WHISTLER

AGENDA

REGULAR MEETING OF MUNICIPAL COUNCIL
TUESDAY, MAY 8, 2018, STARTING AT 5:30 P.M.

Franz Wilhelmsen Theatre at Maury Young Arts Centre
4335 Blackcomb Way, Whistler, BC V0N 1B4

ADOPTION OF AGENDA

Adoption of the Regular Council Meeting Agenda of May 8, 2018.

ADOPTION OF MINUTES

Adoption of the Regular Council Meeting Minutes and Public Hearing Minutes of April 24, 2018.

PUBLIC QUESTION AND ANSWER PERIOD

PRESENTATIONS AND DELEGATIONS

2017 Transportation Monitoring Results

A presentation by Community Transportation Planner Richard Drudl and General Manager of Infrastructure Services James Hallisey regarding the 2017 transportation monitoring results.

Whistler Off Road Cycling Association Fee for Service Report Back

A presentation by Director of Trails of the Whistler Off Road Cycling Association Nina Cairns regarding the Whistler Off Road Cycling Association Fee for Service Report Back.

MAYOR’S REPORT

INFORMATION REPORT

Drinking Water Guidelines Update
File No. 200.2
Report No. 18-057

A presentation by municipal staff.

That Information Report No. 18-057 regarding Drinking Water Guidelines be received.

ADMINISTRATIVE REPORTS

Whistler Transit System: Annual Operating Agreement (AOA) 2018/2019 and Transit Management Advisory Committee (TMAC) Update
File No. 534
Report No. 18-060

A presentation by municipal staff.

That Council authorize the Mayor and Municipal Clerk to execute the “2018-2019 Whistler Annual Operating Agreement” for the period April 1, 2018 through March 31, 2019 attached as Appendix “A” to Administrative Report to Council No. 18-060.

Transportation Action Plan Winter 2017/2018 Monitoring Results and Transportation Advisory Group (TAG) Recommendations
File No. 546
Report No. 18-059

A presentation by municipal staff.

That Council direct staff to publish the Transportation Action Plan Winter 2017/2018 Monitoring Results Report on the municipal website when finalized;

That Council receive and endorse the Transportation Advisory Group (TAG) recommendations from the March 15, 2018 TAG Workshop; and

That Council direct staff to work with Transportation Advisory Group members and partners to start implementing TAG recommended next steps as described in Administrative Report to Council 18-059.

RZ1143 – 1501 Alta Lake Road (Prism Lands) Amenity Zoning
File No. RZ1143
Report No. 18-058

A presentation by municipal staff.

That Council consider giving first and second readings to “Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018”; and

That Council authorize staff to schedule a Public Hearing for “Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018”; and further

That Council direct staff to advise the applicant that before consideration of adoption of “Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018”, the following matters shall be completed to the satisfaction of the General Manager of Resort Experience:

1. The applicant is to assume responsibility for any hazardous trees that are located on the lands to be transferred to the municipality, which may impact the proposed development. The applicant must conduct a hazardous tree assessment and an appropriate mechanism put in place to insure any identified hazards are addressed prior to the lands being transferred to municipality; and further
2. Registration of a Section 219 development covenant in favour of the Resort Municipality of Whistler (“RMOW”) requiring development on the five estate lots to:
   a) achieve a minimum of BC Energy Step Code 3;
   b) meet the FireSmart BC Guidelines, or sprinkler buildings and meet the exterior building recommendations of the FireSmart BC Guidelines; and
   c) maintain a minimum of 20 per cent undisturbed land, ensure no development in the three small wetlands, retain a minimum 5 metre vegetated buffer around the three small wetlands, and require that site servicing, road and driveway works be monitored by a qualified environmental monitor.

MINUTES OF COMMITTEES AND COMMISSIONS

Transportation Management Advisory Committee	Workshop Meeting Minutes of the Transportation Management Advisory Committee of April 3, 2018.

BYLAWS FOR FIRST AND SECOND READINGS

Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018	**That “**Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018” be given first and second readings.

BYLAWS FOR THIRD READING

Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018	**That** “Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018” be given third reading.

BYLAWS FOR ADOPTION

Delegation of Signing Authority Bylaw No. 2181, 2018	**That** “Delegation of Signing Authority Bylaw No. 2181, 2018” be adopted.
Tax Rates Bylaw No. 2182, 2018	**That** “Tax Rates Bylaw No. 2182, 2018” be adopted.
Sewer User Fee Amendment Bylaw No. 2183, 2018	**That** “Sewer User Fee Amendment Bylaw No. 2183, 2018” be adopted.
Sewer Tax Bylaw No. 2184, 2018	**That** “Sewer Tax Bylaw No. 2184, 2018” be adopted.
Solid Waste /Recycling Rates Amendment Bylaw No. 2185, 2018	**That** “Solid Waste/Recycling Rates Amendment Bylaw No. 2185, 2018” be adopted.
Water User Fee Amendment Bylaw No. 2186, 2018	**That** “Water User Fee Amendment Bylaw No. 2186, 2018” be adopted

OTHER BUSINESS

Whistler Community Services Society Appointment	**That** Council appoint Councillor Cathy Jewett to the Whistler Community Services Society Board.

CORRESPONDENCE

BC Transit Bus Stop File No. 3009	Correspondence from Erron Holden, dated March 15, 2018, regarding the current BC Transit bus stop at Legacy Way.
Support for Human Trafficking Task Force and Protection of Communities and Exploited Persons Act File No. 2014	Correspondence from Mayor Shane Brienen, dated March 29, 2018, requesting support for the establishment of a Human Trafficking Task Force and the enforcement of the federal Protection of Communities and Exploited Persons Act.
Employer Health Tax File No. 2014	Correspondence from Mayor John Harwood, District of Clearwater, dated April 13, 2018, regarding the implementation of the Employer Health Tax.
UBCM Resolution Re: Collection of Unpaid Bylaw Fines File No. 2014	Correspondence from Mayor Lorraine Michetti, dated April 18, 2018, supporting the Resort Municipality of Whistler's UBCM Resolution regarding the collection of unpaid bylaw fines.
National Missing Children's Month and Missing Children's Day Proclamation Request File No. 3009.1	Correspondence from Crystal Dunahee, President, Child Find BC, dated April 20, 2018, requesting that Council proclaim May as Missing Children's Month and that May 25, 2018 be proclaimed as Missing Children's Day.
2018 Emergency Operations Centres and Training Grant Approval File No. 2014	Correspondence from Rebecca Bishop, Program Officer, Local Government Program Services, Union of British Columbia Municipalities, dated April 20, 2018, notifying that the Resort Municipality of Whistler's 2018 Emergency Operations Centres and Training Grant has been approved.
Traffic Study for District Lot No. 8078 File No. 3009	Correspondence from Patrick Smyth, dated April 19, and April 23, 2018 regarding the traffic study for the proposed development at District Lot No. 8078.
Provincial Rental Restricted Housing Development File No. 3009	Correspondence from Patrick Smyth, dated April 25, 2018, regarding the new legislation for rental restricted housing development.
Passenger Rail Service File No. 2014	Correspondence from Patrick Smyth, dated April 25, 2018, regarding passenger rail service.

LMLGA Resolution Re: Disqualification from Holding Elected Office File No. 2014	Correspondence from Mayor John Becker, City of Pitt Meadows, dated April 25, 2018 requesting support for the City of Pitt Meadows LMLGA Resolution regarding the disqualification of Council members from holding elected office upon conviction of a criminal offence.
Artificial Turf Field File No. 3009	Correspondence, received between April 23 to April 30, 2018 regarding the artificial turf field from the following individuals: • Crosland Doak; • William Trousdale; • Dave Craig; • John, Fiona, Robyn & Fern Minton; • Luke Soane; • Karen Willms; • Caroline Bagnall; • Dale Barker; • Roger Soane; • Luke Ferdinands; and • Ann Duffy.
RZ1144- 2077 Garibaldi Lane File No. RZ1144	Correspondence received from April 25 to May 2, 2018, regarding Rezoning Application No. RZ1144- 2077 Garibaldi Lane from the following individuals: • Stella Benteau; and • Jane and Paul Manning.
RZ1135 – Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018	Correspondence received from May 1 to May 2, 2018 regarding Rezoning Application No. RZ1135 – “Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018” from the following individuals: • Colin Solly; • Dave and Laura Kinney; • Jason Tarbet; • Tim Wake; • Wili and Leslie Disler; • Steve Bayly; • Tim Coulson; and • Matt Woods.
Cystic Fibrosis Canada Light-Up Request File No. 3009.1	Correspondence from Sandra Niven, Associate, Fund Development, Cystic Fibrosis Canada, dated May 1, 2018, requesting that the Fitzsimmons Bridge be lit up blue on May 16, 2018 in support of Cystic Fibrosis Awareness Month.

TERMINATION

That the Regular Council Meeting of May 8, 2018 be terminated.

WHISTLER

MINUTES

REGULAR MEETING OF MUNICIPAL COUNCIL
TUESDAY, APRIL 24, 2018, STARTING AT 5:30 P.M.

Franz Wilhelmsen Theatre at Maury Young Arts Centre
4335 Blackcomb Way, Whistler, BC V0N 1B4

PRESENT:

Mayor: N. Wilhelm-Morden
Councillors: S. Anderson, J. Crompton, J. Ford, J. Grills, C. Jewett and S. Maxwell

Chief Administrative Officer, M. Furey
General Manager of Infrastructure Services, J. Hallisey
General Manager of Corporate and Community Services, N. McPhail
General Manager of Resort Experience, J. Jansen
Director of Finance, K. Roggeman
Director of Planning, M. Kirkegaard
Municipal Clerk, B. Browning
Manager of Communications, M. Comeau
Manager of Financial Services, M. Peatfield
Capital Projects Manager, T. Shore
Senior Planner, J. Belobaba
Planner, R. Brennan
Planner, A. Antonelli
Planner, F. Savage
Planning Analyst, R. Licko
Bylaw Supervisor, L. DeBou
Council Coordinator, S. Termuende

ADOPTION OF AGENDA

Agenda

Moved by Councillor J. Crompton
Seconded by Councillor S. Anderson

That Council adopt the Regular Council Meeting Minutes of April 24, 2018.

CARRIED

ADOPTION OF MINUTES

Minutes

Moved by Councillor J. Ford
Seconded by Councillor J. Grills

That Council adopt the Regular Council Meeting Minutes of April 10, 2018 as amended to strike out "2208 Lake Placid Road" and insert "2038 Karen Crescent" in the resolution for Admin Report No. 18-042.

CARRIED

PRESENTATIONS AND DELEGATIONS

Mayor's Poetry Challenge

Mayor Nancy Wilhelm-Morden gave a presentation regarding the Mayor's Poetry Challenge.

Mayor Nancy Wilhelm-Morden announced the winners of the 2018 Poet's Pause Poetry Competition.

In recognition of National Poetry Month, the Resort Municipality of Whistler (RMOW) annually invites writers to submit original, unpublished poems for the competition. This year marked the tenth year that RMOW has run this creative contest. Twenty one submissions were received for the two theme categories of Listening and Togetherness. Winning poems are displayed for one year at the two "Poet's Pause" sculpture sites in Alta Lake Park. Poet's Pause is part of a public art concept created by the late Joan Baron. Joan Baron developed the sculpture sites with the intention of inspiring creativity. The quality of the winning poems and the hundreds of submissions over the past decade are a testament to this. The winning poems are selected by a jury of poetry lovers. Winning poets also each receive a $200 prize.

Jurors selected Anne Crowley's poem "Listen" as the winner for the theme of Listening. Jurors noted that Anne's poem encouraged readers to stop and listen to the sounds associated with spring. Jurors selected Bronwyn Preece's poem "Untitled" for the theme of Togetherness. Jurors noted that Bronwyn's poem evokes emotional togetherness and tied the Sea to Sky together.

Mayor Nancy Wilhelm-Morden welcomed Anne Crowley and Bronwyn Preece to the podium to read their poems.

An honorable mention was bestowed upon Linda McGraw for her moving poem "For Andree" in the Listening Theme.

Mayor Nancy Wilhelm-Morden welcomed Manager of Parks Planning, Martin Pardoe to read the poem on Linda's behalf.

Mayor Nancy Wilhelm-Morden congratulated the winners and thanked the poets for reading their moving poems.

PUBLIC QUESTION AND ANSWER PERIOD

Anne Duffy
New Resident of Whistler
Re: Artificial Turf Field

Ms. Duffy expressed support for the artificial turf field and sought further information regarding the sourcing information being used to determine the type of materials being used on the field surface.

Mayor Nancy Wilhelm-Morden stated that Council will make a decision on the material used for the surface of the field at a later Council Meeting date. She stated that there has been tremendous public consultation on this issue.

General Manager of Resort Experience Jan Jansen stated that staff are planning on bringing forward a Report regarding proposed surface materials for the artificial turf field for the first Meeting in June.

Dawn Titus
8440 Bear Paw Trail
Re: Artificial Turf Field

Ms. Titus asked regarding the cork nut surface and how many fields of that type would be assessed before making decision. She asked for clarification regarding which active artificial turf fields had been looked at as part of the decision on the type of turf being considered.

General Manager of Resort Experience Jan Jansen stated that staff are looking at a number of different infield materials, and that staff are receiving input from consultants regarding materials and staff have been in touch with lower mainland facility managers to discuss performance of those fields.

Ms. Titus sought clarification regarding how many parks staff have travelled to and assessed as part of considering the type of material for the artificial turf field surface.

Ms. Titus sought clarification regarding the current plan to dispose of the plastic after the lifespan of the Artificial Turf Field.

Mr. Jansen stated that Ms. Titus's questions were premature. He stated that staff are waiting for the Administrative Report to Council and stated that staff are still collecting information. Mr. Jansen stated that disposal plans will be included in the Report.

Ms. Titus asked where artificial field turf being shipped to currently.

Mayor Nancy Wilhelm-Morden stated Ms. Titus' question is premature, and stated that the RMOW cannot determine disposal before deciding the type of turf.

Chief Administrative Officer Mike Furey stated that staff will be bringing this information forward in a later Report.

Ms. Titus asked if staff know that recycle of plastic turf is being shipped to Malaysia for disposal.

Mr. Jansen stated that staff is currently looking at all options available.

Marcus Culver
30-2110 Whistler Road
Re: Artificial Turf Field

Mr. Culver asked for staff to name three fields that have lasted longer than 10 years. Mayor Nancy Wilhelm-Morden stated that this information was included in staff reports, and stated that the reports are available online.

General Manager of Resort Experience Jan Jansen stated that a number of factors determine artificial turf longevity. Mr. Jansen stated that there are elements unique to Whistler. For example, sunlight, UV, and snow cover could have an impact as to the speed of degradation. Mr. Jansen stated that staff are currently investigating artificial turf fields in similar climates.

Mr. Culver asked if the artificial turf field contradicts the Whistler2020 Vision. Mayor Nancy Wilhelm-Morden stated this question has been answered before. She stated that all facilities in the municipality leave a footprint and the Council and staff try to mitigate as best as possible. Mayor Nancy WIlhelm-Morden stated that the community needs to weigh the cost benefit analysis if the environmental footprint is greater than the community benefit of the Artificial Turf Field.

MAYOR'S REPORT

Mayor's Report

Condolences to Toronto

Mayor Nancy Wilhelm-Morden stated that she shared condolences with the Mayor of Toronto on behalf of Council and the members of the community of Whistler. Mayor Nancy Wilhelm-Morden shared her condolences to those affected by the incident that took place in Toronto yesterday. She stated it was a tragic event and that Council and staff's thoughts are with the family and friends of the 10 people who lost their lives, and those who were injured.

National Volunteer Week

Last week marked National Volunteer Week. On behalf of Council and the Resort Municipality of Whistler, Mayor Nancy Wilhelm-Morden thanked all the volunteers around Whistler for their commitment, dedication and contribution to the Whistler community. Many of the RMOW's community programs are supported by the invaluable contribution of volunteers.

These volunteers help with:

- Hosting workshops for the community to learn new skills at the Whistler Library;
- Youth activities at LUNA;
- Providing friendly help to visitors and locals via the Village Hosts and Bike Hosts programs;
- Patrolling our Cross Country Ski trails;
- Sitting as members of committees of Council;
- And much more.

Volunteers also support many of Whistler's not-for-profit organizations and societies. Council and staff thank these volunteers for all their work.

Energy Step Code Public Information Session April 26
There is a Public Information Session on the proposed integration of the BC Energy Step Code in Whistler this Thursday, April 26, 2018. The Session will provide information about the energy step code, how it was developed, the changes that are being considered locally and effects on local building regulations. There will be a gallery walk, presentations and an opportunity to ask questions. The Public Information Session will be held at the Millar Room at the Myrtle Philip Community School from 5:15 to 7 p.m. You can read more about the BC Energy Step Code on the website at whistler.ca/stepcode.

Community Pitch-In Day, April 28
This Saturday, April 28, 2018, the RMOW is running the annual Pitch-In Day. Pitch-In Day helps protect Whistler's natural assets and will begin with a focus on cleaning Whistler's roadways. We encourage community members, community groups and sports associations, to join the hundreds of other volunteers gathering to clear litter on the roads from Emerald to Function Junction. The meeting point for volunteers is the Public Works Yard on Nesters Road between 8 and 9 a.m. There will be a barbeque for volunteers at the Village Fire Hall at 12 p.m.

FireSmart Message: Clearing Garden Debris
The RMOW and Whistler Fire Service are sharing important FireSmart messages as the community moves into the warmer months. Managing garden debris is an important part of ensuring homes reduce the risk and impact of wildfire in Whistler. To assist with this, homeowners can now dispose of garden debris for free year-round at the Nesters Depot between 7 a.m. and 7 p.m. Safe burning of garden debris is also available between April 28 and May 13, 2018 but homeowners are reminded that they need to apply for a permit. Mayor Nancy Wilhelm-Morden stated that FireSmart is not about preventing wildfires and is about managing them because they will happen. There is more information on the website at whistler.ca/FireSmart.

Bear Management Workshop
Last week, the RMOW hosted a Bear Management Workshop at the Squamish Lil'Wat Cultural Centre. There were 45 attendees comprising government employees and non-government organizations from the Sea to Sky region involved in bear management. The event provided a forum to discussion bear management best practices and set actions. This is an important part of the work being done to protect Whistler's bears.

World Earth Day RMOW/AWARE Expo:
To mark world Earth Day on Sunday, an Environmental Action Expo was hosted by AWARE Whistler and supported by the RMOW. The Expo presented the environmental work being done throughout the Sea-to-Sky region. There were interactive activities, informative talks and a seed swap. The Expo provided a wonderful opportunity to continue to activate and support the Whistler community's efforts in protecting our environment.

Ken Roggeman Leaving RMOW
Tonight marks the final Council meeting for one of the RMOW's long-standing employees, Ken Roggeman. Ken will be leaving the RMOW and Whistler to take on a new opportunity at the water improvement district on Salt Spring Island. Ken has been part of the Whistler community for 27 years and part of the RMOW staff for 14 years. As the Director of Finance, Ken has been an integral part of the RMOW team bringing a wealth of knowledge, commitment and integrity to his work on behalf of the community. On behalf of Council and the RMOW, Mayor Nancy Wilhelm-Morden thanked Ken for his dedication to the Whistler community and wished him all the best for his new journey.

Councillor Jewett and Councillor Crompton attended the dedication of the Peak to Peak for retiring Vice President of Government Relations & Special Projects, Doug Forseth.

Councillor Jewett and Councillor Crompton also attended the dedication of Brownley Basin on Blackcomb for retiring staff member, Dave Brownley. Councillor Jewett noted that Darrin Martin from Audain Art Gallery is moving to Peel County Museum and will be missed. She stated that Mr. Martin's contributions have greatly contributed to the success of the Audain Art Museum in its first few years of operation.

Councillor Ford and Councillor Maxwell attended the Whistler Centre for Sustainability Resilient Streets session. Councillor Maxwell encouraged those interested to apply for available grants and to check out whistlercentre.ca/resilientstreets.

Mayor N. Wilhelm-Morden called a Recess of the Regular Council Meeting at 6 p.m. for a Public Hearing.

Mayor N. Wilhelm-Morden reconvened the Regular Council Meeting at 6:16 p.m.

ADMINISTRATIVE REPORTS

LLR1308/1309 – National (Whistler) Liquor Licences and Covenant Modifications for Bowling/Games Facility
File No. LLR1308/1309
Report No. 18-051

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That Council authorize staff to convene an open house to engage the community and solicit public input as part of the review of an application by National (Whistler) Beerhall Inc. for liquor licences for a bowling/games facility, a lounge and a restaurant at 4295 Blackcomb Way.

CARRIED

Process for Employee Housing Analysis
File No. 7734
Report No. 18-040

Moved by Councillor J. Ford
Seconded by Councillor J. Grills

That Administrative Report No. 18-040 regarding a process for moving forward with the Mayor's Task Force on Resident Housing Recommendation No. 6 (to allow for development of resident restricted rental housing on private lands that may be currently under-developed) be endorsed by Council.

Moved by Councillor S. Maxwell
Seconded by Councillor J. Ford

That the motion be amended to include, between review and processing steps 4 and 5 a requirement for a public open house.

OPPOSED: Mayor N. Wilhelm-Morden, Councillors J. Crompton, S. Anderson and J. Grills

DEFEATED

That Administrative Report No. 18-040 regarding a process for moving forward with the Mayor's Task Force on Resident Housing Recommendation No. 6 (to allow for development of resident restricted rental housing on private lands that may be currently under-developed) be endorsed by Council.

CARRIED

RZ1135 – Nesters Crossing – CTI1 Zone Amendment
File No. RZ1153
Report No. 18-052

Councillor J. Crompton declared a conflict of interest due to his business interests at this site and left Council Chambers at 7:19 p.m.

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That Council consider giving first and second readings to "Zoning Amendment Bylaw (CTI1 Zone), No. 2187, 2018"; and further

That Council authorize staff to schedule a Public Hearing for "Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018".

CARRIED

Councillor J. Crompton reentered Council Chambers at 7:28 p.m.

DVP1146 and SEC0024 – 7413 Ambassador Crescent
File No. DVP1146 and SEC0024
Report No. 18-045

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That Council approve the issuance of Development Variance Permit DVP1146 for the existing development located at 7413 Ambassador Crescent to vary the south (rear) setback from 7.6 metres to 2.7 metres to ratify the existing dwelling in its current location as shown in the Survey Plan 17023D prepared by Doug Bush Survey Services, dated January 30, 2017, attached as Appendix "B" to Administrative Report to Council No. 18-045; and further

That Council grant an exemption in accordance with Section 524 of the *Local Government Act* – "Requirements in Relation to Flood Plain Areas", to ratify the existing basement level below the required flood control elevation specified in "Zoning and Parking Bylaw No. 303, 2015" as shown in Architectural Plans A-01, A-02, A-03, A-04, A-05, A-06 prepared by Progressive Concept Design, dated December 20, 2017 attached as Appendix "C" to Administrative Report to Council No. 18-045, subject to registration of a Section 219 covenant for the exemption, indemnifying the Municipality and attaching the geotechnical report prepared by EXP Geotechnical, dated December 18, 2017 confirming that the proposed building location and design are safe for the intended residential use.

