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Review of Guidelines for Shock Chlorination in Private Wells

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evidence review

Summary

- Microbial contamination of groundwater from private wells can pose a significant health risk to rural Canadians. To mitigate risk, Health Canada currently recommends shock chlorination along with microbial well testing, voluntary measures most often performed by the homeowner.

- However, infrequent testing and paucity of research assessing the effectiveness of shock chlorination guidance as practiced by homeowners, may leave private well users vulnerable to persistent or periodic groundwater contamination.

- Although shock chlorination is important for both health protection and well maintenance, it is not sufficient on its own to guarantee safe drinking water. Rather, shock chlorination should be integrated into a well stewardship approach consisting of adequate well protection and maintenance, a water-monitoring program, and responsible decommissioning of abandoned wells.

Introduction

Groundwater from private wells supports 5 million people across Canada.[1] Although water present in aquifers is usually of very high quality, previous surveys in Alberta,[2,3] Saskatchewan,[4] Ontario,[5] and Nova Scotia[6] have found that 9–34% of wells surveyed exceeded Health Canada's Maximum Acceptable Concentrations (MACs) for total and/or faecal coliforms, among other contaminants.

To mitigate microbiological risk, health agencies and water well installers recommend owners to periodically "shock chlorinate their wells using a simplified version of the original American Water Works Association professional standard[7] for well disinfection. These simplified procedures are inexpensive and can be performed by the well owner; however, methods vary and there is little evidence as to their efficacy.

The purpose of this review is to inform public health inspectors and/or drinking water officers of evidence-based recommendations related to shock chlorination by individual homeowners.

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Methods

Guidelines from Canadian provincial and federal institutions, professional associations, and related academic research were reviewed. Details related to the search strategy are described in Appendix A.

Background

What microbial communities are commonly found in wells?

A well microbial population is divided into "nuisance" bacteria, which affect water quality and pathogens. *Nuisance microorganisms* mainly include iron bacteria, which form a red slime that can clog the well screen,[8] and sulphate-reducing bacteria (SRB). SRB produce H_2S gas (rotten egg odour) and contributes to the corrosion of the well casing and equipment. Although these nuisance bacteria are not themselves considered harmful, they are a health concern because they can form pathogen-protecting biofilms and interfere with water quality testing for faecal coliforms.[9]

Harmful microorganisms include pathogenic bacteria, protozoa, and viruses. A wide variety of pathogens have been identified in groundwater in the United States.[10] In Canada, research suggests that rural Canadians may be subject to increased health risks due to the use of untreated well water: previous work found that not only were indicator bacteria (total coliforms and *Escherichia coli*) prevalent among wells surveyed, but their presence was significantly associated with gastrointestinal illness in rural families.[11,12] In British Columbia, a GIS-based survey linking the incidence of five common water-borne diseases with water source showed that individuals obtaining their water from untreated private wells had an overall 5.25-fold greater risk of disease compared to those obtaining their water from a treated municipal groundwater system[13]; these diseases (in order of most to least prevalent) included campylobacteriosis, salmonellosis, giardiasis, cryptosporidiosis, and verotoxigenic *E. coli* infection.

How does contamination occur?

Water present in aquifers can be of very high quality; however, well water can become contaminated at the wellhead,[10] where faulty sealing or damage may permit flow down the inside or outside of the well casing. Other common causes include non-hygienic handling of the well equipment during installation or repair, the entry of flood water, or the entry or nearby activity of wildlife.[14]

Sub-surface contamination is another route of microbial contamination, in which pathogens are carried into aquifers by infiltrating water. This inbound movement may be continuous (as from a leaking septic tank) or may be event-driven (manure application). Common point sources include overloaded septic fields, leaking septic tanks, or abandoned wells. Common non-point sources include the presence of animals, and manure or sewage application. These sources may also introduce chemical contaminants into the well (e.g., nitrate (NO_3^-), salts, pesticides, and heavy metals) particularly in agricultural contexts.[4,5]

Weather also plays a role in water well contamination. Previous work on water-borne disease outbreaks in small drinking water systems in Canada showed that illness attributable to well contamination was more likely to occur after heavy rain or spring thaw.[15,16]

What is shock chlorination and what are its limitations?

