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Understanding microbial indicators for drinking water assessment: interpretation of test results and public health significance

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Introduction

Boil water advisories are issued when water testing detects higher than accepted amounts of microbial indicators or when there are deficiencies with water treatment. The fear of not issuing a boil water advisory when there is truly a health risk associated with water consumption can lead water operators to call for boil water advisories as a precautionary measure. Yet, issuance of boil water advisories can have unintended consequences. Repetitive boil water advisories affect their effectiveness and can translate into a loss of confidence in drinking water systems.¹ There is also an economic impact at the local level, causing a financial loss for the community.¹

Often practitioners interpret the presence of microbial indicators to mean that there is a public health risk, when this is not always true. This document aims to assist environmental health officers in interpreting drinking water laboratory results by describing the types of microbial indicators used, the ways in which they are reported, and their limitations. This document is meant to help EHOs in their decision-making regarding whether or not to intervene (e.g., calling some type of advisory).

Most common microbial indicators: current use

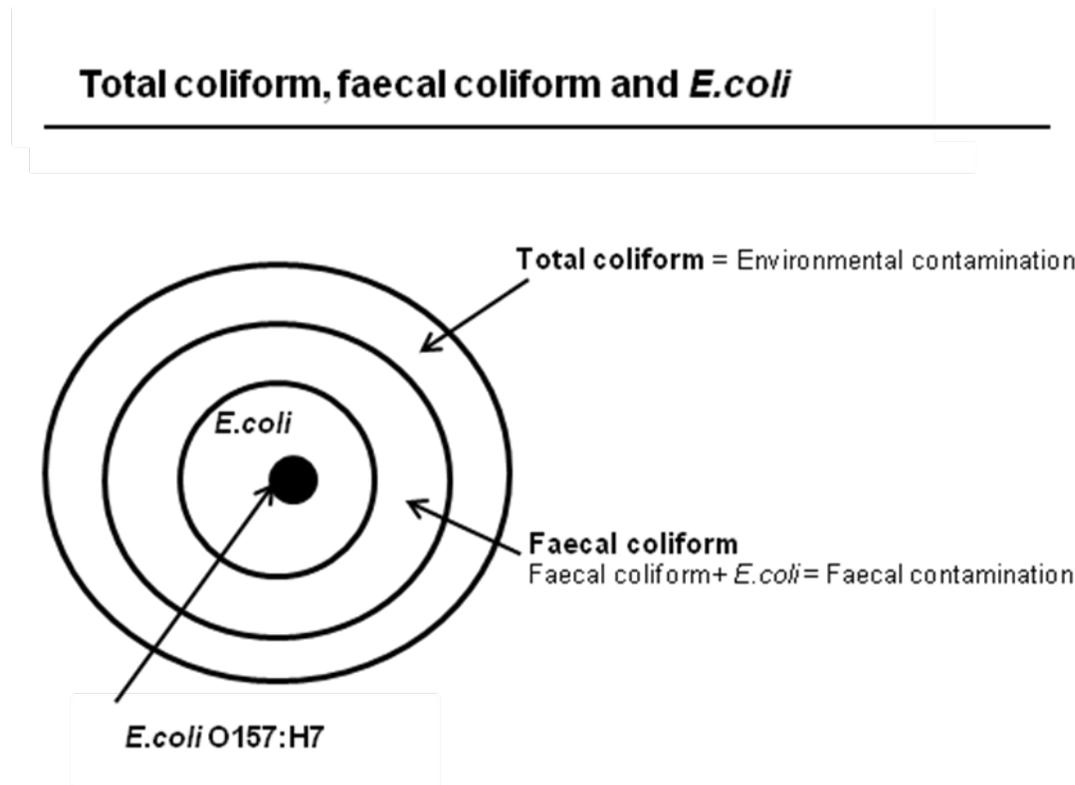
From a microbial perspective, the main public health concern associated with drinking water is enteric disease.²⁻⁴ Because it is impractical to look for all known enteric pathogens that may contaminate drinking water, microbial safety is assessed through detection of indicators of faecal pollution.⁵ A microbial indicator of faecal pollution is an organism occurring in high numbers in human or animal faeces. If detected, it indicates potential faecal (human or animal) contamination of the water body or distribution system under investigation and the consequent potential presence of enteric pathogens. These microbial indicators are generally not themselves human pathogens.