CARRIED

Solid Waste Amendment Bylaw No. 2175, 2018, Municipal Ticket Information System Amendment Bylaw No. 2178, 2018, and Bylaw Notice Enforcement Amendment Bylaw No. 2180, 2018
File No. 2175, 2178, and 2180
Report No. 18-047

Moved by Councillor J. Crompton
Seconded by Councillor C. Jewett

That Council consider giving first, second and third readings to the "Solid Waste Amendment Bylaw No. 2175, 2018";

That Council consider giving first, second and third readings to the "Municipal Ticket Information System Amendment Bylaw No. 2178, 2018"; and

That Council consider giving first, second and third readings to the "Bylaw Notice Enforcement Amendment Bylaw No. 2180, 2018".

OPPOSED: Councillor S. Maxwell

CARRIED

Mayor N. Wilhelm-Morden called a five minute recess of the Regular Council Meeting at 7:59 p.m.

Mayor N. Wilhelm-Morden reconvened the Regular Council Meeting at 8:04 p.m.

Tender Award – 2018 Road and Trail Reconstruction Program
File No. 523.1
Report No. 18-053

Moved by Councillor J. Crompton
Seconded by Councillor J. Ford

That Council authorize the Mayor and Municipal Clerk to execute the contract with Alpine Paving (1978) Ltd. for the 2018 Road and Trail Reconstruction Program in the amount of $1,333,144.00.

CARRIED

Council Procurement Policy and Delegation of Authority Bylaw
File No. F29, 2181
Report No. 18-054

Moved by Councillor J. Ford
Seconded by Councillor J. Grills

That Council replace Council Policy F-29: *Purchasing Policy* with the new Council Policy F-29: *Procurement Policy* attached as Appendix "A" to Administrative Report to Council No. 18-054; and further,

That Council consider giving first, second and third readings to the "Delegation of Authority Bylaw No. 2181, 2018".

Moved by Councillor S. Maxwell
Seconded by Councillor J. Ford

That the motion be amended to refer the procurement policy back to staff and that a new procurement policy be brought forward that promotes sustainable local purchasing elements.

OPPOSED: Mayor N. Wilhelm-Morden, Councillors S. Anderson, J. Crompton and J. Grills

DEFEATED

That Council replace Council Policy F-29: *Purchasing Policy* with the new Council Policy F-29: *Procurement Policy* attached as Appendix "A" to Administrative Report to Council No. 18-054; and further,

That Council consider giving first, second and third readings to the "Delegation of Authority Bylaw No. 2181, 2018".

OPPOSED: Councillor S. Maxwell

CARRIED

Protocol Agreement between Lil'wat Nation, Squamish Nation and RMOW
File No. 3024
Report No. 18-055

Moved by Councillor J. Crompton
Seconded by Councillor J. Ford

That Council endorse the Protocol Agreement attached as Appendix "A" to this Administrative Report to Council No. 18-055, between Lil'wat Nation, Squamish Nation and Resort Municipality of Whistler which provides a framework for the establishment of stronger government-to-government relationships; and

That Council authorize the Mayor and Chief Administrative Officer to sign the Protocol Agreement.

CARRIED

Tax Deferment – Memorandum Of Understanding With The Province of BC
File No. VAULT
Report No. 18-048

Moved by Councillor J. Crompton
Seconded by Councillor S. Anderson

That Council endorse the "Memorandum of Understanding" between the Property Taxation Branch of the Ministry of Finance and the Finance department of the Resort Municipality of Whistler, and further,

That Council authorize the Director of Finance to execute the agreement.

CARRIED

2018 Property Tax and Utility Rate Bylaws
File No. 2182, 2183, 2184, 2185, 2186
Report No. 18-056

Moved by Councillor J. Crompton
Seconded by Councillor J. Grills

That Council consider giving first, second and third readings to the following bylaws:

"Tax Rates Bylaw No. 2182, 2018"
"Sewer User Fee Amendment Bylaw No. 2183, 2018"
"Sewer Tax Bylaw No. 2184, 2018"
"Solid Waste/Recycling Rates Amendment Bylaw No. 2185, 2018"
"Water User Fee Bylaw No. 2186, 2018".

CARRIED

Proclamation of Wildfire Community Preparedness Day and Emergency Preparedness Week
File No. 3009.1
Report No. 18-049

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That Council proclaim May 5, 2018 as "Wildfire Community Preparedness Day" in the Resort Municipality of Whistler; and

That Council proclaim May 6 to 12, 2018 as "Emergency Preparedness Week" in the Resort Municipality of Whistler.

CARRIED

2018 Drinking Water Week Proclamation
File No. 200.2
Report No. 18-044

Moved by Councillor J. Grills
Seconded by Councillor J. Ford

That Council proclaim "Drinking Water Week" within the Resort Municipality of Whistler for the week of May 6 to 12, 2018.

CARRIED

DVP1148 – 6666 Cedar Grove Lane – Side Setback Variance for Swimming Pool
File No. DVP1148
Report No. 18-046

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That Council approve the issuance of Development Variance Permit DVP1148 for the proposed development located at 6666 Cedar Grove Lane to vary the side setback from 3.0 metres to 1.5 metres for a proposed uncovered, in-ground swimming pool as shown on the Landscape Plans Revision 11, dated 18-03-06 prepared by Hunter Office Architecture attached as Appendix "B" to Administrative Report to Council No. 18-046.

OPPOSED: Councillor S. Maxwell

CARRIED

CM100 – 2930 Heritage Peaks Trail – Covenant Modification
File No. CM100
Report No. 18-043

Moved by Councillor S. Anderson
Seconded by Councillor J. Crompton

That Council approve modification of Covenant BB4047307 for 2930 Heritage Peaks Trail to raise the allowable maximum floor elevation of the second storey by 2.5 meters, as shown on the architectural plans A1.1 and A1.3 prepared by TOK Design Studio, dated March 29, 2018 and revised on April 9, 2018 attached as Appendices "B" and "C" to Administrative Report to Council No. 18-043 and further,

That Council authorize the Mayor and Municipal Clerk to execute the covenant modification.

CARRIED

MINUTES OF COMMITTEES AND COMMISSIONS

May Long Weekend Committee

Moved by Councillor J. Grills
Seconded by Councillor C. Jewett

That Council receive the Regular Meeting Minutes of the May Long Weekend Committee of June 19, 2017.

CARRIED

Emergency Planning Committee

Moved by Councillor J. Crompton
Seconded by Councillor J. Ford

That Council receive the Regular Meeting Minutes of the Emergency Planning Committee of December 7, 2017.

CARRIED

Forest and Wildland Advisory Committee

Moved by Councillor S. Maxwell
Seconded by Councillor C. Jewett

That Council receive the Regular Meeting Minutes of the Forest and Wildland Advisory Committee of March 14, 2018.

CARRIED

Whistler Bear Advisory Committee

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That Council receive the Regular Meeting Minutes of the Whistler Bear Advisory Committee of March 14, 2018.

CARRIED

BYLAWS FOR FIRST AND SECOND READINGS

Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018

Councillor J. Crompton declared a conflict of interest due to his business interests at this site and left Council Chambers at 8:39 p.m.

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That "Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018" be given first, and second readings.

Moved by Councillor S. Anderson
Seconded by Councillor J. Ford

That the motion be amended to change under Other Regulations, subsection (15) of the Bylaw, to have an additional three auxiliary residential dwelling units, so it reads "A maximum of 4 auxiliary residential dwelling units are permitted per parcel".

OPPOSED: Mayor N. Wilhelm-Morden, Councillors J. Grills and *S. Maxwell*

DEFEATED

That "Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018" be given first, and second readings.

OPPOSED: Councillors C. Jewett and J. Ford

CARRIED

Councillor J. Crompton reentered Council Chambers at 8:53 p.m.

BYLAWS FOR FIRST, SECOND AND THIRD READINGS

Solid Waste Amendment Bylaw No. 2175, 2018

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That "Solid Waste Amendment Bylaw No. 2175, 2018" be given first, second and third readings.

Moved by Councillor S. Maxwell
Seconded by Councillor J. Ford

That the motion be amended to change Schedule D of the Bylaw so that the first column "Current Tipping Fee" is removed and change the heading of the second column saying "Current Tipping Fee"; and

That the unsecured loads at the fee that it was for the previous levels be added back in.

CARRIED

That "Solid Waste Amendment Bylaw No. 2175, 2018" be given first, second and third readings.

OPPOSED: Councillor S. Maxwell

CARRIED

Municipal Ticket Information System Amendment Bylaw No. 2178, 2018

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That "Municipal Ticket Information System Amendment Bylaw No. 2178, 2018" be given first, second and third readings.

CARRIED

Bylaw Notice Enforcement Amendment Bylaw No. 2180, 2018

Moved by Councillor J. Grills
Seconded by Councillor S. Maxwell

That "Bylaw Notice Enforcement Amendment Bylaw No. 2180, 2018" be given first, second and third readings.

CARRIED

Delegation of Authority Bylaw No. 2181, 2018

Moved by Councillor J. Crompton
Seconded by Councillor J. Ford

That "Delegation of Authority Bylaw No. 2181, 2018" be given first, second and third readings.

CARRIED

Tax Rates Bylaw No. 2182, 2018

Moved by Councillor J. Grills
Seconded by Councillor C. Jewett

That "Tax Rates Bylaw No. 2182, 2018" be given first, second and third readings.

CARRIED

Sewer User Fee Amendment Bylaw No. 2183, 2018

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That "Sewer User Fee Amendment Bylaw No. 2183, 2018" be given first, second and third readings.

CARRIED

Sewer Tax Bylaw No. 2184, 2018

Moved by Councillor J. Crompton
Seconded by Councillor J. Ford

That "Sewer Tax Bylaw No. 2184, 2018" be given first, second and third readings.

CARRIED

Solid Waste /Recycling Rates Amendment Bylaw No. 2185, 2018

Moved by Councillor J. Grills
Seconded by Councillor C. Jewett

That "Solid Waste/Recycling Rates Amendment Bylaw No. 2185, 2018" be given first, second and third readings.

CARRIED

Water User Fee Amendment Bylaw No. 2186, 2018

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That "Water User Fee Amendment Bylaw No. 2186, 2018" be given first, second and third readings.

CARRIED

BYLAWS FOR THIRD READING

Land Use Contract Termination Bylaw (Alpine Meadows) No. 2166, 2017

No action was taken regarding this Agenda item.

BYLAWS FOR ADOPTION

Five-Year Financial Plan 2018 – 2022 Bylaw No. 2176, 2018

Moved by Councillor J. Crompton
Seconded by Councillor J. Ford

That "Five-Year Financial Plan 2018 – 2022 Bylaw No. 2176, 2018" be adopted.

OPPOSED: Councillor S. Maxwell

CARRIED

Outdoor Potable Water Usage Bylaw No. 2179, 2018

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That "Outdoor Potable Water Usage Bylaw No. 2179, 2018" be adopted.

CARRIED

OTHER BUSINESS

CORRESPONDENCE

RZ1144 – 2077 Garibaldi Way
File No. RZ1144

Moved by Councillor J. Crompton
Seconded by Councillor J. Ford

That correspondence, received from March 20, 2018 to April 12, 2018, regarding Rezoning Application No. 1144 – 2077 Garibaldi Way from the following individuals be received and referred to staff:

- Tim Schumacher;
- Christine d'Eça; and
- Laura Wetaski.

CARRIED

Artificial Turf Field
File No. 3009

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That correspondence, received from April 6, 2018 to April 7, 2018, regarding the Artificial turf field from the following individuals be received and referred to staff:

- Karina Sykes;
- Patricio Cabrera;
- Sarita Cabrera; and
- Manon Pelletier.

CARRIED

Canada Infrastructure Plan
File No. 2014

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That correspondence from Pamela Goldsmith-Jones, Member of parliament, dated April 2, 2018, regarding the Canada Infrastructure Plan be received and referred to staff.

CARRIED

Green Burials
File No. 3009

Moved by Councillor S. Anderson
Seconded by Councillor J. Ford

That correspondence from Margaret Berthelsen, dated April 5, 2018, regarding green burials at the Whistler Cemetery be received and referred to staff.

CARRIED

SLRD Proclamation Request
File No. 2014

Moved by Councillor J. Grills
Seconded by Councillor C. Jewett

That correspondence from Brooke Carere, Communications Coordinator – Solid Waste and Resource Management, Squamish-Lillooet Regional District, dated April 4, 2018, requesting Council proclaim April 22 to 29, 2018 as Pitch-In Week be received and

Pitch-In Week be proclaimed.

CARRIED

Strategic Wildfire Prevention Initiative FireSmart 2018 Grant Approval File No. 2014

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That correspondence from Danyta Welch, Manager, Local Government Program Services, Union of BC Municipalities, dated April 5, 2018, notifying that the RMOWs FireSmart 2018 Grant has been approved be received and referred to staff.

CARRIED

LMLGA Newsletter and CivX 2018 Event Reminder

Moved by Councillor J. Grills
Seconded by Councillor C. Jewett

That correspondence from Jamee Justason, Executive and Association Services Coordinator, Union of BC Municipalities, LMLGA, dated April 9, 2018, regarding the LMLGA Newsletter and reminding of CivX 2018 be received and referral to staff.

CARRIED

AVICC Fish Farm Resolutions File No. 3009

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That correspondence from Jim Horner, dated April 10, 2018, requesting Council support the AVICC resolutions that protect wild salmon from the impacts of fish farms be received and referred to staff.

CARRIED

BC Stone, Sand and Gravel Association Briefing Note File No. 3009

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That correspondence from Paul Allard, Executive Director and Derek Holmes, President the British Columbia Stone, Sand and Gravel Association, dated April 12, 2018 regarding aggregate production in British Columbia be received and referred to staff.

CARRIED

Whistler Learning Centre OCP Endorsement File No. 3009

Moved by Councillor C. Jewett
Seconded by Councillor J. Grills

That correspondence from Stephen L. Milstein, Ph.D, Chairperson of Whistler Learning Centre, dated April 15, 2018, endorsing and supporting the education goals as outlined in the RMOW's Official Community Plan be received and referred to staff.

CARRIED

LMLGA Special Resolution Notice File No. 2014

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That correspondence from Jamee Justason, Executive and Association Services Coordinator, Union of BC Municipalities, LMLGA, dated April 18, 2018, regarding a Special Resolution for the May LMLGA Conference be received and referred to staff.

CARRIED

TERMINATION

Motion to Terminate

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That the Regular Council Meeting of April **24, 2018** be terminated at 9:06 p.m.

CARRIED

Nancy Wilhelm-Morden
Mayor

Brooke Browning
Municipal Clerk

WHISTLER

MINUTES

PUBLIC HEARING OF MUNICIPAL COUNCIL
TUESDAY, APRIL 24, 2018 STARTING AT 6:00 P.M.

In the Franz Wilhelmsen Theatre at Maury Young Arts Centre
4335 Blackcomb Way, Whistler, BC V0N 1B4

PRESENT:

Mayor: N. Wilhelm-Morden
Councillors: S. Anderson, J. Crompton, J. Ford, J. Grills, C. Jewett and S. Maxwell

Chief Administrative Officer, M. Furey
General Manager of Infrastructure Services, J. Hallisey
General Manager of Corporate and Community Services, N. McPhail
General Manager of Resort Experience, J. Jansen
Director of Finance, K. Roggeman
Director of Planning, M. Kirkegaard
Municipal Clerk, B. Browning
Manager of Financial Services, M. Peatfield
Manager of Communications, M. Comeau
Senior Planner, J. Belobaba
Planner, F. Savage
Planning Analyst, R. Licko
Planner, A. Antonelli
Bylaw Supervisor, L. DeBou
Council Coordinator, S. Termuende

This Public Hearing is convened pursuant to section 464 of the *Local Government Act* to allow the public to make representations to Council respecting matters contained in "Land Use Contract Termination Bylaw (Alpine Meadows) No. 2166, 2017" (the "proposed Bylaw").

Everyone present shall be given a reasonable opportunity to be heard or to present written submissions respecting matters contained in the proposed Bylaw. No one will be discouraged or prevented from making their views known. However, it is important that remarks be restricted to matters contained in the proposed Bylaw.

When speaking, please commence your remarks by clearly stating your name and address.

Members of Council may ask questions following presentations; however, the function of Council at a Public Hearing is to listen rather than to debate the merits of the proposed Bylaw.

As stated in the Notice of Public Hearing, the purpose of the "Land Use Contract Termination Bylaw (Alpine Meadows) No. 2166, 2017" is to terminate the Alpine Meadows Land Use Contract and to rezone the above-noted

	properties to RS1.
Presentation by municipal staff	Senior Planner Jake Belobaba gave a presentation regarding the proposed Bylaw.
Submissions from the Public	Mayor N. Wilhelm-Morden called for submissions by the public.
Craig Ross 7315 Spruce Grove Lane	Mr. Ross expressed opposition to the proposed Bylaw. He stated that he considered the proposed zoning as a downzoning and unfair to owners. Mr. Ross said currently, the owners are allowed a 2,500 square foot residence and out buildings. Under LUC zoned RS1, owners are not looking for more out buildings. He stated that they feel staff has not consulted with the property owners, and that the owners felt ignored until the first Public Hearing. Mr. Ross stated that it seemed like staff is forcing zoning. Mr. Ross stated that applying for rezoning after termination of the LUC is challenging and unfair to owners. Mr. Ross stated that owners have received very little support from the RMOW Planning department and staff regarding access, building requirements and zoning. Mr. Ross stated staff are misguided. He stated that over the years, the property owners have been turned away from developing. Mr. Ross stated that the owners don't agree with how application has been handled. Mr. Ross asked Council to direct staff to work with owners to provide winning solutions to all involved.
Submissions from the Public	Mayor N. Wilhelm-Morden called twice more times for submissions by the public.
Richard Diamond 1435 Northlands Boulevard	Mr. Diamond stated that access to the large lots is an issue. He stated that this issue is addressed under the LUC and argued that the access currently is impossible to meet under the current standards of the Zoning Bylaw. Mr. Diamond stated that the RMOW needs to resolve access before putting zoning on properties. Mr. Diamond felt that the RMOW was using access as a way of blocking development. He stated that as part of process of putting zoning on, development and access need to be addressed.
Paul Bragg Lot 32 Alpine Meadows	Mr. Bragg gave a history of Lot 32 and the history of development of Lot 29, 31 and 32. Mr. Bragg met with other lot owners over the years and he stated that if this rezoning welcomes owners, the RMOW needs to leave it tight and right. Mr. Bragg stated that currently he has suffered a 6 month stop work order from conflicting zoning interpretations.
Submissions from the Public	Mayor N. Wilhelm-Morden called three more times for submissions by the public.
Correspondence	The Municipal Clerk Brooke Browning indicated that four pieces of correspondence have been received regarding the proposed Bylaw.

MOTION TO CLOSE THE PUBLIC HEARING

Moved by Councillor J. Ford
Seconded by Councillor J. Crompton

That the Public Hearing for "Land Use Contract Termination Bylaw (Alpine Meadows) No. 2166, 2017" be closed at 6:15 p.m.

CARRIED

Mayor, N. Wilhelm-Morden

Municipal Clerk, B. Browning

REPORT | INFORMATION REPORT TO COUNCIL

PRESENTED:	May 8, 2018	**REPORT:**	18-057
FROM:	Infrastructure Services	**FILE:**	200.2
SUBJECT:	DRINKING WATER GUIDELINES UPDATE		

COMMENT/RECOMMENDATION FROM THE CHIEF ADMINISTRATIVE OFFICER

That the recommendation of the General Manager of Infrastructure Services be endorsed.

RECOMMENDATION

That Information Report No. 18-057 regarding Drinking Water Guidelines be received.

REFERENCES

Appendix “A” – Vancouver Coastal Health 2017 Evaluation Reports

Appendix “B” – Guidelines for Canadian Drinking Water Quality - Guideline Technical Document pH

Appendix “C” – Interim Guidelines on Evaluating and Mitigating Lead in Drinking Water Supplies, Schools, Daycares and Other Buildings.

Appendix “D” – Copper in Drinking Water Guideline Technical Document for Public Consultation

PURPOSE OF REPORT

The purpose of this Report is to share information regarding the operational and interim guidelines either in place or under review, which, if they become regulation may impact of the long-term management of Whistler’s drinking water system. As requested in the 2017 Vancouver Coastal Health (VCH) Evaluation Report, RMOW water managers are reviewing operational and interim guidelines published by the federal and provincial governments.

DISCUSSION

Complexity of Source Water Supply

The water chemistry characteristics of the RMOW systems (Community and Emerald) are complex because both surface and groundwater sources may be used.

The RMOW Community water supply can be from:

- only surface water;
- only groundwater; or
- both (blended).

The surface water, 21 Mile Creek supply, is not utilized when the creek water is turbid (cloudy), this occurs during rainfall and snowmelt events.

The groundwater is supplied from fourteen (14) active well locations, which are used when 21 Mile Creek supply is offline or water demand exceeds what 21 Mile Creek can supply alone. The well supplies would only be unavailable due to an emergency event such as contamination or equipment malfunction.

Distributed Water Treatment System

Treatment of the surface water occurs at one location with UV disinfection and addition of chlorine, but no filtration.

Treatment of the groundwater occurs at eight (8) locations and only includes the addition of chlorine with the exception of the Emerald groundwater wells which will also be treated with UV disinfection once the Emerald System Upgrade project is complete.

Who is responsible for the water quality at the tap?

The *Drinking Water Protection Act* requires water suppliers (such as RMOW) to deliver potable water to users with defined quality standards, but does not have a requirement to test the water after delivery to customers.

The water produced and distributed by the RMOW meets or exceeds all federal and provincial drinking water standards. RMOW staff sample water at 24 locations in the distribution system every second week, and the water is tested for bacteriological data (E. coli & Total Coliform), pH, residual chlorine, temperature and turbidity. Overall chemistry is sampled and tested at least annually.

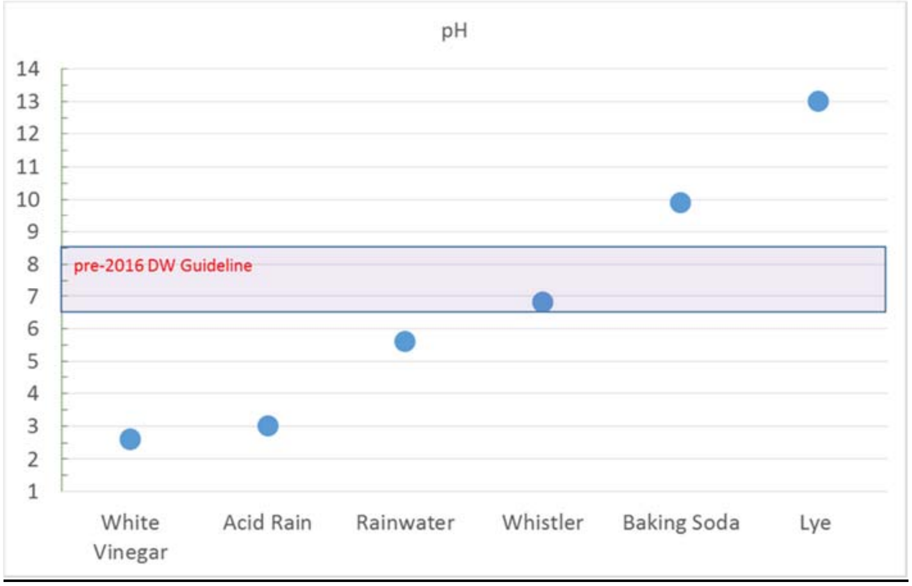
Definition and ranges of pH for Whistler water

pH is a measure of the acidity/basicity of water, it is measured on a logarithmic scale from 1 to 14.