Shock chlorination involves introducing sodium or calcium hypochlorite at the wellhead, and then allowing this treated water to run through the household water distribution system to eliminate all potential bacterial reservoirs (e.g., dead spaces, toilet tanks, washing machine hoses).

Shock chlorination is cheap, fast, and can be performed on an as-needed basis (e.g., after a flood, suspicious GI illness, or a positive test for *E. coli*). In addition, it is widely recommended to shock chlorinate at least once a year, in the spring or fall, as part of a well maintenance program to control nuisance bacteria. However, shock chlorination presents its limitations:

- The effect of shock chlorination is temporary if the source of contamination is not addressed before treatment. In a survey of rural wells in Pennsylvania, it was found that shock chlorination combined with limiting wellhead entry (through grouting and capping) suppressed *E. coli* for only 1–2 months in previously contaminated wells.[17] Likewise, in Bragg Creek, Alberta, wells drawing from a heavily contaminated aquifer remained *E. coli*-free for only one to several weeks after shock chlorination, and microbes returned sporadically several times throughout the year.[2] In such cases, the short-lived effect of chlorination may provide homeowners with a false sense of security when an on-going drinking water treatment system is in fact required. This may explain why point-of-entry and point-of-use treatment systems are increasingly used in rural homes.[18]

The short-lived effect of shock chlorination highlights the need for more frequent testing of private wells. A survey showed that fewer than 17 and 10% of people in Ontario and Alberta, respectively, tested their wells more than once per year,[18,19] making it unlikely that contamination events will be detected promptly.

- Shock chlorination does not reliably eradicate all microbial populations. For example, *Cryptosporidium* oocysts show remarkable free chlorine tolerance, especially at cooler temperatures. In a previous study, treatment with 968 mg L^{-1} free chlorine for 24 hours resulted in only 85% inactivation of oocysts at 10°C,[20] falling well short of the required 99.9% guideline for drinking water.[21] In addition, biofilms may further hinder disinfection[9] and facilitate rapid resurgence.[22]
- Lastly, shock chlorination is not an appropriate treatment option for other non-microbiological contaminants, such as nitrate, heavy metals, or pesticides, which may enter wells and aquifers through similar pathways.[10,23]

Shock Chlorination Overview

In this section, each step in the "standard" shock chlorination method is identified based on published guidelines (Appendix B, Table 1). Differences in practice and their potential health risks are identified accordingly (Appendix B, Table 2). Where possible, scientific literature is used to justify the best approach and to identify gaps.

Preparation and hazard identification

The underlying causes of quality breaches need to be addressed before chlorinating. This includes an inspection of the wellhead and immediate surroundings and performing necessary repairs to the wellhead (cracked caps, gaps between the well casing and the ground, etc.). Non-point contamination risks can be difficult to assess. Hydrogeological factors, including soil quality (e.g., texture, and thickness), depth to groundwater, and geological context, may allow contaminants to be carried some distance (and depth) from the original point of contamination.[14]

Homeowners also need to be aware of risks that can be associated with shock chlorination:

- *Health risks* include corrosivity/burns, vapour hazards (especially in pit wells), and even electrical shock from exposed pump wiring. Personal protective equipment is required from the start of the procedure.
- There are *environmental risks* (to lawns and aquatic habitat) as well as potentially costly *equipment risks* (Table 2). Risks to equipment include: damaging water softeners and filtration units; altering septic systems efficiency by killing beneficial bacteria; corroding the pump and well casing; overpumping wells and aggravating sedimentation; and the potential for well collapse due to physical stress on old corroded wells.[24]

Chlorine options and dose calculation

Chlorine options include sodium hypochlorite (liquid bleach*)* or calcium hypochlorite (tablets), although liquid bleach is generally favoured as it is less hazardous and easier to mix in the well column. When using liquid bleach, it is important to use only detergent-free, unscented product that has been recently purchased. Heavy biofilms of nuisance bacteria in older or infrequently chlorinated wells may require additional chemical treatments, scrubbing, or surging, and a professional is strongly recommended in these cases.[25,26]