Four main indicators of microbial safety of drinking water have been used: Heterotrophic plate counts (HPC), total coliform (TC), faecal coliform (FC) and *Escherichia coli* (*E.coli*).

The heterotrophic group of bacteria encompass a broad range of bacteria that uses organic carbon sources to grow. Colony counts of heterotrophic bacteria, referred to as HPC, provide an indication of the general load of aerobic and facultative anaerobic bacteria of a water sample. This indicator is also known as standard plate count (SPC), aerobic plate count (APC) and total plate count (TPC). The total coliform group is a large collection of bacteria that are mostly found in the environment (Figure 1). The faecal coliform group is a subset of the total coliform group

that principally exists in faeces, while *E. coli* belongs to the faecal coliform group and is the only member that is specific to the intestinal tract of warm-blooded animals.

Figure 1. The total coliform, faecal coliform and *E.coli* groups



*Adapted from Washington State Department of Health. "Coliform bacteria in drinking water - Total coliform, faecal coliform and *E.coli* (figure)." Retrieved Oct 31, 2012, from <http://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/Contaminants/Coliform.aspx>.*

Heterotrophic Plate Count Bacteria (HPC)

HPC reflects the load of general aerobic bacteria in the water system. Although HPC was used in the late 1800s to assess the "purity" of source water,⁶ it is no longer used as a health-related indicator.⁷ Today, significant changes in HPC serve as an alert for possible deterioration of water quality, triggering further investigation.⁶ An increase in HPC in finished water can indicate a problem with water treatment or a change in quality of the water source, prior to treatment.⁶ When HPC levels leaving the treatment plant are acceptable, but levels in the distribution system are above baseline levels, regrowth may be occurring in the distribution system.⁶

Total Coliforms (TC)

TC are no longer used as an indicator of faecal contamination because advances in the science of taxonomy show that they are not specific to the intestine of humans or warm-blooded

mammals and can also be found in the environment.^{5,8} The presence of TC in water samples can indicate the presence of a biofilm or can serve as an indicator of treatment efficiency because of their sensitivity to chlorine. However, HPC is a better indicator for that purpose because it covers a wider range of bacteria.⁹

Faecal Coliform (FC) or Thermotolerant Coliform

As mentioned above, the faecal coliform group is a subset of the total coliform group and comprises bacteria such as *E. coli* and *Klebsiella pneumoniae*. Although still in use in some jurisdictions, the lack of specificity of the coliform test to faecal pollution of drinking water has long been documented.^{5,10,11} For example, the presence of high *Klebsellia* spp. counts has been associated with various vegetation and pulp and paper effluent in the absence of faecal contamination.^{5,10-12} This is why a positive result for FC should be interpreted with caution.^{5,13} Boil water advisories solely based on FC-positive samples should be eliminated.¹⁴

E.coli

E.coli is the most reliable indicator of enteric diseases and is therefore the indicator of choice to indicate occurrence of recent faecal contamination in drinking water systems.^{4,5,8,15} One exception is in tropical climates where *E.coli* may be present and multiply in waters not directly subject to faecal pollution.¹⁶ Only some strains of *E.coli* bacteria are capable of causing disease^{8,17,18} and only under certain conditions (e.g., *E.coli* O157:H7). When a water sample is tested for the presence of the indicator *E.coli*, results refer to mainly non-pathogenic strains of *E.coli*.

Limitations of microbial indicators

None of the microbial indicators currently in use for routine monitoring of drinking water quality is perfect because no single indicator represents all potential pathogens that can be present in the water. In order to respond to evolving challenges posed by water microbiology, researchers continue to search for the perfect suite of microbial indicators. In this regard, a few other indicators have been proposed, however most of them are not conducive to routine monitoring or have not been integrated into routine monitoring programs. More information regarding their identities and roles are provided in the review by Payment.⁴

The major drawback associated with microbial indicators is the length of time needed to culture the microorganisms. Methods for water analysis are described in detail in the *Standard Method for The Examination of Water and Wastewater*,¹⁹ a reference book for analysis of water microbiology. Depending on the method used, it takes 24 to 48 hours for laboratory results to come back, which means the water has already been consumed before the operator knows it is safe to drink. Another disadvantage of microbial tests is related to the cost of analysis compared with the cost of physical and chemical tests performed on site. Finally, as suggested by a few researchers²⁰ and described in the section on “Public health significance of laboratory results” of this document, the absence of microbial indicators does not guarantee that water is safe to drink.