- pH 7 is “neutral”
- pH below 7 is “acidic”
- pH above 7 is “basic”

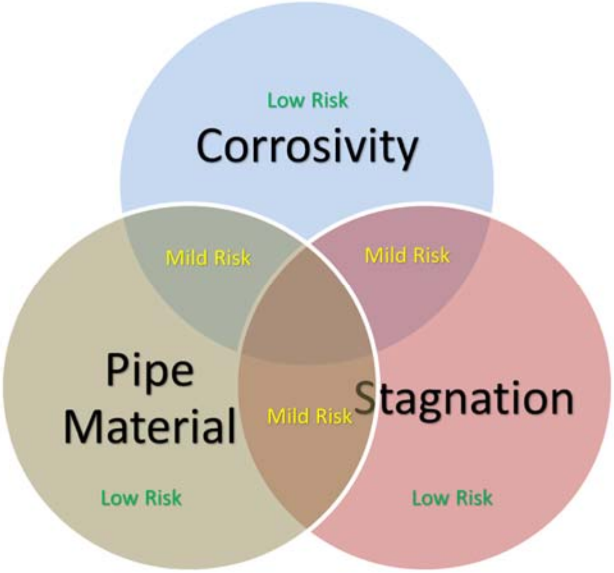
The more the pH is above or below 7 the more chemically reactive the water is. pH influences drinking water treatment effectiveness and efficiency, and in the distribution system, the potential for corrosion.

When 21 Mile Creek is available as a sole source (which is about half the time), the pH is approximately neutral. When the wells are being utilized they each supply water with a different pH value, but on a yearly average the pH of the well water is between 6.5 and 7.



<u>What is water corrosivity and why is it of concern?</u>
Sometimes described as “acidic” or “aggressive”, corrosivity is the extent to which the water can cause a chemical reaction that will cause a deterioration in the material used in plumbing pipes and fixtures. The three most important characteristics of corrosivity are low pH, low alkalinity and low hardness (referred to commonly as soft water).

Private and municipal plumbing systems have some metal components. In private buildings and homes the risk of the metals leaching into water can result from three variables: water corrosivity, pipe material, and water stagnation time. In the municipal distribution system, for which the water quality sampling results meet or exceed all existing guidelines for metals, the risk of metals leaching into water in the distribution system is low, because the water is almost constantly moving due to demand.



What Are the Interim Guidelines Proposing?

Lead - Interim Guideline on Reducing Exposure to Lead through Drinking Water
(released July 2017)

- Last updated in 1992;
- Maximum acceptable concentration (MAC) of 0.01 mg/L; and
- The document proposes a MAC of 0.005 mg/L.

Copper – Technical Document for Consultation
(released March 2018)

- Last updated in 1992,
- Aesthetic objective of ≤1.0 mg/L, and
- The document proposes a health-based MAC of 2 mg/L.

Both guidelines propose that sampling occur at the tap inside of private property in addition to the sampling and testing already being completed for the water sources and in the distribution systems.

What Are the Next Steps?

Per the VCHA 2017 Evaluation Report (released on March 21, 2018):

"The new Operational Guideline for pH has been recently revised under the GCDWQ, now specifying a higher pH range from 7.0 to 10.5. Please provide a report outlining which of the RMOW Community sources do not meet this guideline and outline any remediation strategies under consideration.

As discussed, the MOH Health Protection Branch has developed Interim Guidelines (July 2017) on evaluating and mitigating lead in drinking water supplies, schools, daycares and other buildings. VCH has been reviewing the development of this interim guidance and are unsure if centralized water conditioning will relieve the need for a multifaceted approach by property owners (including plumbing upgrades; flushing and/or filters).

As these Interim Guidelines have not as yet had industry/stakeholder review, we welcome any comments you wish to offer."

Before proceeding to treat the well water supply for pH the RMOW will need to inform the community, collect feedback and understand the cost impacts of proceeding, especially considering the following factors:

- That the pH when 21 Mile Creek is being utilized is neutral;
- That pH is only one of the factors that contributes to water corrosivity; and
- That homes with newer plumbing, if sampling were to take place at the tap, may already have levels of metals below the proposed maximum allowable concentrations.

The following steps are planned / underway at this time:

1. Reiterating public safety message that VCH recommends all homeowners freshen water by flushing until cold before drinking;
2. Commissioning RFP for conceptual design for pH treatment at eight (8) locations;
3. Educating private property owners regarding their responsibility;

4. Comment to VCH re: Interim Guidelines.

WHISTLER 2020 ANALYSIS

Whistler 2020 Strategy	TOWARD Descriptions of success that resolution moves us toward	Comments
Water	Residents and visitors are educated about and encouraged to protect and conserve natural water resources.	The goal of this report (and accompanying presentation) is education, in order to raise awareness of the value of our water and the need to protect and conserve it.
Water	All potable water is used sparingly and only used to meet appropriate needs.	By raising awareness of the value of our drinking water we are ensuring future generations recognise the importance of conservation efforts.

The Drinking Water Guidelines Update does not move our community away from any of the adopted Whistler2020 Descriptions of Success.

OTHER POLICY CONSIDERATIONS

There are no other identified policy considerations at this time.

BUDGET CONSIDERATIONS

The capital and operations and maintenance costs that would be required to treat the water supply for pH or other corrosivity factors would be significant and will be factored into an updated to Comprehensive Water Conservation and Supply Plan, scheduled for early 2019.

COMMUNITY ENGAGEMENT AND CONSULTATION

There is no proposed community engagement or consultation at this time. This would occur after additional information is collected.

SUMMARY

As requested in the 2017 Vancouver Coastal Health (VCH) Inspection Report, RMOW water managers are reviewing operational and interim guidelines published by the federal and provincial governments.

The RMOW is responsible for the water distribution system up to the property line. After delivery to Whistler properties, the risk of lead and copper leaching into water results from a combination of three variables: water corrosivity, pipe material, and water stagnation time.

Property owners are responsible for the condition of their building’s plumbing and for taking any necessary remedial action to minimize potential exposure deriving from the plumbing and fixtures in their property.

The RMOW is commissioning an RFP for conceptual design for pH treatment at eight (8) locations in order to update the Comprehensive Water Conservation and Supply Plan, scheduled for completion in early 2019.

Respectfully submitted,

Gillian Woodward
UTILITIES GROUP MANAGER
for
James Hallisey
GENERAL MANAGER INFRASTRUCTURE SERVICES

Appendix A

These reports are located at https://healthspace.ca/Clients/VCHA/CoastGaribaldi/CoastGaribaldi_Website.nsf

RMOW Community Water System - Inspection Report

Inspection Information:

Facility Type:	WS1A
Inspection type:	Evaluation
Inspection date:	March 21, 2018
Follow-up Required:	No

This facility was given a **low** hazard rating.
- More information on hazard ratings.

Violations:
No violations were found during the inspection

Comments:
The bacteriological sample range report for 2017 is attached. Of the 435 samples submitted for analysis, none (0%) were positive for total coliform or E Coli bacteria. This indicates satisfactory water quality was maintained throughout the year. As per VCH 2017 report, the water chemistry characteristics within the RMOW Community system are complex in view of the number of sources, both surface water and groundwater.

The new Operational Guideline for pH has been recently revised under the GCDWQ, now specifying a higher pH range from 7.0 to 10.5. Please provide a report outlining which of the RMOW Community sources do not meet this guideline and outline any remediation strategies under consideration. As we discussed, the MOH Health Protection Branch has developed Interim Guidelines (July 2017) on evaluating and mitigating lead in drinking water supplies, schools, daycares and other buildings. VCH has been reviewing the development of this interim guidance and are unsure if centralized water conditioning will relieve the need for a multifaceted approach by property owners (including plumbing upgrades; flushing and/or filters). As these Interim Guidelines have not as yet had industry/stakeholder review, we welcome any comments you wish to offer.

With respect to the subject of what constitutes a domestic water system pursuant to the DWPR, strata and other development are considered as a 'system within a system' and therefore exempt from the requirements of the Drinking Water Protection Regulations (DWPR). VCH will review the service connection to these developments for the purpose of issuing a Construction Permit to the RMOW as well as assessing the need for backflow protection. However the piping arrangements within the private / strata property are left to the design engineer to follow good engineering practice. Please provide an update on your progress with implementing a cross connection control program. VCH continues to advocate that by-law authority is essential to ensure all backflow protection assemblies are tested annually, and we can see no method by which it can be assured otherwise. At this time the GCDWQ limits for manganese continue to list that parameter as an aesthetic objective, although we are anticipating some change in view of the draft revisions previously circulated for public comment. Thank you for the extensive work on developing a Source Water

Protection Plan (SWPP) for the 21 Mile Creek supply source. From a VCH perspective it appears that the current level of public education and access into the watershed seems reasonable, however it must be understood that the 21 Mile Creek supply is an unfiltered surface water source. The advanced disinfection processes (comprising UV followed by chlorination) complies with the pathogen reduction requirements of the BC Surface Water Treatment Objectives - but may not protect against spills or other contamination events. Accordingly, we recommend the SWPP be reviewed at a high level within the RMOW to develop a common understanding. We are pleased to note the close interdepartmental relationship that exists within the RMOW which will continue to be important for issues such as trail maintenance activities and waste removal (which should be scheduled when the intake is in by-pass mode). A review of the SWPP for the RMOW Community groundwater sources should also be scheduled for review, including land use activities in the well capture zones. The RMOW Emergency Response and Contingency Plan (ERCP) will need some revision - as a minimum to reflect new staff and contact numbers, including those for VCH staff. VCH anticipates being able to send our staff updates next month once new staff arrive.

RMOW - Emerald Estates Water System - Inspection Report

Inspection Information:

Facility Type:	WS1A
Inspection type:	Evaluation
Inspection date:	March 23, 2018
Follow-up Required:	No

This facility was given a **low** hazard rating.

- More information on hazard ratings.

Violations:
No violations were found during the inspection

Comments:
For 2017, the bacteriological sample range report indicates satisfactory water quality was maintained within the distribution system throughout the year. Of the 45 samples submitted for analysis, none (0%) were positive for total coliform bacteria. This is very consistent with the results from previous years. VCH is pleased to note construction work on the new UV treatment system is underway. Please advise once the construction has been completed so that we can arrange an inspection in at the time of commissioning. From our review of the source water chemistry, the groundwater supplying the Emerald Estate wells appears to be soft with respect hardness and low in alkalinity, with a typical pH value close to 7.0. The new Operational Guideline for pH has been recently revised under the GCDWQ, now specifying a higher pH range from 7.0 to 10.5. We understand the new UV treatment facility may facilitate supplementation for pH adjustment. As we discussed, the MOH Health Protection Branch has developed Interim Guidelines (July 2017) on evaluating and mitigating lead in drinking water supplies, schools, daycares and other buildings. VCH has been reviewing the development of this interim guidance and are unsure if centralized water conditioning will relieve the need for a multifaceted approach by property owners (including plumbing upgrades; flushing and/or filters). As these Interim Guidelines have not as yet had industry/stakeholder review, we welcome any comments you wish to offer. A review of the SWPP for the RMOW - Emerald Estates groundwater sources should also be scheduled for review, including land use activities in the well capture zones. The RMOW Emergency

Response and Contingency Plan (ERCP) will need some revision - as a minimum to reflect new staff and contact numbers, including those for VCH staff. VCH anticipates being able to send our staff updates next month once new staff arrive.

Health Canada Santé Canada
Your health and safety… our priority. Votre santé et votre sécurité… notre priorité.

Guidelines for Canadian Drinking Water Quality

Guideline Technical Document

pH

Canada

Health Canada is the federal department responsible for helping the people of Canada maintain and improve their health. *We assess the safety of drugs and many consumer products, help improve the safety of food, and provide information to Canadians to help them make healthy decisions. We provide health services to First Nations people and to Inuit communities. We work with the provinces to ensure our health care system serves the needs of Canadians.*

Published by authority of the Minister of Health.

Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – pH

is available on Internet at the following address:
www.healthcanada.gc.ca

Également disponible en français sous le titre :
Recommandations pour la qualité de l'eau potable au Canada : Document technique – Le pH

Pub. Number: 150224
Cat.: H144-28/2016E-PDF
ISBN: 978-0-660-04436-1

Guidelines for Canadian Drinking Water Quality

Guideline Technical Document

pH of Drinking Water

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

Health Canada
Ottawa, Ontario

August, 2015

This document may be cited as follows:

Health Canada (2015). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — pH. Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No H144-28/2016E-PDF).

The document was prepared by the Federal-Provincial-Territorial Committee on Drinking Water of the Federal-Provincial-Territorial Committee on Health and the Environment.

Any questions or comments on this document may be directed to:

Water and Air Quality Bureau
Healthy Environments and Consumer Safety Branch
Health Canada
269 Laurier Avenue West, Address Locator 4903D
Ottawa, Ontario
Canada K1A 0K9

Tel.: 613-948-2566
Fax: 613-952-2574
E-mail: water_eau@hc-sc.gc.ca

Other Guideline Technical Documents for the Guidelines for Canadian Drinking Water Quality can be found on the following web page: www.healthcanada.gc.ca/waterquality

Table of Contents

August 2015

pH

Part I. Overview and Application

1.0 Guideline

The operational guideline for pH is a range of 7.0 to 10.5 in finished drinking water.

2.0 Executive summary

pH is a measure of the acidity/basicity of water. The control of pH is important during drinking water treatment, to maximize treatment effectiveness and efficiency, and in the distribution system, to control corrosion and reduce leaching from distribution system and plumbing components.

This guideline technical document reviews and assesses the relationships between pH and other water quality characteristics, water treatment processes and distribution system considerations. It also outlines health risks associated with exposure to extreme pH levels. Although the document includes information on pH throughout treatment and distribution, the operational guideline for pH is intended to apply to finished water in the distribution system.

Health Canada recently completed its review of the considerations associated with the pH of drinking water. Based on this review, the operational guideline for the pH of finished drinking water is an acceptable range of 7.0 to 10.5.

2.1 Water quality characteristics

The pH level of water is interrelated with other water characteristics. These include physical properties (primarily temperature); chemical characteristics, such as the levels of dissolved organic carbon and hardness, as well as the alkalinity and buffering properties of the water; and microbiological characteristics, such as biofilm.

2.2 Treatment processes

pH can have a major effect on water chemistry, which will also significantly affect the performance of many treatment processes, including coagulation and disinfection. Although water pH is an important parameter in the formation of disinfection by-products, its effects vary from one by-product to another. It is necessary to monitor pH throughout the treatment process and to adjust it as needed.

2.3 Distribution systems

The adjustment and control of pH in the distribution system, including through adequate buffering, are essential to control corrosion and minimize exposure to metals such as lead. Buffering will reduce the impact that other water characteristics can have on pH. A higher pH (up to 10.5) in the distribution system will result in lower concentrations of lead and other metals at the tap.

2.4 Health effects

There is no evidence of an association between the pH of the diet (food or drinking water) and direct adverse health effects. Extreme levels of pH have been linked to some health effects, including irritation of the skin and eyes. The most significant impact of pH on health is indirect and related to exposure to metals leached from the distribution system and to disinfection by-products formed as a result of treatment processes.

3.0 Application of the guideline

Note: Specific guidance related to the implementation of drinking water guidelines should be obtained from the appropriate drinking water authority in the affected jurisdiction.

Current science indicates that the guideline for the pH of finished drinking water should be flexible to allow systems to determine the most appropriate pH for their individual water quality goals. The acceptable pH range of 7.0-10.5 would provide utilities the flexibility required to achieve water quality goals and to control contaminant concentrations and corrosion by combined treatment approaches appropriate to the materials in the distribution system and premise plumbing. It is important to note that pH cannot be considered in isolation for controlling corrosion. Adjustment of pH by itself is not considered appropriate; other parameters, such as alkalinity and dissolved inorganic carbon, also need to be considered.

3.1 Monitoring

The monitoring frequency for pH will be dependent on the specific purpose or objective of the monitoring. Operational and process-specific pH monitoring may vary in frequency and is generally not done in isolation. On-site analysis of water quality parameters includes pH, chlorine residual, turbidity and temperature to provide a baseline for specific trends in water quality throughout the treatment plant. Additionally, monitoring of these and other water quality parameters, such as dissolved inorganic carbon, alkalinity, nitrate and nitrite, can help a utility maintain drinking water quality in the distribution system and identify changes that can lead to corrosion. Monitoring should be done in the distribution system. Locations of particular importance for pH monitoring in the distribution system include areas with high residence times (e.g., dead-ends), areas where maintenance or upgrades are being conducted (e.g., application of cement lining in pipes) and points in the distribution system where drinking water sources are blended. The sampling frequency required for small systems will depend on the water quality and the complexity of treatment and distribution systems. Since disinfection efficacy is impacted by pH, even systems with minimal treatment should monitor pH. Where there are complex sources and distribution systems (e.g., multiple wells with varying water quality, mixing zones), the frequency and number of sites monitored may need to be increased.

The monitoring of pH should be done continuously at the point where the treated water enters the distribution system and throughout the distribution system. Where continuous monitoring is not possible, grab samples should be regularly taken and analyzed to ensure that any fluctuations in the quality of the finished drinking water are identified and the causes addressed.

For effective operation of the distribution system, it is good practice to ensure that finished drinking water in the distribution system maintains a pH within 0.2 pH units. Changes in distribution system pH can be indicative of deteriorating drinking water quality, and fluctuations in pH should be minimized. If an unusual or unexpected change in distribution system pH occurs, it should be investigated and its cause determined.

Monitoring of pH is used in conjunction with monitoring of disinfectant residual, alkalinity, dissolved inorganic carbon and nitrite to ensure that the quality of drinking water in the distribution system is maintained and that corrosion is being controlled.

Part II. Science and Technical Considerations

4.0 Definition and measurement

4.1 Definition of pH

At a given temperature, the intensity of the acidic or basic property of the water is indicated by the pH, which is the negative logarithm of the hydrogen ion activity (APHA et al., 2012). The hydrogen ion activity is nearly equal to its concentration in most potable waters and, for this reason, is generally stated as a concentration (Sincero and Sincero, 2003; Schock and Lytle, 2011). Pure water is slightly ionized; when the reaction is at equilibrium, the ion product (K_w) can be expressed by the following equation (Sincero and Sincero, 2003; APHA et al., 2012):

$$K_w = [H^+] \times [OH^-] = 1.01 \times 10^{-14} \text{ at } 25°C \qquad \text{(Equation 1)}$$

and

$$[H^+] = [OH^-] = 1.005 \times 10^{-7}$$

where:
- $[H^+]$ is the activity of hydrogen ions (mol/L); and
- $[OH^-]$ is the activity of hydroxide ions (mol/L).

The activity of hydrogen ions, also called an effective concentration, refers to the ions that participate in the reaction and is different from the actual concentration of ions in a solution. A logarithmic scale is a convenient way to express the ionic activities:

$$(-\log_{10}[H^+]) + (-\log_{10}[OH^-]) = -\log_{10} K_w = 14 \text{ at } 25°C \qquad \text{(Equation 2)}$$

or

$$pH + pOH = pK_w \qquad \text{(Equation 3)}$$

where:
- $pH = -\log_{10}[H^+]$;
- $pOH = -\log_{10}[OH^-]$; and
- $pK_w = -\log_{10}K_w$.

Equation 3 shows that as pH increases, pOH decreases correspondingly, and vice versa, as pK_w is a constant at a given temperature. The pH scale is usually represented as a range from 0 to 14, with pH 7.0 representing neutrality (at 25°C), and the activities of the hydrogen and hydroxide ions are each approximately 10^{-7} mol/L. The neutral point is temperature dependent, and the pH neutral points are 7.5 and 6.5 at 0°C and 60°C, respectively. Natural waters usually have pH values in the range of 4.0 to 9.0; however, most are slightly basic because of the presence of bicarbonates and carbonates of the alkali and alkaline earth metals. As the scale is logarithmic, a drop in pH by 1.0 unit is equivalent to a 10-fold increase in acidity (APHA et al., 2012).

In a national survey conducted by Health Canada in 2009 and 2010, the pH levels of 129 samples of raw water were measured at 64 treatment plants in winter and summer. Data for raw water showed that pH ranged from 4.6–8.57 for 93 surface water samples and 6.1–9.18 for 36 groundwater samples (Health Canada, 2012b).

4.2 Measurement of pH

pH is one of the most important operational water quality parameters. Measurement of pH is one of the most frequently used tests in water chemistry. Every process in water treatment, including coagulation, precipitation, water softening, disinfection and corrosion control, is dependent on pH.

The most accurate method to measure the pH of a water sample is the potentiometric method. The potentiometric method is based on the Nernst equation, which describes the relationship between the galvanic potential of a defined electrode pair and the activity of the hydrogen ion (Dye, 1952; Kohlmann, 2003):

$$E = E_0 - (2{,}303\ RT/nF) \times \log a_{H^+}$$

where:

- E is the total potential between two electrodes (mV);
- E_0 is the temperature-dependent standard potential of electrode;
- R is the gas constant ($Jmol^{-1}K^{-1}$);
- T is the absolute temperature (°K);
- n is the valency (charge) of the ion (n = 1 for H^+);
- F is the Faraday constant ($C\ mol^{-1}$); and
- a_{H^+} is the activity of the hydrogen ion.

The potentiometric method uses a pH meter, which includes a pH-measuring electrode (usually a glass electrode), a reference electrode, a high impedance voltmeter and a temperature-compensating device. The reference electrode is calomel, silver–silver chloride or some other reference electrode of constant potential. The pH-measuring and reference electrodes can be two physically separate electrodes, known as an electrode pair. For convenience, the majority of modern pH meters have both electrodes joined in a single glass body assembly known as a combination electrode.

When the electrodes are immersed in a reference solution, a circuit is completed through the potentiometer, and the potentiometer measurement is used to determine the activity of the hydrogen ions. The reference electrode must have a constant and stable potential to be able to provide an accurate measurement. Deviation in the potential of the reference electrode will cause the overall potential to change, which will affect the pH reading at the measuring device (Kohlmann, 2003).

Based upon the Nernst equation, the term “2.303 RT/nF” is called a “slope factor” and describes the change in the total potential between the measuring and the reference electrodes for every 10-fold change in the activity of the H^+ ion. The slope factor is 59.16 mV for every 10-fold change in hydrogen ion activity at 25°C. In theory, the potential measured at pH 7.0 (isopotential point) is 0 mV (Kohlmann, 2003).

An accurate pH measurement requires calibration of the pH meter using buffers of known pH and adjusting the meter accordingly. The calibration is performed to compensate for the changes in the potential within the measuring and the reference electrodes, as well as any changes in the potential between them. The calibration also involves checking the slope of the measuring electrode and should be done, at minimum, daily (U.S. EPA, 1982). As ionic strength of the water can have an effect on pH measurement, other quality assurance/quality control measures, such as the use of a control or reference solution with a similar ionic strength to the sample water, should be considered.

The potentiometric measurement of pH in a closed system is affected by temperature in two ways: 1) a mechanical effect due to the physical changes in the electrode properties; and 2) a chemical effect caused by the equilibrium changes of the water sample (APHA et al., 2012). As the glass electrode is an ionic conductor, temperature fluctuations will affect the resistance of the electrode and will result in incorrect pH readings. As the temperature rises, the resistance across the glass bulb of the electrode decreases.

