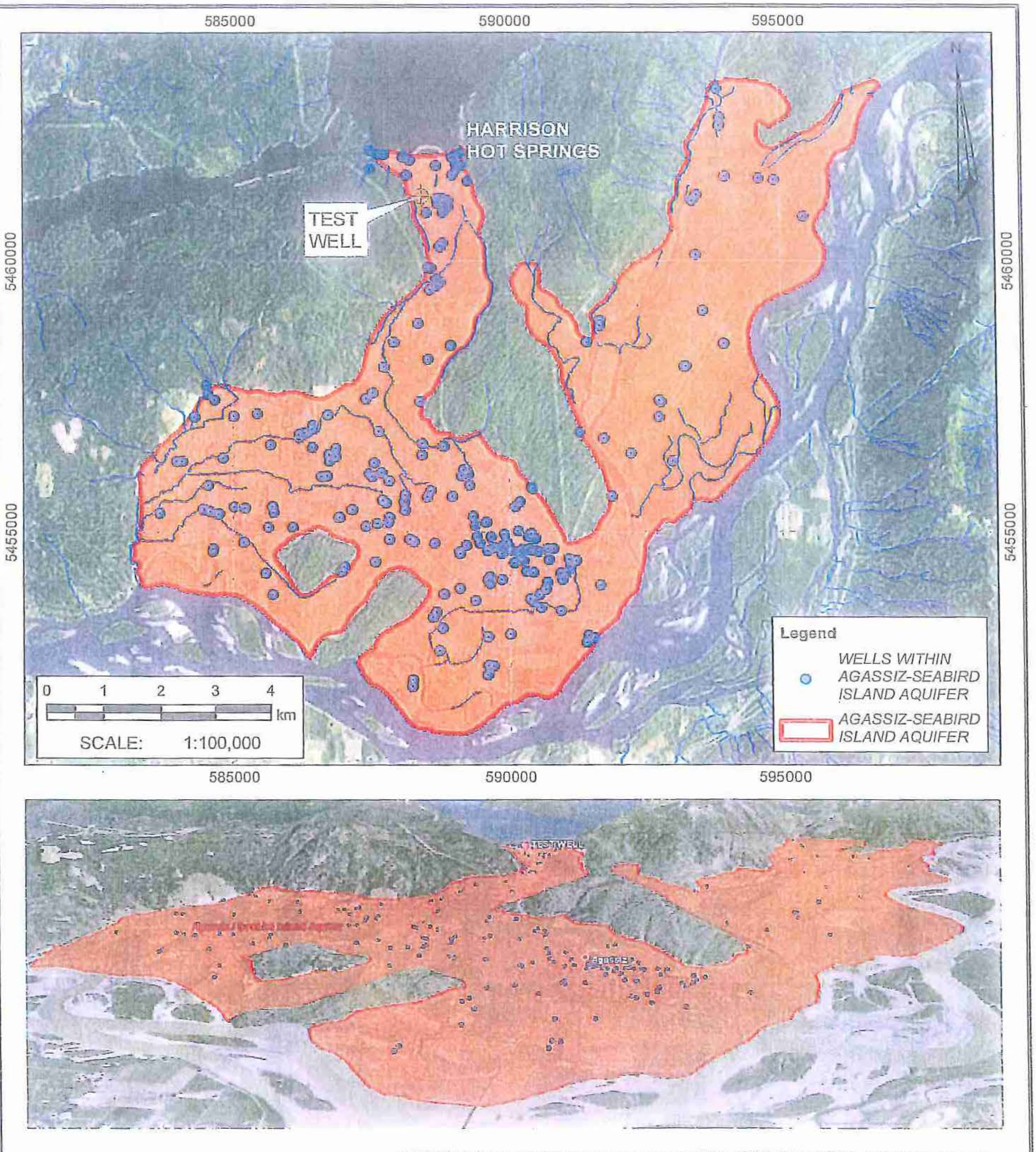
H:\Project\3127\2011\[Water Quality Summary 30Aug11.xlsx]Results of Analysis

Notes:

1. Sample results from April 14, 2010 following well construction
2. Sample results from Corix (2011) pilot study
3. Canadian Drinking Water Quality Guidelines - Maximum acceptable concentrations (GCDWQ, 2010)
4. Canadian Drinking Water Quality Guidelines - Aesthetic objectives (GCDWQ, 2010)
5. "Generally, hardness levels between 80 and 100 mg/L (as CaCO3) are considered acceptable; levels greater than 200 mg/L are considered poor but can be tolerated; those in excess of 500 mg/L are normally considered unacceptable." (GCDWQ, 2010)
6. Canadian Drinking Water Quality Guidelines - Aesthetic objective for sulphide (H_2S) is 0.05 mg/L (GCDWQ, 2010)

FIGURES

H:\Project\3127\2011\ArcGIS\Arcmaps\Aug2011 review Figrue 1.mxd



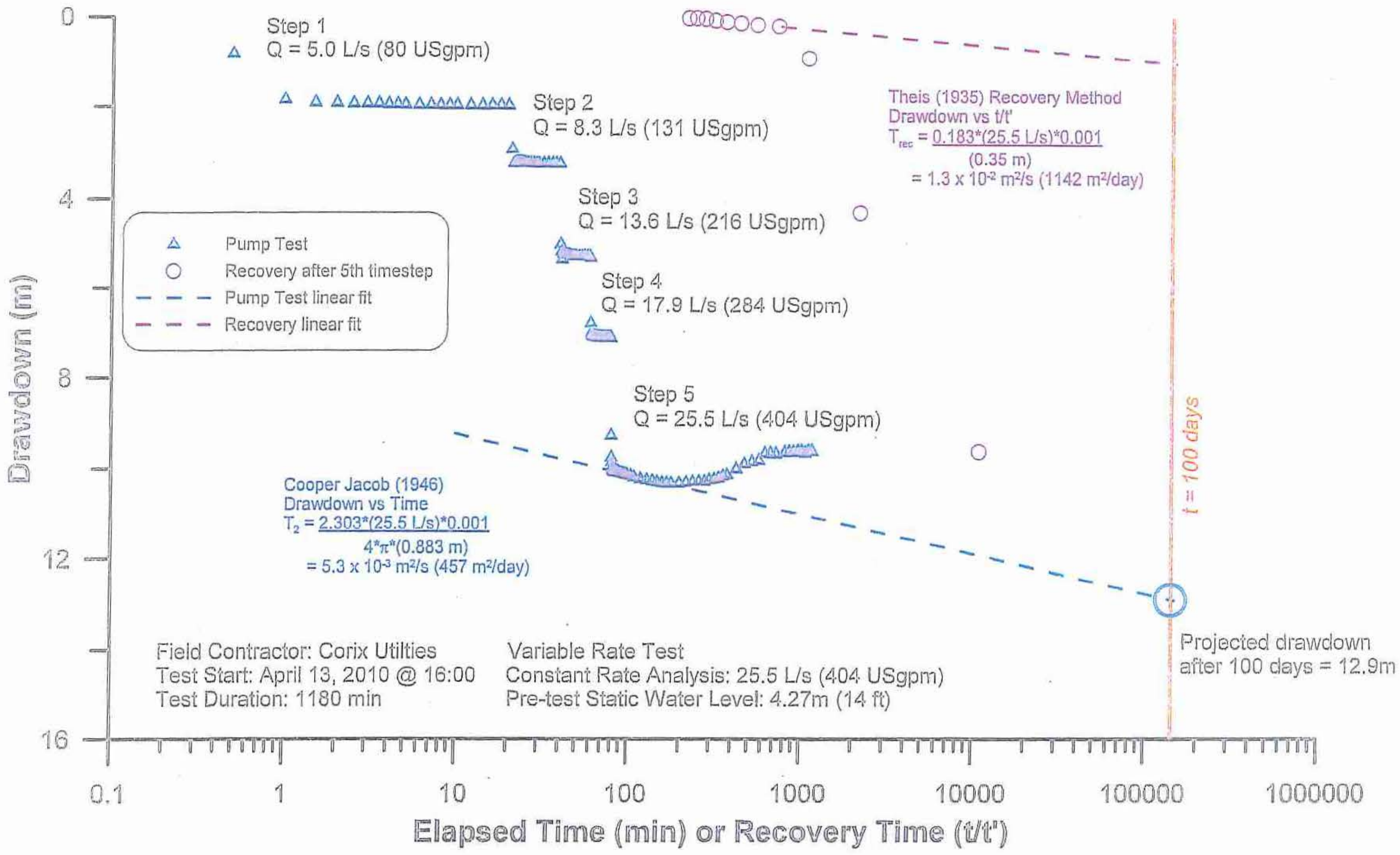
VILLAGE OF HARRISON HOT SPRINGS
WELL WATER PILOT STUDY REVIEW

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

PLAN MAP AND OBLIQUE AERIAL VIEW OF HARRISON HOT SPRINGS
AND THE AGASSIZ -SEABIRD ISLAND AQUIFER

BY: MLS	DATE: AUG 11
APPROVED: DJT	FIG: 1

H:\Project\3127\2011\Test Well Pumping rate Test.grf



Theis (1935) Recovery Method
Drawdown vs t/t'

$$T_{rec} = \frac{0.183 * (25.5\ L/s) * 0.001}{(0.35\ m)} = 1.3 \times 10^{-2}\ m^2/s\ (1142\ m^2/day)$$

Cooper Jacob (1946)
Drawdown vs Time

$$T_2 = \frac{2.303 * (25.5\ L/s) * 0.001}{4 * \pi * (0.883\ m)} = 5.3 \times 10^{-3}\ m^2/s\ (457\ m^2/day)$$

Field Contractor: Corix Utilties
Test Start: April 13, 2010 @ 16:00
Test Duration: 1180 min

Variable Rate Test
Constant Rate Analysis: 25.5 L/s (404 USgpm)
Pre-test Static Water Level: 4.27m (14 ft)

Cooper and Jacob (1946)

$$T = \frac{2.303 * Q * 0.001}{4 * \pi * \Delta s}$$

Theis (1935)

$$T = \frac{0.183 * Q * 0.001}{\Delta(s-s')}$$

CIVIC CONSULTANTS LTD
VILLAGE OF HARRISON HOT SPRINGS

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

SEMI-LOG PLOT OF WATER LEVELS IN HARRISON HOT SPRINGS TEST WELL; VARIABLE RATE PUMP TEST RESULTS AND CALCULATED TRANSMISSIVITY

BY: MLS	DATE: AUG 11
APPROVED: DJT	FIG: 2

APPENDIX A

A & H DRILLING WELL RECORD

A & H Drilling Ltd.

WELL RECORD

48987 CHILLIWACK CENTRAL ROAD CHILLIWACK, BC V2P 6H5
TEL: (604)794-5544 CELL: (604)864-1919 FAX: (604)794-5545
TOLL FREE: 1(877)794-5544

C\O:	CIVIC CONSULTANTS
OWNER:	CITY OF HARRISON
ADDRESS:	410-3TH STREET
CITY:	NEW WESTMINSTER, BC V3L 2S2
PHONE:	

DATE:	MARCH 31 2010	INVOICE:	2825
SITE ADDRESS:	495 HOT SPRINGS ROAD		
CITY:	HARRISON HOT SPRINGS		
NAD: 83	ZONE: 10	UTM EASTING:	588455
ELEVATION:	36 FEET	UTM NORTHING:	5461207
ACCURACY:	59 FEET	WELL ID PLATE #	29881

CONSTRUCTION X

CLOSURE : ______ ALTERATION: ______

FROM	TO	WELL LOG INFORMATION
0	4	SAND GRAVEL/FILL
4	10	CLAY GRAVEL WITH WOOD
10	17	SILTY SAND
17	30	SAND GRAVEL
30	35	MEDIUM SAND/SOME GRAVEL
35	45	MEDIUM SAND/WOOD MIXED
45	80	FINE SAND W.B.
80	85	FINE TO MEDIUM SAND
85	110	MEDIUM TO COARSE SAND SOME GRAVEL SMALL
110	135	FINE SAND

START DATE:	MARCH 29 2010		
COMPLETION:	MARCH 30 2010		
RIG NO: 5		TYPE:	DUAL ROTARY
DRILLER:	JOHN McDONALD		WD#04110301
HELPER:	BILL CLARKE		
CASING SIZE:	8	INCH	
SURFACE CASING:	12	INCH	
SURFACE CASING DEPTH	15	FEET	
CASING SHOE:	8	INCH	

HOLE DEPTH:	104	FEET		INCHES
CASING BOTTOM:	89	FEET		INCHES
STICK UP:	2	FEET	6	INCHES
OPEN HOLE FROM:		FEET	TO:	FEET

SCREENS

NO. OF SCREENS:	THREE				
SLOT:	20	SLOT:	20	SLOT:	20
SLOT:		SLOT:		SLOT:	
SCREEN LENGTH:	16	FEET		2	INCHES
TOP AT:	87	FEET		10	INCHES
BOTTOM AT:	104	FEET			INCHES
K PACKER:	YES	BAIL BOTTOM:			YES
RISER:	NO	TAIL PIPE:			NO

IRON CONTENT: APPROX 0.5 P.P.M.

REMARKS: PULLED BACK TO 104 FEET

WELL SHOULD BE PUMP TESTED

SET 15 FEET OF 12 INCH SURFACE CASING AND BENTONITE SEAL

WELL PRODUCING

APPROXIMATE FLOW RATE :	300	GPM
APPROXIMATE STATIC H20 :	11	FEET
SET SCREEN & DEVELOP:	5.5	HOURS
RECOMMENDED PUMP SETTING:	80	FEET

APPENDIX B

CORIX UTILITIES WELL TEST REPORT

Corix™

Water Systems

Harrison Hot Springs Pilot Study
April 2011

Objective of the study

To determine if removal of unacceptable levels of Manganese and Hydrogen Sulphide from a well water source is possible using Greensand filter media at a pumped flow rate equivalent to what would be required to service the community's treated water needs.

Provide raw water analysis of the parameters required in the Canadian Drinking Water Guidelines (CDWG).

Description of water source

Harrison Hot Springs well head behind the fire hall. The well was drilled and tested for draw down characteristics in April, 2010 by Corix Utilities.

Source water testing parameters

Source flow rates for testing: 10 and 400 GPM
Time line: 3 days of testing with 2 samples taken per day.
The first 2 days at low flow, 3rd day at high flow

Filtering parameters

Filter Media used: 610 mm (24") of Greensand plus, 505 mm (12") of anthracite
The Pilot Plant flow rate for the testing: 1 Litre/min. (0.264 gal/min.)
Surface area of the filter: 12.57 sq.in. (0.087 sq.ft.)
Surface loading: 3.03 GPM/ sq.ft.

Batch regeneration of the media was accomplished using Potassium Permanganate powder. See the "Testing Methods" section at the end of the document for details.

Analysis

Analysis of the water samples was by Maxxam Analytical, Burnaby BC.

Results of lab analysis

A summary of the comparison of the Guidelines for Canadian Drinking Water Quality to the Maxxam lab results is as follows.

General Drinking Water Parameter Test:

All raw water measured parameters were below regulated and aesthetic limits except for Manganese.

Manganese Tests

GCDWQ aesthetic objective:	<0.05 mg/l
Raw water average:	0.12 mg/l
Treated water average	0.008 mg/l
Average removal efficiency	93%

Sulphide Tests
GCDWQ aesthetic objective: <0.05 mg/l
Raw water average: 0.023 mg/l 400 gpm value 0.027 mg/l
Treated water average 0.007 mg/l
Average removal efficiency 70%

The results indicate that all measured treated water parameters were within GCDWQ by a safe margin. This result is indicative that the manganese green sand filter system would safely and economically meet VHHS's potable water objectives.

The pilot test operator also indicated that the water taste quality was good with only very faint odours before treatment and no odours following treatment.

Please see the test results below.

Pictures of the pilot equipment and site are included on the last page

Please note that the Mn and H2SO4 test results for the first day's tests are included as part of the CDWG spreadsheets.

A complete copy of the Maxxam Analytical analysis documents is available from Corix Water Systems on request.

<u>Sample results</u>
Day 1 - 10 GPM well flow rate.
One Raw Water sample taken at the same time as the first filtered (Filtered 1) sample.
Raw Water sample taken for CDWG analysis.