Laboratory test results

This section explains the main coding systems found in laboratory reports and examines results through a public health lens.

Deciphering laboratory reports

Three examples of laboratory reports for water sampling results are included in the Appendix. The type of information included in laboratory reports can vary greatly from one laboratory to another. Some reports will only provide the type of test, the results, and whether there is significant evidence for bacterial contamination. Others will be more comprehensive with the name of the test, the results with reference to guidelines for drinking water, and the detection limit of the test. Although, any questions regarding tests results can be addressed to the manager of the laboratory who completed the test, this section explains some of the information that may be found.

- Example of coding systems related to microbial tests: MF, MPN, PA.

There are two types of tests: presence/absence and quantitative tests.

Quantitative tests include the Most Probable Number test (MPN) and Membrane Filtration tests (MF). The MPN technique, also referred to as the Multiple Tube Fermentation Technique, is a technique based on serial dilution of the sample in test tubes containing a selective liquid media. At the end of the incubation, the analyst counts the number of positive test tubes to estimate the number of coliforms or *E.coli* present in the sample. The MF test refers to a technique where 100 ml of the sample is filtered onto a membrane. The membrane is placed on a growth selective media for coliforms/*E.coli*. After incubation, colonies are counted.

MF tests are considered the “gold standard” but both methods, MPN and MF, have advantages and disadvantages that are not discussed in this document. Although quantitative methods are still in use, the tendency is to move away from numerical data for drinking water analysis due to statistical and methodological uncertainties associated with counts.²¹ The US Environmental Protection Agency (USEPA) has already embraced the presence/absence concept for compliance monitoring.^{14,21}

Presence/absence tests (PA) consist of an enzyme-substrate liquid-broth medium usually sold as test kits like colilert®, or colitag™. These tests do not provide any information regarding the concentration of the indicator present in the sample.

- Example of coding system to qualify results: EST, TMTC, TNTC, ND, NDOG

For quantitative methods, bacteria can be overgrown, which is defined as “the crowding and/or confluent and/or non-identifiable microbial growth on a plate”²²; in practice terms, “overgrown” means too many bacteria to provide an accurate count. This would appear as NDOG (no data, overgrown plate), ND (no data), TNTC (too numerous to count), TMTC (too many to count) or EST (estimated count).

- Detection limit

The detection limit is the lowest number of microorganisms that can be reliably detected under the stated experimental conditions. When no organisms are detected, the result is reported as < detectable level per volume analysed. Results are usually reported per 100 ml of sample. If 100 ml of water was analysed, the detection limit is < 1 colony forming units (CFU) per 100 ml. If the sample had to be diluted by half, only 50 ml of the sample was analysed; the detection limit becomes < 2 CFU per 100 ml.

Public health significance of laboratory test results

This section explains the limitations associated with the non-detection or the detection of microbial indicators.

No detection

The non-detection of *E.coli* does not guarantee that water is safe to drink because a water sample is only a snapshot^{1,21} of the water being distributed and because some organisms are more resistant to chlorine/disinfectant than the indicator *E.coli*.⁴ A negative *E.coli* result does not necessarily reflect sanitary water conditions because *E.coli* and coliforms, in general, are more sensitive to disinfection than more chlorine-resistant pathogens such as viruses²³ and *Cryptosporidium* oocysts.²⁴

One famous example is the prospective epidemiological study published by Payment et al. (1997).²³ In this study, authors examined self-reported gastrointestinal diseases in persons who drank water that met drinking water standards for faecal coliforms. Results showed that 14–40% of gastrointestinal illnesses were attributable to tap water that met drinking water standards.²³ Due to the short duration of illnesses, authors suggested that viruses may have been the cause. The 1993 Millwaukee outbreak²⁴ is another illustration of the limitations associated with current water quality indicators: water samples were free of total and faecal coliforms throughout the outbreak, but were contaminated by *Cryptosporidium* oocysts.¹⁸ This deficiency is important, knowing that of the 185 reported outbreaks attributed to known pathogens associated with drinking water between 1974 and 2003 in Canada, 41% were caused by protozoa.¹