Glass electrodes are relatively free from interference related to colour, turbidity, oxidizing and reducing agents. However, at pH levels above 10, they experience interference caused by lithium, sodium and potassium cations. To reduce the possibility of such error (alkaline error), measurements at pH above 10 should be conducted with special “low sodium error” electrodes (APHA et al., 2012). Acid error affects the low end of the pH scale, usually below 1.0. As most water process applications are well above this pH, acid error is uncommon (Kohlmann, 2003).

In a closed system, any change in the temperature of the tested sample also results in a change in the activity of the hydrogen ions in that solution and subsequently in its pH value. A decrease of about 0.45 pH units occurs as the temperature is raised by 25°C in pure water (Langelier, 1946). For this reason, pH meters typically include a temperature compensation device in the measuring circuit. It is important to measure the pH as soon as possible after the sample collection to minimize the impact of temperature (Larson, 1975; Kohlmann, 2003). The temperature of the sample may take time to stabilize during cold water conditions. As such, analysts must ensure that the pH meter has reached equilibrium during cold water analysis to ensure an accurate measurement.

As the pH of water is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system, any change in the carbon dioxide (CO_2) concentration will affect the pH level of water. When continuous monitoring is not possible, a grab sample should be collected carefully to minimize aeration and splashing. Samples should be analyzed as soon as possible after sampling, while taking extreme care not to shake the sample or stir rapidly during the measurement. Waters that are not at equilibrium with the atmosphere (e.g., groundwater, high-pH waters) are subject to changes when exposed to the atmosphere (see Figure 1); therefore, the sample containers should be filled completely and kept sealed prior to analysis and measured in a closed system configuration, if possible.

pH meters for laboratory or field use are readily available from various vendors and suppliers. Pocket-sized, battery-powered, portable meters are suitable for field use. The portable meters can measure pH values with an accuracy of ± 0.05 pH units. Larger, more sophisticated models of pH meters can attain an accuracy of ± 0.01 pH units. Care must be taken when handling such equipment. The electrodes generally need to be replaced periodically.

Alternative methods for determining the pH of a solution are the use of indicators and colorimeters. The indicators (litmus) are specifically designed materials that change colour when exposed to different pH values. The colour of a wetted sample paper is compared with a standard

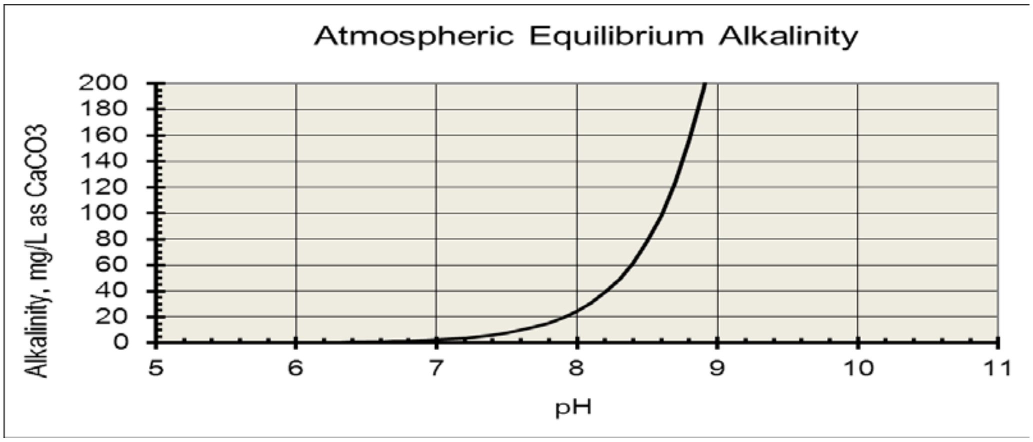


Figure 1 Effect of CO_2 loss on pH when sample is exposed to the atmosphere (at 25°C) (Schock, 2013)

colour scale. pH indicator strips are typically used for preliminary measurement or for small-volume samples and cannot be used for continuous monitoring of pH. The colorimeter device uses a vial filled with an appropriate volume of sample, to which a reagent is added. The colour of the sample changes and is compared with a colour wheel or spectral standard to interpolate the pH value (Kohlmann, 2003).

4.2.1 Approved analytical methods

The U.S. Environmental Protection Agency (EPA) has two approved analytical methods (Methods 150.1 and 150.2) to measure pH in drinking water (U.S. EPA, 2011). Both methods are potentiometric methods, whereby the pH of the sample is determined electrometrically using either a glass electrode in combination with a reference electrode or a combination electrode. Method 150.2 can be used for continuous online measurement of the pH of samples.

The following methods, developed by voluntary consensus standard organizations, are approved by the U.S. EPA and available to measure pH: ASTM-D 1293 (ASTM, 1984, 1995, 1999) and SM 4500-H^+ B (APHA et al., 1992, 1995, 1998 and 2005), as well as the online version of SM 4500-H^+ B-00 (APHA et al., 2011).

5.0 Relationship between pH and water quality characteristics

The pH level of water can affect, and in some cases be affected by, the physical, chemical and microbiological characteristics of the water, as described below.

5.1 Physical characteristics

Physical characteristics of water include temperature, colour, taste, odour, turbidity and total dissolved solids. Temperature is the single most important physical characteristic affecting the pH of water.

5.1.1 Temperature

Changes in temperature will affect the ionization equilibrium of any weak acids and bases that are present in the water. Increases in water temperature will cause the water to dissociate more, resulting in a decrease in pH. In pure water, a decrease in pH of about 0.45 units occurs as the temperature is raised by 25°C from 75°C to 100°C (Langelier, 1946; Dye, 1952; Larson and

Henley, 1955a,b). However, when the weak acids and bases are present in the water, the magnitude of this effect depends on the alkalinity and dissolved inorganic carbon (DIC) content of the water. Figure 2 provides an example of how a pH observed at 10°C needs to be corrected to obtain the corresponding pH at 25°C for waters of different alkalinities.

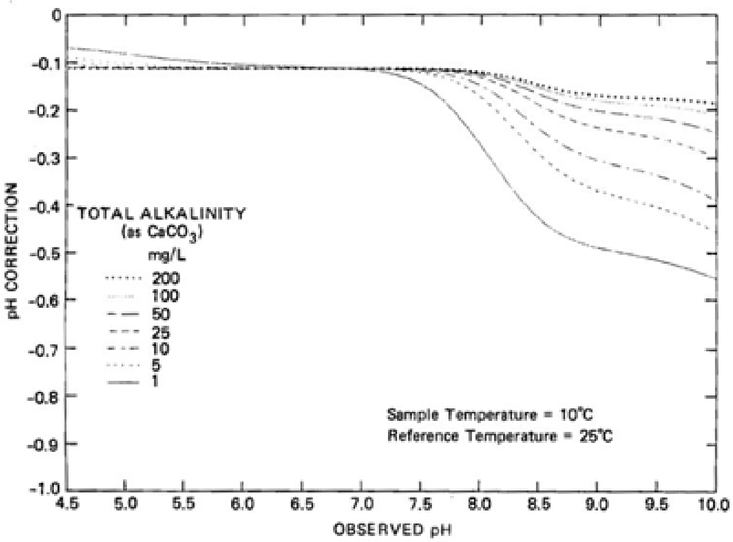


Figure 2 Example of pH correction from 10°C to 25°C for waters of different alkalinities (Schock, 2013)

5.2 Chemical characteristics

5.2.1 Dissolved inorganic carbon

Inorganic carbon chemistry is important in many water treatment applications, including coagulation, water softening, corrosion, oxidation and many processes involving acid–base reactions.

DIC is the sum of the concentration of the total inorganic carbon species in the water, including dissolved carbon dioxide (CO_2), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}), as well as carbonate species bound to metals as ion pairs or complexes. Commonly, DIC is expressed in milligrams of carbon per litre (mg C/L).

When dissolved in water, carbon dioxide is hydrated by the water molecules to form carbonic acid (H_2CO_3):

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

However, for this reaction, the concentration of the dissolved carbon dioxide exceeds that of carbonic acid, and only a small fraction of carbonic acid exists. The symbol $H_2CO_3^*$ denotes the sum of the concentrations of CO_2 and H_2CO_3 in the water (Stumm and Morgan, 1996; Butler and Cogley, 1998; Edzwald and Tobiason, 2011; Crittenden et al., 2012). For pure water in contact with the atmosphere, DIC is simply defined as:

$$DIC = [H_2CO_3^*] + [HCO_3^-] + [CO_3^{2-}]$$

As $H_2CO_3^*$ has acidic properties, the DIC concentration is an important parameter in many processes in surface water and groundwater, where it can affect the pH. The weathering of aluminum silicate and/or carbonate minerals increases the concentration of bicarbonate in the source water and thus the pH. The respiration of algae or the biodegradation of organic matter increases the carbon dioxide concentration and decreases the pH of the water. All of these reactions affect the DIC concentration, pH and chemical composition of the water (Edzwald and Tobiason, 2011). The bicarbonate and carbonate species affect many important reactions in corrosion chemistry, such as the ability of the water to form protective metallic carbonate-based scale or passivating film (Schock and Lytle, 2011). The DIC concentration plays an important role in stabilizing the pH of the water and can be calculated if the pH, alkalinity, temperature and ionic strength are known. However, in some water applications, if the DIC concentration is low (below 5 mg/L), the presence of weak acids (e.g., phosphoric acid) and bases (e.g., dissociated sodium and calcium hypochlorite) may contribute to the alkalinity and complicate the computation of the DIC concentration from pH and alkalinity results (Butler and Cogley, 1998; Schock and Lytle, 2011).

Closed system conditions (i.e., no contact with air) occur in groundwater, in the bottom stratified water layer in lakes and reservoirs, in distribution systems and in many water treatment processes. The total inorganic carbon content is constant in closed systems (Edzwald and Tobiason, 2011). Several authors have shown that when plotting the inorganic carbon concentration of 10^{-3} M (or 12 mg/L, a common condition for water supplies) as a function of pH at 25°C, the dominant form of inorganic carbon is $H_2CO_3^*$ at pH less than 5; HCO_3^- at pH ranging from 6.3 to 10.3; and CO_3^{2-} at pH greater than 10 (Stumm and Morgan, 1996; Butler and Cogley, 1998; Edzwald and Tobiason, 2011; Crittenden et al., 2012).

5.2.2 Alkalinity

Alkalinity is a measure of the capacity of the water to neutralize acids. It is influenced by the presence of the conjugate bases of inorganic carbon ($HCO_3^-$and CO_3^{2-}) and organic acids, as well as orthophosphate ($H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}), ammonia and silicate, all of which consume acid (H^+) when it is added to the water. Alkalinity can also be influenced by the presence of OH^- ion when it is in excess relative to the H^+ ion. For most water supplies and water treatment applications, the dominant conjugate bases are those from inorganic carbon. For the simple case of negligible contributions of other weak acids and bases relative to the carbonic acid system, the total alkalinity (T_{ALK}) is described by the following relationship (Edzwald and Tobiason, 2011):

$$T_{ALK} \quad = \quad [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$$

Alkalinity has historically been characterized as having operational forms expressed as phenolphthalein alkalinity and as total alkalinity (APHA et al., 2012). Phenolphthalein alkalinity and total alkalinity are both measured by titration, but each has a different titration endpoint.

Water that has a pH higher than 8.3 is said to have “phenolphthalein alkalinity,” which is alkalinity due primarily to the presence of carbonate or hydroxide ions. Phenolphthalein alkalinity is determined by titration to an endpoint pH of 8.3, which corresponds to the conversion of carbonate ions to bicarbonate ions. The phenolphthalein indicator changes from pink to colourless at pH 8.3 when this conversion occurs.

Total alkalinity is the final endpoint for the alkalinity titration and is determined by titration to the carbonic acid equivalence point. In drinking water practice in North America, alkalinity is most frequently expressed in milligrams of calcium carbonate per litre (mg/L as $CaCO_3$) (Edzwald and Tobiason, 2011). Commonly, in water supply and treatment applications, the endpoint of the titration is assumed to be a pH of 4.5, which corresponds to an equivalence point pH for an alkalinity of slightly over 150 mg/L as $CaCO_3$ (APHA et al., 2012). However, the pH of the equivalence point varies depending on the concentrations of carbonate, bicarbonate, hydroxide and other proton-consuming anions weaker than this endpoint and can lie between pH 8.3 and 4.5 (Stumm and Morgan, 1996; Butler and Cogley, 1998). For higher-alkalinity waters, the endpoint of titration is an approximation.

The endpoint of the total alkalinity titration can be identified by four principal approaches of varying levels of accuracy (APHA et al., 2012):

1) the use of an indicator dye, such as the mixed methyl red–bromocresol green indicator, which changes colour from green to pink at pH 4.5;
2) direct pH meter titration to pH 4.5;
3) a full titration to the carbonic acid equivalence point, identified with any of several different mathematical or graphical approaches; or
4) for alkalinities below 20 mg/L as $CaCO_3$, Method 2320B-4d, a two-point acid addition/pH measurement method developed by Larson and Henley (1955a,b). This method uses the linear relationship between the amount of acid added and the change in pH to calculate the alkalinity.

5.2.3 *Buffer intensity*

The difference between alkalinity and buffer intensity of the water is often misunderstood. Whereas alkalinity is a measure of the capacity of the water to neutralize acids, buffer intensity is an ability of the water to provide resistance against the pH fluctuations caused by the addition of water treatment chemicals or by water quality changes in the distribution system. Buffer intensity is defined as the derivative of the total alkalinity titration curve (Stumm and Morgan, 1996; Butler and Cogley, 1998). This ability of the water to resist pH fluctuations is strongly influenced by the DIC concentration, pH and alkalinity of the water and is also a function of temperature and ionic strength. As shown in Figure 3, at a specific pH, water with a higher DIC concentration (and therefore higher alkalinity) will have higher buffer intensity (Kirmeyer et al., 2000; Schock and Lytle, 2011).

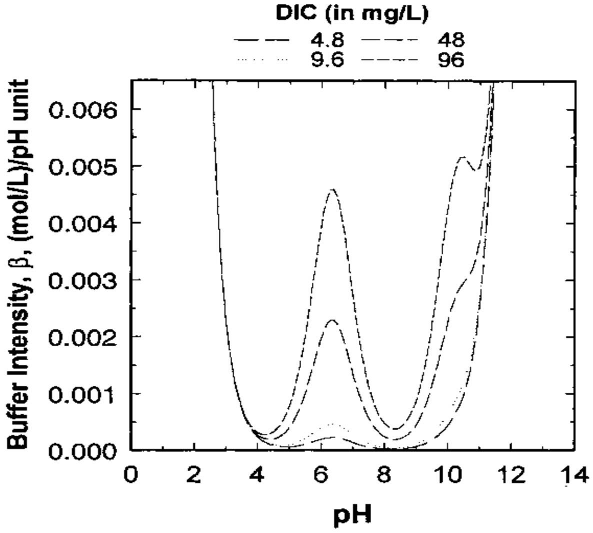


Figure 3 Effect of DIC concentration and pH on buffer intensity at 25°C and ionic strength of 0 (Schock, 2013)

Generally, the buffer intensity of natural waters is greater at pH levels of approximately 6.3 and 10.3, which correspond to the equilibrium constants pK_1 and pK_2, respectively, of the carbonate system. The minimum buffer intensity of water is approximately at pH 8.3, which corresponds to the point where pH is equal to ½($pK_1 + pK_2$) of the carbonate system (Butler and Cogley, 1998; Clement and Schock, 1998; Kirmeyer et al., 2000; Schock and Lytle, 2011).

5.2.4 *Hardness*

Hardness is primarily caused by the presence of calcium and magnesium in the water and is reported in mg/L as $CaCO_3$. Generally, the carbonate hardness is defined as the concentration of Ca^{2+} and Mg^{2+} cations in water that are associated with the anions that comprise the alkalinity (HCO_3^- and CO_3^{2-}) (Randtke, 2011; Crittenden et al., 2012). In general, waters with a calcium carbonate concentration less than 75 mg/L are considered soft; between 75 and 150 mg/L, moderately hard; between 150 and 300 mg/L, hard; and more than 300 mg/L, very hard (Post et al., 2011). Calcium carbonate, magnesium hydroxide and many carbonate oxide solids are less soluble at higher pH values; therefore, increasing the pH of hard water may cause unintended side effects, such as increased scaling in the treatment plant and distribution system.

The Langelier saturation index (LSI) identifies whether a calcium carbonate scale will form or not, based on the following equation:

$$LSI = pH - pH_s$$

where pH_s is the pH at which water is saturated with calcium carbonate.

When the LSI is greater than 0, the water will tend to precipitate $CaCO_3$ scales, whereas when the LSI is less than 0, the water will tend to dissolve $CaCO_3$ scales. The LSI is not a corrosion index; although it tends to predict whether $CaCO_3(s)$ will precipitate or dissolve, it does not predict how much will precipitate or whether the structure of the precipitated solid will provide resistance to corrosion (Larson, 1975). Predicting calcium carbonate formation is important because (1) it identifies a constraint (the formation of a detrimental scaling deposit) on the ability to adjust pH; (2) it can be considered to minimize deterioration of cement linings; and (3) it can help monitor treatment process consistency (e.g., lime softening). Many computational and empirical methods exist to estimate the onset of scaling. Accurate estimation is not straightforward, because many water chemistry parameters interfere with the nucleation, growth and deposition of hardness-derived scales. Challenges include knowledge of (1) the concentrations, identities and formation constants for the important complexing ligands that can solubilize calcium carbonate; (2) the kinetics of nucleation and growth of the calcium carbonate form; and (3) the presence of cations and anions that can inhibit the nucleation and growth of calcium carbonate (Schock and Lytle, 2011). Available software currently does not address these limitations.

5.2.5 *Metals*

Metals present in distributed water as a result of the internal corrosion of lead, copper, iron and other materials will be affected by pH. The properties of solid and aqueous metal species in water are dependent on pH. In general, as pH decreases, the solubility of metal species increases, resulting in elevated levels of metals in the water. By changing the aqueous forms (complexes, free ions, ion pairs) of metals, pH can dramatically alter the solubility, surface charge and sometimes the aquatic toxicity of the metals. This relationship is dependent on other water quality factors, such as alkalinity, DIC concentration, oxidant levels and concentrations of other constituents in the water, such as chloride, sulphate, natural organic matter (NOM), corrosion inhibitors and ammonia.

5.3 Microbiological characteristics

The pH range commonly found in water supplies generally supports the growth of biofilm. Biofilms are communities of microorganisms that adhere to surfaces and may be released to the bulk water, depending on its physical and chemical characteristics. Biofilms that form on distribution and premise piping systems may be associated with the scale that forms as a result of corrosion (corrosion by-products), and this association with the scale may shield them from disinfection. This interrelationship can result in microbiologically influenced corrosion (MIC), in the distribution system: bacteria react with the pipe material, creating microenvironments that can alter pH and other chemical characteristics of the water and also change the corrosion by-product scales formed on the surface of the material (LeChevallier et al., 1993). MIC can produce lower localized pH conditions, resulting in corrosion and pitting, and can affect metal solubility and the oxidation–reduction potential of the water (Lee et al., 1980; Schock and Lytle, 2011). Nitrification is caused by nitrifying bacteria in the distribution system and frequently occurs when chloramine is used as a secondary disinfectant. Nitrification can lower the pH of the water and cause lead corrosion (Douglas et al., 2004; Edwards and Dudi, 2004; Zhang et al., 2008, 2010).

6.0 Drinking water treatment processes and pH

It is necessary to characterize the source water to identify potential treatment challenges and to evaluate the technologies that can reasonably be expected to meet water quality goals. pH is one of several general water quality variables that must be considered when selecting and configuring the treatment sequences for a given water source. Since pH can have a major effect on the performance of treatment processes (e.g., coagulation, disinfection, precipitative softening) and on water chemistry, pH adjustment at various points in the treatment train will be needed to optimize the efficiency of treatment processes. As the pH of the source water may be impacted by environmental factors, characterization of the raw water quality is an important component in determining the initial treatment steps. The pH of water during the coagulation process will affect the coagulant’s chemistry and must be controlled in order to optimize performance and minimize the amount of coagulant in the treated water. The efficiency of the different disinfectants used in water treatment also strongly depends on the pH of the water. Daily and seasonal pH variations may have an impact on disinfectant stability and CT (the product of residual concentration of disinfectant [C] and disinfectant contact time [T]) requirements for disinfection.

The pH of the water has also been characterized as one of the most important parameters affecting the formation and speciation of disinfection by-products (DBPs) (Stevens et al., 1989). Studies and field observations show that the formation of trihalomethanes (THMs) typically increases at high pH, whereas the formation of haloacetic acids (HAAs) follows an opposite trend. pH has also been shown to affect the formation of other DBPs, such as bromate (von Gunten, 2003) and *N*-nitrosodimethylamine (NDMA) (Mitch and Sedlak, 2002). However, the adjustment of pH to control DBP formation is not a simple process, as the altering of the water chemistry may have an impact on other processes (e.g., coagulation, disinfection).

The effect of pH on the solubility of corrosion by-products formed during the corrosion process (e.g., lead solids, passivating scales) is key to understanding the concentration of metals at the tap.

In general, the specific processes and overall treatment objectives (e.g., coagulation, disinfection, DBP formation, corrosion control) must be considered when selecting the most appropriate pH. Although pH is integral to the individual processes, it may be necessary to adjust pH for optimum water quality in the distribution system and, ultimately, at the tap. It is imperative to control the pH throughout the treatment process and to routinely monitor the pH of the source water and of the water in the distribution system (Kirmeyer et al., 2002). The pH of water during individual treatment processes in a treatment train and that of the finished drinking water will vary between utilities, depending on the quality of the water sources and the treatment strategy.

6.1 Conventional and enhanced coagulation

The coagulation process is an essential step of conventional water treatment, and its efficiency is strongly affected by several factors, including pH. Coagulants added to water hydrolyze rapidly and form insoluble precipitates that destabilize the negatively charged colloidal particles, such as clays, algae, cysts and viruses. This destabilization allows aggregation of particles to occur via chemical and van der Waals interactions (Stumm and Morgan, 1969; Crittenden et al., 2012).

Aluminum and ferric salts are the primary coagulants used in drinking water treatment. The solubility of the resulting aluminum and ferric hydroxide precipitates depends on the pH of the water, and pH must be considered in order to maximize coagulant performance and minimize the amount of residual aluminum and iron in the treated water. Soluble hydrolysis products are formed when metal hydroxide precipitates undergo dissolution. Positively charged hydrolysis products as well as Al^{3+} and Fe^{3+} ions are formed at low pH, whereas only negatively charged hydrolysis products are formed at higher pH. Thus, the operating region for aluminum hydroxide precipitation is in the pH range of 5.5 to 7.7, with minimum solubility occurring at a pH of approximately 6.3 at 25°C. The pH range for iron precipitation is approximately 5.0 to 8.5, with minimum solubility occurring at about pH 8.0. The ferric species are less soluble over a wider pH range (Letterman and Yiacoumi, 2011; Crittenden et al., 2012). The minimum solubility for any coagulant depends on the specific water quality and needs to be determined on a case-by-case basis. Some utilities that use alum as a coagulant and operate their process at a pH below 6.0 may be affected by the solubility of aluminum (i.e., aluminum carry-over into finished water) (U.S. EPA, 2007). Conversely, pH above the optimum level in a given water with a particular mix of coagulants and polymer coagulant aids can also result in excessive aluminum solubility and carry-over to the distribution system.