Guidelines do not generate a standardized dose for a given well. Currently, Health Canada recommends a minimum free chlorine concentration of 50 mg L^{-1} for established wells and 250 mg L^{-1} for new wells for 24 hours.[27] Other guidelines propose concentrations up to 1530 mg L^{-1} (Table 2). However, more is not always better; Schnieders[28] showed through a laboratory study that 50–200 mg L^{-1} free chlorine was most effective in eliminating total coliforms, whereas higher doses were less so. The author postulated that very high doses altered the surface characteristics of biofilms in such a way that chlorine was less likely to penetrate. Although a single study, these results emphasize the need to better understand free chlorine dose, disinfection efficacy, and the effect of biofilms in water wells. In addition to potential corrosive damage to well equipment at concentrations > 500 mg L^{-1},[29] applying very high doses may in fact reduce disinfection efficiency. This is because the chemical equilibrium of free chlorine species is determined by pH, with maximum biocidal efficiency at a slightly acidic pH.[30] Thus, adding large amounts of bleach without concomitant acidification may hinder disinfection. Lastly, high chlorine doses may increase hazard to the operator as well as intensify potential chemical releases in the well (see *Purging chlorine and other potentially released contaminants*).

Calculating an appropriate chlorine dose for the specific needs of the well is not straightforward and dose calculation may be a barrier to performing shock chlorination. Most guidelines use tables (ranging in complexity) that relate a given well casing diameter and water column height to a specific reagent volume or weight. Some provide options for multiple casing sizes, multiple reagent choices (sodium or calcium hypochlorite), and instructions for older or large-diameter wells, which may facilitate (or complicate) home use. Other guidelines, however, use large increments in water depth to calculate dose,[25] which may lead to large discrepancies in the final dose for wells of varying depths.

Because of the lack of or confusing information around dose calculation, and because homeowners may be referring to the internet for well information,[19] it may be useful to provide an online calculator, as offered by the province of Quebec,[31] to avoid dose miscalculation and increase homeowner confidence.

Application and mixing

Once an appropriate dose is calculated, it must be introduced to the well, mixed, and pushed throughout the distribution system. Pouring concentrated bleach or dropping tablets down the well is not recommended; it cannot guarantee mixing and will expose the well equipment (e.g., the pump, pitless adaptor, and wiring) to elevated chlorine concentrations that can be difficult to clear even with extensive pumping.[32] As an alternative, Alberta Agriculture and Rural Development[24] recommends mixing the chlorine in an above-ground tank containing two well volumes of clean water, and then using a length of clean hose to siphon this solution as deeply as possible into the well. Then, the user is instructed to connect the garden hose to an external tap and circulate the water from the well into the household distribution system and back again to promote mixing.

It is essential to introduce chlorinated water throughout the entire household distribution system. Although most guidelines instruct users to open all faucets, the plumbing (including dead ends and cross connections) and associated devices (pressure tanks, hot water heaters, dehumidifiers, sprinkler systems, toilets and washers, etc.) are all potential reservoirs for microbial growth that can re-contaminate a system through backflow.

Disinfection time and dose verification

Once the appropriate dose has been confirmed, the recommended disinfection times range from 8–48 hours, with a mean minimum disinfection time of 12 hours. However, because shock chlorination is often performed with a limited amount of information about well characteristics (e.g., presence of substances that may affect the free chlorine residual and disinfection efficiency), it is important to verify that a sufficient disinfection dose has been achieved.[33] Although this is rarely suggested in guidelines from Canadian agencies, it is easily achieved using inexpensive, commercially available chlorine test strips to determine free chlorine at the tap. The free chlorine residue should be verified at the beginning of the disinfection period (being at least 50 mg L^{-1}), adjusted as necessary, and should not drop below 10 mg L^{-1} within 12 hours.[29]

Purging chlorine and other potentially released contaminants

After disinfection is complete, most guidelines recommend slowly purging the well over several hours, or until the “strong” chlorine smell is gone.

Generally, consumption of highly chlorinated water is not a health concern due to strong taste aversion. Even so, previous studies have reported human consumption of chlorinated water of $\leq$ 50 mg L^{-1} for weeks to months with no adverse effects, although contact dermal irritation is possible.[34] However, the possible release of metals and formation of chlorine disinfection by-products (DBPs) during shock chlorination is something to monitor.