Positive results or above baseline results

Of the indicators described here (HPC, TC, FC and EC), *E.coli* is the only microbial indicator associated with public health significance. However, because of the limitations associated with the use of indicators, prescribed microbial monitoring only indicates possible water quality issues.¹⁸ A positive *E.coli* is not a confirmation that the water is contaminated by waterborne pathogens; *E.coli* assays detect indicators of faecal pollution but do not target *E.coli* O157:H7 and may or may not capture other pathogenic *E.coli* strains. Specialised assays and methods are needed to identify waterborne pathogens.¹⁴ Therefore, a positive result for *E.coli* is not necessarily a measure of waterborne pathogen occurrence.¹⁴ A positive *E.coli* test can also result from contamination during the process of sampling and may not be representative of the water body; this is ruled out by collecting another sample to confirm the presence/absence of this indicator.

Because of the above limitations, a positive result for *E.coli* should always trigger further investigation. Indicators and possible reasons for their presence in drinking water are found in Table 1. Positive results for microbial indicators (EC, FC) or any number above baseline levels (HPC) should be compared to non-microbial treatment performance parameters such as chlorine residual and turbidity.

Conclusion

Although not perfect, *E.coli* is the best common microbial indicator available to date to inform of public health risks associated with the consumption of drinking water. Due to uncertainties associated with numerical data, the tendency of regulatory agencies is to move towards a

presence/absence concept for compliance monitoring. It is important for practitioners to understand that the presence of indicators (*E.coli* or faecal coliforms) is not a confirmation that the water is contaminated. Microbial test results, whether positive or negative, should be interpreted from a water source to tap perspective.

Acknowledgements

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Table 1. Common microbial indicators and possible reasons for their presence in drinking water

Microbial Indicator	Possible reasons for detection of indicators	MAC* or baseline level ²⁵
<i>E. coli</i>	<ul style="list-style-type: none"> Recent faecal contamination, possible presence of pathogenic organisms. 	<ul style="list-style-type: none"> None detectable per 100 mL.
Faecal coliforms	<ul style="list-style-type: none"> Inadequate treatment and disinfection, bacterial re-growth, or infiltration in the distribution system. 	<ul style="list-style-type: none"> None detectable per 100 mL in treated water.
Total coliforms	<ul style="list-style-type: none"> When present in the water leaving the drinking water treatment plant, indicates a serious treatment failure.²⁵ When present in the water sampled from the distribution system (but not in water leaving the treatment plant), indicates that the distribution system may be vulnerable to contamination or may be experiencing bacterial re-growth.²⁵ May not be related to the occurrence of a faecal contamination. 	<ul style="list-style-type: none"> None detectable per 100 mL in water leaving the plant. For the distribution system, it depends on the sampling frequency and therefore the system size.²⁵
Heterotrophic plate count	<ul style="list-style-type: none"> A spike in finished water can indicate a problem with water treatment or a change in quality of the water source, prior to treatment. A spike within the distribution system indicates that bacterial re-growth may be occurring in the distribution system. 	<ul style="list-style-type: none"> Baseline level and range will be specific to each system, depending on site-specific characteristics.

*Maximum Acceptable Concentration

Appendix

ENVIRONMENTAL BACTERIOLOGY

Phone Number : Printed :2012 JUL 26

Requisition :B2WW050000
Submitter Ref :

BCCDC (FOOD PROTECTION SERVICES) - 537
655 12TH AVE W
VANCOUVER BC V5Z 4R4

Specimen Submitter
:537-BCCDC (FOOD PROTECTION SER#

Site Information

Code/Name :04G7573 - 04G7573
Site Desc :WINNIE WATER, POOH'S CORNER, 100 WOODLAND DRIVE, BEAR LAKE,
B.C., V1R 1W
City/Area : Type :COM.W.S.-2
Source :[SURFACE WATER]

Specimen

Treatment:TREATED Ph Level: Free Chlorine Level: ppm
Nature :WATER Exams Req :Total Coliform

EHO ; :Escherichia coli

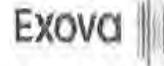
Collected:2012 JUL 25

Received :2012 JUL 26

RESULTS

Reported on 2012 JUL 26

<u>Test</u>	<u>Result</u>	<u>Units</u>
1. Total Coliform (MF-Chromocult)	EST 100	TC Count/100ml
2. Escherichia coli (MF-Chromocult)	EST 2	EC Count/100ml
EST:ESTIMATED COUNT		
3. EST RESULT INDICATES HIGH COLONY DENSITY ON MEMBRANE PREVENTING ACCURATE COLIFORM COUNTING.		