Historically, coagulation was practised and optimized for turbidity (particle) removal. However, coagulation processes can also be optimized for NOM removal with higher doses of coagulants and optimization of pH. Enhanced coagulation is considered to be one of the best available technologies for the removal of DBP precursors for conventional water treatment facilities that treat surface water or groundwater under the influence of surface water. The treatment process associates the total organic carbon (TOC) removal requirement with the raw water alkalinity to avoid adding high dosages of the coagulants to reduce the pH to between 5 and 6, a range where the coagulants appear to be most effective (Krasner and Amy, 1995; Letterman and Yiacoumi, 2011). TOC, pH and alkalinity levels are the controlling factors in determining the effectiveness of enhanced coagulation for a particular source water. Jar tests are an effective tool to determine the target pH of coagulation and to identify the precursor removal trends during the process. As the addition of alum and ferric salts decreases the pH, the target pH level for TOC removal for a specific water quality can be achieved by progressively increasing the coagulant dosage, adding an acid or a combination of both (Krasner and Amy, 1995; Vrijenhoek et al., 1998; U.S. EPA, 2008). However, the target pH value is dependent on the alkalinity of the raw water and should account for the fact that higher coagulant dosages are needed to reduce the pH in higher-alkalinity water. To achieve the desire TOC removal, the pH levels are 5.5, 6.3, 7.0 and 7.5 for waters with alkalinity levels of 0 – 60, > 60 – 120, > 120 – 240 and > 240 mg/L as $CaCO_3$, respectively (U.S. EPA, 1999a, 2008). For water with low alkalinity (< 60 mg/L as $CaCO_3$), when the addition of small amounts of coagulant drives the pH below its target value before TOC removal is achieved, an addition of base is required to maintain the pH (U.S. EPA, 1999a).

DBP precursor removal by cationic polymers can also be influenced by the pH of the treated water (Amy and Chadik, 1983; U.S. EPA, 1999a). Amy and Chadik (1983) examined THM precursor removal from seven different natural water sources by coagulation with cationic polymer as the sole coagulant. The results demonstrated that decreasing the pH from approximately 7.6 to 6.0 increased the removal of THM precursors for each of the tested waters.

The changes in water chemistry associated with pH reduction in enhanced coagulation will affect other treatment processes. Potentially significant secondary effects of enhanced coagulation are identified for four treatment processes: (1) primary disinfection, (2) control of inorganic contaminants, (3) particle and pathogen removal and (4) residuals handling. The reduction of pH improves the disinfection characteristics of chlorine and ozone (O_3), decreases the effectiveness of chlorine dioxide and tends to destabilize monochloramine (Carlson et al., 2000). A lower pH may lead to the formation of less dense and more fragile flocs, resulting in decreased efficiency of the clarification process, including shorter run times of the filters and premature breakthrough. The appropriate optimal pH levels should be selected by balancing the benefits of improving precursor removal with possible negative impacts on turbidity removal and the corrosion of concrete and mechanical equipment within the plant at lower pH (Singer, 1999; Carlson et al., 2000; U.S. EPA, 2008), and it may be necessary to subsequently increase the pH.

6.2 Disinfection and formation of by-products

6.2.1 Disinfection

In general, all drinking water supplies should be disinfected, and a disinfectant residual should be maintained throughout the distribution system. The disinfection efficiency may be affected by a variety of physical, chemical and biological factors. Temperature and pH are two physical factors that are known to play an important role in the inactivation process for most commonly used disinfectants (U.S. EPA, 1999b; Clark and Boutin, 2001).

Chlorine is the most common disinfectant in water treatment for both primary and secondary disinfection. It is typically used in one of three forms: (1) chlorine gas under pressure, which is dissolved in water at the point of application; (2) a solution of sodium hypochlorite; and (3) solid calcium hypochlorite (U.S. EPA, 1999b). The disinfection efficiency of chlorine strongly depends on the pH of the water. When chlorine gas is added to water, it is rapidly hydrolyzed to form hypochlorous acid (HOCl), a weak acid that dissociates to produce hypochlorite (OCl^-) ion with a dissociation constant (pK_a) of approximately 7.6 at 20°C. The distribution of both chlorine species (HOCl/ OCl^-) depends on the pH of the water. HOCl is the dominant species between pH 6.0 and pH 7.6, while the OCl^- ion is the dominant species above pH 7.6. At pH 6.0, greater than 95% of the chlorine exists as HOCI, while at pH 10.0, 99.7% of the free chlorine exists as OCl^- (Scarpino et al., 1972; Haas, 2011). As the germicidal effect of HOCl is higher than that of the OCl^- ion, chlorine disinfection is more effective at low pH values (U.S. EPA, 2007). However, it is important to note that HOCl still provides excellent inactivation for bacteria and viruses, because free chlorine is a very strong oxidant, even at elevated pH values.

The inactivation efficiency of gaseous chlorine and hypochlorite is the same as that of chlorine at the same pH value. However, the addition of chlorine gas can reduce the pH of the water and the addition of sodium and/or calcium hypochlorite yields a hydroxide ion, which may increase the pH; both of these potential effects depend on the buffer intensity of the water. Therefore, without a pH adjustment to maintain the pH of the treated water, gaseous chlorine will have greater disinfection efficiency than hypochlorite (U.S. EPA, 1999b).

With increasing pH, inactivation using chlorine is less efficient, and therefore the required CT value must be increased. When using free chlorine at 20°C, increasing the pH from a range of 6–9 to 10 reduces the level of virus inactivation by a factor of 8 to 10 times, depending on the log inactivation sought (Health Canada, 2011a). The required CT value to achieve a 4-log inactivation of viruses using free chlorine at 20°C is increased from 3 to 22 mg·min/L when the pH increased from a range of 6.0–9.0 to pH 10.0 (U.S. EPA, 2003). Similarly, the CT requirements to achieve 3 log inactivation of *Giardia lamblia* cysts with a chlorine residual of less than 0.4 mg/L at 20°C and at pH levels of 6.5, 8.5 and 9.0 were 44 mg·min/L, 89 mg·min/L and 105 mg·min/L, respectively (Health Canada, 2012a). At 10°C for a 0.5 log inactivation, a contact time of 16 minutes corresponds to an increase in the required free chlorine residual from 1.0 mg/L at pH 6.5 to 1.2 mg/L at pH 7.0 (U.S. EPA, 2007).

Chlorine dioxide (ClO_2) is a disinfectant that can be used instead of chlorine as a primary disinfectant. Chlorine dioxide disinfects by oxidation; it is very effective against bacteria, viruses and *Giardia* cysts and can provide some inactivation of *Cryptosporidium* oocysts at higher temperatures (Health Canada, 2012a). It effectively oxidizes iron, manganese and taste- and odour-causing compounds and produces low concentrations of THMs and HAAs, but can form other DBPs, such as chlorite and chlorate (U.S. EPA, 2007). Chlorine dioxide exists in drinking water as an undissociated gas at pH values ranging from 6 to 9, and its disinfection efficiency increases with increasing pH within this range (Benarde et al., 1965; Berman and Hoff, 1984; Chen et al., 1985; Clark and Boutin, 2001). Berman and Hoff (1984) reported a greater than 99% virus inactivation with a chlorine dioxide dose of 0.5 mg/L at pH 6 in one minute. At pH 10, the same rate of inactivation was achieved in less than 15 seconds with the same disinfectant dose. Barbeau et al. (2005) found that the efficiency of chlorine dioxide against bacteria spores and bacteriophage was greater at pH 8.5 than at pH 6.5.

Ozone (O_3) is a potent disinfectant/oxidant that can be used for a variety of treatment objectives, such as disinfection, oxidizing organics (including taste- and odour-causing compounds), removing trace contaminants and pretreatment prior to biological processes. Ozone is most effective against viruses and slightly less effective against *Cryptosporidium* oocysts (U.S. EPA, 2007). Like chlorine dioxide, ozone exists in water as a dissolved gas. It is subject to losses due to volatilization and oxidant demand in water. Reports suggest that the disinfection efficiency of ozone does not depend on pH in the range normally encountered in water treatment (Clark and Boutin, 2001; U.S. EPA, 2007; Health Canada, 2012a). However, the ozone decomposition rate increases in solutions at higher pH in which various oxidants with different reactivities are formed, which may affect the inactivation of microorganisms (U.S. EPA, 1999b; Carlson et al., 2000; Haas, 2011). The major ozonation by-products are not subject to reactions favoured at high pH (i.e., alkaline hydrolysis reactions). Instead, pH plays a role by altering the rate of decomposition of ozone to hydroxyl radicals. As pH increases, the rate of decomposition of ozone is accelerated. It has been postulated that this decomposition process is responsible for a decrease in the classical formation of ozonation by-products (e.g., aldehydes; Reckhow and Singer, 2011).

The efficiency of ultraviolet (UV) light for primary disinfection of water depends on the intensity of the light and the length of time the microorganisms are exposed to it. As the mechanism of inactivation by UV light appears to be photochemical, pH is not expected to alter its efficiency. However, certain water quality parameters (i.e., pH, alkalinity and temperature) influence lamp sleeve fouling rates. Polyvalent cations such as iron, calcium and magnesium may deposit onto the quartz sleeve, causing fouling and reducing the UV transmittance to the water. pH may affect the light absorption characteristics of humic material in the water, and it may indirectly affect the efficiency of disinfection by changing the disinfection demand (U.S. EPA, 2007; Haas, 2011).

The use of chloramination as a secondary disinfectant in drinking water treatment has gained increasing popularity as concerns have grown regarding adverse health effects attributed to chlorinated DBPs. Chemically, chloramines are a complex group of disinfectants (mono-, di- and trichloramines); monochloramine is the preferred species for disinfection purposes because of its biocidal properties as well as the taste and odour problems associated with di- and trichloramines (Kirmeyer et al., 2004). The chlorine to ammonia ratio, pH and method of application are critical parameters to consider when using chloramine as a secondary disinfectant (Hoff, 1986). The rate of monochloramine formation is highly dependent upon pH. The optimum conditions for the formation of monochloramine are pH in the range of 6.5 to 9.0 (the ideal pH is 8.3) and a chlorine:ammonia-nitrogen weight ratio between 3:1 and 5:1 (Daniel, 1998; Kirmeyer et al., 2004). A pH in the range of 4 to 6 favours the formation of dichloramine, whereas a pH below 4.4 favours the formation of trichloramine (U.S. EPA, 1999b). The disinfection efficiency of monochloramine is pH dependent and increases at lower pH, with partial hydrolysis of monochloramine to free chlorine likely being a factor (Fleischacker and Randtke, 1983; Hoff, 1986; Clark and Boutin, 2001). Generally, for monochloramine disinfection, pH is maintained at a value greater than 8.3. Although monochloramine is more stable than free chlorine, it decomposes and releases free ammonia, a factor contributing to nitrification in the distribution system. An acidic water pH catalyzes the monochloramine decay, and the disinfectant residual drops rapidly at pH 6 or below (Reckhow and Singer, 2011). In addition, nitrification may lower the pH of the water and has been cited as a cause of the release of lead into drinking water (Douglas et al., 2004).

6.2.2 Disinfection by-products

DBPs are chemical compounds produced as an unintended consequence of disinfection or oxidation processes in drinking water treatment. A number of factors in addition to the nature of the NOM determine the composition of DBPs. The choice of the disinfectant and its dose, pH and temperature can all affect DBP formation. Current scientific data show that the benefits of disinfecting drinking water (reduced rates of infectious illness) are much greater than any health risks from DBPs.

The overall reaction between chlorine and NOM is relatively insensitive to pH over the range of typical water treatment practices (Reckhow and Singer, 2011). However, the formation of specific halogenated DBPs is strongly influenced by the pH level of the water (Fleischacker and Randtke, 1983). THMs and HAAs are the two major groups of halogenated DBPs found in drinking water. With increasing pH, THM formation increases, whereas HAA formation decreases (Krasner et al., 1989; Pourmoghaddas and Stevens, 1995). THMs show generally low formation at pH 5, increased formation by approximately 20% in the pH range of 7.0 to 8.2 and an increase of 40% when the pH is greater than 8.5 (Edwards and Reiber, 1997a,b; Navalon et al., 2008; U.S. EPA, 2008; Reckhow and Singer, 2011). The increased formation of THMs at high pH is due to base hydrolysis reactions, which promote THM formation. HAAs are unaffected by base hydrolysis reactions, but their formation pathways at high pH result in a lower formation potential

(Rechhow and Singer, 2011). It is important to note that dihaloacetic acid and trihaloacetic acid have different pathways of formation and hence different pH dependencies: dihaloacetic acid formation tends to be relatively independent of pH, whereas trihaloacetic acid formation decreases with increasing pH (U.S. EPA, 2008; Reckhow and Singer, 2011). Detailed information may found in the guideline technical documents for THMs and HAAs (Health Canada, 2006, 2008a).

Chlorite and chlorate ions are formed in drinking water when chlorine dioxide is used in the treatment process. For potable water applications, chlorine dioxide is generated on-site from sodium chlorite in reaction with either gaseous chlorine or hypochlorous acid under acidic conditions. Typically, pH values in the range of 3.5 to 5.5 are preferred, as more acidic conditions (i.e., pH 2.5 to 3) lead to the formation of chlorate (Gates et al., 2009). To overcome the basicity of sodium chlorite and the hydroxide produced in the reaction, acid is added along with the hypochlorous acid to maintain the optimum pH for chlorine dioxide generation (Gordon et al., 1990; U.S. EPA, 1999b; Singer and Reckhow, 2011). Precise operation ("tuning"), proper maintenance and the generation technology employed with the chlorine dioxide generator have a large bearing on the chlorine dioxide production efficiency and the rate at which chlorite and other undesirable by-products, such as chlorate, hydrogen peroxide and perchlorate, are formed (Gordon, 2001; Gates et al., 2009). Hypochlorite solutions are known to contain various impurities, including bromate, chlorate and chlorite. These may be present during manufacturing, or they may form during transportation and storage. Chlorate and chlorite are known degradation products of hypochlorite (Gordon et al., 1995). Hypochlorite degradation is associated with factors such as pH and temperature. Snyder et al. (2009) found that controlling the pH of hypochlorite solutions within the 11 to 13 range, even after dilution, helps prevent rapid decomposition and the subsequent formation of chlorate. However, it must be noted that decomposition at pH greater than 13 results in perchlorate formation. Approximately 50–70% of the chlorine dioxide consumed by oxidation reactions is reduced to chlorite under typical water treatment conditions (Werdenhoff and Singer, 1987). The production of chlorite and chlorate may increase in a water system with a high oxidant demand and a pH greater than 9. In alkaline conditions, chlorine dioxide disproportionates to form both chlorite and chlorate (Aieta and Berg, 1986; U.S. EPA, 2007). More detailed information on chlorine dioxide DBPs may found in the guideline technical document on chlorite and chlorate (Health Canada, 2008b).

The application of ozone to water naturally containing bromide will result in the formation of aqueous bromine species (hypobromite [OBr^-] ions and hypobromous acid [HOBr]), which lead to the formation of both inorganic and organic DBPs (Haag and Hoigné, 1983; Krasner et al., 1993; Siddiqui and Amy, 1993). At pH 8.86 and 20°C, the two bromine species are equally distributed. Bromide oxidation to inorganic and/or organic bromine compounds during ozonation is a function of water quality and water treatment variables (Amy et al., 1997). Bromate (BrO_3^-), an inorganic DBP, can form through a number of possible pathways (Song et al., 1997; von Gunten and Oliveras, 1998). The pH of water during ozonation has two main impacts on bromate formation. In the direct pathway, the oxidation driven by molecular ozone, bromide is oxidized sequentially to $HOBr/OBr^-$, bromite (BrO_2^-) and finally BrO_3^-. A lower pH shifts the equilibrium between the aqueous bromine species ($HOBr/OBr^-$) to the hypobromous acid and decreases the concentration of the more reactive hypobromite ion. Decreasing the pH generally decreases bromate formation (Amy et al., 1997; Song et al., 1997; Williams et al., 2003). Song et al. (1997) and Williams et al. (2003) observed an approximately 50% decrease in bromate formation when the pH was decreased from 7.5 to 6.5. Benefits of decreasing the pH to control bromate formation may be offset by the formation of total organic bromine compounds, such as bromoform and bromoacetic acids. Since hypobromous acid and NOM serve as primary reactants for the formation of total organic bromine compounds, the production is expected to be favoured at low pH (Haag and Hoigné, 1983; Amy et al., 1997; Song et al., 1997). More detailed information on bromate may found in the guideline technical document on bromate (Health Canada, 1998). Little information exists in the literature on by-products formed by direct UV photolysis or the factors that may affect by-product formation (Malley et al., 1995). Although UV light does not contribute to the formation of DBPs such as THMs and HAAs, it may influence DBP precursors at high UV doses, outside of the disinfection practices (Linden and Rosenfeldt, 2011).

Wang et al. (2015) observed BrO_3^- formation during UV/chlorine treatment, with greater formation occurring at lower pH (6.5). It was reported that chlorine photolysis produced hydroxyl radical and ozone, which play important roles in the formation of BrO_3^- in the presence of bromide (Forsyth et al., 2013; Wang et al., 2015). Small changes in the structure of NOM have been reported, but no effects on THM or HAA formation were noted (Magnuson et al., 2002). A potential concern for UV-induced by-products is the photolysis of nitrate to nitrite. The formation of nitrite is a complex process and may be influenced by the presence of organic matter and pH. However, when the nitrate concentration is below10 mg/L as nitrogen, there is only a minimal chance that nitrite formation would occur (Linden and Rosenfeldt, 2011).

NDMA is a nitrogen-containing DBP that may be formed during the treatment of drinking water, particularly during chloramination and, to a lesser extent, chlorination (Charrois and Hrudey, 2007; Nawrocki and Andrzejewski, 2011; Reckhow and Singer, 2011). A laboratory study (Schreiber and Mitch, 2005) suggested that the chlorination state of the organic nitrogen precursors and the partial formation of dichloramine are the two important factors that may affect NDMA formation. The study showed that NDMA formation, involving dichloramine and dimethylamine, was highly pH dependent. When chloramines were formed *in situ* in deionized water and at chlorine to ammonia molar ratios less than 1 (chlorine to ammonia-nitrogen weight ratio of 5:1), approximately 1–2 orders of magnitude less NDMA was formed at pH 5.1 than at pH 6.9 and pH 8.8, respectively. In addition, reactions involving dichloramine showed higher NDMA formation from dimethylamine compared with chlorinated dimethylamine at pH 6.9, whereas at pH 5.6, more NDMA was formed by reaction with chlorinated dimethylamine (Schreiber and Mitch, 2005). More detailed information on NDMA may found in the guideline technical document on NDMA (Health Canada, 2011b).

6.3 Precipitative softening

Precipitative softening, commonly referred to as lime softening, relies on the precipitation of calcium carbonate and magnesium hydroxide [$Mg(OH_2)$] primarily to remove hardness (Ca^{2+} and Mg^{2+} ions). It can also be used to remove various dissolved organic and inorganic contaminants. Lime softening processes are generally divided into three groups: (1) conventional lime softening to remove carbonate hardness (only lime is used); (2) lime–soda ash softening to remove carbonate and non-carbonate hardness (e.g., sulphate or chloride salt); and (3) excess lime softening to remove both calcium and magnesium and sometimes silica (U.S. EPA, 2007).

The conversion of bicarbonate to carbonate is a function of the pH of the water. Theoretically, a complete utilization of bicarbonate alkalinity for calcium precipitation requires a pH value of greater than 12. In practice, the optimum pH for calcium carbonate precipitation may be as low as 9.5, as a significant amount of carbonate is in equilibrium with bicarbonate, and more carbonate is formed as precipitation occurs (Crittenden et al., 2012). Precipitation of magnesium hydroxide requires a pH greater than 10.5, higher than can be achieved by the stoichiometric addition of lime. Therefore, an excess of lime is added to raise the pH to the point where magnesium hydroxide will precipitate (Randtke, 2011).

Enhanced softening refers to the process of improved removal of DBP precursors by precipitative softening. Generally, enhanced softening involves adding a coagulant and increasing the lime dose to raise the pH and achieve greater organic carbon removal, presumably through stronger interactions between calcium ions and precursors. If magnesium is present in the raw water and pH is increased to between 10.5 and 10.8, the co-precipitation of magnesium hydroxide and calcium carbonate will enhance precursor removal (U.S. EPA, 1999a, 2008).

Precipitative softening produces water with significant scale formation potential, and the higher pH level can increase THM formation. In general, finished water from softening plants tends to be less corrosive towards materials in the distribution system. Historically, the pH of finished water in softening plants has ranged between 7.5 and 10 (U.S. EPA, 2007; Elder and Budd, 2011). However, to prevent encrustation of filter media and excessive deposition of $CaCO_3$ scale in the distribution system, some softening plants will add carbon dioxide (recarbonation) to reduce the pH and stabilize the water prior to distribution. When selecting an appropriate finished water pH goal, the optimum pH for corrosion control should be taken into consideration.

6.4 Adsorption

Activated alumina, granular ferric oxide and granular ferric hydroxide adsorbents, and iron oxides coated on or incorporated into various media can be used for the removal of inorganic contaminant anions, including arsenic, fluoride, selenium, silica, phosphate, vanadate and NOM (fulvate) anions, from drinking water.

Adsorption by activated alumina is a physicochemical process by which ions in the feed water are adsorbed to the oxidized activated alumina surface. Owing to the amphoteric nature of activated alumina, this process is sensitive to pH. The activated alumina adsorbs anions at pH values below its isoelectric point. The isoelectric point or the pH of zero-point-of-charge is defined as the pH value where the net surface charge is zero. For activated alumina, the pH of zero-point-of-charge is in the range of 8.2–9.2, depending on the purity of the medium. A number of studies have shown that optimum removal is achieved at a pH range of 5.5–6.0 for arsenic and fluoride and in the range of 5.0–6.0 for selenium (Clifford, 1999; U.S. EPA, 2002, 2004; Meenakshi and Maheshwari, 2006). Above the pH of zero-point-of-charge, activated alumina may predominantly adsorb cations, but the use of activated alumina as a cation exchanger is rare in water treatment (Clifford et al., 2011), with the exception of its use for the removal of radium (Clifford et al., 1988).

Several iron-based media demonstrate an affinity to adsorb both forms of arsenic [As(III) and As(V)]. The performance of the adsorptive media depends on factors such as arsenic concentration and species, pH, presence of competing anions and media-specific characteristics, such as media life and empty bed contact time requirements. However, the adsorptions of As(III) and As(V) are affected very differently by the pH of the water. The adsorption of As(V) decreases with increasing pH in the 3 to 10 range because, as the pH increases, the surface charge of the medium becomes less positive and there is less attraction to the negatively charged As(V) species of $H_2AsO_4^-$ and $HAsO_4^{2-}$. The $H_2AsO_4^-$ species dominates between pH 2.0 and 7.0, and $HAsO_4^{2-}$ dominates between pH 7.0 and 11.0. The adsorption of As(III) increases with higher pH values, with the maximum adsorption at pH 9.0. This is likely because the uncharged species, H_3AsO_3, predominates for As(III) in the pH range of natural waters. At pH 9.0, the $H_2AsO_3^-$ form occurs, thus increasing the affinity for the positively charged iron solid surface. The range of effective adsorption of both As(III) and As(V) overlaps in the pH range of 6.0 to 7.5, with more As(V) adsorbed at lower pH and more As(III) adsorbed at higher pH (Jain and Loeppert, 2000). The optimal pH range for arsenic removal is specific to each tested medium type and can range from 5.5 to 9.0 (U.S. EPA, 2004).