Several US studies showed transient increased concentrations of arsenic, lead, copper, iron, and zinc in the well water[32,35,36] after shock chlorination; but, the release could not be related to a specific disinfection dose (which ranged from 200–800 mg L^{-1}) and the volume required to purge these contaminants ranged greatly among metals and wells (range, approximately 10 to 90 well volumes). In contrast, others[22] found no increase in arsenic concentration after shock chlorination with 1200 mg L^{-1} of chlorine, highlighting the role of site specificity. In addition to metals, Walker and Newman[35] noted the transient production of low levels of DBPs (e.g., trihalomethanes and haloacetic acids), which are suspected carcinogens when long-term, continuous exposure occurs. However, the levels of both metals and DBPs decreased rapidly in parallel with free chlorine concentration.[35]

These results emphasize the importance of thoroughly flushing the well and testing for free chlorine, both for dose verification and purging, rather than relying on the smell of chlorine alone.

The fear of metals and DBPs should not be a reason to avoid shock chlorination: these research studies are limited in scale (nine wells in total) and the health risk due to pathogens in drinking water is overall much greater and more immediate than those due to DPBs,[37] particularly when DBP exposure is short-lived and infrequent. Rather, the potential for both metals and DPB generation should be addressed proactively. For example, in regions with identified problems (e.g., trace metals or high dissolved organic matter, which favours the formation of DBPs), adding the relevant parameters to the microbiological water quality tests performed soon after shock chlorination may be a way to quell fear over shock chlorination.

Follow-up water quality testing

All guidelines recommend at least one to two follow-up microbiological tests for total and/or faecal coliforms after shock chlorination. The first sample is taken 48 hours to five days post-chlorination, and the second after several weeks to a month. If microbial indicators are still detected post-chlorination, this may indicate faulty chlorination, a problem with the water sampling protocol, or a more serious subsurface contamination issue requiring further investigation.

In addition to post-chlorination testing, well water should be tested several times a year for microbial indicators given that groundwater quality can change rapidly, with sporadic contamination throughout the year.[2] The guidance from Quebec also suggests monitoring for non-microbial parameters, including nitrate (semi-annually), heavy metals (at least once in the lifetime of a well), and any other substance of regional concern.[31]

Research Gaps

- There is a lack of research on how guidelines are implemented by homeowners and how actual practice is related to microbiological water quality. Such a study would serve to probe identified issues, such as dose variation and high dose concentrations, dose calculation, and the usefulness of dose verification, as well as to perform much-needed engagement to promote well stewardship and to increase the data available regarding microbiological quality of rural wells.

- There is little information comparing the practice of homeowners vs. professionals. This distinction is important given that the “homeowner version” of shock chlorination excludes activities deemed too difficult for a non-professional; these include mechanical agitation or cleaning to disrupt biofilms and their encrustations,[32] as well as acidification to maintain the well at the pH optimum for chlorine biocidal activity.[14] If these activities make a substantial difference in shock chlorination efficacy, then it may be necessary to incorporate them into existing guidances, as already attempted by British Columbia.[26]

Recommendations

- Water wells and their related equipment represent a large investment for rural families; in the recent Alberta Well Survey, a subset of respondents (28%) did not shock chlorinate their well because they believed that shock chlorination would damage it.[19] This is understandable given that some guidelines, particularly those from non-health-related organizations,[24,38] tend to strongly emphasize well equipment risks and even potential well failure from corrosion and physical disturbance (see *Preparation and hazard identification*). Guidelines should better address this concern and provide ways to address and/or minimize the risk of equipment damage.

- Further research is needed to arrive at a robust shock chlorination protocol.

- The most important point to be taken from this review is that shock chlorination alone is not sufficient to ensure water quality. Rather, safe well water requires a well stewardship approach,[39] which describes a suite of voluntary actions aimed at first ensuring that wells are made less vulnerable through proper sitting and construction, and then encouraging regular well maintenance, monitoring, and finally responsible decommissioning. Such an approach may prevent some of the broader contamination and well safety issues identified in *Methods*.

- Beyond well stewardship, public health workers should emphasize the importance of preventative shock chlorination (annual or semi-annual) and frequent testing (2–3 times a year or upon suspicion, as recommended by Health Canada).[27] Positive results should be followed by shock chlorination using a standard re-circulation method with free chlorine verification, and most importantly, use of an alternate drinking water source until pathogen elimination has been confirmed through 2–3 “safe” microbiological tests. These suggestions are in line with the most comprehensive guidelines presented in Table 2.