Analytical Report

 Bill To:
Report To:

 All:
Sampled By:
Company:

 Project:
ID:
Name:
Location:
LSD:
P.O. #:
Acct code:

 Lot ID: **752671**
Control Number:
Date Received: Jul 20, 2010
Date Reported: Jul 23, 2010
Report Number:

 Reference Number:
Sample Date: July 20, 2010
Sample Time: 13:25
Sample Location:
Sample Description: City Water
Sample Matrix: Drinking Water

Analyte		Units	Result	Nominal Detection Limit	Guideline Limit	Guideline Comments
Metals Extractable						
Aluminum	Extractable	mg/L	0.073	0.005	0.1	Below OG
Antimony	Extractable	mg/L	<0.0002	0.0002	0.005	Below MAC
Arsenic	Extractable	mg/L	<0.0002	0.0002	0.010	Below MAC
Barium	Extractable	mg/L	0.001	0.001	1	Below MAC
Boron	Extractable	mg/L	<0.005	0.005	5	Below MAC
Cadmium	Extractable	mg/L	<0.00007	0.00007	0.005	Below MAC
Chromium	Extractable	mg/L	<0.0005	0.0005	0.05	Below MAC
Copper	Extractable	mg/L	0.002	0.001	1.0	Below AO
Iron	Extractable	mg/L	0.03	0.01	0.3	Below AO
Lead	Extractable	mg/L	0.0011	0.0001	0.01	Below MAC
Manganese	Extractable	mg/L	0.0006	0.0002	0.05	Below AO
Selenium	Extractable	mg/L	<0.0006	0.0006	0.01	Below MAC
Uranium	Extractable	mg/L	<0.0005	0.0005	0.02	Below MAC
Vanadium	Extractable	mg/L	0.0003	0.0001		
Zinc	Extractable	mg/L	0.002	0.001	5.0	Below AO
Microbiological Analysis						
Total Coliforms	Enzyme Substrate Test	MPN/100 mL	<1.0	1.0	0 per 100 mL	Below MAC
Escherichia coli	Enzyme Substrate Test	MPN/100 mL	<1.0	1.0	0 per 100 mL	Below MAC
Heterotrophic Count - Aerobic	SimPlate	MPN/mL	15	2		
Physical and Aggregate Properties						
Turbidity		NTU	0.2	0.1		
Colour	Apparent	Colour units	<5	5		
Routine Water						
pH	@ 25 °C		7.58		6.5-8.5	Within AO
Calcium	Extractable	mg/L	0.8	0.1		
Magnesium	Extractable	mg/L	<0.1	0.1		
Phosphorus	Extractable	mg/L	<0.01	0.01		
Potassium	Extractable	mg/L	0.8	0.1		
Silicon	Extractable	mg/L	0.38	0.05		
Sodium	Extractable	mg/L	7.9	0.1	200	Below AO
T-Alkalinity	as CaCO ₃	mg/L	13	5		
Chloride	Dissolved	mg/L	2.54	0.02	250	Below AO
Fluoride	Dissolved	mg/L	<0.01	0.01	1.5	Below MAC
Nitrate - N	Dissolved	mg/L	0.14	0.01	10	Below MAC

Barcode/Code à barre(s)

Date Received/Reçu le

Laboratory No (N°) du laboratoire

Public Health Ontario

Santé publique Ontario

Public Health Laboratories

Bacteriological Analysis of Drinking Water for Private Citizen SINGLE HOUSEHOLD ONLY Analyse bactériologique de l'eau potable - Particuliers, MÉNAGES UNIFAMILIAUX SEULEMENT

Submitter's name and mailing address Nom et adresse postale de l'auteur de la demande d'analyse