6.5 Chemical oxidation

Chemical oxidation processes play an important role in the treatment of drinking water. These processes change the oxidation state of constituents to a form that can be more readily removed by subsequent treatment steps. The most common chemical oxidants are chlorine, ozone, chlorine dioxide and permanganate. Most of these chemicals are also disinfectants, so to some degree, oxidation will occur even when these chemicals are used primarily to inactivate microbes. These oxidants will reduce inorganic species (e.g., iron, manganese, sulphide) and synthetic organic compounds, and can also be used to destroy taste- and odour-causing compounds and to eliminate colour. Ozone is very reactive and undergoes spontaneous decomposition resulting in the formation of hydroxyl radicals (advanced oxidation process). Contaminants that are not degraded by molecular ozone can be appreciably oxidized by hydroxyl radicals. In many cases, the oxidation of these contaminants is enhanced at higher pH values due to the more rapid generation of hydroxyl radicals (Singer and Reckhow, 2011).

The treatment effectiveness of many oxidative processes is influenced by pH, as well as temperature, oxidant dose, reaction time and the presence of interfering substances. Oxidation reactions with chlorine tend to be more effective at low pH values, whereas the kinetic rates of oxidation involving permanganate tend to be higher with increasing pH levels (Singer and Reckhow, 2011).

The key variables that affect the oxidation of DBP precursors by ozone, prior to chlorination, are pH, alkalinity, ozone dose and the nature of the organic contaminants. At low pH, the oxidation of DBP precursors by ozone is quite effective. However, above a given critical pH, ozone is less effective and may increase the level of chlorination by-product precursors. For most humic substances, the critical pH is 7.5, as the decomposition rate of ozone to hydroxyl radicals increases rapidly. Therefore, at pH levels in the 6,0–7.0 range where molecular ozone predominates, the initial THM precursor by-products are different in nature than those formed by hydroxyl radical oxidation at higher pH levels (U.S. EPA, 1999b).

Manganese is typically removed from water using direct oxidation/coagulation/filtration or adsorption/oxidation (e.g., greensand) in a filter bed (Singer and Reckhow, 2011). Manganese in the form of dissolved Mn(II) can be directly oxidized to a MnO_2(s) precipitate, which is removed downstream by a physical process such as clarification and filtration or membrane filtration. The rates of the oxidation reactions, and therefore the size of the contact basin required, are pH dependent. The principles of manganese treatment using adsorption/oxidation are based on the presence of manganese oxides on filter media. Manganese oxides are capable of adsorbing dissolved Mn(II). The oxide surface then acts as a catalyst for the oxidation of the adsorbed Mn(II) so that more oxides are produced. When employing manganese oxide–coated filter media, care must be exercised to maintain the optimal pH and oxidizing conditions in the filter bed. Both the sorption kinetics and sorption capacity are increased with increasing water pH; to ensure effective removal of manganese, slightly alkaline pH values (7.0–8.0) are recommended (Knocke et al., 1988, 1991; Kohl and Medlar, 2006).

6.6 Membrane filtration

Membrane processes incorporate semi-permeable barriers that allow selective passage of constituents. There are two main groups of membranes: (1) microfiltration (MF) and ultrafiltration (UF), which remove particles; and (2) reverse osmosis (RO) and nanofiltration (NF), which remove particles and dissolved materials (Elder and Budd, 2011). MF and UF use low-pressure membranes that remove particles larger than the pore size of the membrane. Microbes (bacteria, *Cryptosporidium, Giardia*) and some organic carbon can be removed by these processes. NF membranes have pore sizes between those used in UF and RO. NF and RO will remove minerals (e.g., sodium, sulphate, chloride, calcium, magnesium and bicarbonate ions), which may result in more corrosive finished water and exacerbate the release of metals in the distribution system (Duranceau and Taylor, 2011). The removal of contaminants can cause mineral imbalances that could increase the corrosive nature of the treated water (Schock and Lytle, 2011). Post-treatment adjustment of the pH and alkalinity may be required as a corrosion control measure following RO and NF (U.S. EPA, 2007).

Charge repulsion is an important rejection mechanism for RO and NF membranes. The polymeric membranes acquire surface charge when in contact with an aqueous medium, which has a significant influence on the membrane rejection characteristics (Duranceau and Tyler, 2011). Childress and Elimelech (1996) investigated the effect of the pH of the water on the surface charge of commercial RO and NF membranes. All membranes surfaces were amphoteric, being positively charged in the lower pH range, and negatively charged at pH greater than 5.0, with their isoelectric points (no charge) ranging between pH 3.0 and 5.0. Hong and Elimelech (1997) investigated the influence of pH on fouling of NF membranes by NOM, in the presence of divalent cations. The authors observed a decline in product water flux when the pH of the water was decreased to 4.0. The observation was attributed to decreased electrostatic repulsion between the membrane surface and the NOM molecules, resulting in an increased sorption rate of NOM on the membrane surface.

6.7 Ion exchange

Ion exchange is used to remove dissolved ionic constituents in the water. In drinking water treatment applications, the ion exchange process is primarily used for water softening and demineralization (e.g., removal of Ca^{2+}, Mg^{2+}, SO_4^{2-}). Water softening is the most widely used cation exchange process, whereby positively charged ions on the surface of the ion exchange medium are exchanged with positively charged ions in the water. This process does not alter the pH, DIC concentration, dissolved oxygen concentration, chlorine concentration, temperature or alkalinity of the finished water, but it does increase the dissolved solids content (Sorg et al., 1999; Elder and Budd, 2011). Anion exchange media replace negatively charged ions in solution (nitrate, fluoride, sulphate and arsenic) with negatively charged ions on the media (typically chloride) to remove these contaminants from water (U.S. EPA, 2012).

Strong acid cation resins operate over a very wide pH range because the functional groups attached to the matrix (sulphonate groups) are strongly acidic and are ionized throughout the entire pH range. Weak acid cation resins can exchange ions only in the neutral to alkaline pH range, as the functional groups (carboxylates) are not ionized at lower pH values. Maximum resin capacity is reached between pH 10 and 11 (Clifford et al., 2011).

The quaternary amine functional groups of strong base anion resins are ionized in the pH range of 1–13. Weak base anion exchange resins are useful only at acidic pH (< 6), where functional groups can act as positively charged exchange sites for anions (Clifford et al., 2011).

6.8 Air stripping and aeration

Air stripping and aeration are gas transfer processes that can remove dissolved gases such as hydrogen sulphide (H_2S) and carbon dioxide, oxidize iron and manganese, and remove some tastes and odours from water. These processes are also used to remove volatile organic compounds (VOCs) and radon from solution. The rate of the gas transfer process for these constituents in solution is affected by pH and the constituent's solubility in water relative to its corresponding partial pressure in the gas phase. For example, at neutral pH, ammonia exists as an ion in water and cannot be stripped. At higher pH (above 9 or 10), however, it becomes soluble and can be stripped (Hand et al., 2011).

6.9 pH adjustment in drinking water treatment and distribution systems

In drinking water treatment plants, pH can be adjusted at various points to optimize the efficiency of treatment processes such as coagulation or disinfection. Adjusting the pH will affect the effectiveness of coagulation to remove organic matter and turbidity and can affect the efficiency of primary and secondary disinfection. It also affects the formation of DBPs. Adjusting the pH of treated water may help reduce the release of metals in distributed water; for example, raising the pH remains one of the most effective methods for minimizing lead and iron levels in distributed drinking water.

Treatment chemicals used for adjusting pH include caustic soda, potash, lime and sulfuric acid. Minimal pH adjustment can also be achieved using CO_2, with either sodium carbonate or sodium bicarbonate; however, this combination primarily adjusts alkalinity. Aeration is a non-chemical treatment method that introduces air in the water, removing CO_2 and resulting in a pH increase. Another method of adjusting pH is the use of limestone contactors: water flows through a bed of crushed limestone, dissolving the limestone and causing the pH (as well as alkalinity [or DIC concentration] and calcium level) to increase. These last two methods offer less precise control of the pH adjustment. A combination of lime or caustic soda and carbon dioxide offers more precise control, as it allows the pH and alkalinity of the water to be independently adjusted.

7.0 Distribution system considerations

7.1 Water distribution systems and pH changes

Chemical, physical and biological factors can affect the pH of treated water throughout the treatment and distribution systems. The ability of water to provide buffering against a pH change is related to pH, alkalinity and DIC concentration. As discussed previously, waters with enough DIC will be less prone to pH fluctuations because bicarbonate and carbonate ions in the water will buffer the change. The greatest buffering occurs at pH 6.3 and above pH 9. Therefore, distributed waters in the pH 8–8.5 range with low concentrations of DIC (< 10 mg C/L) will tend to have highly variable pH in the distribution system. These waters will be prone to pH decreases caused by uncovered storage facilities, nitrification activity in the distribution system and corrosion of cast iron pipes. They may also experience pH increases in the distribution system if cement pipes are present. Degradation of cement-based materials can be a source of calcium hydroxide (lime) in distributed water, potentially resulting in an increase in pH and alkalinity.

Adequate buffering in the distribution system is important to control corrosion (Schock and Lytle, 2011). If pH is adjusted to control the release of lead and copper, it is essential that the target pH be maintained in the distribution system out to the premise piping where the release of metals occurs. Use of phosphate corrosion inhibitors to control the release of lead and copper requires strict pH ranges for the inhibitors to be effective. Even when the pH of the finished water is maintained in the appropriate range for the inhibitor (pH 7.2–7.8), pH changes in the distribution system from inadequate buffering may decrease the effectiveness of the orthophosphate inhibitor.

Nitrification in the distribution system is associated with the use of chloramines as a secondary disinfectant and the presence of excess ammonia. Nitrification may lower the pH and alkalinity of the water, potentially accelerating brass corrosion and causing problems with lead release (Skadsen, 2002; Douglas et al., 2004).

Spikes in pH due to the long retention time in asbestos-cement or other cement-lined piping can create regions in the distribution system with high pH (Leroy et al., 1996; Kirmeyer et al., 2000) and elevated levels of THMs (Kirmeyer et al., 2000).

7.2 Relationship between pH and corrosion

The effect of pH on the solubility of by-products formed during the corrosion process (e.g., lead solids, passivating scales) is key to understanding the concentration of metals at the tap. The release of metals from materials used in distribution and premise piping systems will be affected by pH, but also by the alkalinity and DIC levels of the water, as they influence the formation of the passivating scale on the surface of the material. The presence of these passivating scales on pipe surfaces will help prevent the release of lead or copper to the water (Schock and Lytle, 2011). The impact of pH on the release of each of these metals is discussed below.

Lead can be released from a variety of lead-based materials used in the distribution and premise piping systems. These materials include smaller-diameter lead service lines, galvanized piping, lead solder, brass and bronze components, faucets and fittings in residences and other buildings. The solubility of the main lead corrosion by-products—namely, divalent lead [Pb(II)] solids such as cerussite ($PbCO_3$), hydrocerussite [$Pb_3(CO_3)_2(OH)_2$] and lead hydroxide [$Pb(OH)_2$]—largely determines the lead levels at the tap (Schock, 1980, 1990; Sheiham and Jackson, 1981; Boffardi, 1988, 1990; U.S. EPA, 1992; Leroy, 1993). Depending on the pH and alkalinity of the water, minerals in the passivating scales will vary. For example, a study by McNeill and Edwards (2004) showed that at pH 7.2, hydrocerussite was the dominant scale present at an alkalinity of 15 mg/L as $CaCO_3$, but that cerussite dominated when the alkalinity was 300 mg/L as $CaCO_3$. However, at an alkalinity of 45 mg/L as $CaCO_3$, cerussite was the dominant scale at pH 7.2, whereas hydrocerussite dominated at pH 7.8.

In distribution systems, lead corrosion by-products are typically less soluble in water with higher pH. The examination of utility data shows that the lowest levels of lead at the tap are associated with pH levels above 8 (Karalekas et al., 1983; Lee et al., 1989; Dodrill and Edwards, 1995; Douglas et al., 2004). Several water systems have increased pH to the 9–10 range for optimum control of lead release (Douglas et al., 2004; MOE, 2009; Massachusetts Water Resources Authority, 2010). Theoretical lead solubility models for Pb(II) show that the lowest lead levels occur when the pH is around 9.8 (Schock, 1989; Schock et al., 1996). However, theoretical solubility relationships have not yet been developed for Pb(IV) solids; as a result, this optimum pH may not be valid for controlling lead release when water quality conditions favour the formation of tetravalent lead [Pb(IV)] scales, such as lead dioxide (PbO_2). Interestingly, Pb(IV) solids have been found on lead pipes from several water systems with high oxidation–reduction potential (Schock et al., 1996; Schock and Lytle, 2011). Lead dioxide has been found to be present in waters of low pH and frequently in waters with high alkalinity (Schock et al., 2001, 2005). Lytle and Schock (2005) also showed that Pb(IV) compounds formed rapidly at pH 6–6.5 in water with relatively high free chlorine residuals (highly oxidative conditions).

Release of lead from leaded solder is primarily controlled by galvanic corrosion, and increasing pH has been associated with a decrease in the corrosion of leaded solders (Oliphant, 1983; Schock and Lytle, 2011). Use of orthophosphates for lead control depends on strict maintenance of distribution system pH in the 7.2–7.8 range in order to form Pb(II) orthophosphate passivating films.

The release of copper is highly pH dependent. When copper corrodes, it is oxidized to Cu(I) (cuprous) and Cu(II) (cupric) species, which may form protective copper carbonate–based (passivating) scales on the surface of copper plumbing materials. The formation of scales depends on pH and on levels of DIC and oxidizing agents in the water (Atlas et al., 1982; Pisigan and Singley, 1987; Schock et al., 1995; Ferguson et al., 1996). In general, copper solubility increases (i.e., copper levels increase) with increasing DIC concentration and decreasing pH (Schock et al., 1995; Ferguson et al., 1996). Copper levels may be adequately controlled at pH levels that are lower than those that might be considered optimum for controlling lead release. Groundwaters that have high alkalinity and high DIC levels are prone to copper corrosion problems. In these cases, adjusting pH may be impractical because of the potential for calcium carbonate precipitation.

Release of iron from iron-based drinking water materials, such as cast iron, steel and ductile iron, has been modelled based on the formation of protective ferrous solid scales ($FeCO_3$). Iron levels in the bulk water were generally reported to decrease with increasing pH (Karalekas et al., 1983; Kashinkunti et al., 1999; Sarin et al., 2003), as both the corrosion rate and the degree of tuberculation of iron generally increase with increasing pH, particularly in the pH range of 7.0–9.0 (Larson and Skold, 1958; Stumm, 1960; Pisigan and Singley, 1987). The rate of oxidation of iron increases with increasing pH, resulting in both decreased iron release and red water episodes. Waters with high buffer intensity will mitigate changes in pH, and a relatively stable pH will encourage the formation of the more protective ferrous-based solids and result in lower iron release.

Zinc coatings on iron and galvanized steel corrode similarly to iron, but the corrosion reactions are typically slower. When the pipe is new, corrosion depends strongly on pH. Pisigan and Singley (1985) found that below pH 7.5, zinc levels increased in drinking water (DIC concentration of 50 mg C/L). At pH levels of 7.5–10.4, hydrozincite, the most stable corrosion by-product, predominates. Very alkaline waters (i.e., pH > 10.4) can be aggressive to zinc and will often remove galvanized coatings (zinc hydroxides predominate). The nature of the passivating film formed on the pipe changes in response to various chemical factors. Water with moderate levels of DIC and high buffer intensity appear to produce good passivating films (Crittenden et al., 2012). Studies have shown increases in the corrosion rate of zinc with increasing carbonate hardness, even in the presence of orthophosphate. This increase may be caused by the formation of aqueous carbonate complexes that increase zinc solubility (Schock and Lytle, 2011).

Water with low pH, low alkalinity and low calcium is aggressive towards cement materials. Asbestos-cement pipes are particularly susceptible to low-pH (pH < 7.5–8.0) waters with high (400 mg/L) sulphate levels (Leroy et al., 1996; Schock and Lytle, 2011). Lime from the cement releases calcium and hydroxide ions into the drinking water and can result in a substantial pH increase, depending on the buffering capacity of the water (Leroy et al., 1996). More detailed information on corrosion control may found in the guidance document on controlling corrosion in the distribution system (Health Canada, 2009).

7.3 Examples of utilities distributing water at pH above 8.5

In a national survey conducted by Health Canada in 2009 and 2010, the pH levels of 127 samples of treated and distribution system water were measured at 64 treatment plants in winter and summer. Data showed that 12.5% of the treatment plants distributed water at a pH above 8.5, with one plant achieving a distributed water pH of 9.6 (Health Canada, 2012b). In both Canada and the United States, many systems have adjusted the distributed water pH to levels above 8.5 specifically to control lead. These include treatment plants in Ottawa, Ontario (Douglas et al., 2007); Saskatoon, Saskatchewan (City of Saskatoon, 2012); Boston, Massachusetts (Massachusetts Water Resources Authority, 2010); Cincinnati, Ohio (Miller and Bolton plants) (Greater Cincinnati Water Works, 2012); San Francisco and Oakland, California (Wilczak et al., 2010); Ann Arbor, Michigan (Skadsen, 2002); and Providence, Rhode Island (Yanonni and Covellone, 1998; Marchand and Rabideau, 2011). Eight of these systems (all systems listed above, except for the Miller Plant in Cincinnati) provide finished drinking water at pH 9.0 or above, with Providence maintaining a pH of 10.2 in the distributed water (Marchand and Rabideau, 2011). These water systems are operating their treatment processes to provide optimum removal or inactivation of microbiological, physical and chemical contaminants while also attempting to minimize metal release in their distribution systems.

8.0 Health effects of pH

Taken as a whole, the evidence shows no association between the pH of the diet (food or drinking water) and direct adverse health effects, although irritation of the skin and mucosa can occur following dermal exposure to extreme pH values (WHO, 2007). However, pH can influence the solubility of certain substances in the distribution system, increasing the risk of exposure to contaminants and potentially resulting in adverse health effects.

8.1 Regulation of pH in the human body

The digestion of most food items and physiological processes such as cell respiration can produce variations in the acid or base load within the human body (Cordain et al., 2005). The human body maintains homeostasis by continuously absorbing and handling pH variations to maintain the pH in the blood between 7.36 and 7.4 (Arnett, 2007; Vormann and Remer, 2008). The human body has three main systems to do this, including chemical buffers (e.g., carbonate, carbonic acid), which prevent immediate pH changes. In addition, ventilation through the lungs and reabsorption and excretion of ions by the renal system are systems for the short- and long-term regulation of pH. Metabolic acidosis (low pH of body fluids) or alkalosis (increased pH of body fluids) may result from critical illnesses or extreme events, such as severe vomiting, diarrhea, renal, bronchial or gastrointestinal disease, diabetes and excessive protein intake, as well as intense exercise, aging or menopause (Swenson, 2001; Cordain et al., 2005; Institute of Medicine, 2005; Arnett, 2007; Kaplan and Kallum, 2011).

8.2 Diet and pH

Whether the pH of the diet can influence the pH of the blood is controversial (Buclin et al., 2001; Vormann and Goedecke, 2006; Fenton and Lyon, 2011). It has been hypothesized that a diet comprising food items that generate high doses of acid compounds after metabolism (high in protein, low in fruits and vegetables) lowers the acid-buffering capacity of the body (Vormann and Goedecke, 2006). An increase in the risk of developing chronic diseases, such as osteoporosis, has been suggested in observational studies (Marsh et al., 1988; Tucker et al., 1999; Frassetto et al., 2000).

A lower physiological pH (based on sodium and serum bicarbonate levels) was associated with higher levels of metabolic inflammation markers (C-reactive protein and leukocyte count) in adults participating in the U.S. National Health and Nutrition Examination Survey during 1999–

2006 (Farwell and Taylor, 2010). However, the cross-sectional study design prevents the conclusion of a cause–effect relationship, and multiple biases (e.g., the participants did not eat controlled diets) could have influenced the results.

The effects reported above are not applicable to drinking water pH. The acids and bases found in drinking water are extremely diluted and, as such, do not influence the pH of the body. Similarly, food items that have a naturally low pH (e.g., lemon juice and vinegar, with pH values of 3.4 and 2.8, respectively) do not represent a health risk to individuals who consume them (WHO, 2007).

8.3 Secondary effects of pH

As mentioned in previous sections, the pH of drinking water is closely related to other aspects of water quality (Nordberg et al., 1985; NHMRC, 1996). Acidic water can mobilize certain metals from the soil and pipe systems, make them more bioavailable and change their toxicity (Nordberg et al., 1985; Traina and Laperche, 1999; Langmuir et al., 2005). For example, the concentrations of aluminum, cadmium, selenium, arsenic, lead and copper in drinking water can be increased by low pH, which may present a risk to human health (NHMRC, 1996). However, the change in toxicity with altered pH is metal and organism specific (Ho et al., 1998; Tan and Wang, 2011).

8.4 Effects on skin

8.4.1 Skin irritation in humans

Extreme pH values (over 11 and under 4) can enhance the skin irritation effects of certain solutions.

Healthy men in the U.S. Army developed rashes, vesicles, bullae and subungual purpura (bleeding under the fingernails) on their hands after they were immersed in very hot water containing a strong machine detergent (sodium metasilicate, sodium tripolyphosphate and sodium carbonate) at pH 11.35 for an estimated 4 to 8 hours (Goldstein, 1968). It was not possible to clearly distinguish which agent was responsible for the effects.

Skin vapour loss (a measure of damage of the stratum corneum of the skin) was measured in 19 healthy volunteers exposed to one of five commercial soaps (pH 3.6–10.33) or distilled water (pH 5.6) for 24 hours (Hassing et al., 1982). The effect of soaps with pH 10.33 or 5.86 did not differ from that of distilled water. However, soaps with pH 5.78 and pH 3.6 induced a significant increase in skin vapour loss. Skin vapour loss on the forearm increased sharply in two male volunteers after exposure to sodium hydroxide (NaOH) in solution at a pH of over 11.3 for 1 hour (Spruit and Malten, 1968). Blisters formed at pH 11.95. Solutions at pH 7.0, 8.0, 9.0 or 10.0 had no effect on intact skin.

Hand cleaners with pH in the range 3.5 to 10.07 were tested for irritancy (van Ketel et al., 1984). The scores were based on the severity of erythema, scaling and fissuring of hand skin. Only the most acidic one (pH 3.5) significantly increased the severity of erythema and fissuring.

Wahlberg (1984) applied different concentrations of sodium hydroxide in distilled water (pH 11.6, 11.7 and 12.7) or soluble oil (pH 10) on the thighs of a healthy man for 5 minutes. Only the solution at pH 12.7 produced a significant increase in blood flow and erythema. Hansen (1983) investigated skin disease in 541 cleaning women working in a hospital in Denmark and in a control group of 157 shop assistants doing mostly dry work. The cleaning women were exposed to trademark detergents (often alkaline) via patches on their back for 48 hours. The cleaners had significantly more occupational dermatosis (prevalence of 15.3%), characterized by erythema with infiltration of papules or vesicles, compared with the control group (odds ratio = 2.00, $P <$

0.025). The detergents contained many substances, among which were allergens (formaldehyde, nickel, etc.), alkaline compounds (sodium carbonate, trisodium phosphate, sodium metasilicate, etc.) and acidic compounds (phosphoric acid, hydrochloric acid, etc.). It was not possible to clearly determine which agent was responsible for the effects.