Maxxam

Maxxam Job #: B131477
Report Date: 2011/04/27

Corix Water Systems Inc.

RESULTS OF CHEMICAL ANALYSES OF WATER

Maxxam ID		AJ2988	AJ2989	AJ3007	AJ3008		
Sampling Date		2011/04/19 12:15	2011/04/19 12:15	2011/04/19 12:15	2011/04/19 15:00		
COC#		G033607	G033607	G033607	G033607		
	Units	1L - CDWG, 240ML MICROBIOLOGY, 120ML METAL	120ML - RW MN/SULPHIDE	120ML - FILTERED 1 MN/SULPHIDE	120ML - FILTERED 2 MN/SULPHIDE	RDL	QC Batch
ANIONS							
Nitrite (N)	mg/L	<0.005				0.005	4804541
Calculated Parameters							
Filter and HNO3 Preservation	N/A		FIELD	FIELD	FIELD	N/A	ONSITE
Total Hardness (CaCO3)	mg/L	135				0.5	4800415
Nitrate (N)	mg/L	<0.02				0.02	4800334
Misc. Inorganics							
Fluoride (F)	mg/L	0.07				0.01	4810203
Alkalinity (Total as CaCO3)	mg/L	140				0.5	4801188
Alkalinity (PP as CaCO3)	mg/L	<0.5				0.5	4801188
Bicarbonate (HCO3)	mg/L	170				0.5	4801188
Carbonate (CO3)	mg/L	<0.5				0.5	4801188
Hydroxide (OH)	mg/L	<0.5				0.5	4801188
Anions							
Dissolved Sulphate (SO4)	mg/L	1.9				0.5	4804488
Dissolved Chloride (Cl)	mg/L	3.5				0.5	4804485
MISCELLANEOUS							
True Colour	Col. Unit	<5				5	4802659
Sulphide	mg/L		0.017	0.007	<0.005	0.005	4802907
Nutrients							
Nitrate plus Nitrite (N)	mg/L	<0.02				0.02	4804492
Physical Properties							
Conductivity	uS/cm	272				1	4801186
pH	pH Units	8.10					4801179
Physical Properties							
Total Dissolved Solids	mg/L	170				10	4809605
Turbidity	NTU	0.2				0.1	4802366

N/A = Not Applicable
RDL = Reportable Detection Limit

Maxxam Job #: B131477
Report Date: 2011/04/27

Corix Water Systems Inc.

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

Maxxam ID		AJ2988	AJ2989	AJ3007	AJ3008		
Sampling Date		2011/04/19 12:15	2011/04/19 12:15	2011/04/19 12:15	2011/04/19 15:00		
COC#		G033607	G033607	G033607	G033607		
	Units	1L - CDWG, 240ML MICROBIOLOGY, 120ML METAL	120ML - RW MN/SULPHIDE	120ML - FILTERED 1 MN/SULPHIDE	120ML - FILTERED 2 MN/SULPHIDE	RDL	QC Batch
Dissolved Metals by ICPMS							
Dissolved Manganese (Mn)	ug/L		111	5	2	1	4801840
Total Metals by ICPMS							
Total Aluminum (Al)	ug/L	<3				3	4806525
Total Antimony (Sb)	ug/L	<0.5				0.5	4806525
Total Arsenic (As)	ug/L	5.7				0.1	4806525
Total Barium (Ba)	ug/L	36				1	4806525
Total Boron (B)	ug/L	<50				50	4806525
Total Cadmium (Cd)	ug/L	<0.01				0.01	4806525
Total Chromium (Cr)	ug/L	<1				1	4806525
Total Cobalt (Co)	ug/L	<0.5				0.5	4806525
Total Copper (Cu)	ug/L	<0.2				0.2	4806525
Total Iron (Fe)	ug/L	70				5	4806525
Total Lead (Pb)	ug/L	<0.2				0.2	4806525
Total Manganese (Mn)	ug/L	115				1	4806525
Total Mercury (Hg)	ug/L	<0.05				0.05	4806525
Total Molybdenum (Mo)	ug/L	1				1	4806525
Total Nickel (Ni)	ug/L	<1				1	4806525
Total Selenium (Se)	ug/L	<0.1				0.1	4806525
Total Silver (Ag)	ug/L	<0.02				0.02	4806525
Total Uranium (U)	ug/L	<0.1				0.1	4806525
Total Vanadium (V)	ug/L	<5				5	4806525
Total Zinc (Zn)	ug/L	<5				5	4806525
Total Calcium (Ca)	mg/L	39.1				0.05	4801203
Total Magnesium (Mg)	mg/L	6.98				0.05	4801203
Total Potassium (K)	mg/L	2.15				0.05	4801203
Total Sodium (Na)	mg/L	3.11				0.05	4801203
Total Sulphur (S)	mg/L	<3				3	4801203

RDL = Reportable Detection Limit

Corix Water Systems Inc.

Maxxam Job #: B131477
Report Date: 2011/04/27

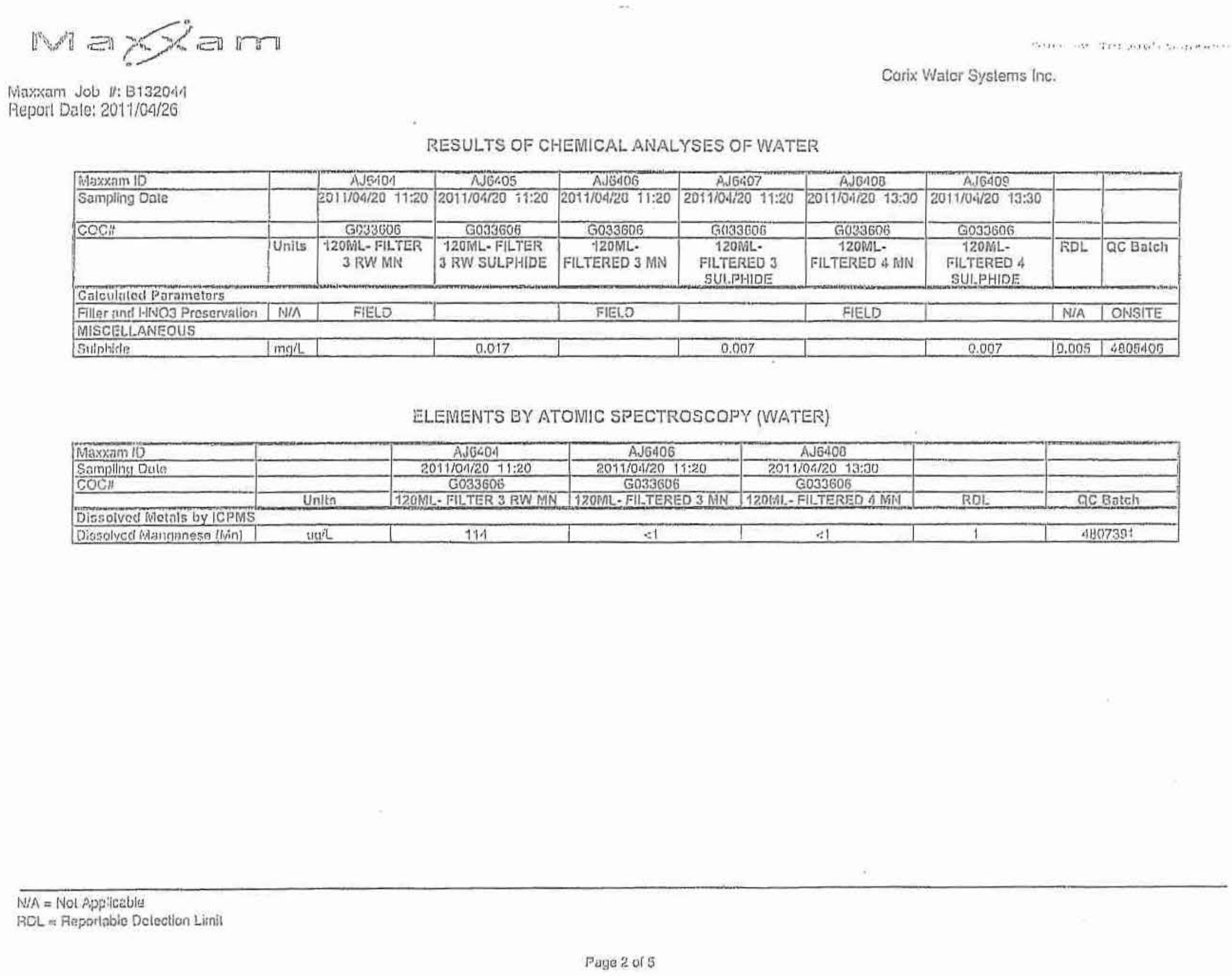
ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

Maxxam ID		AJ2988	AJ2989	AJ3007	AJ3008		
Sampling Date		2011/04/19 12:15	2011/04/19 12:15	2011/04/19 12:15	2011/04/19 15:00		
COC#		G033607	G033607	G033607	G033607		
	Units	1L - CDWG, 240ML MICROBIOLOGY, 120ML METAL	120ML - RW MN/SULPHIDE	120ML - FILTERED 1 MN/SULPHIDE	120ML - FILTERED 2 MN/SULPHIDE	RDL	QC Batch
Dissolved Metals by ICPMS							
Dissolved Manganese (Mn)	ug/L		111	5	2	1	4801840
Total Metals by ICPMS							
Total Aluminum (Al)	ug/L	<3				3	4806525
Total Antimony (Sb)	ug/L	<0.5				0.5	4806525
Total Arsenic (As)	ug/L	5.7				0.1	4806525
Total Barium (Ba)	ug/L	36				1	4806525
Total Boron (B)	ug/L	<50				50	4806525
Total Cadmium (Cd)	ug/L	<0.01				0.01	4806525
Total Chromium (Cr)	ug/L	<1				1	4806525
Total Cobalt (Co)	ug/L	<0.5				0.5	4806525
Total Copper (Cu)	ug/L	<0.2				0.2	4806525
Total Iron (Fe)	ug/L	76				5	4806525
Total Lead (Pb)	ug/L	<0.2				0.2	4806525
Total Manganese (Mn)	ug/L	115				1	4806525
Total Mercury (Hg)	ug/L	<0.05				0.05	4806525
Total Molybdenum (Mo)	ug/L	1				1	4806525
Total Nickel (Ni)	ug/L	<1				1	4806525
Total Selenium (Se)	ug/L	<0.1				0.1	4806525
Total Silver (Ag)	ug/L	<0.02				0.02	4806525
Total Uranium (U)	ug/L	<0.1				0.1	4806525
Total Vanadium (V)	ug/L	<5				5	4806525
Total Zinc (Zn)	ug/L	<5				5	4806525
Total Calcium (Ca)	mg/L	39.1				0.05	4801203
Total Magnesium (Mg)	mg/L	8.98				0.05	4801203
Total Potassium (K)	mg/L	2.15				0.05	4801203
Total Sodium (Na)	mg/L	3.11				0.05	4801203
Total Sulphur (S)	mg/L	<3				3	4801203

RDL = Reportable Detection Limit

Sample results

Day 2 - 10 GPM well flow rate.
One Raw Water sample taken at the same time as the first filtered (Filtered 3) sample



Maxxam Job #: B132044
Report Date: 2011/04/26

Corix Water Systems Inc.

RESULTS OF CHEMICAL ANALYSES OF WATER

Maxxam ID		AJ6404	AJ6405	AJ6406	AJ6407	AJ6408	AJ6409		
Sampling Date		2011/04/20 11:20	2011/04/20 11:20	2011/04/20 11:20	2011/04/20 11:20	2011/04/20 13:30	2011/04/20 13:30		
COC#		G033606	G033606	G033606	G033606	G033606	G033606		
	Units	120ML- FILTER 3 RW MN	120ML- FILTER 3 RW SULPHIDE	120ML- FILTERED 3 MN	120ML- FILTERED 3 SULPHIDE	120ML- FILTERED 4 MN	120ML- FILTERED 4 SULPHIDE	RDL	QC Batch
Calculated Parameters									
Filter and HNO3 Preservation	N/A	FIELD		FIELD		FIELD		N/A	ONSITE
MISCELLANEOUS									
Sulphide	mg/L		0.017		0.007		0.007	0.005	4805406

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

Maxxam ID		AJ6404	AJ6406	AJ6408		
Sampling Date		2011/04/20 11:20	2011/04/20 11:20	2011/04/20 13:30		
COC#		G033606	G033606	G033606		
	Units	120ML- FILTER 3 RW MN	120ML- FILTERED 3 MN	120ML- FILTERED 4 MN	RDL	QC Batch
Dissolved Metals by ICPMS						
Dissolved Manganese (Mn)	ug/L	114	<1	<1	1	4807391

N/A = Not Applicable
RDL = Reportable Detection Limit

Sample results
Day 3 - 400 GPM well flow rate.

Maxxam

Maxxam Job #: B132081
Report Date: 2011/04/28

Corix Water Systems Inc.
Client Project #: HARRISON WELL TEST
Site Reference: HARRISON HOT SPRINGS

RESULTS OF CHEMICAL ANALYSES OF WATER

Maxxam ID		AJ6663	AJ6664	AJ6665	AJ6666		
Sampling Date		2011/04/21 10:00	2011/04/21 10:00	2011/04/21 12:00	2011/04/21 12:00		
COC#		G033608	G033608	G033608	G033608		
	Units	FILTER 5 RW MN/SULPHIDE	FILTERED 5 MN/SULPHIDE	FILTERED 6 RW MN/SULPHIDE	FILTERED 6 MN/SULPHIDE	RDL	QC Batch
Calculated Parameters							
Filter and HNO3 Preservation	N/A	FIELD	FIELD	FIELD	FIELD	N/A	ONSITE
MISCELLANEOUS							
Sulphide	mg/L	0.024	0.007	0.027	0.007	0.005	4813393

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

Maxxam ID		AJ6663	AJ6664	AJ6665	AJ6666		
Sampling Date		2011/04/21 10:00	2011/04/21 10:00	2011/04/21 12:00	2011/04/21 12:00		
COC#		G033608	G033608	G033608	G033608		
	Units	FILTER 5 RW MN/SULPHIDE	FILTERED 5 MN/SULPHIDE	FILTERED 6 RW MN/SULPHIDE	FILTERED 6 MN/SULPHIDE	RDL	QC Batch
Dissolved Metals by ICPMS							
Dissolved Manganese (Mn)	ug/L	126	22	124	10	1	4809118

N/A = Not Applicable
RDL = Reportable Detection Limit

One Raw Water sample was taken at the same time as each of the filtered samples (Filtered 5 & 6). This provides a direct comparison for the flow over time.

Testing method, details and notes

Monday, April 18th

I traveled to Harrison Hot Springs on the morning of April 18th. The pilot equipment was picked up from our yard by Corix Utilities and arrived at site shortly afterward. It was placed (and operated) outside near the well head at the back of the fire hall.

Corix Utilities installed a 10 GPM pump for the first set of tests. Power for the pump was provided from the distribution panel in the fire hall via our connection box. The first day was spent setting up the equipment and making the connections for power for the filter skid and 10 GPM pump. After set-up was completed the plant was run overnight.

Tuesday, April 19th

The plant ran all night without incident and the clearwell was full to allow for backwashing. The filter media was soaked in a 0.5% KMNO4 solution for about an hour then backwashed until clear. The plant was put back on line and run continuously for the 2 days of testing at the 10 GPM flow rate.

Samples were taken as follows:

CDWG	12:15
Raw water - Mn	12:15
Raw water - Sulphide	12:15
Filtered water - Mn	12:15
Filtered water - Sulphide	12:15
Filtered water - Mn	15:00
Filtered water - Sulphide	15:00

The samples were delivered to UPS depot in Chilliwack for overnight shipping to Maxxam Analytical.

Wednesday, April 20th

Samples were taken as follows:

Pilot plant had run all night without incident.

Raw water - Mn	11:20
Raw water - Sulphide	11:20
Filtered water - Mn	11:20
Filtered water - Sulphide	11:20
Filtered water - Mn	13:30
Filtered water - Sulphide	13:30

The samples were delivered to UPS depot in Chilliwack for overnight shipping to Maxxam Analytical.