Name/Nom (First/Prénom, Last/Nom de famille), Street #/Rue No. (Street/R.R. number/postal), City/Town/Ville, Province (ON), Postal Code/Code postal

Location of Water Source/Emplacement de la source d'eau

Street address/Adresse municipale, Point of Contamination/Point d'inséction, Township/Municipalité, County/Comté (ON), Postal Code/Code postal

Location of Water Source same as Property owner or resident's mailing address? Emplacement de la source d'eau identique à l'adresse postale du propriétaire ou du résident? No Phone / Pas de téléphone

Date collected/Date du prélèvement: 2012/10/29, Health Unit #/N° du bureau de santé: 2 2 3 3, Your Daytime Telephone #/Votre n° tél. le jour

Time Collected: 3:00 AM - PM (Circle AM or PM), Heure du prélèvement: Matin - Après-midi (Encerclaz « matin » ou « après-midi »)

I will pick up report at the laboratory./Je viendrai chercher le rapport au laboratoire. Please mail to my mailing address above./Veuillez le faire parvenir à mon adresse postale indiquée ci-dessus.

WATER WILL NOT BE TESTED IF THE SHADED AREAS OF THIS FORM ARE NOT COMPLETELY AND ACCURATELY FILLED IN/ NOUS N'ANALYSERONS PAS L'ÉCHANTILLON D'EAU SI LES PARTIES OMBRÉES DE LA FORMULE N'ONT PAS ÉTÉ REMPLIES EN ENTIER ET DE FAÇON EXACTE

Instructions - Please read instructions page carefully before sampling and note information on reverse of this page./Prérez de lire la page d'instructions attentivement avant l'échantillonnage et prenez note des renseignements figurant au verso de cette page.

For Laboratory Use Only/Réserve à l'usage du laboratoire

Interpretation for this water sample/Interprétation de cet échantillon d'eau This water sample was only tested for the presence of both Total Coliform and E. coli bacterial indicators of contamination, by Membrane Filtration. / Cet échantillon d'eau n'a été analysé que pour détecter la présence des coliformes totaux et des bactéries colibacillaires, indicateurs de contamination par filtration sur membrane.

- NO SIGNIFICANT EVIDENCE OF BACTERIAL CONTAMINATION (Total Coliform <=5, E. coli = 0)
AUCUNE PREUVE DE CONTAMINATION BACTÉRIENNE SIGNIFICATIVE (Coliformes totaux <=5, E. coli = 0)
SIGNIFICANT EVIDENCE OF BACTERIAL CONTAMINATION (Total Coliform >5, E. coli = 0)
PREUVE DE CONTAMINATION BACTÉRIENNE SIGNIFICATIVE (Coliformes totaux >5, E. coli = 0)
UNSAFE TO DRINK Evidence of faecal contamination. (E. coli > 0)
EAU NON POTABLE Preuve de contamination par des matières fécales. (E. coli > 0)

Table with 2 columns: Total Coliform per 100 mL/Coliformes totaux par 100 mL (71) and E. coli per 100 mL (1). Includes Date of Analysis/Date de l'analyse (OCT 30 2012) and Authorized by (Technologist)/Autorisé par (Technologist).

These results relate only to the sample tested. / Le résultat obtenu se rapporte seulement à cet échantillon d'eau analysé. End of report / Fin du rapport