8.4.2 Skin irritancy in animals

The pH of different substances applied to animal skin was not found to be a good indicator of irritancy, but it seemed to enhance the skin-damaging effects of substances.

The irritancy of 56 chemicals (liquid or solid form) used in the cosmetic industry on the skin of albino rabbits (New Zealand strain) exposed for 4 or 23 hours was evaluated by three different protocols: 1) the official French government test method for assessing irritancy of cosmetics and toiletries, 2) the methods of the Association française de Normalisation (AFNOR) and 3) the Organisation for Economic Co-operation and Development (OECD) method for skin products (Guillot et al., 1982b). pH was not found to be a good indicator of the irritant potency of these chemicals. For example, whereas dimethyl sulphate (pH 1) was a severe irritant, oxalic acid (pH 1) was only moderately irritating, and three other compounds with pH values between 2 and 3 were not irritating. The authors indicated that alkaline substances tended to be irritants, but other chemical properties were responsible for enhancing the effects. Similar results were obtained with chemicals with pH values above 10, which were classified as non-irritant to moderately irritant, for both liquid and solid forms.

Mice injected intracutaneously in the abdominal skin with an isotonic solution (1:1 histidine glutamate and lysine glutamate) showed signs of irritation at and below pH 4 and at and above pH 10 (Bucher et al., 1979). pHs were adjusted with hydrochloric acid (HCl) and sodium chloride (NaCl).

8.5 pH effects on human and animal eyes

Swelling and opacities of the cornea, conjunctivitis, pannus and keratoconus were observed after animal eyes were exposed to acids and alkalis. The irritating effect of water depends on the pH level and the buffering capacity of the water and the exposed tissue. In theory, water with low buffering capacity (low concentration of carbonic species) and a pH between 3.5 and 10.5 can be neutralized by lacrimal fluid (McKean and Nagpal, 1991).

Normal eyes of humans (six men) and rabbits (21 rabbits) were exposed to lake water samples (two inland lakes in Ontario: Clearwater Lake, pH 4.5, acid neutralizing capacity of −40 µeq/L; and Red Chalk Lake, pH 6.5, acid neutralizing capacity of 70 µeq/L) for 5 and 15 minutes, respectively. Except for conjunctival congestion, no symptoms or adverse effects were observed on the external eye for any subjects. The authors concluded that lake water having a pH as low as 4.5 is not harmful to the external ocular tissues (Basu et al., 1982, 1984).

Rabbit and human corneas (from donors to the Wisconsin Lions human eye bank) were exposed for 3 hours to a solution of varying pH (3.5–10) composed of salts used as vehicles for intraocular drugs (Gonnering et al., 1979). A significant increase in swelling of rabbit corneas occurred outside of the pH range 6.5–8.5 ($P > 0.001$). Electron microscopy revealed ultrastructural alterations of the corneal endothelial cells (cytoplasmic swelling and disrupted cellular junctions). No details were provided for the effects of solutions with pH above 8.5 on human corneas. The only information provided on human effects was swelling of the cornea at pH 5.5. The authors stated that the swelling of the cornea in rabbits and humans could have been prevented with the use of a more complete solution (i.e., containing glucose and bicarbonate).

The ocular irritancy of 56 chemicals (liquid or solid form) used in the cosmetic industry was evaluated using albino rabbits (New Zealand strain) exposed for 4 or 23 hours (Guillot et al., 1982a). The substances were instilled into the lower conjunctiva of one eye of the rabbits and observed for 1 hour and 1, 2, 3 and 4 days afterward. The substances' irritancy (non-irritant, slightly irritant, moderately irritant or severely irritant) was scored on a 1–8 scale based on the severity of erythema and oedema at the treatment site. Substances with pH lower than 2 were all classified as severely irritant; pH 2 to 3, moderately to severely irritant; pH 10 to 11, moderately to severely irritant; and pH 7, generally non-irritant or slightly irritant, except for two substances classified as severely irritant.

Another study looked at the effects of exposure time and different concentrations of acids and alkalis dropped on the corneas of the eyes of New Zealand rabbits (two groups of at least six rabbits per test material; Murphy et al., 1982). Generally, acids (pH 0.1 to 2.7) and alkalis (pH 11.3 to 13.5) produced opacities of the corneas, conjunctivitis, pannus and keratoconus. Acid-caused opacities resulted from coagular necrosis, whereas alkali-caused opacities resulted from liquefaction necrosis. All alkalis produced toxicity above pH 12.8. Severity increased with length of exposure, and weaker acids and bases required longer exposure to produce opacities. The authors stated that other factors probably contribute to irritancy, such as the concentration of the substance, its penetrability and its intrinsic activity. For example, solutions of hydrochloric acid (pH 1.28), citric acid (pH 2.1) and sodium hydroxide (pH 12.8) did not have an effect, whereas phenol (pH 7.7) produced opacities.

Generally, small pH variations have no effect on the eye because of its buffering capacity. The evidence for adverse effects on the eye is not detailed enough to conclude on a safe pH range, although conjunctivitis, swelling and opacities of the corneas tend to occur at extreme values of pH of the tested solutions (outside the range of pH 5–11).

8.6 pH and dental caries

Groeneveld and Arends (1975) suggested that buccal pH influenced the development of dental caries. To test this, 15 extracted human premolars were exposed to a decalcifying agent (hydroxybutylcellulose and lactic acid) in a buffering solution of varying pH (4, 4.5 or 5) for 4, 6, 9 or 11 days. The pH influenced the demineralization and the thickness of the surface layer only slightly. However, the depth of sub-surface lesions increased by a factor of 2 at pH levels between 5 and 4 after 11 days. There was also a marked increase in phosphate loss below pH 3 (Cutress, 1966; de Rooij and Arends, 1983).

Powdered human dental enamel and dentine exposed *in vitro* to alkaline phosphatase enzyme preparations from *Escherichia coli* resulted in higher liberation of phosphate by enzymatic hydrolysis of organic constituents at pH 7 (Makinen and Paunio, 1970).

8.7 pH and hair

A man's head received drops of a pipe anti-clotting agent (product not specified) containing sodium hydroxide at pH 13.5 (Morris, 1952). The following day, loss of hair, pustules and erythematous skin of the affected area occurred, all of which eventually subsided (time frame not mentioned).

A solution of caustic soda or potash with pH above 9.2 has been shown to hydrolyze and decompose disulphide bonds of the cystine of keratin of wool, similar to its effects on human hair and nails *in vitro* (Chiego and Silver, 1942).

9.0 Assessment

The main direct adverse effect induced by extreme pH values (under 5 and over 11) is an increase in skin and eye irritancy. There is no convincing evidence that pH at the levels found in drinking water can significantly alter the pH of the body. Extreme pH values can produce secondary health effects by changing the solubility and toxicity of certain substances potentially found in drinking water distribution systems. This involves many factors, such as the composition of the piping system and the source water quality, rendering the assessment very complex. These health effects would be addressed in the appropriate guideline technical document.

There are insufficient data available to allow the establishment of a health-based guideline for pH. The main health considerations associated with pH are indirect. Protection of health is achieved through the control of pH for the proper operation of processes for contaminant removal, maintaining water quality, maintaining the integrity of the drinking water distribution system components and effectively and safely implementing the disinfection process.

9.1 International considerations

No recognized organization has established a health-based value for the pH of drinking water. All the regulations and recommendations have set a pH range of 6.5–8.5 based on drinking water disinfection optimization and what was believed to be minimization of corrosion of plumbing components at the time they were developed. The U.S. EPA (1988) listed pH in the National Secondary Drinking Water Regulations (non-mandatory standard) based on aesthetic concerns, noting that drinking water with a low pH could cause a bitter metallic taste, whereas high pH could cause a slippery feel and a soda taste. However, corrosion control knowledge has dramatically advanced in recent years, and regulatory authorities have permitted many utilities to operate above this range to address lead release and disinfection considerations (e.g., chloramine stability). To this end, the U.S. EPA (2013) is currently considering revising its Secondary Maximum Contaminant Level for pH.

WHO (2007) and Australia (NHMRC, 2011) stated that any effect of pH on health is likely to be indirect and related either to increased ingestion of metals from plumbing and pipes or to inadequate disinfection. WHO (2007) listed the optimum pH for water supplies as 6.5–9.5 and also stated that the optimum level will vary, depending on the composition of the water and the materials used in the distribution system.

10.0 Rationale

There is no convincing evidence that pH at the levels found in drinking water can directly affect health. As such, there are no specific health effects on which to base limits for the pH of finished drinking water. pH is an important parameter to monitor and control throughout the treatment and distribution systems, in order to maximize the efficiency of treatment processes while minimizing the formation of DBPs and the leaching of metals from materials.

Current science indicates that the acceptable pH range for finished drinking water should be flexible to allow systems to determine the most appropriate pH for their individual water quality goals. The acceptable pH range of 7.0 to 10.5 for finished drinking water provides utilities the flexibility required to achieve water quality objectives and control contaminant concentrations and corrosion by combined treatment approaches that are appropriate to the materials in the distribution system and premise plumbing.

11.0 References

Aieta, E. and Berg, J. (1986). A review of chlorine dioxide in drinking water treatment. J. Am. Water Works Assoc., 78(6): 62–72.

Amy, G. and Chadik, P. (1983). Cationic polyelectrolytes as primary coagulants for removing trihalomethane precursors. J. Am. Water Works Assoc., 75(10): 527–531.

Amy, G., Westerhoff, P., Minear, R. and Song, R. (1997). Formation and control of brominated ozone by-products. Water Research Foundation, Denver, Colorado.

APHA, AWWA, WEF (1992). Standard methods for the examination of water and wastewater, 18th edition. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

APHA, AWWA, WEF (1995). Standard methods for the examination of water and wastewater, 19th edition. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

APHA, AWWA, WEF (1998). Standard methods for the examination of water and wastewater, 20th edition. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

APHA, AWWA, WEF (2005). Standard methods for the examination of water and wastewater, 21st edition. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

APHA, AWWA, WEF (2011). Standard methods for the examination of water and wastewater, 4500-H^+ pH value. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC. Available at: www.standardmethods.org/Store/ProductView.cfm?ProductID=185

APHA, AWWA, WEF (2012). Standard methods for the examination of water and wastewater, 22nd edition. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

Arnett, T.R. (2007). Acid–base regulation of bone metabolism. Int. Congr. Ser., 1297: 255–267. Available at : www.homepages.ucl.ac.uk/~ucgatma/Anat3048/PAPERS%20etc/International%20Congress%20Series%201297,%20255-267%20(2007).pdf

ASTM (1984). D1293-84: Standard test methods for pH of water. ASTM International, West Conshohocken, Pennsylvania.

ASTM (1995). D1293-95: Standard test methods for pH of water. ASTM International, West Conshohocken, Pennsylvania.

Atlas, D., Coombs, J. and Zajicek, O.T. (1982). The corrosion of copper by chlorinated drinking waters. Water Res., 16: 693–698.

Barbeau, B., Huffman, D., Mysore, C., Desjardins, R., Clément, B. and Prévost, M. (2005). Examination of discrete and confounding effect of water quality parameters during the inactivation of MS2 phages and *Bacillus subtilis* spores with chlorine dioxide. J. Environ. Eng. Sci., 4: 139–151.

Basu, P.K., Avaria, M. and Hasany, S.M. (1982). Effects of acidic lake water on the eye. Can. J. Ophthalmol., 17(2): 74–78.

Basu, P.K., Avaria, M., Cutz, A. and Chipman, M. (1984). Ocular effects of water from acidic lakes: an experimental study. Can. J. Ophthalmol., 19(3): 134–141.

Benarde, M., Israel, B., Olivieri, V. and Grandstorm, M. (1965). Efficiency of chlorine dioxide as bactericide. Appl. Microbiol., 13(5): 776–780.

Berman, D. and Hoff, J. (1984). Inactivation of simian rotavirus SA11 by chlorine, chlorine dioxide, and monochloramine. Appl. Environ. Microbiol., 48(2): 317–323.

Boffardi, B.P. (1988) Lead in drinking water-causes and cures. Public Works, 119(11): 67-70.

Boffardi, B.P. (1990) Minimization of lead corrosion in drinking water. Mater. Perform., 29(8): 45-49.

Bucher, K., Bucher, K.E. and Walz, D. (1979). Irritant actions of unphysiological pH values. A controlled procedure to test for topical irritancy. Agents Actions, 9(1): 124–132.

Buclin, T., Cosma, M., Appenzeller, M., Jacquet, A.F., Decosterd, L.A., Biollaz, J. and Burckhardt, P. (2001). Diet acids and alkalis influence calcium retention in bone. Osteoporos. Int., 12(6): 493–499.

Butler, J.N. and Cogley, D.R. (1998). Ionic equilibrium solubility and pH calculations. John Wiley & Sons, New York, New York.

Carlson, K., Via, S., Bellamy, B. and Carlson, M. (2000). Secondary effects of enhanced coagulation and softening. J. Am. Water Works Assoc., 92(6): 63–75.

Charrois, J.W.A. and Hrudey, S.E. (2007). Breakpoint chlorination and free-chlorine contact time: implications for drinking water *N*-nitrosodimethylamine concentration. Water Res., 41: 674–682.

Chen, Y., Sproul, O. and Rubin, A. (1985). Inactivation of *Naegleria gruberi* cysts by chlorine dioxide. Water Res., 19(60): 783–789.

Chiego, B. and Silver, H. (1942). The effect of alkalis on the stability of keratins. J. Invest. Dermatol., 5(95).

Childress, A. and Elimelech, M. (1996). Effect of solution chemistry on the surface of polymeric reverse osmosis and nanofiltration membranes. J. Memb. Sci. 119:253–268.

City of Saskatoon (2012). Typical water quality characteristics. Water and Wastewater Treatment Branch, Saskatoon, Saskatchewan. Available at: www.saskatoon.ca/DEPARTMENTS/Utility%20Services/Water%20and%20Wastewater%20Treatment/Water%20Treatment%20Plant/Treatment%20Process/Pages/WaterQualityDetails.aspx

Clark, R. and Boutin, B. (2001). Controlling disinfection by products and microbial contaminants in drinking water. National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. (EPA/600/R-01/110).

Clement, J.A. and Schock, M.R. (1998). Buffer intensity: what it is, and why it’s critical for controlling distribution system water quality. In: Proceedings of the AWWA Water Quality Technology Conference, San Diego, California. American Water Works Association, Denver, Colorado.

Clifford, D.A. (1999). Chapter 9: Ion exchange and inorganic adsorption. In: Water quality and treatment: a handbook of community water supplies, 5th edition. Letterman, R.D. (ed.). American Water Works Association, Denver, CO; McGraw-Hill, New York, New York.

Clifford, D.A., Vijjeswarapu , W. and Subramonian , S. (1988). Evaluating various adsorbents and membranes for removing radium from groundwater. J. Am. Water Works Assoc., 80: 94–104.

Clifford, D., Sorg, T. and Ghurye, G. (2011). Chapter 12: Ion exchange and adsorption of inorganic contaminants. In: Water quality and treatment: a handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, CO; McGraw-Hill, New York, New York.

Cordain, L., Eaton, S.B., Sebastian, A., Mann, N., Lindeberg, S., Watkins, B.A., O’Keefe, J.H. and Brand-Miller, J. (2005). Origins and evolution of the western diet: Health implications for the 21st century. Am. J. Clin. Nutr., 81(2): 341–354.

Crittenden, J.C., Trussell, R.R., Hand, D.W., Howe, K.J. and Tchobanoglous, G. (2012). Water treatment: principles and design, 3rd edition. John Wiley & Sons, Hoboken, New Jersey.

Cutress, T.W. (1966). Effect of sodium fluoride solutions of varying pH on solubility of bovine enamel. Arch. Oral Biol., 11(1): 121–130.

Daniel, P. (1998). Balancing multiple water quality objectives. American Water Works Association Research Foundation, Denver, Colorado. 80235-3098.

de Rooij, J.F. and Arends, J. (1983). Phosphate diffusion in whole bovine enamel. III. pH dependency. Caries Res., 28(7): 575.

Dodrill, D.M. and Edwards, M. (1995). Corrosion control on the basis of utility experience. J. Am. Water Works Assoc., 87(7): 74–85.

Douglas, I., Guthmann, J., Muylwyk, Q. and Snoeyink, V. (2004). Corrosion control in the city of Ottawa—comparison of alternatives and case study for lead reduction in drinking water. In: Proceedings of the 11th Canadian National Drinking Water Conference and 2nd Policy Forum, April 3–6, Calgary, Alberta. Robertson, W. and Brooks, T. (eds.). Canadian Water and Wastewater Association, Ottawa, Ontario.

Douglas, I., Campbell, A. and Muylwyk, Q. (2007). Lead control in soft water: Experience from a Canadian utility. In: Proceedings of the Annual Conference and Exposition, June 2007. American Water Works Association, Denver, Colorado.

Duranceau, S.J. and Taylor, J.S. (2011). Chapter 11: Membranes. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Dye, J.F. (1952). Calculation of effect of temperature on pH, free carbon dioxide, and the three forms of alkalinity. J. Am. Water Works Assoc., 44(4): 356–372.

Edwards, M. and Dudi, A. (2004). Role of chlorine and chloramine in corrosion of lead-bearing plumbing materials. J. Am. Water Works Assoc., 96(10): 69–81.

Edwards, M. and Reiber, S. (1997a). A general framework for corrosion control based on utility experience. American Water Works Association Research Foundation, Denver, Colorado (AwwaRF Report 90712A).

Edwards, M. and Reiber, S.H. (1997b). Predicting Pb and Cu corrosion by-product release using CORRODE software. American Water Works Association Research Foundation, Denver, Colorado (AwwaRF Report 90712B).

Edzwald, J.K. and Tobiason, J.E. (2011). Chapter 3: Chemical principles, source water composition, and watershed protection. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado; McGraw-Hill, New York, New York.

Elder, D. and Budd, G. (2011). Chapter 5: Overview of water treatment processes. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado; McGraw-Hill, New York, New York.

Farwell, W.R. and Taylor, E.N. (2010). Serum anion gap, bicarbonate and biomarkers of inflammation in healthy individuals in a national survey. Can. Med. Assoc. J., 182(2): 137–141.

Fenton, T.R. and Lyon, A.W. (2011). Milk and acid–base balance: proposed hypothesis versus scientific evidence. J. Am. Coll. Nutr., 30(5 Suppl. 1): 471S–475S.

Ferguson, J.L., von Franqué, O. and Schock, M.R. (1996). Corrosion of copper in potable water systems. In: Internal corrosion of water distribution systems, 2nd edition. American Water Works Association Research Foundation and DVGW Technologiezentrum Wasser, Denver, Colorado, pp. 231–268.

Fleischacker, S. and Randtke, S. (1983). Formation of organic chlorine in public water supplies. J. Am. Water Works Assoc., 75(3): 132–138.

Forsyth, J., Zhou, P., Mao, Q., Asato, S., Mashke, J. and Dodd, M. (2013). Enchanced inactivation of *Bacillus subtilis* spores during solar photolysis of free available chlorine Environ.. Sci.Technol., 47:12976–12984

Frassetto, L.A., Todd, K.M., Morris, R.C., Jr. and Sebastian, A. (2000). Worldwide incidence of hip fracture in elderly women: Relation to consumption of animal and vegetable foods. J. Gerontol. A Biol. Sci. Med. Sci., 55(10): M585–M592.

Gates, D., Ziglio, G. and Ozekin, K. (2009). State of science of chlorine dioxide in drinking water. Water Research Foundation and Fondazione AMGA, Denver, Colorado 80235.

Goldstein, N. (1968). “KP” dermatitis. J. Occup. Med., 10(8): 423–425.

Gonnering, R., Edelhauser, H.F., Van Horn, D.L. and Durant, W. (1979). The pH tolerance of rabbit and human corneal endothelium. Invest. Ophthalmol. Vis. Sci., 18(4): 373–390.

Gordon, G. (2001). Is all chlorine dioxide created equal? J. Am. Water Works Assoc., 93(4): 163–173.

Gordon, G., Slootmaekers, B., Tachiyashiki, S. and Wood, D., III (1990). Minimizing chlorite ion and chlorate ion in water treated with chlorine dioxide. J. Am. Water Works Assoc., 82(4): 160–165.

Gordon, G., Adam, L. and Bubnis, B. (1995). Minimizing chlorate formation in drinking water when hypochlorite ion is the chlorinating agent. American Water Works Association Research Foundation, Denver, Colorado.

Greater Cincinnati Water Works (2012). 2010 annual report. Greater Cincinnati Water Works, Cincinnati, Ohio. Available at: www.cincinnati-oh.gov/water/linkservid/D146DA6A-B1D7-4099-AD3A66E6D2FCF553/showMeta/0/

Groeneveld, A. and Arends, J. (1975). Influence of pH and demineralization time on mineral content, thickness of surface layer and depth of artificial caries lesions. Caries Res., 9(1): 36–44.

Guillot, J.P., Gonnet, J.F., Clement, C., Caillard, L. and Truhaut, R. (1982a). Evaluation of the ocular-irritation potential of 56 compounds. Food Chem. Toxicol., 20(5): 573–582.

Guillot, J.P., Martini, M.C., Giauffret, J.Y., Gonnet, J.F. and Guyot, J.Y. (1982b). Safety evaluation of some humectants and moisturizers used in cosmetic formulations. Int. J. Cosmet. Sci., 4(2): 67–80.

Haag, W.R. and Hoigné, J. (1983). Ozonation of bromide-containing waters: kinetics of formation of hypobromous acid and bromide. Environ. Sci. Technol., 17: 261–267.

Haas, C.N. (2011). Chapter 17: Chemical disinfection. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado. McGraw-Hill, New York, New York.

Hand, D.W., Hokanson, D.R. and Crittenden, J.C. (2011). Chapter 6: Gas–liquid processes: Principles and applications. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado; McGraw-Hill, New York, New York.

Hansen, K.S. (1983). Occupational dermatoses in hospital cleaning women. Contact Derm., 9(5): 343–351.

Hassing, J.H., Nater, J.P. and Bleumink, E. (1982). Irritancy of low concentrations of soap and synthetic detergents as measured by skin water loss. Dermatologica, 164(5): 314–321.

Health Canada (1998). Guidelines for Canadian drinking water quality: Guideline technical document—Bromate. Bureau of Chemical Hazards, Health Protection Branch, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/index-eng.php#tech_doc

Health Canada (2006). Guidelines for Canadian drinking water quality: Guideline technical document—Trihalomethanes. Water Quality and Health Bureau, Healthy Environments and Consumer Safety Branch, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/index-eng.php#tech_doc

Health Canada (2008a). Guidelines for Canadian drinking water quality: Guideline technical document—Haloacetic acids. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/index-eng.php#tech_doc

Health Canada (2008b).Guidelines for Canadian drinking water quality: Guideline technical document — Chlorite and chlorate. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/index-eng.php#tech_doc

Health Canada (2009). Guidance on controlling corrosion in drinking water distribution systems. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/index-eng.php#guidance

Health Canada (2011a). Guidelines for Canadian drinking water quality: Guideline technical document — Enteric viruses. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/enteric-enterovirus/index-eng.php

Health Canada (2011b).Guidelines for Canadian drinking water quality: Guideline technical document — *N*-Nitrosodimethylamine (NDMA). Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/ndma/index-eng.php.