After the last samples were taken at 13:30 the Corix Utilities crew arrived with the 40 GPM pump and portable generator. The 10 GPM pump was removed and the 400 GPM pump installed and tested. The media was backwashed and soaked overnight in a 0.5% KMNO4 solution.

Thursday, April 21st

The media was backwashed until clear then the generator and 400 GPM pump were started (8:30). The plant was run until about 13:00 and samples taken as follows:

Raw water - Mn	10:00
Raw water - Sulphide	10:00
Filtered water - Mn	10:00
Filtered water - Sulphide	10:00
Raw water - Mn	12:00
Raw water - Sulphide	12:00
Filtered water - Mn	12:00
Filtered water - Sulphide	12:00

The samples were delivered to UPS depot in Chilliwack for overnight shipping to Maxxam Analytical.

The water level in the well was measured when the Utilities crew arrived to remove the pump. Water level before starting the pump was approx 14' below the well casing. After 5 hours of pumping at 400 GPM the water level was 42.2 ' below the well casing.

Two raw water samples were taken to determine how pumping at the high flow rate will affect the amount of Mn and Sulphide in the water over time.

At 13:00 the pump and generator were stopped and the equipment disconnected, packed up and loaded on the Utilities truck for shipping.
The last set of samples were hand delivered to Maxxam Analytical in Burnaby at 16:00, as there was no delivery service available from Chilliwack due to the Easter Friday holiday.

Note

It was mentioned by Dave Harris that there was a strong Sulfur odor during the initial 400GPM draw down test when the well was bored in April of 2010. This was not the case during this testing. Although there was some odor present it was not overpowering. No odor or taste of Sulfur could be detected from the filtered water in the clearwell.

Report compiled by:
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2011/4/29


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October 2003

Turbidity

Guideline

Waterworks systems that use a surface water source or a groundwater source under the direct influence of surface water should filter the source water to meet the following health-based turbidity limits, as defined for specific treatment technologies. Where possible, filtration systems should be designed and operated to reduce turbidity levels as low as possible, with a treated water turbidity target of less than 0.1 NTU at all times. Where this is not achievable, the treated water turbidity levels from individual filters shall be:

1. *For* ***chemically-assisted filtration,*** *less than or equal to* ***0.3 NTU*** *in at least 95% of the measurements made, or at least 95% of the time each calendar month and not exceed 1.0 NTU at any time.*
2. *For* ***slow sand or diatomaceous earth filtration,*** *less than or equal to* ***1.0 NTU*** *in at least 95% of the measurements made, or at least 95% of the time each calendar month and not exceed 3.0 NTU at any time.*
3. *For* ***membrane filtration,*** *less than or equal to* ***0.1 NTU*** *in at least 99% of the measurements made, or at least 99% of the time each calendar month and not exceed 0.3 NTU at any time. If membrane filtration is the sole treatment technology employed, some form of virus inactivation*[†] *should follow the filtration process.*

It is not expected that all water supplies will be able to meet this revised turbidity guideline immediately. Therefore, suplimentary treatment should be considered in the interim to ensure delievery of a safe drinking water.

Executive Summary

Particles of matter are naturally suspended in water. These particles can be clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms. Turbidity is a measurement of how light scatters when it is aimed at water and bounces off the suspended particles. It is not a measurement of the particles themselves. In general terms, the cloudier the water, the more the light scatters and the higher the turbidity.

The best means of reducing turbidity and safeguarding a drinking water supply is to apply a multiple-barrier approach (i.e., source to tap) to protect drinking water. The focus of this approach is to look at the entire drinking water supply, identify potential and existing hazards and then develop strategies to deal with each of the hazards.

Treatment plants can reduce turbidity by filtering particles out of the water. All filtration systems should be designed and operated to reduce turbidity levels as low as possible. The treated water turbidity target is 0.1 NTU at all times. However, even though effective filtration can be accomplished using any one of a number of technologies, the actual levels of turbidity

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[†] Some form of virus inactivation is required for all technologies. The difference is that chemically-assisted, slow sand and diatomaceous earth filters are credited with log virus reductions and membrane filters receive no credit.

achieved will vary from technology to technology. For this reason, the turbidity guideline is broken down by type of technology.

The most important consideration when dealing with turbidity is to make sure the levels remain low and fairly constant over time. Concerns are most likely to result from a spike in the level of turbidity, due either to an increase in the amount of particulate matter in the source water (e.g., from heavy rains) or to a breakdown in the treatment process (e.g., inadequate coagulation, a ruptured filter). Because it might otherwise be difficult to notice a spike in turbidity when only one filter in a plant is not be working properly, the guideline applies to each individual filter within a filtration system.

Health considerations

It is important to control turbidity in public water supplies for both health and aesthetic reasons. Suspended matter can contain toxins such as heavy metals and biocides and can also harbour microorganisms, protecting them from disinfection. Recent research has correlated turbidity levels with treated water supplies being contaminated with *Giardia* and *Cryptosporidium.* These microorganisms can cause outbreaks of illness. As such, turbidity may be used as a health parameter to indicate the safety of water leaving a filtration system. Because turbidity can affect the microbiological quality of drinking water, this guideline should be read in conjunction with the bacteriological guidelines. Excessive turbidity may also be associated with unpleasant tastes and odours.

In addition, high turbidity can lead to an increase in the amount of disinfection by-products that form in treated water. Trihalomethanes (THMs), for instance, are a group of chemical compounds that form when chlorine reacts with organic material in water. By filtering out the organic matter to reduce turbidity, treatment plants also reduce the amount of THMs that may form in the water. For more information on these disinfection by-products, see the THMs guideline and supporting document.

The nature of turbidity and its health implications vary with the type of source water. Turbidity in surface water and groundwater that comes into contact with surface water (referred to as groundwater under the direct influence of surface water), however, is generally organic in nature and may contain toxins, harbour pathogens, or lead to the formation of THMs. Turbidity in secure groundwater supplies (i.e., not under the influence of surface water) is generally non-organic and should pose no health threat. The health-based guideline and target for turbidity therefore only apply to surface water sources and groundwater under its influence.

Analytical and Treatment Considerations

Turbidity is easy and inexpensive to measure. In addition to being a indicator for determining the relative safety of drinking water, it is a useful tool for assessing the performance of water treatment processes.

Turbidity is measured in nephelometric turbidity units, or NTU, using a device called a turbidimeter. Modern turbidimeters can make measurements of 0.1 NTU or lower. Levels of turbidity in raw waters can range from 1.0 NTU to more than 1000.0 NTU. Levels vary at individual locations over time.

A number of studies indicate that properly designed and well-operated conventional, chemically-assisted and direct filtration water treatment plants can readily achieve a safe finished water with turbidity levels lower than 0.2 NTU. Meeting the guideline level of 0.3 NTU for these systems should be straightforward. Slow sand and diatomaceous earth filtration plants can consistently achieve a safe finished water turbidity levels of less than 1.0 NTU. Membrane filtration plants can consistently achieve finished water turbidity of less than 0.1 NTU. For all filtration technologies, these limits are achievable and expected in 95-99% of measurements, but a target of 0.1 NTU should be sought at all times.

Application of the guideline

The health-based turbidity guideline applies to drinking water produced by systems that use either a surface water source or a groundwater source under the direct influence of surface water. The guideline is applied to individual filter turbidity. However, good operating practices suggest that both the individual filter turbidity and the combined filter turbidity should be continuously monitored. Drinking water taken from pristine sources may be exempt from the filtration requirements if it meets all of the criteria outlined below (see "Criteria for the exclusion of filtration in waterworks systems").

Surface water is defined as all waters open to the atmosphere and subject to surface runoff. Groundwater under the direct influence of surface water is defined as "any water beneath the surface of the ground with (i) significant occurrence of insects or other macro-organisms, algae, organic debris, or large-diameter pathogens such as *Giardia lamblia*, *Cryptosporidium*, or (ii) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions."[1] Key issues that should be considered when determining whether groundwater is under the influence of surface water are given in Appendix A.

The health-based turbidity guideline does not apply to secure groundwater sources, i.e., those not under the direct influence of surface water. Turbidity in these cases is non-organic, should pose no health threat and should not hinder disinfection. However, for effective operation of the distribution system , it is good practice to ensure water entering the distribution system has low turbidity levels of around 1.0 NTU.

Monitoring turbidity levels

For chemically-assisted filtration (i.e., continuous feed of a coagulant with mixing ahead of filtration), source water turbidity levels should be measured at least once per calendar day directly in front of where the first treatment chemical is applied. Treated water turbidity levels from individual filters should be continuously measured (with an on-line turbidimeter)at intervals no longer than five minutes apart at a point upstream of the combined filter effluent line or the clear water tank.

For slow sand or diatomaceous earth filtration, water turbidity levels from individual filters should be continuously measured (with an on-line turbidimeter) at intervals no longer than five minutes apart at a point upstream of the combined filter effluent line or the clear water tank. However, the frequency of monitoring may be reduced to one grab sample per day if it can be demonstrated that this frequency gives a reliable measure of filter performance.

For membrane filtration, treated water turbidity levels from individual filters should be continuously measured (with an on-line turbidimeter) at intervals no longer than five minutes apart at a point upstream of the combined filter effluent line or the clear water tank. An individual membrane filter may be defined as a unit or group of membrane stacks or cartridges within a train that may be valved and isolated from the rest of the system for testing and maintenance. Process designs should include a minimum of two parallel trains, if practical. Consideration should be given to installing on-line turbidity meters to analyze the water unique to each "individual" filter.

Use of alternative filtration technology by waterworks systems

A waterworks system can use a filtration technology other than the technologies stipulated if, in combination with disinfection, it reliably achieves at least a 3-log reduction of *Giardia lamblia* cysts and *Cryptosporidium* oocysts and a 4-log reduction of viruses. Pilot studies or equivalencies from other jurisdictions should demonstrate that the technology meets these criteria.

Criteria for exclusion of filtration in waterworks systems

Filtration of a surface water source or a groundwater source under the direct influence of surface water may not be necessary if *all* of the following conditions are met:

1. Overall inactivation is met using a minimum of two disinfectants:
   - ultraviolet irradiation or ozone to inactivate cysts/oocysts;
   - chlorine (free chlorine) to inactivate viruses; and
   - chlorine or chloramines to maintain a residual in the distribution system.

   Disinfection should reliably achieve at least a 99% (2-log) reduction of *Cryptosporidium* oocysts[‡], a 99.9% (3-log) reduction of *Giardia lamblia* cysts and a 99.99% (4-log) reduction of viruses. If mean source water cyst/oocyst levels are greater than 10/1000 L, more than 99% (2-log) reduction of *Cryptosporidium* oocysts, and 99.9% (3-log) reduction of *Giardia lamblia* cysts should be achieved. Background levels for *Giardia lamblia* cysts and *Cryptosporidium* oocysts in the source water should be established by monitoring as described in the most recent "Protozoa" guideline document, or more frequently during periods of expected highest levels (e.g., during spring runoff, or after heavy rainfall).
2. Prior to the point where the disinfectant is applied, the number of *Escherichia coli* bacteria in the source water does not exceed 20/100 mL (or, if *Escherichia coli* data is not available, the number of total coliform bacteria does not exceed 100/100 mL) in at least 90% of the weekly samples from the previous six months.

[‡] Studies on human volunteers have demonstrated that *Cryptosporidium* oocysts are less infectious than *Giardia* cysts by about one order of magnitude.

3. Average daily source water turbidity levels measured at equal intervals (at least every four hours), immediately prior to where the disinfectant is applied, range around 1.0 NTU but do not exceed 5.0 NTU for more than two days in a 12-month period. Source water turbidity also does not show evidence of protecting microbiological contaminants.
4. A watershed control program (e.g., protected watershed, controlled discharges, etc.) is maintained that minimizes the potential for faecal contamination in the source water.

Considerations for groundwater systems

In keeping with the multi-barrier approach to drinking water quality management, systems using secure groundwater sources should:

1. Ensure groundwater wells are properly constructed, are located in areas where there is minimum potential for contamination, and have appropriate wellhead protection measures in place. These source protection measures protect public health by reducing the risk of the drinking water source becoming contaminated.
2. Ensure treatment is sufficient to achieve 4-log reduction of viruses by disinfection. It is important to confirm that elevated turbidity levels will not compromise the disinfection process.
3. Maintain a chlorine residual throughout the distribution system and ensure water quality is monitored and maintained. Well-designed and operated distribution systems are key to providing safe, clean drinking water to consumers.

Identity and Sources in the Environment

The sources and nature of turbidity are varied and complex and are influenced by the physical, microbiological and chemical characteristics of water. In surface waters and groundwater under the direct influence of surface water, turbidity can vary significantly over time which has important implications for drinking water treatment processes and the microbiological safety of the drinking water. Particulate matter is frequently a source of nutrients for microorganisms and can protect microorganisms from both chemical and ultraviolet light disinfection. Particles contributing to turbidity may also carry undesirable chemical contaminants such as heavy metals. Turbidity can seriously affect the safety and acceptability of drinking water to consumers.

Description of turbidity

Turbidity is a "measure of the relative clarity of water."[3] Turbidity in water is caused by suspended and colloidal matter, such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms. However, turbidity is not a direct measure of suspended particles suspended in the water. It is, rather, a measure of the scattering effect such particles have on light. A directed beam of light remains relatively undisturbed when transmitted through absolutely pure water, but even the molecules in a pure fluid will scatter light to a certain degree. *Standard Methods for the Examination of Water and Wastewater* defines turbidity as an "expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample."[4]

In samples containing suspended solids, the manner in which water interferes with light transmittance is related to the size, shape and composition of the particles in the water and to the wavelength (colour) of the light that falls on the particles (incident light).[5] A minute particle absorbs the incident light falling on it and then re-radiates the light in all directions.

The detection, measurement and visual perception of turbidity is influenced by a number of factors. Particle size has an impact on the direction in which light is scattered and on the intensity of scattered light of differing wavelengths (colours). The shape of the particle also influences light scattering, as does the refractive index of the water and the colour of the particles.

Light scattering intensifies as particle concentration increases. However, as scattered light strikes more and more particles, multiple scattering occurs, and absorption of light increases. When particulate concentration exceeds a certain point, detectable levels of both scattered and transmitted light drop rapidly, marking the upper limit of measurable turbidity. By decreasing the path length of light through the sample, the number of particles between the light source and light detector is reduced, extending the upper limit of turbidity measurement.

Because several factors affect the intensity of light scattering, it is not possible to relate scattered light measurements directly to the number or weight of suspended solids in a given volume of water with any accuracy. Direct correlations can be made only if such factors as the size, distribution, shape, refractive index and absorptive capacity of the suspended solids causing the turbidity remain constant; this can only be achieved in a laboratory and is therefore impractical and unnecessary in most cases.[5]

Sources

Levels of turbidity in raw water can range from less than 1.0 NTU to more than 1000.0 NTU. The particles that cause turbidity in water range in size from colloidal dimensions (approximately 10 nm) to diameters of the order of 0.1 mm and can be divided into three general classes: clays, organic particles resulting from decomposition of plant and animal debris, and fibrous particles from asbestos minerals.[20] Clay particles generally have an upper diameter limit of about 0.002 mm, but can be as large as 0.02 mm. Biological organisms may also cause turbidity.

Particulate material in natural waters is mostly made up of eroded soil particles from the surrounding area. Coarser sand and silt fragments are at least partially coated with organic material. Clay particles are composed of clay minerals, usually phyllosilicates, as well as non-clay material, such as iron and aluminum oxides and hydroxides, quartz, amorphous silica, carbonates and feldspar.[20] Clays and organic particles are often found together as a "clay organic complex."[20] To a certain extent, it is artificial to treat the organic (humic) component in isolation from the inorganic component when considering the behaviour of suspended matter. However, humic substances have a much higher adsorptive capacity than clays (870 meq/100 g and 80 100 meq/100 g, respectively[21]); the effect of humic components likely predominates in many instances.

Other particles in raw water and drinking water supplies include the group of naturally occurring hydrated silicate minerals with fibrous structures known as asbestos; inorganic precipitates, such as metal (iron or manganese) oxides and hydroxides; and biological organisms, such as algae, cyanobacteria, zooplankton, and filamentous or macrobacterial growths.[22,23] Due to the numerous types of source particles and their implications in the treatment process, raw water quality monitoring for turbidity should be done at least daily, and preferably more often.