Conclusion

Shock chlorination is important for both health protection and well maintenance. However, it is essential that homeowners understand its limitations, in terms of the contaminants it can reduce or eliminate, as well as the need to test and chlorinate frequently. Furthermore, the efficacy of shock chlorination is heavily dependent on whether it is correctly performed. Although shock chlorination is widely promoted as a “do-it-yourself” activity, and indeed most people who shock chlorinate are doing it independently, further information is needed to judge to what extent this practice is effective and how the standard protocol may be made more robust to protect rural Canadians.

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References

1. Environment Canada. Groundwater. Ottawa ON: Environment Canada; 2013 [cited 2013 Nov]; http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=300688DC-1#sub5.
2. Oliphant JA, Ryan MC, Chu A, Lambert TW. Efficacy of annual bacteria monitoring and shock chlorination in wells finished in a floodplain aquifer. Ground Water Monitoring & Remediation. 2002;22(4):66-72. http://doi.wiley.com/10.1111/j.1745-6592.2002.tb00772.x
3. Fitzgerald D, Kiely D, Neilson D, Shaw R, Audette S, Prior R, et al. Alberta farmstead water quality survey. 1997.
4. Corkal D, Schutzman WC, Hilliard C. Rural water safety from the source to the on-farm tap. Journal of Toxicology and Environmental Health Part A. 2004;67(20-22):1619-42. http://dx.doi.org/10.1080/15287390490491918
5. Goss MJ, Barry DAJ, Rudolph DL. Contamination in Ontario farmstead domestic wells and its association with agriculture. Journal of Contaminant Hydrology. 1998;32(3-4):267-93. http://dx.doi.org/10.1016/S0169-7722(98)00054-0
6. Moerman D, Briggins D. Nova Scotia farm well water quality assurance study. 1994. http://www.gov.ns.ca/nse/groundwater/docs/NSFarmWellWaterQualityAssuranceStudy1994.pdf.
7. American Water Works Association. ANSI/AWWA C 654-03 – “Disinfection of Wells.” Denver, CO; 2003. http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_076337.pdf.
8. Cullimore DR, McCann AE. The identification, cultivation and control of iron bacteria in ground water. In: Skinner FA, Shewan JM, editors. London: Academic Press, Inc.; 1977. p. 219-61. http://www.dbi.sk.ca/Books/PDFs/Water-Paper.PDF.
9. Wingender J, Flemming H-C. Biofilms in drinking water and their role as reservoir for pathogens. International Journal of Hygiene and Environmental Health. 2011;214(6):417-23. http://dx.doi.org/10.1016/j.ijheh.2011.05.009
10. Macler BA, Merkle JC. Current knowledge on groundwater microbial pathogens and their control. Hydrogeology Journal. 2000;8(1):29-40. http://www.springerlink.com/index/10.1007/PL00010972
11. Raina PS, Pollari FL, Teare GF, Goss MJ, Barry DA, Wilson JB. The relationship between E. coli indicator bacteria in well-water and gastrointestinal illnesses in rural families. Canadian Journal of Public Health Revue Canadienne de Sante Publique. 90(3):172-5. http://www.ncbi.nlm.nih.gov/pubmed/10401167
12. Strauss B, King W, Ley A, Hoey JR. A prospective study of rural drinking water quality and acute gastrointestinal illness. BMC Public Health. 2001;1:8. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=57004&tool=pmcentrez&rendertype=abstract
13. Uhlmann S, Galanis E, Takaro T, Mak S, Gustafson L, Embree G, et al. Where's the pump? Associating sporadic enteric disease with drinking water using a geographic information system, in British Columbia, Canada, 1996-2005. Journal of Water and Health. 2009;7(4):692-8. http://www.ncbi.nlm.nih.gov/pubmed/19590137
14. Simpson H. Promoting the management and protection of private water wells. Journal of Toxicology and Environmental Health Part A. 2004;67(20-22):1679-704. http://www.ncbi.nlm.nih.gov/pubmed/15371209
15. Auld H, MacIver D, Klaassen J. Heavy rainfall and waterborne disease outbreaks: the Walkerton example. Journal of Toxicology and Environmental Health Part A. 2004;67(20-22):1879-87. http://dx.doi.org/10.1080/15287390490493475
16. Moffatt H, Struck S. Water-borne disease outbreaks in Canadian small drinking water systems. Ottawa 2011. http://www.nccph.ca/docs/SDWS_Water-borne_EN.pdf.
17. Swistock BR, Sharpe WE. The influence of well construction on bacterial contamination of private water wells in Pennsylvania. Journal of Environmental Health.