References

1. Hruday SE, Hruday EJ. Safe drinking water: lessons from recent outbreaks in affluent nations. London, UK: IWA Publishing; 2004.
2. U.S. Environmental Protection Agency. Distribution system indicators of drinking water quality. Washington, DC: EPA; 2006 Dec.
http://www.epa.gov/ogwdw/disinfection/tcr/pdfs/issuepaper_tcr_indicators.pdf.
3. Maal-Bared R, Bartlett KH, Bowie WR. Dealing with waterborne disease in Canada: challenges in the delivery of safe drinking water. *Rev Environ Health*. 2008;23(2):119-33.
4. Payment P, Waite M, Dufour A. Introducing parameters for the assessment of drinking water quality. London, UK: IWA Publishing; 2003.
http://www.who.int/water_sanitation_health/dwg/9241546301_chap2.pdf.
5. Leclerc H, Mossel DAA, Edberg SC, Struijk CB. Advances in the bacteriology of the coliform group: their suitability as markers of microbial water safety. *Annu Rev Microbiol*. 2001;55(1):201-34.
6. Bartram J, Cotruvo J, Exner M, Fricker C, Glasmacher A, editors. Heterotrophic counts and drinking-water safety: the significance of HPCs for water quality and human health. London, UK: IWA publishing; 2003. http://www.who.int/water_sanitation_health/dwg/hpc/en/index.html.
7. Edberg SC, Smith DB. Absence of association between total heterotrophic and total coliform bacteria from a public water supply. *Appl Environ Microbiol*. 1988;55:380-4.
8. Tallon P, Magajna B, Lofranco C, Leung KT. Microbial indicators of faecal contamination in water: a current perspective. *Water Air Soil Pollut*. 2005;166:139-66.
9. Ainsworth R. Safe piped water: managing microbial water quality in piped distribution systems. London, UK: IWA publishing; 2004.
http://www.who.int/water_sanitation_health/dwg/924156251X/en/.
10. Caplenas NR, Kanarek MS. Thermotolerant non-fecal source *Klebsiella pneumoniae*: validity of the fecal coliform test in recreational waters. *Am J Public Health*. 1984;74(11):1273-5.
11. Knittel MD. Occurrence of *Klebsiella pneumoniae* in surface waters *Appl Microbiol*. 1975 May; 29:595-7.
12. Beauchamp CJ, Simao-Beauvoir A, Beaulieu C, Chalifoura F. Confirmation of *E. coli* among other thermotolerant coliform bacteria in paper mill effluents, wood chips screening rejects and paper sludges. *Water Res*. 2006 Jul;40(12):2452-62.
13. Figueras MJ, Borrego JJ. New perspectives in monitoring drinking water microbial quality. *Int J Environ Res Public Health*. 2010;7(12):4179-202.
14. U.S. Environmental Protection Agency. Proposed revised total coliform rule; assessments and corrective actions guidance manual. Washington, DC: U.S. EPA Office of Ground Water and Drinking Water; Standards and Risk Management Division; 2010 Aug 2010.
<http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/regulation.cfm>.
15. Wade TJ, Pai N, Eisenberg JNS, Colford JM. Do U.S. Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. *Environ Health Perspect*. 2003;111(8):1102-9.
16. Rivera SC, Hazen TC, Toranzos GA. Isolation of fecal coliforms from pristine sites in a tropical rain forest. *Appl Environ Microbiol*. 1988 Feb;54(2):513-7.
17. Hunter PR. Drinking water and diarrhoeal disease due to *Escherichia coli*. *J Water Health*. 2003;1(2):65-72.
18. Hruday SE. Safe drinking water policy for Canada--turning hindsight into foresight. Commentary. Toronto, ON: C.D. Howe Institute Feb 2011.

19. Clesceri LS, Greenberg AE, Eaton AD, editors. Standard methods for the examination of water and wastewater. Washington, DC: American Public Health Association; 2005.
<http://www.standardmethods.org/>.
20. Payment P, Richardson L, Siemiatycki J, Dewar R, Edwardes M, Franco E. A randomized trial to evaluate the risk of gastrointestinal disease due to consumption of drinking water meeting current microbiological standards. Am J Public Health. 1991 Jun;81(6):703-8.
21. Allen MJ, Edberg SC, Clancy J, Hrudey SE. Drinking water microbial myths - a primer for utility managers, engineers and non-microbiologists. 15th National Conference & 6th Policy Forum on Drinking Water Kelowna, B. C. 2012.
22. Ontario. Ministry of the Environment. Laboratory update bulletin. 2010.
23. Payment P, Siemiatycki J, Richardson L, Renaud G, Franco E, Prevost M. A prospective epidemiological study of gastrointestinal health effects due to the consumption of drinking water. Int J Environ Health Res. 1997;7(1):5-31.
24. Mac Kenzie WR, Hoxie NJ, Proctor ME, Gradus MS, Blair KA, Peterson DE, et al. A massive outbreak in Milwaukee of Cryptosporidium infection transmitted through the public water supply. N Engl J Med. 1994 Jul;331:161-7.
25. Health Canada. Canadian drinking water guidelines. Ottawa, ON: Health Canada; 2010.
<http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php>.

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