Relationship between turbidity and other water quality parameters

Table 1 summarizes some of the relationships between the source of turbidity and water quality/treatment implications.

Microbiological characteristics

Relationship between turbidity and the presence of pathogenic/non-pathogenic organisms

The microbiological quality of drinking water can be significantly affected by turbidity. Microbial growth in water is most extensive on the surfaces of particles and inside loose flocs, both naturally occurring and those formed during treatment(see section "Treatment technology"). This growth occurs because nutrients adsorb to surfaces, allowing bacteria to grow more efficiently than when in free suspension.[56,57] Similarly, river silt has been shown to readily adsorb viruses.[58]

Studies of distribution systems have shown conflicting findings with respect to turbidity and microorganisms. Haas *et al.*[59] noted that increased values of pH, temperature and turbidity were associated with increased concentrations of microorganisms. HPC increases that parallel increases in turbidity have been found at turbidity levels lower than 2.0 NTU.[60] Similarly, work by Goshko *et al.*[61] found positive correlations between HPCs and turbidities in the 0.83–8.89 NTU range. On the other hand, a study reported by Reilly and Kippin[62] suggested that turbidity around 1.0 NTU does not affect the frequency with which either coliforms or HPC organisms occur in the analysis.

Table 1: Turbidity and implications for water quality and water treatment

Source of turbidity	Possible water quality/chemistry implications	Treatment implications
Inorganic particles (silt, clay, natural precipitants, e.g., $CaCO_3$, MnO_2, Fe_2O_3, etc.)	- raise/lower pH and alkalinity - source of micronutrients - affect zeta potential - source of metals and metal oxides - cloudy/turbid appearance - affect taste	- major influence on coagulation, flocculation and sedimentation design - harbour/protect microorganisms
Organic particles (decomposed plant and animal debris, humic substances)	- source of energy and nutrients for microorganisms - cause colour - impart taste and odour - serve as precursors for the formation of chlorinated or ozonated compounds	- high disinfectant demand - potential to form chlorinated organics - potential to form ozonation by-products - high coagulant dose - reduce clarifier overflow rates

Source of turbidity	Possible water quality/chemistry implications	Treatment implications
	- possess ion exchange and complexing properties that include association with toxic elements and micropollutants - affect pH - affect zeta potential	- increase flocculation/sedimentation times - harbour/protect microorganisms - reduce filter runs - can compete with pollutant compounds for adsorption sites in activated carbon adsorption - can precipitate in the distribution systems
Biological organisms (algae, cyanobacteria, zooplankton, filamentous or macrobacterial growth)	- impart taste and odour - potential source of toxin (microcystin-LR) - disease transmission - corrode tanks, pipes, etc. - stain fixtures - cause aesthetic problems due to sloughing of growths from tanks, filters, reservoirs and distribution system	- plug filters - high disinfectant demand - need multiple barriers to ensure effective microbial inactivation - flotation may be more effective than sedimentation - microbial inactivation required

In water with turbidities ranging from 3.8 to 84.0 NTU, Sanderson and Kelly[63] found coliform organisms even after the water was treated with chlorine (free chlorine residuals between 0.1 and 0.5 mg/L after a minimum contact time of 30 minutes).

Huck *et al.*,[64] in their investigation of *Cryptosporidium* removal by granular media filtration, noted that an increase in turbidity associated with suboptimal coagulation and breakthrough at the end of filtration runs resulted in deterioration in oocyst reduction, even at turbidity levels less than 0.3 NTU. Utilities should therefore carefully consider the effects of reducing coagulant dosage. To avoid breakthrough, plants should specify a maximum head loss and filter run times and should consider using particle counters to monitor for early breakthrough.

Effect of turbidity on disinfection

Particulate matter (e.g., organic, inorganic, higher microorganisms) can protect bacteria and viruses from the effects of disinfection. LeChevallier *et al.*,[65] studying the efficiency of chlorination in killing coliforms in unfiltered surface water supplies, found a negative correlation with turbidity. A derived model predicted that an increase in turbidity from 1.0 to 10.0 NTU would result in an eight-fold decrease in the disinfection efficiency at a fixed chlorine dose. A study by Hoff,[66] which examined the efficiency of disinfection at turbidities of 1.0 and 5.0 NTU on poliovirus and sewage effluent coliforms, found that viruses and coliforms that adsorbed to organic matter were more resistant to disinfection than those that adsorbed to inorganic material such as clay and aluminum phosphate. For organic particulates, a reduction of turbidity from 5.0 to 1.0 NTU reduced the concentrations of disinfectant-resistant organisms approximately five-fold.

Hoff and Geldreich[67] reiterated that particulate characteristics have a significant impact on protection effects. Studies with ozone by Sproul *et al.*[68] confirmed that alum and bentonite afforded little protection to a variety of test organisms at 1.0 and 5.0 NTU, whereas faecal material and, in particular, human epithelial carcinoma cells did provide protection. Chlorine dioxide studies by Scarpino *et al.*[69] suggested that temperature and turbidity affected the rate of inactivation of bentonite-adsorbed poliovirus. At 25°C, turbidities in excess of 2.29 NTU reduced inactivation rates.

Free-living nematodes are relatively common in North American municipal water supplies. Nematodes of the Rhabditae family are known to ingest pathogenic bacteria and viruses, and hence are able to protect these pathogens from chlorine disinfection.[70] Studies indicate that more nematodes are found in higher-turbidity raw and treated waters.[71,72] In a study of the San Francisco water supply, coliform organisms were detected at chlorine levels of 0.35 mg/L or greater. Crustaceans apparently harboured the coliforms; on passing through a spigot, the crustaceans ruptured, and viable coliforms were released.[73] In laboratory tests, various clays and humic acid were shown to protect *Klebsiella aerogenes* from ultraviolet light disinfection.[74]

Chlorine (as hypochlorous acid) reacts readily with organic matter containing unsaturated bonds, phenolic groups and nitrogen groups, giving rise to taste- and odour-producing compounds[75] and trihalomethanes.[76] Hence, waters with high turbidity from organic sources may give rise to a substantial chlorine demand. This could result in reductions in the free chlorine residual in distribution systems as protection against possible recontamination. For Ottawa River plants, Otson *et al.*[77] noted that increased pre-chlorination dosage requirements were strongly correlated with increases in turbidity. In Oregon surface waters, chlorine demand had a positive correlation with both turbidity and total organic carbon levels.[65] The resultant model suggested a 180% increase in chlorine demand for a turbidity increase from 1.0 to 5.0 NTU.

In the United States, well-operated slow sand filtration plants may be allowed to have higher turbidity in filter effluents if there is no interference with disinfection and the turbidity level never exceeds 5.0 NTU.[78] Non-interference with disinfection may be assumed if the finished water meets the coliform maximum contaminant level and if there are fewer than 10 heterotrophic plate count bacteria per mL during times of highest turbidity.[78]

Effect of turbidity on microbial enumeration

The presence of turbidity may interfere with the quantification of bacteria and viruses. Bacteria are enumerated by counting the number of visible colonies that form on nutritive media when bacterial cells are incubated on the media for a fixed period of time. This process assumes that each colony represents one cell; however, a single colony could emanate from a particle containing many bacterial cells adsorbed on its surface. Fewer cells than were actually present would then be recorded. This phenomenon would also lead to an underestimation of bacterial numbers with the most probable number technique.

Geldreich *et al.*[79] noted that turbidity in a potable water sample may make membrane filtration impractical because of the volume of water the filter can pass, the character of the suspended material and the thickness of the deposit on the surface of the membrane. Although crystalline or siliceous materials may not be a problem, other substances may clog filter pores or cause a confluent growth to develop during incubation, hampering microbial enumeration. Coliform masking has been observed with membrane filters, with false-negative results occurring 17, 45 and more than 80% of the time for turbidities of less than or equal to 1.0, 5.0

and more than 10.0 NTU, respectively.[65,80] Additional studies suggested that levels of turbidity *per se* (up to approximately 10.0 NTU) did not greatly affect coliform discovery, although associated non-coliform bacteria seriously inhibited detections.[81]

Viruses can also be adsorbed on or within particulate matter and may be very difficult to remove; 1% recovery is not unusual.[82] A review of virus detection methods concluded that no simple and accurate system for enumerating viruses in highly turbid waters was available.[83]

Relationship between Turbidity Removal and Microbial Quality of Treated Water

Historically, filtration has been shown to substantially block disease-causing organisms from entering into the drinking water supply.[81] During coagulation, protozoa, bacteria and viruses, along with other sources of turbidity, become trapped in the floc and are removed by the filter.[85,86] However, sometimes floc breaks through filter beds; such breakthroughs have been shown to be accompanied by an increase in virus penetration, even though the turbidity of the finished water remained below 0.5 NTU.[82]

Studies have shown a correlation between decreased filtrate turbidity (down to 0.1 NTU) and reduced bacterial and algal counts.[84] Increases in the turbidity of filter effluent can signal the potential for increasing passage of unwanted organisms, even if the turbidity in the effluent is less than 1.0 NTU. For example, increasing concentrations of *Giardia* cysts can occur with turbidity increases of only 0.2–0.3 NTU.[87,88]

The Pennsylvania Department of Environmental Protection, in its 1996 Regulatory Basics Initiative Program report ,[89] gave its view of the relationship between turbidity and pathogen occurrence in finished filtered water. It stated that a relationship exists between turbidity spikes and *Giardia* breakthrough such that a stable filter with low turbidities that experiences a 0.1 NTU increase in turbidity can experience a 10- to 50-fold increase in cyst breakthrough from disturbance of the media.

In evaluating plant performance using endospores, researchers found that the log reduction of spores was similar in magnitude to the individual reduction of turbidity, total particles and particles in the *Cryptosporidium* oocyst size range. More important, spore removal closely paralleled particle and turbidity removal in response to coagulant dosage under all the water quality conditions examined.[90]

In examining relationships between turbidity and parasites, it was found that for every log removal of turbidity, a 0.89-log removal was achieved for *Giardia* and *Cryptosporidium*.[91] Conversely, increases in filtrate turbidity paralleled increases in the risk of *Cryptosporidium* breaking through the filter due to floc material breaking through that contained, or was associated with, oocysts. These increases occurred even with efficient chemical coagulation. It is therefore reasonable to assume that during the filter 'ripening' period at the beginning of a run, when turbidity is often greater than normal for the filter, the risk of *Cryptosporidium* breakthrough is higher.[92]

Table 2 shows average potential removal credits estimated for *Giardia lamblia*, *Cryptosporidium* and viruses, when treated water meets the prescribed turbidity limits. The log reduction credits outlined in Table 2 are based on the mean or median removal established by the US EPA as part of the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR).[126] Facilities that do not meet the requirements, or facilities that believe they can achieve a higher log credit than is automatically given, can be granted a log reduction credit based on a demonstration of performance by the appropriate regulatory agency.

Table 2: *Giardia lamblia, Cryptosporidium* and virus potential reduction credits for various technologies.

Technology	Cyst/oocyst credit [c]	Virus credit
Conventional filtration [a]	3.0 log	2.0 log
Direct filtration [a]	2.5 log	1.0 log
Slow sand or diatomaceous earth filtration [a]	3.0 log	2.0 log
Micro- and ultrafiltration, nanofiltration and reverse osmosis [b]	Removal efficiency demonstrated through challenge testing and verified by direct integrity testing	No credit for micro- and ultrafiltration; for nanofiltration and reverse osmosis, removal efficiency demonstrated through challenge testing and verified by direct integrity testing

Notes:

[a] Conventional/direct/slow sand/diatomaceous earth filtration should be followed by free chlorination to obtain additional virus credit.

[b] Micro- and ultrafiltration should be followed by free chlorination for the inactivation of viruses.

[c] Depending on cyst/oocyst levels in source water, additional treatment is required using ultraviolet light, ozone, chlorine or chlorine dioxide (refer to protozoa/virological quality supporting documents for the level of inactivation required and the CT/IT tables for various disinfectants).

Chemical characteristics

Because of their adsorption capacity, suspended particulates have the ability to entrap undesirable organic and inorganic compounds; as such, an indirect relationship exists between turbidity and the chemical characteristics of these compounds in water. Most important in this respect is the organic or humic component of turbidity.

Humic substances are able to bind substantial amounts of metals and hydrous oxides together, forming complexes. An excellent review of metal–humate complexes, the mechanism of their formation and their properties is provided by Schnitzer and Kahn.[93] The ability of a number of natural waters in Ontario to complex copper has been demonstrated, with complexing capacities of up to 2.35 μmol Cu/L (0.149 mg/L) being reported.[94] A wide variety of heavy metal ions were found to be complexed in sediments of the Ottawa and Rideau rivers. A positive correlation between the unit surface area of the sediment and the concentration of adsorbed metal ions was observed.[95] In a study of mercury sorption and desorption characteristics of Ottawa River sediments, it was found that sorption rates were higher for organic-rich sands. Desorption of mercury was difficult, with less than 1% of the mercury being leached during a seven-hour contact period.[96] The strength of some metal–humate complexes may lead to negative errors in the analytical measurement of trace metals in natural water samples if turbidity exists.[97]

One method that is used to remove undesirable metal ions during water treatment is adsorption with activated carbon. This process is aided by the presence of organic matter.[98] Organic molecules are also adsorbed by natural organic matter. DDT, for example, is solubilized in 0.5% sodium humate solution by a factor of at least 20 over its solubility in pure water.[99]

Herbicides such as 2,4-D, paraquat and diquat can be adsorbed onto clay/humic acid particulates, the adsorption being greatly influenced by metal cations present in the humic material.[100] The presence of turbidity, therefore, might also interfere with the detection of biocides in water samples.

Chlorination of water containing organic matter such as humic acids can produce trihalomethanes, a group of chemical compounds that includes chloroform, bromodichloromethane, chlorodibromomethane and bromoform. The Canadian drinking water guideline for trihalomethanes is based on the known health effects associated with chloroform. Morris and Johnson[101] observed a relationship between raw water turbidity and trihalomethane concentration in finished Iowa City water. In laboratory tests, Stevens and co-workers[102] found that trihalomethane production was reduced if the water was filtered prior to chlorination. Harms and Looyenga[103] also reported that raw water turbidity was positively correlated with chloroform concentration in a South Dakota water supply. Strategies for addressing turbidity have implications related to controlling the potential formation of trihalomethanes, including the removal of organic matter, the use of alternative disinfectants, disinfectant application points and dosages, and the use of activated carbon.[104]

For plants using aluminum salts as coagulants, highest particulate aluminum concentrations (>200 µg/L) were measured when the turbidity was greater than 0.5 NTU.[105] The results of the study suggest that filtered water turbidity should be less than 0.1 NTU to minimize particulate aluminum concentrations that contribute to residual aluminum.[105]

At the asbestos levels commonly found in drinking water (of the order of 10^4–10^6 fibres/L),[106] very little, if any, correlation has been observed between turbidity and asbestos concentration.[3,107,108] However, a general but non-linear relationship has been reported at high levels of asbestos (10^9–10^{11} fibres/L).[109] Further studies on treatment efficiencies for asbestos removal have resulted in a recommendation by Logsdon and co-workers[110,111] that plants designed for asbestos removal should produce filtered waters with turbidities of 0.1 NTU or lower. McGuire *et al.*[112] suggested that this objective would help but not necessarily guarantee low asbestos counts (<10^6 fibres/L). Boatman[113] reported that turbidity could impede asbestos analyses because of restricted filter volumes. Asbestos-cement pipes are used in some localities to transport drinking water, and it has been demonstrated that water with an aggressivity index of less than 10 can cause the release of asbestos fibres into the drinking water.[114]

Physical characteristics

A considerable body of evidence suggests that a large part of colour in water arises from colloidal particles. These tiny particles have physical and chemical properties that allow them to stay suspended in the water, rather than settling down or dissolving. Black and co-workers[52,53] used electrophoretic studies to demonstrate the predominantly colloidal nature of colour in water; it has been claimed that about 50% of colour is due to a "colloidal fraction" of humic substances.[54] True colour is therefore defined as the colour of water from which turbidity has been removed.[3]

The relationship between high turbidity, in both raw and filtered water, and taste and odour has long been recognized.[55] Algal growths, actinomycetes and their debris also contribute to taste and odour problems.[22] At 5.0 NTU and above, there is an increasing visual detection, which many consumers find unacceptable.