2005;68(2):17-22, 36. http://www.ncbi.nlm.nih.gov/pubmed/16220718

18. Jones AQ, Dewey CE, Doré K, Majowicz SE, McEwen SA, David W-T, et al. Public perceptions of drinking water: a postal survey of residents with private water supplies. BMC Public Health. 2006;6:94. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1458329&tool=pmcentrez&rendertype=abstract

19. Summers RJ. Alberta water well survey: a report prepared for Alberta Environment. Edmonton, Alberta; 2010.

20. Ransome ME, Whitmore SN, Carrigton EG. Effect of disinfectants on the viability of *Cryptosporidium parvum* oocysts. Water Supply. 1993;11(1):103-17.

21. Health Canada. Enteric protozoa: *Giardia* and *Cryptosporidium*. Ottawa; 2012. http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/protozoa/index-eng.php.

22. Gotkowitz M, Ellickson K, Clary A, Bowman G, Standridge J, Sonzogni W. Effect of well disinfection on arsenic in ground water. Ground Water Monitoring & Remediation. 2008;28(2):60-7. http://doi.wiley.com/10.1111/j.1745-6592.2008.00192.x

23. Ritter KS. Sources, pathways and relative risks of contaminants in surface water and groundwater: a perspective prepared for the Walkerton Inquiry. Journal of Toxicology and Environmental Health, Part A. 2002;65(1):1-142. http://dx.doi.org/10.1080/152873902753338572

24. Alberta Agriculture and Rural Development. Shock chlorination Edmonton, Alberta: Alberta Agriculture and Rural Development; 2001. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/wwg404.

25. Alberta Water Well Drilling Association. Shock chlorination information. Lougheed AB: AWWDA; 2010 [cited 2013 Nov]; http://www.awwda.com/shock.html.

26. Government of British Columbia. Water well disinfection using the simple chlorination method. Victoria: Government of British Columbia; 2008.

27. Health Canada. Environmental and Workplace Health. What's in your well? A guide to well water treatment and maintenance. Ottawa: Health Canada; 2004 [cited 2013 Nov 5]; http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/well-puits-eng.php.

28. Schnieders JH. Coliforms and disinfection of water wells. Water Well Journal. 2001(October).

29. Advanced Water Systems. AWS technical report: sanitizing pipelines & distribution systems by shock-chlorination Santa Cruz CA; 2003. http://www.advanced-water-systems.com/technical/guides/Tech_Sanitizing_Pipelines.pdf.

30. Le Chevallier MW, Au KK. Water treatment and pathogen control: process efficiency in achieving safe drinking water. London, UK: WHO. http://www.who.int/water_sanitation_health/dwq/9241562552/en/.

31. Québec. Développement durable E, Faune et Parcs. The quality of my well water Québec City: Gouvernement du Québec; 2002 [cited 2013 Nov 5]; http://www.mddefp.gouv.qc.ca/eau/potable/depliant/index-en.htm.

32. Seiler RL. Mobilization of lead and other trace elements following shock chlorination of wells. The Science of the Total Environment. 2006;367(2-3):757-68. http://www.ncbi.nlm.nih.gov/pubmed/16545430

33. Alberta Health Services. Shock chlorination procedure for contaminated wells Edmonton, AB: Alberta Health Services; 2011 [cited 2013 Nov 5]. http://www.albertahealthservices.ca/4323.asp.

34. Health Canada. Environmental and Workplace Health. Guidelines for Canadian drinking water quality.- chlorine technical guideline document. Ottawa: Heatlh Canada; 2009 [cited 2013 Nov 5]; http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/chlorine-chlore/index-eng.php#a4.

35. Walker M, Newman J. Metals releases and disinfection byproduct formation in domestic wells following shock chlorination. Drinking Water Engineering and Science. 2011;4:1-8. http://drink-water-eng-sci-discuss.net/3/177/2010/dwesd-3-177-2010.pdf

36. Sonzogni WC, Clary A, Bowman G, Standridge J, Johnson D, Gotkowitz M. Importance of disinfection on arsenic release in wells Madison WI: University of Wisconsin; 2005: http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?type=header&id=EcoNatRes.SonzogniImport&isize=M&pview=hide.

37. Ashbolt NJ. Risk analysis of drinking water microbial contamination versus disinfection by-products (DBPs). Toxicology. 2004;198(1-3):255-62. http://dx.doi.org/10.1016/j.tox.2004.01.034

38. Alberta Agriculture and Rural Development. Shock chlorinating your well Edmonton AB: Alberta Agriculture and Rural Development; 2009.

39. Kreutzwiser R, de Loë R, Imgrund K, Conboy MJ, Simpson H, Plummer R. Understanding stewardship behaviour: factors facilitating and constraining private water well stewardship. Journal of Environmental Management. 2011;92(4):1104-14. http://dx.doi.org/10.1016/j.jenvman.2010.11.017

40. Government of Saskatchewan. High level chlorine well disinfection. Regina SK: Government of Saskatchewan; 2012 [cited 2013 Nov]. http://www.health.gov.sk.ca/water-well-disinfection-chlorine-highlevel.

41. Manitoba Health. How to reduce the risk of well water contamination. Winnipeg MB: Manitoba Health; 2013.

42. Manitoba Health. How to test well water for bacteria. Winnipeg MB: Manitoba Health; 2013.

43. Manitoba Health. How to disinfect a well full chlorination method. Winnipeg MB: Manitoba Health; 2013 [cited 2013 Nov]. http://www.gov.mb.ca/health/publichealth/environmentalhealth/water.html.

44. New Brunswick Department of Health. How to chlorinate your well water. St. John NB: The Department; 2013.

45. Newfoundland Labrador. Department of Environment and Conservation. Guidelines for disinfecting dug and drilled wells. St John's NL: The Department; 2013 [cited 2013 Nov]. http://www.env.gov.nl.ca/env/waterres/cycle/groundwater/well/disinfecting.html.

46. Nova Scotia Environment and Labour. Disinfection of water wells by chlorination. Halifax NS: Environment and Labour.

47. Ontario Ministry of the Environment. Technical bulletin wells regulation - well disinfection. Toronto ON: The Ministry; 2011.

48. Prince Edward Island Department of Environment LJ. Disinfecting your well. Charlottetown PE: The Department; 2012 [cited 2013 Nov]. http://www.gov.pe.ca/environment/index.php3?number=1015749&lang=E.

Appendix A – Literature Search Strategy

The shock chlorination guidelines reviewed here were identified through Google web searches using the following keyword combinations: (shock chlorination/well chlorination/well disinfection) + Canada. The five most popular (top rated) web pages aimed at the general public were accessed; however, an attempt was also made to find guidelines from each province and territory. The guidelines reviewed were limited to those from governmental agencies or recognized professional associations. These guidances took a variety of forms, from short pamphlets and factsheets to booklet guides and an online modular course. These guidelines were reviewed and compared across more than 50 parameters related to objectives of chlorination, preparation and hazard identification, dose calculation and mixing, disinfection of the household distribution system, purging, and information that sets shock chlorination within a water stewardship context. A highly condensed version of this evaluation is shown in Table 2.

The academic literature was searched much more broadly using Web of Knowledge and Google Scholar and the search terms shown in the matrix below:

Concept 1: *Water source*	**Concept 2:** *Treatment*	**Concept 3:** *Factors affecting effectiveness*
Groundwater well	Maintenance	Biofilm
Private well	Shock chlorination	Chlorine concentration
Water well	Well chlorination	Dissolved organic matter
Well	Well disinfection	Dose
		Effectiveness
		Frequency
		Microbes
		Microbial contamination
		pH

Unlike the guidelines, papers related to the effectiveness of shock chlorination were reviewed from international sources as long as they were generally comparable to the Canadian context in terms of well design and construction (primarily drilled wells with a sanitary cap and annular sealing) and immediate influences on the well.

Appendix B – Tables

Table 1. Standard shock chlorination steps described in provincial, federal, and other guidelines. *Please note: This table is not intended to be used as a shock chlorination protocol*.