Analytical methods

Turbidity is measured using the nephelometric method. Nephelometry determines turbidity using the intensity of scattered light. Table 3 lists four nephelometric methods that meet the criteria of the American Water Works Association/American Public Health Association (AWWA/APHA) or the U.S. Environmental Protection Agency (USEPA) and one International Organization for Standardization (ISO) criteria for determining turbidity in drinking water.

Table 3: Recognized Analytical Methods for Measuring Turbidity in Drinking Water[a]

Method	Citation	Description
Nephelometric	AWWA/APHA 2130B[4]	Tungsten lamp@2200-3000°K and one or more perpendicular detectors (&filters) with spectral response peak of 400-600nm. Light path ≤10 cm.
Nephelometric	USEPA 180.1[6]	Tungsten lamp@2200-3000°K and one or more perpendicular detectors (&filters) with spectral response peak of 400-600nm. Light path ≤10 cm.
Optical	ISO 7027[8]	Tungsten lamp (&filters),Diode or Laser as radiation source at 860 nm (or 550nm if sample is colourless) with a perpendicular detector and aperture angle 20-30°
Great Lakes Instruments	USEPA GLI 2[7]	Two perpendicular 860nm light sources alternately pulse each 0.5 seconds & two perpendicular detectors alternately measure "reference" and "active" signals.
Hach Filter Trak	USEPA 10133[125]	Laser Diode @660 nm at 90° to detector/receiver (light path ≤10 cm) which may use Photo-Multiplier Tube and fibre-optic cable. Range is 0-1000 mNTU's.

Notes:
[a] Additional methods may be approved before this guideline is revised/updated in the future.

Nephelometric turbidity instrumentation varies in design, range, accuracy and application. The design of nephelometric instruments should take into account the physics of scattered light. As noted in a previous section (Identity and Sources in the Environment), the size, shape and concentration of the particles affect the intensity pattern and distribution of the scattered light. Small particles less than one-tenth of the light wavelength will scatter light uniformly in both forward and backward directions. As the particle size approaches and exceeds the wavelength of the incident light, more light is transmitted in the forward direction. Because of this intensity pattern, the angle at which the light is measured is a critical factor; the current international standards have determined the most appropriate angle to be 90 degrees.[8] As noted above in a previous section, as the concentration of particles increases, more particles reflect the incident light, which increases the intensity of the scattered light. As the concentration exceeds a certain point determined by the specific optical characteristics of the process, the particles themselves begin to block the transmission of the scattered light. The result is a decrease in the intensity of the scattered light. The intensity at which various wavelengths of light are reflected or absorbed is also determined by the colour of the liquid and the reflecting surface. Industry standards require nephelometers to operate in the visible or infrared ranges: 400–600 and 800–900 nm, respectively.[9]

All these factors, along with the optical geometry of a particular instrument, cause measured values between instruments to vary widely; thus, criteria for instrument design have been developed to minimize these variables. Manufacture of turbidimeters is guided by recommendations provided by the U.S. Environmental Protection Agency[10] and the International Organization for Standardization (ISO 7027).[8]

Using special experimentation methods with a quartz iodine light source, the nephelometric response of exhaustively filtered de-ionized water has been shown to be 0.022–0.003 NTU.[11] Air bubbles and dirty sample tubes can cause false high readings for turbidity; very turbid samples or samples with colour due to dissolved substances will give low readings.[4,12]

For a finished water turbidity goal of 0.1 NTU, rigorous standard operating procedures and a high level of quality control are required; a small numeric change may result in a large percent change.[13,14] However, according to USEPA *Analytical Methods for Turbidity Measurement (180.1 and GLI 2)* and *Standard Methods for the Examination of Water and Wastewater (2130B)*, the sensitivity of nephelometers is such that turbidity differences of 0.02 NTU or less can be detected in waters having a turbidity of less than 1.0 NTU.[4,6,7] All three methods cite "reporting to the nearest 0.05 NTU where the turbidity range is 0–1.0 NTU." Thus, the practical lower limit of the standard nephelometric method can be considered to be 0.1 NTU.

Laser turbidimeters have recently entered the market. The manufacturers claim that these instruments are far more sensitive than the standard turbidimeters; purporting to accurately measure in the mNTU range. The USEPA has approved a laser turbidity method, "Method 10133, Determination of Turbidity by Laser Nephelometry." [125] Currently they are not widely used in the industry.[15]

Turbidity, as defined by the above methods, is a non-scientific measure of particle concentration. Electronic particle counters are now available that are capable of accurately counting and recording the number of particles as a function of size (often in the 1–150 µm range). Although there is a general relationship between particle counts and turbidity (below 1.0 NTU), a firm correlation does not exist.[16–18]

A simple conversion factor relating particle counting and turbidity measurements is not possible because the two techniques differ fundamentally in terms of discernment. Particle counting measures two characteristics of particulates: particle number and particle size. Samples with identical clarity can be distinguished on the basis of these two features; one sample may contain many small particles, whereas another may contain few large particles. Turbidity, on the other hand, cannot distinguish between two samples of identical clarity and different particulate composition.[19]

Particle counters are an excellent tool for optimizing treatment processes and for detecting the onset of filter breakthrough. Particle counters are restricted to performance verification only, and no limit is set as a maximum acceptable concentration for the number of particles in the treated water.

Treatment technology

Turbidity is reduced by removing particles from the water through filtration. Adequate filtration can be achieved by a variety of technologies: chemically-assisted filtration, slow sand filtration, diatomaceous earth filtration, membrane filtration or an alternative proven filtration technology.

Chemically-Assisted Filtration

The chemically-assisted filtration process generally includes chemical mixing, coagulation, flocculation, sedimentation (or dissolved air flotation) and rapid gravity filtration. Aluminum and ferric salts are used as primary coagulants. Cationic and anionic polymers are most commonly used as flocculation aids, and both, along with non-ionic polymers, have been used as filter aids. The coagulants and polymers are used to destabilize the generally negatively charged colloidal particles, which allows aggregation to occur via chemical and van der Waals interactions.[24,25] The resulting (much larger) particles are filtered out when the water passes through sand beds or other single-, dual- or mixed-media granular filters. In systems where the combined water from all filters is monitored continuously, this treatment process is capable of producing water with a turbidity of less than 0.3 NTU; turbidities of less than 0.2 NTU have been demonstrated to be achievable on an ongoing basis. Filter loading rates generally range from 3.0 to 12.0 m/h.[26,27]

Changes in alkalinity, colour, turbidity and orthophosphate concentrations affect coagulation reactions, and the properties and rate of settling of resulting floc particles. Temperature affects efficiency by influencing the rate of chemical reactions and the viscosity of water, thereby affecting the particle settling velocity and the filter backwash rate. The lower the temperature of the water, the more difficult it is to treat the water.

All filtration plants should provide for continuous monitoring of the effluent turbidity from each individual filter, as well as for continuous monitoring of the combined filtered water turbidity from all filters. Continuous monitoring is required because short-term turbidity spikes represent a process failure and potential health risk. Peak turbidity levels in the filtered water are a particular concern immediately after filter backwashing; therefore, all filters should be designed so that the filtered water immediately after filter backwashing is directed into a waste stream ('filter-to-waste' provision). When operating the filters, every effort should be made to minimize the magnitude and duration of turbidity spikes.[28]

Discharge of filter backwash water into a raw water reservoir should not be permitted unless the filter backwash water receives off-line treatment, or is returned to a location upstream of the coagulant dosage point, so that all processes of a conventional or direct filtration plant are employed. The off-line treatment may be acceptable depending on the method used to treat the backwash water.

Following filtration, turbidity in a waterworks may increase if any of the following occur:

- coagulants escape into the filtered water;
- dissolved metals oxidize;
- bacteria and other microflora grow;
- chemicals are added for stability or corrosion control;
- deposited materials (especially in low-flow parts of the system) are resuspended; or
- pipes corrode or lines break.[29,30]

Uncovered distribution system reservoirs may also lead to increased turbidities, mainly by encouraging biological production.[31,32]

In 1989, the American Water Works Association Research Foundation sponsored a study that identified design provisions and operational practices at high-rate filtration plants. For the study, researchers chose 21 plants that were successful in producing finished water with turbidity of less than 0.2 NTU.[27] In choosing the participating plants, consideration was given to geographic coverage as well as diversity of raw water types and treatment processes. In a different study, the Pennsylvania Department of Environmental Protection undertook performance evaluations of 150 surface water treatment plants that used filtration from 1988 to 1990 and found that a goal of 0.2 NTU was achievable for most plants.[33] An internal report, prepared in 1995 for the same department, also found that filtration plants can readily achieve finished water with turbidities of less than 0.5 NTU and that most plants can achieve less than 0.2 NTU.[26] In pilot tests involving treatment of Boston's low-turbidity surface water supply with dissolved air flotation, the turbidity goal of 0.1 NTU was met in more than 90% of the runs.[34] Operational studies at specific plants have indicated that low turbidities in plant effluent are readily achievable when competent operations are in place.[35,36] In another study, it was demonstrated that well-operated conventional treatment plants or direct filtration plants that produce water with low turbidity (less than 0.5 NTU) can achieve up to a 3-log reduction of *Giardia* cysts and up to a 2-log reduction of viruses.[37] The same study demonstrated that source waters with low raw water turbidity require filter effluent turbidities to be substantially lower than 0.5 NTU in order to effectively remove *Giardia* cysts and viruses.

The U.S. Environmental Protection Agency's 1997 Notice of Data Availability for Interim Enhanced Surface Water Treatment Rule shows that systems serving greater than 10 000 people are able to meet low turbidity limits. The same study indicated that chemically-assisted filtration is able to achieve a 2-log reduction of *Cryptosporidium* through filtration.[38,39] The US EPA has now concluded that conventional treatment plants in compliance with the IESWTR or LT1ESWTR achieve an average of 3-log reduction of *Cryptosporidium*. Direct filtration plants achieve an average of 2.5-log reduction of *Cryptosporidium*.[126]

Slow sand filtration

In slow sand filtration, filter effectiveness depends on the formation of schmutzdecke, which is a layer of bacteria, algae and other microorganisms on the surface of the sand, and the formation of a biopopulation within the sand bed. Raw water passes through the sand bed where physical, chemical and biological mechanisms remove contaminants. The most important removal mechanism has been attributed to the biological process. No chemicals are added, nor is there a need to backwash.

Researchers have observed variation in the ability of slow sand filters to reduce turbidity. Fox *et al.*[40] found that when water was filtered at 0.12 m/h, after an initial ripening period had allowed the biopopulation to become established on new sand, the treated water turbidity was consistently less than 1.0 NTU. Raw water turbidity ranged from 0.2 to 10.0 NTU. Cleasby *et al.*[41] reported that typical effluent turbidity was 0.1 NTU for raw water with turbidity ranging from lower than 1.0 to 30.0 NTU, except during the first two days after scraping of the schmutzdecke. Pyper[42] observed slow sand filtered water with turbidity of 0.1 NTU or lower 50% of the time and 1.0 NTU or lower 99% of the time; raw water turbidity in this study ranged from 0.4 to 4.6 NTU. Slezak and Sims[43] reported that nearly half of the 27 slow sand filtration plants they surveyed produced filtered water turbidity of 0.4 NTU or lower; at the same time, 15% of the plants produced water with an average turbidity of 1.0 NTU or higher. Consistent 3-log reductions of particles sized from 2 to 4 µm upwards were also observed in this study. The size range of 7–12 µm is considered to be representative of the size of *Giardia* cysts. Bellamy *et al.*[44] studied the water treatment efficiency of slow sand filtration to ascertain removal of *Giardia* cysts, total coliform bacteria, heterotrophic plate count (HPC, formerly known as standard plate count) bacteria, particles and turbidity. Results showed that slow sand filtration is an effective water treatment technology. Using a biologically mature filter, *Giardia* cyst removal was virtually 100%; total and faecal coliform removal was approximately 99%; particle removal averaged 98%; HPC bacteria removal ranged from negative to 99%, depending on the influent concentration; and turbidity removal ranged from 0 to 40%.[39] The US EPA has now concluded that slow sand filtration plants in compliance with the IESWTR or LT1ESWTR achieve an average of 3-log reduction of *Cryptosporidium*.[126]

Slow sand filtration is appropriate for use when raw water turbidities are relatively low (e.g., <10.0 NTU).

As is the case with chemically-assisted filtration, a ‘filter-to-waste’ feature should be provided so that the filtered water immediately after filter cleaning is directed into a waste stream.

Diatomaceous earth filtration

Diatomaceous earth filters operate by passing water through a thin layer of diatomaceous earth about 3 mm thick supported on a septum or filter element. To prevent turbid water from clogging the filter, a small amount of diatomaceous earth is continually added as body feed to maintain a permeable filter cake. Once the headloss across the filter cake becomes too great or the filter cake begins to slough, the filter is removed from service and the filter cake is washed and reused. New precoat is applied, and the cycle starts again.

Diatomaceous earth filtration has been shown to attain excellent removal of *Giardia* cysts over a broad range of operating conditions. Cyst removals exceeding 99%, and often 99.9%, were reported by Lange *et al.*[45] for filtration rates of 2.4–9.6 m/h and for temperatures from 3.5 to 15°C. Logsdon *et al.*[46] reported that when sufficient diatomaceous earth and body feed were used, removal of 9-µm radioactive beads was nearly always 99.9% or higher. The same study reported that 11 filter runs were made with *Giardia muris* cysts at filtration rates of 2.2–3.5 m/h. Cyst removal exceeded 99% in all runs and exceeded 99.9% in five of the runs. The US EPA has now concluded that diatomaceous earth filtration plants in compliance with the IESWTR or LT1ESWTR achieve an average of 3-log reduction of *Cryptosporidium*.[126]

Diatomaceous earth filtration is appropriate and effective in treating waters with low turbidity. Logsdon *et al.*[46] reported that turbidity reductions of 56–78% were attained with diatomaceous earth when raw water turbidity ranged from 0.95 to 2.5 NTU. Pyper[42] reported an average turbidity reduction of 75% with an effluent quality of 0.5 NTU.

As is the case with chemically-assisted filtration, a 'filter-to-waste' feature should be provided so that the filtered water immediately after filter backwashing is directed into a waste stream.

Membrane filtration

Four membrane treatment processes are currently used in the water industry, and all involve pressure-driven semi-permeable membranes. The most appropriate type of membrane depends on a number of factors, including targeted materials to be removed, source water quality characteristics, treated water quality requirements, membrane pore size, molecular weight cut-off, membrane materials and system/treatment configuration.[47] The four processes are:

1. **Reverse osmosis**: a high-pressure membrane treatment process originally developed to remove salts from brackish water.
2. **Nanofiltration**: a low-pressure reverse osmosis process for the removal of larger cations (e.g., calcium and magnesium ions) and/or organic molecules.
3. **Ultrafiltration**: a lower-pressure membrane process characterized by a wide band of molecular weight cut-off and pore sizes for the removal of dissolved organics and particulates.
4. **Microfiltration**: a low operating pressure membrane process used to remove particulates, including pathogenic cysts.[47,48]

Reverse osmosis and nanofiltration are very effective for absolute removal of cysts, bacteria and viruses.[48] Ultrafiltration (pore size 0.01 µm) and microfiltration (pore size 0.1 µm) are effective for absolute removal of *Giardia* cysts and partial removal of bacteria and viruses.[49] Filtrate turbidity can be achieved consistently at or below 0.1 NTU.[50,51]

Prefiltration and/or the addition of a scale-inhibiting chemical may be required to protect membranes from plugging effects, fouling and/or scaling.

If membrane filtration is the sole treatment technology in use then a form of virus inactivation should be incorporated into the treatment train after the filtering process.

'Filter-to-waste" feature should be provided for initial start-up and commissioning of the membrane system and for emergency diversion in the event of a membrane integrity breach.