Steps	Description
Preparation and Health Hazard Identification	Identify potential sources of well contamination and resolve first. Advise users, reserve water for human use, and by-pass sensitive water treatment systems. Observe hazards and obtain appropriate safety equipment.
Chlorine dose calculation and mixing	Determine an appropriate reagent volume and mix in an above-ground volume of water; this solution is then applied to the bottom of the well (or as deeply as possible) using a garden hose. It may also be re-circulated from the well to the home and back through the hose.
Disinfecting the household distribution system	Run the chlorinated water through all remaining faucets, plumbing, and associated devices. Keep each faucet open until the water has a strong chlorine odour and then turn them off. Commercial Cl^- test strip kits should be used to verify the minimum desired dosage at the tap.
Disinfection Time	Allow to disinfect (mean minimum, 12 h).
Purging	Drain the system to a non-sensitive area through an external tap (i.e., garden hose) until the chlorine odour has diminished, which may require hours to days of slow pumping. The removal of chlorine should be confirmed through commercial test kit strips.
Follow-up testing	Submit water for total or faecal coliform testing after 2–5 days and again after several weeks; well water is deemed safe to drink after 2–3 sequential safe tests.
Maintenance	Protect year-round water quality through good well stewardship, annual or semi-annual chlorination for nuisance bacteria, and regular testing (2-3 times a year, or under suspicion).

Table 2. Condensed literature review matrix comparing practice across Canadian shock chlorination guidelines from government and professional organizations.

Agency	AB Agriculture[24]	AB Environment[38]	AB Health Services[33]	AB Water Well Drilling Assoc.[25]	Govt of BC[26]	Govt of Saskatchewan[40]	Health Canada[27]	Manitoba Health[41,42,43]	Gouvernement du Québec[31]	NB Dept of Environment[44]	Govt. of Newfoundland & Labrador[45]	NS Environment and Labour[46]	ON MOE[47]	PEI Envt Labour & Justice[48]
Why chlorinate?														
Health protection	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Aesthetics (taste/smell)	✓		✓	✓	✓		✓			✓	✓			
Well maintenance	✓	✓		✓	✓						✓			
Dose Calculation														
Liquid Bleach (NaClO)	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓
Tablets ($Ca(ClO_2)$)				✓							✓			
Single dose						✓		✓						✓
Calculated dose (table)	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	
Online calculator									✓					
Target (mg/L)	200	200	50	200	200	n.s.	50	n.s.	50	n.s.	100	100	n.s.	n.s.
[a]Achieved (mg/L)	128	121	32	183	135	1530	358	605	48	1203	69.5	125	50	432
Dose Verification			✓											
Mixing														
Direct pour							✓		✓	✓			✓	
Aboveground mixing	✓	✓	✓	✓	✓	✓		✓			✓	✓		✓
Recirculation					✓		✓	✓		✓	✓	✓	✓	
Disinfection Time (h)	8–48	12–48	8	12–24	12	12	12–24	12–24	24	8–24	12	12–24	12	12
Follow up Testing														
# Tests	n.s.	n.s.	1	n.s.	2	2	2	2	2	1	2–3	3	1	2
Days following	n.s.	n.s.	7	n.s.	7, 30	5,7	7,21	7,30	7,28	n.s.	10	5,30,90		2
Water Stewardship														
Siting & Construction	n.s.	n.s.	✓	✓	✓	n.s.	✓	✓	✓	n.s.	✓	n.s.	✓	n.s.
Source Protection	n.s.	n.s.	✓	✓	✓	✓	✓	✓	✓	n.s.	✓	✓	✓	n.s.
# Annual chlorinations	n.s.	1	n.s.	1	n.s.	2	n.s.	1	n.s.	>1	n.s.	n.s.	n.s.	1
#Annual Tests	n.s.	2	n.s.	n.s.	n.s.	1	2–3	1	2	n.s.	1	2	n.s.	n.s.
Decommissioning	n.s.	n.s.	n.s.	✓	n.s.	n.s.	n.s.	✓	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a]Achieved doses were calculated for a hypothetical well (75 ft deep, 25 ft of water, 6″-casing diameter) based on the guidance; they also account for volume changes due to the addition of water previously drawn for mixing or dissolving reagent.
n.s., not specified.

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