Health considerations

Microbial

The most important health-related effect of turbidity is probably its ability to protect microorganisms from disinfection. Turbidity, which has been shown to be correlated with the contamination of water supplies by *Giardia* and *Cryptosporidium*,[119] serves as a surrogate measure for indicating the risk of contamination by these pathogens. A dramatic increase in turbidity levels at one of the Milwaukee water treatment plants (levels many times higher than those of the preceding 14 months) was associated with the outbreak of cryptosporidiosis in April 1993, when more than 400 000 people developed symptomatic gastrointestinal infections as a consequence of exposure to contaminated drinking water.[120] An outbreak of giardiasis in Rome, New York, where an unfiltered but chlorinated water supply was used, has been cited as illustrating the problem of particulates possibly protecting pathogens and interfering with marginal disinfection.[108] In another incident, high turbidities (>4.0 NTU), resulting from poor plant operation coupled with a malfunctioning chlorinator, were considered as causal factors in an outbreak of giardiasis.[84]

In most water treatment plants, *Giardia* removal is a physical process involving coagulation, flocculation and filtration; chlorine contact times alone are insufficient to result in complete destruction or removal.[121] Monitoring turbidity can therefore be a useful indicator of plant performance, including cyst removal. Studies have shown that small increases in turbidity (about 0.2 NTU) can result in significant passage of *Giardia* cysts.[87] It has been suggested that 0.1 NTU should be set as a goal or objective for treated water.[84,87,121,122] Giardiasis problems have, however, occurred where turbidity limits have been met, and it should not be assumed that achieving a turbidity limit will by itself prevent waterborne disease.[88,123]

A study in Philadelphia by Schwartz *et al.*,[51] which asserted a correlation between levels of turbidity and hospital admissions of elderly residents with gastrointestinal illnesses, highlights the fact that meeting the turbidity limits does not necessarily mean that disease can be prevented. The authors found that an increase in the weighted average turbidity of approximately 25% (0.035 NTU) was associated with a 9% increase in hospital admissions of elderly residents with gastrointestinal illness 9–11 days after exposure, even though the recorded average turbidities were well below the regulated limits. A similar study by Aramini *et al.*[124] has demonstrated a relationship between reported gastrointestinal illness and turbidities in excess of 1.0 NTU, the previous Canadian health-based drinking water guideline. Using a generalized additive model, the authors demonstrated that excess turbidities during the period 1992–1998 could explain 2.1%, 0.8% and 0.9% of emergency-associated, gastroenteritis-related physician visits by persons residing within the three water distribution areas, respectively. In addition, 1.3%, 0.2% and 0.3% of gastroenteritis-related hospitalizations of persons residing in the same three areas were explained by variations in turbidity. It is evident from these studies that change in turbidity levels in drinking water is a potential indicator for breakthrough of pathogenic organisms and increased consumer risk.

Hudson,[115] using 1953 data on infectious hepatitis and raw water turbidity for 12 U.S. cities, observed that infectious hepatitis incidence was greater with higher turbidity. A similar relationship appeared to exist between turbidity and cases of poliomyelitis, although this finding was based on a smaller sample.[115] Shaffer *et al.*[116] reported detection of poliovirus in waters with chlorine concentrations greater than 1 mg/L and turbidities less than 1.0 NTU, which indicates that protection from disinfection occurs even at very low turbidity levels. Although a study of 16 U.S. cities in 1961 failed to reveal a clearly defined relationship between hepatitis incidence and finished water turbidity, the authors stated that, because of the many factors involved, it should not be inferred that there is none.[117] The infectious hepatitis epidemic in Delhi, India, occasioned by the massive contamination of the raw water source of a treatment plant by sewage, was also accompanied by a significant increase in raw water turbidity. Even though chlorination was practised, it was apparently insufficient to inactivate the infectious hepatitis virus.[118] The protection from disinfection offered by organic or cellular material in particular has been reported in other studies.[66,68]

Chemical

Particulate matter in water is not usually a potential chemical hazard in itself, but may have indirect effects.[20] The concentrations of both heavy metal ions and biocides are usually much higher in suspended solids than in water. The possibility therefore exists that when such contaminated particles enter a different environment, such as the stomach, release of the pollutants could occur, with potentially deleterious effects.

The metal–ligand binding in humate complexes can be represented by the equation:[93]

$$M^{n+} + H_mA \rightleftharpoons M_mA_n + mH$$

where:

- M^{n+} = the metal ion
- H_mA = humic acid
- M_mA_n = the metal complex.

If, for instance, the hydrogen ion concentration is increased by stomach acid, the equilibrium will be displaced in favour of the free ion and the undissociated humic acid.

Similarly, the absorption of some herbicides, in particular s-triazine compounds, by soil organic matter, has been demonstrated to be pH dependent. Maximum absorption occurs at pH levels in the vicinity of the respective pK values of the herbicides (i.e., pH levels of about 4–6). Lowering or raising the pH decreases absorption and hence may lead to the release of free herbicides.[93]

Other considerations

Excessive turbidity has often been associated with unacceptable tastes and odours. Turbidity in excess of 5.0 NTU also becomes visually apparent and may be objected to by consumers. In some cases, if the level of turbidity is not lowered to reduce the organic loading in advance of applying certain chemicals, it may lead to other health concerns (e.g., the formation of trihalomethanes).

As noted above, turbidity measurement does not indicate the type, number or mass of particles. However, because of the ease of analysis and relative inexpensiveness of the equipment, it is a very useful tool to assess the performance of water treatment processes — especially for conventional surface water systems. Moreover, turbidity can serve to signal potential contamination problems or difficulties within a distribution system. Drinking water should be aesthetically pleasing. Every effort should be made to keep the turbidity as low as possible by flushing and cleaning the pipelines. For aesthetic purposes, turbidity should not exceed 5.0 NTU within the distribution system, especially at the point of consumption.

Rationale

Turbidity is a characteristic of all water supplies. In surface waters and groundwaters under the influence of surface water, turbidity is a concern for both health and aesthetic reasons. In these waters, the particulate matter that creates turbidity can contain toxins, harbour microorganisms and interfere with disinfection. In addition, organic matter in the water can react with disinfectants such as chlorine to create by-products. These by-products may cause adverse health effects.

While turbidity may be measured in secure groundwater supplies (i.e., not under the direct influence of surface water), it is not a concern in treated water from these sources provided it does not hinder disinfection. It is good practice to ensure water entering the distribution system from a secure groundwater supply has a low turbidity level around 1.0 NTU.

Turbidity is effectively reduced through filtration, using one of a number of common technologies. The most important consideration when dealing with turbidity is to reduce its level as low as possible and minimize fluctuation. For this reason, while the target is to reduce turbidity levels to below 0.1 NTU at all times, it is considered acceptable for treatment plants to achieve the following levels based on the type of technology used. The levels of turbidity in treated water should be:

1. For chemically-assisted filtration, less than or equal to 0.3 NTU in at least 95% of the measurements made, or at least 95% of the time each calendar month and not exceed 1.0 NTU at any time.
2. For slow sand or diatomaceous earth filtration, less than or equal to 1.0 NTU in at least 95% of the measurements made, or at least 95% of the time each calendar month and not exceed 3.0 NTU at any time.
3. For membrane filtration, less than or equal to 0.1 NTU in at least 99% of the measurements made, or at least 99% of the time each calendar month and not exceed 0.3 NTU at any time. If membrane filtration is the sole treatment technology employed, some form of virus inactivation should follow the filter process.

Most problems associated with turbidity are caused when the level of turbidity in the treated water spikes. Spikes can occur when the natural levels of particulate matter increase in the source water, when the filtration rate increases or when an individual filter breaks down. In order to quickly figure out that a filter is malfunctioning and to identify which one it is, this guideline applies to individual filters within a system.

Turbidity (10/03)

Turbidity measured to be less than 5.0 NTU is not discernable to the naked eye but at higher levels the particulate matter in water may cause colour, taste and odour concerns for consumers. For this reason, utilities should try to maintain the level of turbidity in the distribution system to below 5.0 NTU. An aesthetic objective has not been set in order to avoid confusion with the health-related guideline.

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Appendix A

Determining if Groundwater Is Under the Direct Influence of Surface Water[2]

Determining whether groundwater is under the influence of surface water is a complex process. While there is considerable variation in the circumstances that may result in groundwater becoming contaminated with surface water, some key issues that should be considered include:

?????

Geology

- ☐ What are the characteristics of the aquifer deposit (i.e., lithology, stratigraphy and structure)?
- ☐ How was the deposit created (i.e., geomorphology)?
- ☐ What is the age of the deposit?
- ☐ Is it a confined, semi-confined or unconfined aquifer?
- ☐ If the aquifer was created during a recent geologic event (i.e., alluvial deposits/post-glaciation), is it likely to be connected to an existing surface water body? Is it susceptible to land surface use and influences? What are the consequences? What is the level of risk?
- ☐ If the aquifer was created during an ancient geologic event (i.e., unconsolidated deposits or bedrock deposits/pre-glaciation), is it likely to be connected to an existing surface water body? Is it susceptible to land surface use and influences? What are the consequences? What is the level of risk?
- ☐ What are the effects of local topography (e.g., mountains, foothills, plains)?
- ☐ What are the effects of local geology and geologic events (i.e., facies changes, complex geology, glaciation)?

Hydrogeology

- ☐ Do the aquifer characteristics (i.e., hydraulic head, intrinsic permeability, hydraulic conductivity, transmissivity, storitivity) imply direct surface water and/or land surface influence(s)?
- ☐ Is there evidence of local surface water "discharge/recharge" to/from the aquifer?
- ☐ What is the direction of groundwater flow (i.e., hydraulic gradient)?
- ☐ What is the consequence of pumping groundwater from the aquifer (cone of influence)? Is there a change in gradient?

Hydrochemistry

- ☐ Is there evidence of water quality similarities between the aquifer and surface water (i.e., chemistry, temperature, bacterial count)?
- ☐ Is there evidence through environmental isotope analysis (^{3}H, ^{14}C, ^{18}O, ^{2}H)?
- ☐ What is the chemical age of the groundwater (i.e., mineralization)? How does it compare with that of the local surface water?
- ☐ Is there evidence of a hydrochemical facies change?
- ☐ What is the level of bacterial contamination in the aquifer?

Land use issues

- ☐ What types of local land use are there (e.g., agricultural, industrial, municipal, recreational)?

Soil horizon

- ☐ What type of soil is there?

Tools for making the assessment

- ☐ Cross-sections, isopach maps, topographic maps and geological maps
- ☐ Aquifer pumping test, groundwater modelling and groundwater monitoring (observation wells, piezometers), soil percolation tests
- ☐ Local water balance exercises (groundwater vs. surface water recharge/discharge)
- ☐ Isotope analysis

Trihalomethane

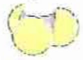
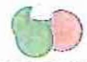
From Wikipedia, the free encyclopedia

Trihalomethanes (THMs) are chemical compounds in which three of the four hydrogen atoms of methane (CH_4) are replaced by halogen atoms. Many trihalomethanes find uses in industry as solvents or refrigerants. THMs are also environmental pollutants, and many are considered carcinogenic. Trihalomethanes with all the same halogen atoms are called **haloforms**.

Contents

Table of common trihalomethanes

Common trihalomethanes (ordered by molecular weight)

Molecular formula	IUPAC name	CAS registry number	Common name	Other names	Molecule
CHF_3	trifluoromethane	75-46-7	fluoroform	Freon 23, R-23, HFC-23	
$CHClF_2$	chlorodifluoromethane	75-45-6	chlorodifluoromethane	R-22, HCFC-22	
$CHCl_3$	trichloromethane	67-66-3	chloroform	methyl trichloride	
$CHBrCl_2$	bromodichloromethane	75-27-4	dichlorobromomethane	BDCM	
$CHBr_2Cl$	dibromochloromethane	124-48-1	chlorodibromomethane	CDBM	
$CHBr_3$	tribromomethane	75-25-2	bromoform	methyl tribromide	
CHI_3	triiodomethane	75-47-8	iodoform	methyl triiodide	

Industrial uses

Refrigerants

Trifluoromethane and chlorodifluoromethane are both used as refrigerants in some applications. Trihalomethanes released to the environment break down faster than chlorofluorocarbons (CFCs), thereby doing much less damage to the ozone layer (if they contain chlorine). Chlorodifluoromethane is a refrigerant HCFC, or hydrochlorofluorocarbon, while fluoroform is an HFC, or hydrofluorocarbon. Fluoroform is not ozone depleting.

Unfortunately, the breakdown of trihalomethane HCFCs does still result in the creation of some free chlorine radicals in the upper atmosphere and subsequent ozone destruction. Ideally, HCFCs will be phased out entirely in favour of entirely nonchlorinated refrigerants.

Solvents

Chloroform is a very common solvent used in organic chemistry. It is a significantly less polar solvent than water, well-suited to dissolving many organic compounds.

Although still toxic and potentially carcinogenic, chloroform is significantly less harmful than carbon tetrachloride. Because of the health and regulatory issues associated with the use of carbon tetrachloride, in modern chemistry laboratories chloroform is used as a cheaper, cleaner alternative wherever possible.

Water pollutants

Trihalomethanes are formed as a by-product predominantly when chlorine is used to disinfect water for drinking. They represent one group of chemicals generally referred to as disinfection by-products. They result from the reaction of chlorine and/or bromine with organic matter present in the water being treated. The THMs produced have been associated through epidemiological studies with some adverse health effects. Many governments set limits on the amount permissible in drinking water. However, trihalomethanes are only one group of many hundreds of possible disinfection by-products—the vast majority of which are not monitored—and it has not yet been clearly demonstrated which of these are the most plausible candidate for causation of these health effects. In the United States, the EPA limits the total concentration of the four chief constituents (chloroform, bromoform, bromodichloromethane, and dibromochloromethane), referred to as total trihalomethanes (TTHM), to 80 parts per billion in treated water.

Chloroform is also formed in swimming pools which are disinfected with chlorine or hypochlorite in the haloform reaction with organic substances (e.g. urine, sweat, hair and skin particles). Some of the THMs are quite volatile and may easily vaporize into the air. This makes it possible to inhale THMs while showering, for example. The EPA, however, has determined that this exposure is minimal compared to that from consumption. In swimmers uptake of THMs is greatest via the skin with dermal absorption accounting for 80% of THM uptake[1]. Exercising in a chlorinated pool increases the toxicity of a "safe" chlorinated pool atmosphere[2] with toxic effects of chlorine byproducts greater in young swimmers than older swimmers[3].

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1. ^ Lindstrom, AB et al. (1997) Alveolar breath sampling and analysis to assess trihalomethane exposures during competitive swimming training. Environ. Health Persp., 105 (6), 636-642
2. ^ Drobnic, F.et al. (1996) Assessment of chlorine exposure in swimmers during training. Medicine and Science in Sports and Exercise, 28 (2), 271-274
3. ^ Aiking,H. et al. (1994) Swimming pool chlorination: a health hazard? Toxicology Letters, 72(1-3), 375-380

External links

- National Pollutant Inventory - Chloroform and trichloromethane (http://www.npi.gov.au/database/substance-info/profiles/23.html)
- How Ozone Technology Reduces Disinfection Byproducts (http://www.biozone.com/trihalomethanes.html)
- Testing for Trihalomethanes (http://www.caslab.com/News/testing-for-trihalomethanes-in-your-water-tthm.html)
- EPA - Trihalomethanes in Drinking Water (http://yosemite.epa.gov/water/owrccatalog.nsf/9da204a4b4406ef885256ae0007a79c7/be44ad7c8f83f25a85256b06007255e9!OpenDocument)

Retrieved from "http://en.wikipedia.org/wiki/Trihalomethane"
Categories: Halomethanes | Halogenated solvents | Refrigerants

- This page was last modified on 22 March 2011 at 03:47.
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Environmental and Workplace Health

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1.0 Guidelines

Trihalomethanes

The maximum acceptable concentration (MAC) for trihalomethanes[1] *(THMs) in drinking water is 0.100 mg/L (100 µg/L) based on a locational running annual average of a minimum of quarterly samples taken at the point in the distribution system with the highest potential THM levels.*

Bromodichloromethane

The maximum acceptable concentration (MAC) for bromodichloromethane (BDCM) in drinking water is 0.016 mg/L (16 µg/L) monitored at the point in the distribution system with the highest potential THM levels.

Other Considerations

Utilities should make every effort to maintain concentrations as low as reasonably achievable without compromising the effectiveness of disinfection.

2.0 Executive summary

Trihalomethanes are a group of compounds that can form when the chlorine used to disinfect drinking water reacts with naturally occurring organic matter (e.g., decaying leaves and vegetation). The use of chlorine in the treatment of drinking water has virtually eliminated waterborne diseases, because chlorine can kill or inactivate most microorganisms commonly found in water. The majority of drinking water treatment plants in Canada use some form of chlorine to disinfect drinking water: to treat the water directly in the treatment plant and/or to maintain a chlorine residual in the distribution system to prevent bacterial regrowth. The health risks from disinfection by-products, including trihalomethanes, are much less than the risks from consuming water that has not been disinfected. Utilities should make every effort to maintain concentrations of all disinfection by-products as low as reasonably achievable without compromising the effectiveness of disinfection.

The trihalomethanes most commonly found in drinking water are chloroform, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform. Of these, chloroform has been most extensively studied, and there are some scientific data available on BDCM. However, insufficient data are available to develop a guideline for either DBCM or bromoform. Since chloroform is the trihalomethane most often found in drinking water, and generally at the highest concentrations, the trihalomethane guideline is based on health risks linked to chloroform. This guideline applies to the total concentration of chloroform, BDCM, DBCM and bromoform.

This Guideline Technical Document reviews all the health risks associated with trihalomethanes in drinking water, incorporating multiple routes of exposure to trihalomethanes via drinking water including ingestion, and both inhalation and skin absorption from showering and bathing. It assesses all identified health risks, taking into account new studies and approaches, and applies appropriate safety factors. Based on this review, the guideline for total trihalomethanes in drinking water is established at a maximum acceptable concentration of 0.1 mg/L.

Although the concentration of BDCM is included in the concentration of trihalomethanes in the guideline, a separate guideline for BDCM is also deemed necessary. The guideline for bromodichloromethane in drinking water is established at a maximum acceptable concentration of 0.016 mg/L.

2.1 Health effects

Chloroform is considered to be a possible carcinogen in humans, based on limited evidence in experimental animals, and inadequate evidence in humans. Animal studies have shown links between exposure to specific trihalomethanes and liver tumours in mice and kidney tumours in both mice and rats; some studies in humans show data that are consistent with these findings. Human studies are suggesting a link between exposure to trihalomethanes and colorectal cancers.

Human studies also suggest a link between reproductive effects and exposure to high levels of trihalomethanes. However, an increase in the concentration of trihalomethanes could not be linked to an increase in risk, suggesting the need for more studies.

Preliminary animal studies indicate that BDCM and other trihalomethanes that contain bromine may be more toxic than chlorinated trihalomethanes such as chloroform. For this reason, and based on the availability of scientific data for BDCM, a separate guideline was also developed for BDCM. BDCM is considered to be a probable carcinogen in humans, with sufficient evidence in animals and inadequate evidence in humans. Animal studies have shown tumours in the large intestine in rats. Among the four trihalomethanes commonly found in drinking water, BDCM appears to be the most potent rodent carcinogen, causing tumours at lower doses and at more target sites than the other three compounds.

Exposure to BDCM at levels higher than the guideline value has also been linked to a possible increase in reproductive effects (increased risk for spontaneous abortion or stillbirth) above what can normally be expected. Further studies are required to confirm these effects.

2.2 Exposure

Levels of trihalomethanes, including BDCM, are generally higher in treated surface water than in treated groundwater, because of the high organic content in lakes and rivers, and will be higher in warmer months, because of the higher concentrations of precursor organic materials in the raw water and especially because the rate of formation of disinfection by-products increases at higher temperatures. Trihalomethanes levels are also affected by the choice and design of treatment processes. Recent data indicate that, in general, average trihalomethanes levels in Canadian drinking water supplies are well below the guideline. However, some systems show average levels well above the guidelines; these systems serve only a small proportion of Canadians (less than 4%) and are generally smaller treatment systems with limited ability to remove organic matter before adding the chlorine disinfectant. It should be noted that the presence of brominated by-products such as BDCM will also depend on the presence of bromine in the source water.

2.3 Treatment

Trihalomethanes and haloacetic acids are the two major groups of disinfection by-products found in drinking water and generally at the highest levels. Together, these two groups can be used as indicators for the presence of all disinfection by-products in drinking water supplies, and their control is expected to reduce the levels of all disinfection by-products and the corresponding risks to health. A guideline for haloacetic acids is expected to be available in 2006-2007.

The approach to reduce exposure to trihalomethanes is generally focussed on reducing the formation of chlorinated disinfection by-products. The concentrations of trihalomethanes and other chlorinated disinfection by-products in drinking water can be reduced at the treatment plant by removing the organic matter from the water before chlorine is added, by optimizing the disinfection process or using alternative disinfection strategies, or by using a different water source. It is critical that any method used to control trihalomethanes levels **must not** compromise the effectiveness of disinfection. The Federal-Provincial-Territorial Committee on Drinking Water also recommends that every effort be made not only to meet the guideline, but to maintain concentrations of trihalomethanes as low as reasonably achievable.

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[1] Trihalomethanes refers to the total of chloroform, bromodichloromethane, dibromochloromethane and bromoform

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Tech Brief

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Line Pigging

By Zane Satterfield, P. E., NESC Engineering Scientist

Summary

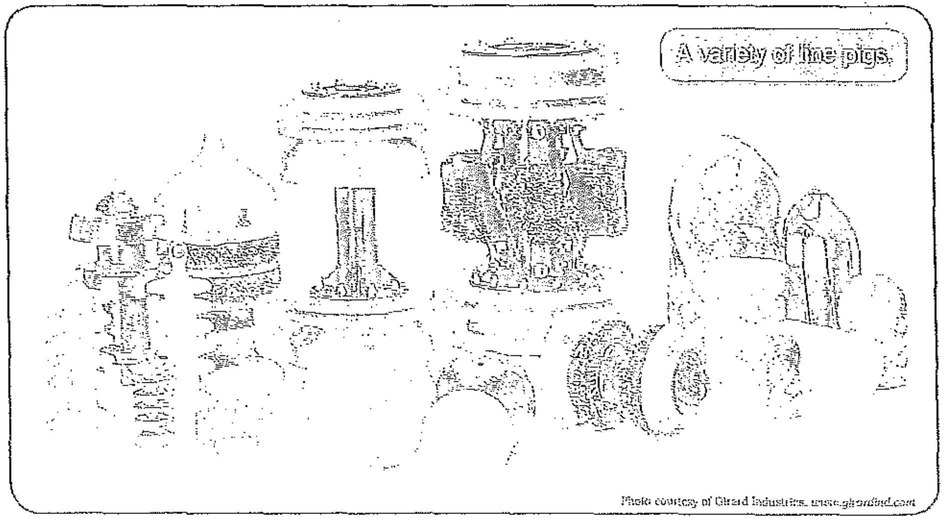
Line pigging is an internal pipe-cleaning process used to remove biofilms or other foreign matter from the inside of water pipes. If performed correctly, line pigging will renew the flow rates to restricted piping systems and reduce pumping pressures. This Tech Brief discusses some of the techniques and processes used in cleaning waterlines in distributions systems.

Line Pigging

Line pigging (or line swabbing, as it sometimes known), is the process of cleaning distribution lines by inserting a small device known as a pig into the lines and pushing it through them. The term "pigging" originated in the gas and oil industry, where metal discs connected by a rod were moved through the oil pipelines to remove buildup of paraffin wax on the internal wall of the pipe. The action of metal on metal made a squealing noise like a pig and the name stuck. More and more, pigs are being used to clean pipelines in all types of industry including waterlines in municipal distribution systems.

What is a pig?

A pig is the object, usually bullet shaped, that is pushed by the water in the pipe in the direction of normal flow. The pig can be made of different materials (foam, steel, plastic, polyurethane), but generally is food-grade silicon, which is tough yet flexible and safe to be in contact with drinking water.



A variety of line pigs.

Photo courtesy of Girard Industries, www.girardind.com

Pigs range in size from 2- to 48-inches in diameter and can be made to order in varying lengths, styles, and configurations for specific applications. Not only are pigs used for cleaning but also for inspecting the inside of pipelines and determining interior dimensions.

Is pigging waterlines really necessary?

States and municipalities typically do not require regular pigging or swabbing of distribution lines in water systems. Some may only require pigging after initial construction of a new line to remove any debris left in the line because flushing alone will not always clean the dirt and debris out of the line.

A photo of a 4 x 4 that was pushed out of an 8" water line. It took several pigs to finally get it out, and it came out in pieces, but they finally pigged it out.

[illegible]

One reason to pig a waterline is that all distribution lines tend to have a biofilm coating the inside of the pipe. The bacteria are dormant until certain conditions activate the bacteria, causing problems. Regular flushing will not eliminate this biofilm. Regular pigging with flushing will reduce or eliminate biofilms.

A second reason to pig a line is inadequate water flow. More flow (volume) of water may be needed to support development or a growing population in the water system or to provide adequate water for fire fighting. In areas of water systems where increased development has caused water demand to surpass the flow output of an existing line, the system will usually need to replace the existing waterline with a line that can support the demand needed. If the existing flow is restricted due to excessive deposits, however, pigging may be the solution to the problem.

Third, most states require a minimum of a 6-inch diameter waterline when connecting a fire hydrant to provide adequate flow. After years of service, the inside of the pipe can become restricted with deposits making the fire hydrant less effective if not useless for its intended job. If fire flow is needed, the solution in the past has been to replace the whole waterline, which is very costly and time consuming. Pigging may restore adequate flow for fighting fires at a fraction of the time and cost.

Finally, pigging waterlines may lessen complaints from water customers regarding the very same deposits that have or can restricted fire flow. These deposits are unwanted foreign matter such as iron oxide (red water), alum, calcium carbonates, barium sulfide and sediment. Pigging, in most cases, provides a solution. Cleaning these deposits can also reduce pumping pressures in areas of water systems that have booster pump stations. Increased pumping pressures can result in line leaks and pipe failures.

Procedure

The procedure starts by determining if the waterline can be pigged. Not every water line is a candidate for line pigging. Is the water line so corroded that pigging can cause failure?

Does the waterline have reducers (i.e., the line getting smaller) that can cause the pig to get stuck? Does the line have increased pipe diameter sizes where the water pressure would be insufficient to move the pig?

One of the main things to look at is the condition of the interior of the pipe. If the pH of the water is low, the interior of the line could be so corroded that pigging could result in failure. If in doubt about the condition of the line, refer to past line repairs or talk to operators who have worked on any repairs of the particular line.

Much of this information can be obtained from as-built drawings or operators who have fixed leaks or installed the original water line. The line will have to be dug up to launch the pig. At that time, a visual inspection should be done to determine if pigging is possible. Another option is to use a low density foam pig in any unknown line and examine the foam pig for wear patterns, tears, or gouges. This may even help determine if the line can be successfully cleaned with a pig.

Before the pigging begins, it's useful to have information about the line:

1. Locate and mark all valves and meters.
2. Approximate all elbows and fittings in the line (again, refer to the as-built drawing if available).
3. Know the pressure and flows in the lines. This will also help determine if any flow increase and possibly pressure decrease was achieved by the pigging.

The more you know before you start, the fewer surprises you'll encounter once you start pigging.

Once the line has been inspected and appears suitable, the actual pigging begins. A pig is inserted into the line to be cleaned by means of a launcher. This is simply an oversized barrel with a reducer mating to the existing line. This allows for easy insertion of the pig, because the pig's outer diameter is larger than the pipe's internal diameter to maintain a good seal. Once in the launcher, clean water is introduced to send the pig on its way. This is usually the same water that is in the line from a nearby flushing hydrant or fire hydrant, or a tanker truck. The pig's path is determined by direction of flow and by isolating the line to be cleaned by closing valves to laterals, if present.

If the waterline is in service, you must notify your customers about the water interruption and possible dirty water after bringing the line back in service. If the water line has a lot of unwanted deposits, it may be wise to pull all water meters just before the pigging process starts and flush at the connection at the end of the process before you replace the meters. Foreign matter could stop-up the meter or cause the meter to malfunction. The debris could also get into the customers' plumbing and cause problems such as plugging the aerators on the faucets, dishwashers, or washing machines.

If the waterline to be pigged has severe scaling (tuberculation) due to iron oxide (red water), alum, calcium carbonates, barium sulfide, or sediment, a progressive or stepped approach must be taken to avoid getting a pig stuck or losing a pig. This approach is simply using a smaller diameter pig at first and working your way up incrementally to the inside diameter of the pipe. The stepped technique will minimize the risk of the pig getting stuck or large amounts of debris plugging the line by cleaning a little bit at a time.

Articles about locating distribution lines and valve exercising programs are available on the National Environmental Services Center Web site at *www.nesc.wvu.edu/ndwc.*

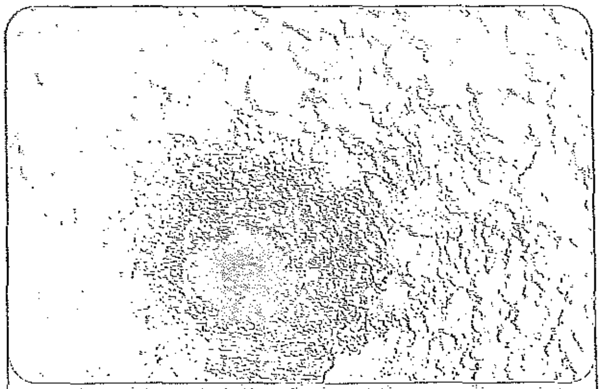
Smart Pigs

There are many different types and sizes of pigs. For waterline use, some nonstandard pigs include:

- Gauging pigs are mainly used after constructing the pipeline or before pigging an old line to determine if there are any obstructions in the pipeline.
- Profile pigs are gauging pigs with multiple gauging plates used to help map the inside condition of the pipe walls.
- Magnetic cleaning pigs are used to pick up ferrous debris left in the pipeline.
- Transmitter pigs or detector pigs are used to map out the location of pipeline or help locate a stuck pig.
- Spheres are round for ease in negotiating short radius 90-degree elbows, irregular turns, bends, and sweeps.

Dealing with a Stuck or Lost Pig

If a pipeline has not been pigged on a routine basis or has never been pigged, a pig can get stuck. If a pig becomes stuck, the first priority



A pipeline prior to line pigging.

Photo courtesy of Girard Industries [illegible]

is to find and retrieve it, but you must identify the cause. Usually one of two conditions exists when a pig is stuck: fluid bypassing around the pig (not pushing the pig) or a blockage of the flow.

In water distribution systems that have loops and multiple tee connections a pig can find its way out of the work area and get lost. It is important to locate all valves and close off the lines that are not being pigged and know the direction of water flow.

If you lose a pig, a smart pig such as a detector pig or transmitter pig can be launched to help find the lost pig. A transmitter can also be installed in the cleaning pig so that a second pig does not have to be launched to help locate it if it should get lost or stuck. Sometimes a pig gets stuck because of a broken or shut gate valve.

Procedures for dealing with a stuck pig or fluid going around the pig:

1. Increase the line pressure and flow rate, but do not exceed the safe limits of the pipeline allowing for age and/or condition of the line. The flow rate and pressure can be increased with a pumper and tanker fire truck.
2. Release pressure from the line and drain the line back toward the launcher. Releasing pressure allows the pig to relax to its normal shape and may even cause the pig to back up in the line. After pressure has dissipated completely for several minutes, re-pressurize the line in an attempted to drive the pig through the restriction. This may be repeated two or three times.
3. For a bypass situation, run a soft swab in behind the stuck pig to try and create a positive seal, stopping the bypass. Repeat step one above.
4. Back the pig up by applying pressure from the opposite end of the waterline using a pump or possibly a pumper fire truck.
5. If a foam pig is used and gets stuck a super-chlorinate mixture (3,000 to 5,000 ppm) in a slug form can be used to dissolve the pig. The line must be flushed and tested to be sure the chlorine residual is allowable limits after the super chlorination.

Water systems are advised not to undertake line pigging on their own. Shop around and find a reputable company with experience in line pigging with water lines. Start with an area of the water system that the line location, size, type, and condition are all known and the lines can be dug up easily if needed.

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Special thanks to Jim Burris at Girard Industries for his assistance.

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Analytical Report

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Attn: Jeniene Lutz
Sampled By:
Company:

Project:
ID: Village of Harrison Springs
Name: THM
Location:
LSD:
P.O.:
Acct code:

Lot ID: 822700
Control Number:
Date Received: Aug 25, 2011
Date Reported: Aug 30, 2011
Report Number: 1465090

Reference Number 822700-1
Sample Date Aug 24, 2011
Sample Time NA
Sample Location
Sample Description Village of Harrison Hot Springs
Matrix Water

Analyte		Units	Results	Results	Results	Nominal Detection Limit
Trihalomethanes Screen - Water						
Chloroform		mg/L	0.038			0.001
Bromodichloromethane		mg/L	<0.001			0.001
Dibromochloromethane		mg/L	<0.001			0.001
Bromoform		mg/L	<0.001			0.001
Total Trihalomethanes		mg/L	0.038			0.001
Trihalomethanes - Surrogate Recovery						
Dibromofluoromethane	EPA Surrogate	%	105			86-118
Toluene-d8	EPA Surrogate	%	101			85-115
Bromofluorobenzene	EPA Surrogate	%	92			86-115

Approved by: Mathieu Simoneau

Mathieu Simoneau
Operations Manager

Health Canada Santé Canada Canada

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Environmental and Workplace Health

Guidelines for Canadian Drinking Water Quality - Summary Table

Prepared by the
Federal-Provincial-Territorial Committee on Drinking Water of the
Federal-Provincial-Territorial Committee on Health and the Environment

December 2010

Help on accessing alternative formats, such as Portable Document Format (PDF), Microsoft Word and PowerPoint (PPT) files, can be obtained in the alternate format help section.

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Introduction

The *Guidelines for Canadian Drinking Water Quality* are published by Health Canada on behalf of the Federal-Provincial-Territorial Committee on Drinking Water (CDW). This summary table is updated regularly and published on Health Canada's website (www.healthcanada.gc.ca/waterquality). It supersedes all previous versions, as well as the published booklet of the *Sixth Edition of the Guidelines for Canadian Drinking Water Quality*.

These guidelines are based on current, published scientific research related to health effects, aesthetic effects, and operational considerations. Health-based guidelines are established on the basis of comprehensive review of the known health effects associated with each contaminant, on exposure levels and on the availability of treatment and analytical technologies. Aesthetic effects (e.g., taste, odour) are taken into account when these play a role in determining whether consumers will consider the water drinkable. Operational considerations are factored in when the presence of a substance may interfere with or impair a treatment process or technology (e.g., turbidity interfering with chlorination or UV disinfection) or adversely affect drinking water infrastructure (e.g., corrosion of pipes).

The Federal-Provincial-Territorial Committee on Drinking Water establishes the Guidelines for Canadian Drinking Water Quality specifically for contaminants that meet all of the following criteria:

1. exposure to the contaminant could lead to adverse health effects;
2. the contaminant is frequently detected or could be expected to be found in a large number of drinking water supplies throughout Canada; and
3. the contaminant is detected, or could be expected to be detected, at a level that is of possible health significance.

If a contaminant of interest does not meet all these criteria, the Federal-Provincial-Territorial Committee on Drinking Water may choose not to establish a numerical guideline or develop a Guideline Technical Document. In that case, a Guidance Document may be developed.

Guidance Documents undergo a process similar to Guideline Technical Documents, including public consultations through the Health Canada website. They are offered as information for drinking water authorities, and help provide guidance relating to contaminants, drinking water management issues or emergency situations. Consultation documents, Guideline Technical Documents and Guidance documents are available from the Health Canada website (www.healthcanada.gc.ca/waterquality).

In general, the highest priority guidelines are those dealing with microbiological contaminants, such as bacteria, protozoa and viruses. Any measure taken to reduce concentrations of chemical contaminants should not compromise the effectiveness of disinfection.

Inquiries can be directed to: water_eau@hc-sc.gc.ca

Membership of the Federal-Provincial-Territorial Committee on Drinking Water

Jurisdictional representatives

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British Columbia	Ministry of Health Services	Mr. Barry Boettger
Manitoba	Department of Water Conservation	Ms. Kim Philip
New Brunswick	Department of Health and Wellness	Ms. Karen White
Newfoundland and Labrador	Department of Environment and Conservation	Mr. Haseen Khan
Northwest Territories	Stanton Territorial Health Authority	Mr. Duane Fleming
Nova Scotia	Department of Environment and Labour	Ms. Judy MacDonald
Nunavut Territory	Department of Health and Social Services	Mr. Peter Workman
Ontario	Ministry of the Environment	Dr. Satish Deshpande
Prince Edward Island	Department of Environment, Energy and Forestry	Mr. George Somers
Québec	Ministère du Développement durable, de l'Environnement et des Parcs	Ms. Caroline Robert
Saskatchewan	Department of the Environment	Mr. Sam Ferris
Yukon Territory	Department of Health and Social Services	Ms. Patricia Brooks
Canada	Department of Health	Dr. John Cooper

Liaison officers

Federal-Provincial-Territorial Committee on Health and the Environment (CHE)	Mr. Peter Workman
Environment Canada/Canadian Council of Ministers of the Environment	Dr. Doug Spry

Committee secretary

Health Canada (Water, Air and Climate Change Bureau, Safe Environments Directorate, Healthy Environments and Consumer Safety Branch)	Ms. Anne Vézina

New, revised, reaffirmed and upcoming guidelines

Guidelines for several chemical, physical and microbiological parameters are new or have been revised since the publication of the *Sixth Edition of the Guidelines for Canadian Drinking Water Quality* in 1996. These new and revised guidelines are presented in Table 1.

Table 1. New and revised guidelines

Parameter	Guideline (mg/L)	Previous guideline (mg/L)	CHE approval
Microbiological parameters[a]			
Bacteriological		0 coliforms/100 mL	
E.coli	0 per 100 mL		2006
Total coliforms	0 per 100 mL		2006
Heterotrophic plate count	No numerical guideline required		2006
Emerging pathogens	No numerical guideline required		2006
Protozoa	No numerical guideline required	None	2004
Enteric viruses	No numerical guideline required	None	2004
Turbidity	0.3/1.0/0.1 NTU[b]	1.0 NTU	2004
Chemical and physical parameters			
Aluminum	0.1/0.2[c]	None	1999
Antimony	0.006	None	1997

[a] Refer to section on Guidelines for microbiological parameters.

[b] Based on conventional treatment/slow sand or diatomaceous earth filtration/membrane filtration.

[c] This is an operational guidance value, designed to apply only to drinking water treatment plants using aluminum-based coagulants. The operational guidance values of 0.1 mg/L applies to conventional treatment plants, and 0.2 mg/L applies to other types of treatment systems.

[d] The separate guideline for BDCM was rescinded based on new science. See addendum to the THM document. In certain situations, the Federal-Provincial-Territorial Committee on Drinking Water may choose to develop guidance documents: for contaminants that do not meet the criteria for guideline development, and for specific issues for which operational or management guidance is warranted.

Parameter	Guideline (mg/L)	Previous guideline (mg/L)	Date approved
Arsenic	0.010	0.025	2006
Benzene	0.005	0.005	2009
Bromate	0.01	None	1999
Chlorate	1.0	None	2008
Chlorine	No numerical guideline required	None	2009
Chlorite	1.0	None	2008
Cyanobacterial toxins--microcystin-LR	0.0015	None	2002
Fluoride	1.5	1.5	1996
Formaldehyde	No numerical guideline required	None	1998
Haloacetic Acids--Total (HAAs)	0.080	None	2008
2-Methyl-4-chlorophenoxyacetic acid (MCPA)	0.1	None	2010
Methyl *tertiary*-butyl ether (MTBE)	0.015	None	2006
Trichloroethylene (TCE)	0.005	0.05	2005
Trihalomethanes--Total (THMs)[d]	0.100	0.100	2006
Uranium	0.02	0.1	2000
Radiological parameters			
Cesium-137 (^{137}Cs)	10 Bq/L	10 Bq/L	2009
Iodine-131 (^{131}I)	6 Bq/L	6 Bq/L	2009
Lead-210 (^{210}Pb)	0.2 Bq/L	0.1 Bq/L	2009
Radium-226 (^{226}Ra)	0.5 Bq/L	0.6 Bq/L	2009
Strontium-90 (^{90}Sr)	5 Bq/L	5 Bq/L	2009
Tritium (^{3}H)	7000 Bq/L	7000 Bq/L	2009

[a] Refer to section on Guidelines for microbiological parameters.

[b] Based on conventional treatment/slow sand or diatomaceous earth filtration/membrane filtration.

[c] This is an operational guidance value, designed to apply only to drinking water treatment plants using aluminum-based coagulants. The operational guidance values of 0.1 mg/L applies to conventional treatment plants, and 0.2 mg/L applies to other types of treatment systems.

[d] The separate guideline for BDCM was rescinded based on new science. See addendum to the THM document. In certain situations, the Federal-Provincial-Territorial Committee on Drinking Water may choose to develop guidance documents: for contaminants that do not meet the criteria for guideline development, and for specific issues for which operational or management guidance is warranted.

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In certain situations, the Federal-Provincial-Territorial Committee on Drinking Water may choose to develop guidance documents: for contaminants that do not meet the criteria for guideline development, and for specific issues for which operational or management guidance is warranted.

Table 2. Guidance documents

[illegible]	[illegible]
Boil water advisories	2009
Chloral hydrate	2008
Corrosion Control	2009
Drinking water avoidance advisories	2009
Potassium from water softeners	2008

The Federal-Provincial-Territorial Committee on Drinking Water has established a science-based process to systematically review older guidelines to assess the need to update them. Table 3 provides the list of parameters whose guidelines remain appropriate and have been reaffirmed as a result of this review. Health Canada and the FPT Committee on Drinking Water will continue to monitor research on these parameters and recommend any revision(s) to the guidelines that is deemed necessary.

Table 3. Reaffirmed guidelines (2005)

- Asbestos
- Azinphos-methyl
- Bendiocarb
- Benzo(a)pyrene
- Bromoxynil
- Cadmium
- Calcium
- Carbaryl
- Carbofuran
- Chloride
- Colour
- Cyanazine
- Diazinon
- Dicamba
- 2,4-Dichlorophenol
- Diclofop-methyl
- Dimethoate
- Diquat
- Diuron
- Ethylbenzene
- Gasoline
- Glyphosate
- Iron
- Magnesium
- Malathion
- Methoxychlor
- Metribuzin
- Odour
- Paraquat
- Pentachlorophenol
- Phorate
- Picloram
- Silver
- Taste
- Temperature
- Terbufos
- 2,3,4,6-Tetrachlorophenol
- Toluene
- 2,4,6-Trichlorophenol
- Trifluralin
- Xylenes
- Zinc

Table 4 outlines documents which are being or have been developed and are awaiting approval through the Federal-Provincial-Territorial process.

Table 4. Upcoming documents (not yet finalized/approved)

[illegible]	[illegible]	[illegible]
Ammonia	GTD	In preparation[b]
Carbon tetrachloride	GTD	In preparation[a]
Chromium	GTD	In preparation[b]
Dichloroethane, 1,2-	GTD	In preparation[a]
Dichloromethane	GTD	In preparation[a]
E.coli	GTD	In preparation[b]
Enteric viruses	GTD	In preparation[a]
Fluoride	GTD	In preparation[a]
Heterotrophic plate count	guidance	In preparation[a]
Nitrate/Nitrite	GTD	In preparation[a]
N-Nitrosodimethylamine (NDMA)	GTD	In preparation[a]
Protozoa	GTD	In preparation[a]

[a] Final guideline technical document or guidance document in preparation for final approval/posting.

[b] Guideline technical document or guidance document being prepared for public consultation.

Parameter or subject	Document type (GTD or guidance)	Current status
Selenium	GTD	In preparation[b]
Tetrachloroethylene	GTD	In preparation[b]
Total coliforms	GTD	In preparation[b]
Turbidity	GTD	In preparation[b]
Vinyl chloride	GTD	In preparation[b]

[a] Final guideline technical document or guidance document in preparation for final approval/posting.

[b] Guideline technical document or guidance document being prepared for public consultation.

Guidelines for microbiological parameters

Currently available detection methods do not allow for the routine analysis of all microorganisms that could be present in inadequately treated drinking water. Instead, microbiological quality is determined by testing drinking water for *Escherichia coli*, a bacterium that is always present in the intestines of humans and other animals and whose presence in drinking water would indicate faecal contamination of the water.

Bacteriological guidelines

Escherichia coli

The maximum acceptable concentration (MAC) of *Escherichia coli* in public, semi-public, and private drinking water systems is none detectable per 100 mL.

Testing for *E. coli* should be carried out in all drinking water systems. The number, frequency, and location of samples for *E. coli* testing will vary according to the type and size of the system and jurisdictional requirements.

Total coliforms

The MAC of total coliforms in water leaving a treatment plant in a public system and throughout semi-public and private supply systems is none detectable per 100 mL.

For distribution systems in public supplies where fewer than 10 samples are collected in a given sampling period, no sample should contain total coliform bacteria. In distribution systems where greater than 10 samples are collected in a given sampling period, no consecutive samples from the same site or not more than 10% of samples should show the presence of total coliform bacteria.

Testing for total coliforms should be carried out in all drinking water systems. The number, frequency, and location of samples for total coliform testing will vary according to the type and size of the system and jurisdictional requirements.

Heterotrophic plate count

No MAC is specified for heterotrophic plate count (HPC) bacteria in water supplied by public, semipublic, or private drinking water systems. Instead, increases in HPC concentrations above baseline levels are considered undesirable.

Emerging pathogens

No MAC for current or emerging bacterial waterborne pathogens has been established. Current bacterial waterborne pathogens include those that have been previously linked to gastrointestinal illness in human populations. Emerging bacterial waterborne pathogens include, but are not limited to, *Legionella*, *Mycobacterium avium* complex, *Aeromonas hydrophila*, and *Helicobacter pylori*.

Protozoa

Although *Giardia* and *Cryptosporidium* can be responsible for severe and, in some cases, fatal gastrointestinal illness, it is not possible to establish MACs for these protozoa in drinking water at this time. Routine methods available for the detection of cysts and oocysts suffer from low recovery rates and do not provide any information on their viability or human infectivity. Nevertheless, until better monitoring data and information on the viability and infectivity of cysts and oocysts present in drinking water are available, measures should be implemented to reduce the risk of illness as much as possible. If the presence of viable, human-infectious cysts or oocysts is known or suspected in source waters, or if *Giardia* or *Cryptosporidium* has been responsible for past waterborne outbreaks in a community, a treatment and distribution regime and a watershed or wellhead protection plan (where feasible) or other measures known to reduce the risk of illness should be implemented. Treatment technologies in place should achieve at least a 3-log reduction in and/or inactivation of cysts and oocysts, unless source water quality requires a greater log reduction and/or inactivation.

Viruses

Although enteric viruses can be responsible for severe and, in some cases, fatal illnesses, it is not possible to establish MACs for enteric viruses in drinking water at this time. Treatment technologies and watershed or wellhead protection measures known to reduce the risk of waterborne outbreaks should be implemented and maintained if source water is subject to faecal contamination or if enteric viruses have been responsible for past waterborne outbreaks. Where treatment is required, treatment technologies should achieve at least a 4-log reduction and/or inactivation of viruses.

Turbidity

Waterworks systems that use a surface water source or a groundwater source under the direct influence of surface water should filter the source water to meet the following health-based turbidity limits, as defined for specific treatment technologies. Where possible, filtration systems should be designed and operated to reduce turbidity levels as low as possible, with a treated water turbidity target of less than 0.1 NTU at all times. Where this is not achievable, the treated water turbidity levels from individual filters:

1. For **chemically assisted filtration**, shall be less than or equal to **0.3 NTU** in at least 95% of the measurements made, or at least 95% of the time each calendar month, and shall not exceed 1.0 NTU at any time.
2. For **slow sand or diatomaceous earth filtration**, shall be less than or equal to **1.0 NTU** in at least 95% of the measurements made, or at least 95% of the time each calendar month, and shall not exceed 3.0 NTU at any time.
3. For **membrane filtration**, shall be less than or equal to **0.1 NTU** in at least 99% of the measurements made, or at least 99% of the time each calendar month, and shall not exceed 0.3 NTU at any time. If membrane filtration is the sole treatment technology employed, some form of virus inactivation* should follow the filtration process.

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Guidelines for chemical and physical parameters