Health Canada (2012a). Guidelines for Canadian drinking water quality: Guideline technical document—Enteric protozoa: *Giardia* and *Cryptosporidium*. Water, Air and Climate Change Bureau, Healthy Environments and

Consumer Safety Branch, Ottawa, Ontario. Available at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/protozoa/index-eng.php

Health Canada (2012b). Personal communication from A.-M. Tugulea, Environmental Health, Science and Research Bureau, Health Canada.

Ho, K.T., Kuhn, A., Pelletier, M.C., Hendricks, T.L. and Helmstetter, A. (1999). pH dependent toxicity of five metals to three marine organisms. Environ. Toxicol., 14(2): 235–240.

Hoff, J. (1986). Inactivation of microbial agents by chemical disinfectants. Water Engineering Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio (EPA/600/2-86/067).

Hong, S. and Elimelech, M. (1997). Chemical and physical aspects on natural organic matter (NOM) fouling of nanofiltration membranes. J. Memb. Sci. 132:159–181

Jain, A. and Loeppert, R.H. (2000). Effect of competing anions on the adsorption of arsenate and arsenite by ferrihydrite. J. Environ. Qual., 29: 1422–1430.

Kaplan, L.J. and Kellum, J.A. (2010). Fluids, pH, ions and electrolytes. Curr. Opin. Crit. Care, 16(4): 323–331.

Karalekas, P.C., Ryan, C.R. and Taylor, F.B. (1983). Control of lead, copper, and iron pipe corrosion in Boston. J. Am. Water Works Assoc., 75(2): 92–95.

Kashinkunti, R.D., Metz, D.H., Hartman, D.J. and DeMarco, J. (1999). How to reduce lead corrosion without increasing iron release in the distribution system. In: Proceedings of the AWWA Water Quality Technology Conference, Tampa Bay, FL. American Water Works Association, Denver, Colorado.

Kirmeyer, G., Friedman, M., Clement, J., Sandvig, A., Noran, P., Martel, K., LeChevallier, M., Volk, C., Anton E., Hiltebrand, D., Dyksen, J. and Chushing, R. (2000). Guidance manual for maintaining distribution system water quality. American Water Works Association Research Foundation, Denver, Colorado.

Kirmeyer, G., Friedman, M., Martel, K., Thompson, G., Sandvig, A., Clement, J. and Frey, M. (2002). Guidance manual for monitoring distribution system water quality. American Water Works Association Research Foundation, Denver, Colorado.

Kirmeyer, G., Martel, K., Thompson, G., Radder, L., Klement, W., LeChevallier, M., Baribeau, H. and Flores, A. (2004). Optimizing chloramine treatment, 2nd edition. American Water Works Association Research Foundation, Denver, Colorado.

Knocke, W., Hamon, J. and Thompson, C. (1988). Soluble manganese removal on oxide-coated filter media. J. Am. Water Works Assoc., 80(12): 65–70.

Knocke, W., Occiano, S. and Huntage, R. (1991). Removal of soluble manganese by oxide-coated filter media: sorption rate and removal mechanism issues. J. Am. Water Works Assoc., 83(8): 64–69.

Kohl, P.M. and Medlar, S.J. (2006). Occurrence of manganese in drinking water and manganese control. American Water Works Association Research Foundation, Denver, Colorado; U.S. Environmental Protection Agency, Washington, DC; IWA Publishing, London, United Kingdom (AwwaRF Report 91147).

Kohlmann, F.J. (2003). What is pH and how is it measured: a technical handbook for industry. Hach Company. Available at: www.hach.com/quick.search-download.search.jsa?keywords=HANDBOOK

Krasner, S. and Amy, G. (1995). Jar-test evaluations of enhanced coagulation. J. Am. Water Works Assoc., 87(10): 93–107.

Krasner, S.W., McGuire, M.J., Jacangelo, J.G., Patania, N.L., Reagan, K.M. and Aieta., E.M. (1989). The occurrence of disinfection by-products in US drinking water. J. Am. Water Works Assoc., 81: 41–53.

Krasner, S., Glaze, W., Weinberg, H., Daniel, P. and Najm, I. (1993). Formation and control of bromate during ozonation of water containing bromide. J. Am. Water Works Assoc., 85(1): 73–81.

Langelier, W.F. (1946). Effect of temperature on the pH of natural waters. J. Am. Water Works Assoc., 38: 179–185.

Langmuir, D. Chrostowski, P., Vigneault, B. and Chaney, R. (2005). Issue paper on the environmental chemistry of metals. U.S. Environmental Protection Agency Risk Assessment Forum. Washington, DC 20460 Contract #68-C-02-060

Larson, T.E. (1975). Corrosion by domestic waters. Illinois State Water Survey, Urbana, Illinois (Bulletin 59).

Larson, T.E. and Henley, L. (1955a). Determination of low alkalinity or acidity in water. Anal. Chem., 27(5): 851–852.

Larson, T.E. and Henley, L. (1955b). Determination of low alkalinity or acidity in water —Correction. Anal. Chem., 27(8): 1286–1286.

Larson, T.E. and Skold, R.V. (1958). Current research on corrosion and tuberculation of cast iron. J. Am. Water Works Assoc., 50(11): 1429–1432.

LeChevallier, M., Lowry, C., Lee, R. and Gibbon, D. (1993). Examining the relationship between iron corrosion and the disinfection of biofilm bacteria. J. Am. Water Works Assoc., 85(7): 111–123.

Lee, R.G., Becker, W.C. and Collins, D.W. (1989). Lead at the tap: sources and control. J. Am. Water Works Assoc., 81(7): 52–62.

Lee, S.H., O'Connor, J.T. and Banerji, S.K. (1980). Biologically mediated corrosion and its effects on water quality in distribution systems. J. Am. Water Works Assoc., 72(11): 636–645.

Leroy, P. (1993). Lead in drinking water—origins; solubility; treatment. J. Water Supply Res. Technol. – Aqua, 42(4): 223–238.

Leroy, P., Schock, M.R., Wagner, I. and Holtschulte, H. (1996). Cement-based materials. In: Internal corrosion of water distribution systems, 2nd edition. American Water Works Association Research Foundation and DVGW Technologiezentrum Wasser, Denver, Colorado. pp. 313–388.

Letterman, R. and Yiacoumi, S. (2011). Chapter 8: Coagulation and flocculation. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Linden, K. and Rosenfeldt, E. (2011). Chapter 18: Ultraviolet light and processes. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Lytle, D.A. and Schock, M.R. (2005). The formation of Pb(IV) oxides in chlorinated water. J. Am. Water Works Assoc., 97(11): 102–114..

Magnuson, M., Kelty, K., Linden, K., Fromme, W., Metz, D. and Kashinkunt, R. (2002). Effect of UV radiation on organic extracted from treated Ohio river water studied through the use of electrospray mass spectrometry. Environ. Sci. Technol., 36: 5252–5260.

Makinen, K.K. and Paunio, I.K. (1970). The pH-dependent liberation of phosphate from human dental enamel and dentine by ammonium sulphate. Acta Chem. Scand., 24(5): 1541–1550.

Malley, J., Shaw, J. and Ropp, J. (1995). Evaluation of by-products produced by treatment of groundwater with ultraviolet irradiation. American Water Works Association Research Foundation, Denver, Colorado.

Marchand, P. and Rabideau, S. (2011). Corrosion control and partial lead service replacement. In: Proceedings of the American Water Works Association Annual Conference and Exhibition, June 12–16, Washington, DC.

Marsh, A.G., Sanchez, T.V., Michelsen, O., Chaffee, F.L. and Fagal, S.M. (1988). Vegetarian lifestyle and bone mineral density. Am. J. Clin. Nutr., 48(3 Suppl.): 837–841.

Massachusetts Water Resources Authority (2010). 90th percentile lead levels for MWRA fully-served communities: 1992–2010. Massachusetts Water Resources Authority, Boston, Massachusetts. Available at: www.mwra.com/watertesting/lead/webgraphs/2010/2010-march-640.jpg

McKean, C.J.P. and Nagpal, N.K. (1991). Ambient water quality criteria for pH. Technical appendix. Water Quality Branch, Water Management Division, Ministry of Environment, Victoria, British Columbia.

McNeill, L.S. and Edwards, M. (2004). Importance of Pb and Cu particulate species for corrosion control. J. Environ. Eng., 130(2): 136–144.

Meenakshi, S. and Maheshwari, R.C. (2006). Fluoride in drinking water and its removal. J. Hazard. Mater., 137(1): 456–463.

Mitch, W.A. and Sedlak, D.L. (2002). Formation of *N*-nitrosodimethylamine (NDMA) from dimethylamine during chlorination. Environ. Sci. Technol., 36(4): 588–595.

MOE (2009). Guidance document for preparing corrosion control plans for drinking water systems. Ontario Ministry of Environment, Toronto, Ontario. Available at: http://dr6j45jk9xcmk.cloudfront.net/documents/1542/4-1a-19-corrosion-control-en.pdf

Morris, G.E. (1952). Chemical alopecia: a unique case. AMA Arch. Ind. Hyg. Occup. Med., 6(6): 530–531.

Murphy, J.C., Osterberg, R.E., Seabaugh, V.M. and Bierbower, G.W. (1982). Ocular irritancy responses to various pHs of acids and bases with and without irrigation. Toxicology. 23(4):281-91.

National Research Council (2005). Dietary reference intakes for water, potassium, sodium, chloride, and sulfate. The National Academies Press, Washington, DC, pp. 285–324.

Navalon, S., Alvaro, M. and Garcia, H. (2008). Carbohydrates as trihalomethanes precursors. Influence of pH and the presence of Cl^{-} and Br^{-} on trihalomethanes formation potential. Water Res., 42: 3990–4000.

Nawrocki, J. and Andrzejewski, P. (2011). Nitrosamines and water. J. Hazard. Mater., 189(1–2): 1–18.

NHMRC (2011). Australia drinking water quality guidelines. National Health and Medical Research Council, Commonwealth of Australia. Available at: www.nhmrc.gov.au/guidelines-publications/eh52

Nordberg, G.F., Goyer, R.A. and Clarkson, T.W. (1985). Impact of effects of acid precipitation on toxicity of metals. Environ. Health Perspect., 63: 169–180.

Oliphant, R.J. (1983). Summary report on the contamination of potable water by lead from soldered joints. Water Research Centre, Swindon, United Kingdom (External Report 125-E).

Osterberg, R.E., Seabaugh, V.M. and Bierbower, G.W. (1982). Ocular irritancy responses to various pHs of acids and bases with and without irrigation. Toxicology, 23(4): 281–291.

Pisigan, R.A. and Singley E. (1985). Effects of water quality parameters on the corrosion of galvanized steel. U.S. Environmental Protection Agency, Cincinnati, Ohio (Report No. EPA/600/J-85/250).

Pisigan, R.A. and Singley, E. (1987). Influence of buffer capacity, chlorine residual, and flow rate on corrosion of mild steel and copper. J. Am. Water Works Assoc., 79(2): 62–70.

Post, G., Atherhold, T. and Cohn, P. (2011). Chapter 2: Health and aesthetic aspects of drinking water. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Pourmoghaddas, H. and Stevens, P.C. (1995). Relationship between trihalomethanes and haloacetic acids with total organic halogen during chlorination. Water Res., 29: 2059–2062.

Randtke, S. (2011). Chapter 13: Precipitation, coprecipitation and precipitative softening. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Reckhow, D. and Singer, P. (2011). Chapter 19: Formation and control of disinfection by products. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Sarin, P., Clement, J.A., Snoeyink, V.L. and Kriven, W.M. (2003). Iron release from corroded, unlined cast-iron pipe. J. Am. Water Works Assoc., 95(11): 85–96.

Scarpino, P., Berg, G., Chang, S., Dahling, D. and Lucas, M. (1972). A comparative study of the inactivation of viruses in water by chlorine. Wat. Res. 6: 959–965.

Schock, M.R. (1980). Response of lead solubility to dissolved carbonate in drinking water. J. Am. Water Works Assoc., 72(12): 695–704.

Schock, M.R. (1989). Understanding corrosion control strategies for lead. J. Am. Water Works Assoc., 81(7): 88–100.

Schock, M.R. (1990). Internal corrosion and deposition control. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Schock, M. (2013). Personal communication from M.R. Schock. Office of Research and Development, U.S. Environmental Protection Agency.

Schock, M.R., Lytle, D.A. and Clement, J.A. (1995). Effect of pH, DIC, orthophosphate, and sulfate on drinking water cuprosolvency. U.S. Environmental Protection Agency, Cincinnati, Ohio (Report No. EPA/600/R-95/085).

Schock, M.R., Wagner, I. and Oliphant, R.J. (1996). Corrosion and solubility of lead in drinking water. In: Internal corrosion of water distribution systems. 2nd edition. American Water Works Association Research Foundation and DVGW Technologiezentrum Wasser, Denver, Colorado. pp. 131-230.

Schock, M.R., Harmon, S.M., Swertfeger, J. and Lohmann, R. (2001). Tetravalent lead: a hitherto unrecognized control of tap water lead contamination. In: Proceedings of the AWWA Water Quality Technology Conference, November 11–15, Nashville, Tennessee. American Water Works Association, Denver, Colorado.

Schock, M.R., Scheckel, K.G., DeSantis, M. and Gerke, T.L. (2005). Mode of occurrence, treatment and monitoring significance of tetravalent lead. In: Proceedings of the AWWA Water Quality Technology Conference, November 6–10, Québec, Quebec. American Water Works Association, Denver, Colorado.

Schreiber, M. and Mitch, W. (2005). Influence of the order of reagent addition on NDMA formation during chloramination. Environ. Sci. Technol., 39(10): 3811–3818.

Sheiham, I. and Jackson, P.J. (1981). The scientific basis for control of lead in drinking water by water treatment. J. Inst. Water Eng. Sci., 35(6): 491–515.

Siddiqui, M., and Amy, G. (1993). Factors affecting the DBP formation during ozone–bromide reaction. J. Am. Water Works Assoc., 85(1): 63–72.

Sincero, A. and Sincero, G. (2003). Physical and chemical treatment of water and wastewater. IWA Publishing, London, United Kingdom.

Singer, P.C. (ed.) (1999). Formation and control of disinfection by-products in drinking water. American Water Works Association, Denver, Colorado.

Singer, P.C. and Reckhow, D.A. (2011). Chapter 7: Chemical oxidation. In: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado.; McGraw-Hill, New York, New York.

Skadsen, J. (2002). Effectiveness of high pH in controlling nitrification. J. Am. Water Works Assoc., (94)7: 73-83

Snyder, S.A., Stanford, B.D., Pisarenko, A.N., Gordon, G. and Asami, M. (2009). Hypochlorite—an assessment of factors that influence the formation of perchlorate and other contaminants. American Water Works Association and Water Research Foundation, Denver, Colorado. (Project No. 4147).

Song, R., Westerhoff, P., Minear, R. and Amy, G. (1997). Bromate minimization during ozonation. J. Am. Water Works Assoc., 89(6): 69–78.

Sorg, T., Schock, M. and Lytle, D. (1999). Ion exchange softening: effect on metal concentrations. J. Am. Water Works Assoc., 8: 85–97.

Spruit, D. and Malten, K.E. (1968). Estimation of the injury of human skin by alkaline liquids. Berufsdermatosen, 16(1): 11–24.

Stevens, A.A., Moore, L.A. and Miltner, R.J. (1989). Formation and control of non-trihalomethane disinfection by-products. J. Am. Water Works Assoc., 81(8): 54–60.

Stumm, W. (1960). Investigation on the corrosive behavior of waters. J. Sanit. Eng. Div. Proc. Am. Soc. Civil Eng., 86: 27–45.

Stumm, W. and Morgan, J.J. (1969). Chemical aspects of coagulation. J. Am. Water Works Assoc., 54(8): 971–994.

Stumm, W. and Morgan, J.J. (1996). Aquatic chemistry: chemical equilibria and rates in natural waters, 3rd edition. Wiley, New York, New York.

Swenson, E.R. (2001). Metabolic acidosis. Respir. Care, 46(4): 342–353.

Tan, Q.G. and Wang, W.X. (2011). Acute toxicity of cadmium in *Daphnia magna* under different calcium and pH conditions: Importance of influx rate. Environ. Sci. Technol., 45(5): 1970–1976.

Traina, S.J. and Laperche, V. (1999). Contaminant bioavailability in soils, sediments, and aquatic environments. Proc. Natl. Acad. Sci. U.S.A., 96(7): 3365–3371.

Tucker, K.L., Hannan, M.T., Chen, H., Cupples, L.A., Wilson, P.W. and Kiel, D.P. (1999). Potassium, magnesium, and fruit and vegetable intakes are associated with greater bone mineral density in elderly men and women. Am. J. Clin. Nutr., 69(4): 727–736.

U.S. EPA (1982). Method 150.1. pH—Electrometric. Office of Groundwater and Drinking Water, U.S. Environmental Protection Agency, Washington, DC (EPA 600/4-79-020).

U.S. EPA (1988). National Secondary Drinking Water Regulations. CFR 40 Part 143, 53 FR 37412, September 26. U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA (1992). Lead and Copper Rule guidance manual. U.S. Environmental Protection Agency, Washington, DC (Report No. EPA/811/B-92/002).

U.S. EPA (1999a). Enhanced coagulation and enhanced precipitative softening guidance manual. Office of Water, U.S. Environmental Protection Agency, Washington, DC (EPA 815-R-99-012).

U.S. EPA (1999b). Alternative disinfectants and oxidants guidance manual. Office of Water, U.S. Environmental Protection Agency, Washington, DC (EPA 815-R-99-014).

U.S. EPA (2002). Review of literature on removal of fluoride from drinking water. Draft report. Office of Water, U.S. Environmental Protection Agency, Cincinnati, Ohio.

U.S. EPA (2003). LT1ESWTR disinfection profiling and benchmarking. Technical guidance manual. U.S. Environmental Protection Agency, Washington, DC (Report No. EPA 816-R-03-004).

U.S. EPA (2004). Technology selection and system design: U.S. EPA arsenic removal technology demonstration program round 1. Prepared by L. Wang, W.E. Condit and A.S.C. Chen, Battelle, Columbus, OH, for U.S. Environmental Protection Agency, Washington, DC (EPA/600/R-05/001; nepis.epa.gov/Adobe/PDF/2000D1MP.pdf).

U.S. EPA (2007). Simultaneous compliance guidance manual for the long term 2 and stage 2 DBP rules. Office of Water, U.S. Environmental Protection Agency, Washington, DC (EPA 815-R-07-017).

U.S. EPA (2008). Stage 2 disinfectants and disinfection by-products rule. Operational evaluation guidance manual. Office of Water, U.S. Environmental Protection Agency, Washington, DC (EPA 815-R-08-018).

U.S. EPA (2011). Analytical methods recommended for drinking water monitoring of secondary contaminants. U.S. Environmental Protection Agency Available at: http://water.epa.gov/scitech/drinkingwater/labcert/upload/815b14005.pdf

U.S. EPA (2012). Drinking water treatability database. Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio. Available at: http://ofmpub.epa.gov/tdb/pages/general/home.do

U.S. EPA (2013). Personal communication from J. Kempic. Office of Ground Water and Drinking Water. U.S. Environmental Protection Agency.

van Ketel, W.G., Bruynzeel, D.P., Bezemer, P.D. and Stamhuis, H.I. (1984). Toxicity of handcleaners. Dermatologica, 168(2): 94–99.

von Gunten, U. (2003). Ozonation of drinking water: Part II. Disinfection and byproduct formation in presence of bromide, iodide or chlorine. Water Res., 37(7): 1469–1487.

von Gunten, U. and Oliveras, Y. (1998). Advanced oxidation of bromide-containing waters: bromate formation mechanisms. Environ. Sci. Technol., 32(1): 63–70.

Vormann, J. and Goedecke, T. (2006). Acid–base homeostasis: latent acidosis as a cause of chronic diseases. Schweiz. Zschr. GanzheitsMedizin, 18(5): 255–266.

Vormann, J. and Remer, T. (2008). Dietary, metabolic, physiologic, and disease-related aspects of acid–base balance: Foreword to the contributions of the Second International Acid–Base Symposium. J. Nutr., 138(2): 413S–414S.

Vrijenhoek, E.M., Childress, A.E., Elimelech, M., Tanaka, T.S. and Beuhler, M.D. (1998). Removing particles and THM precursors by enhanced coagulation. J. Am. Water Works Assoc., 90(4): 139–150.

Wahlberg, J.E. (1984). Skin irritancy from alkaline solutions assessed by laser Doppler flowmetry. Contact Dermatitis, 10(2): 111. doi: 10.1111/j.1600-0536.1984.tb00351.x

Wang, D., Bolton, R., Andrews, S. and Hofmann, R. (2015). Formation of disinfection by products in the ultraviolet/chlorine advanced oxidation processes. Sci. Total Environ. 518–519: 49–57.

Werdenhoff, K. and Singer, P. (1987). Chlorine dioxide effect on THMFP and TOXFP and the formation of inorganic by-products. J. Am. Water Works Assoc., 79(9): 107–113.

WHO (2007). pH in drinking-water. Revised background document for development of WHO Guidelines for Drinking-water Quality. World Health Organization, Geneva, Switzerland (WHO/SDE/WSH/07.01/1; www.who.int/water_sanitation_health/dwq/chemicals/ph_revised_2007_clean_version.pdf).

Wilczak, A., Hokanson, D. R., Trussell, R. R., Boozarpour, M. and Degraca, A.F. (2010). Water conditioning for LCR compliance and control of metals release in San Francisco's water system. J. Am. Water Works Assoc., 102(3): 52–64.

Williams, M.D., Coffey, B.M. and Krasner, S.W. (2003). Evaluation of pH and ammonia for controlling bromate during *Cryptosporidium* disinfection. J. Am. Water Works Assoc., 95(10): 82–93.

Yanonni, C.C. and Covellone, M.A. (1998). Pipe loop demonstration study of corrosion control alternatives at a pH of 10. J. N. Engl. Water Works Assoc., 112(22): 132–146.

Zhang, Y., Griffin, A. and Edwards, M. (2008). Nitrification in premise plumbing: role of phosphate, pH, and pipe corrosion. Environ. Sci. Technol., 42(12): 4280–4284.

Zhang, Y., Edwards, M., Pinto, A., Love, N., Camper, A., Rahman, M. and Baribeau, H. (2010). Effect of nitrification on corrosion in the distribution system. American Water Works Association Research Foundation and American Water Works Association, Denver, Colorado.

Appendix A: List of acronyms

CT	product of residual concentration of disinfectant (C) and disinfectant contact time (T)
DBP	disinfection by-product
DIC	dissolved inorganic carbon
EPA	Environmental Protection Agency (U.S.)
HAA	haloacetic acid
LSI	Langelier saturation index
MF	microfiltration
MIC	microbiologically influenced corrosion
NDMA	*N*-nitrosodimethylamine
NF	nanofiltration
NOM	natural organic matter
RO	reverse osmosis
THM	trihalomethane
TOC	total organic carbon
UF	ultrafiltration
UV	ultraviolet
VOC	volatile organic compound

Appendix C

INTERIM GUIDELINES ON EVALUATING AND MITIGATING LEAD IN DRINKING WATER SUPPLIES, SCHOOLS, DAYCARES AND OTHER BUILDINGS

JULY 2017

HEALTH PROTECTION BRANCH

BRITISH
COLUMBIA

TABLE OF CONTENTS

1. PURPOSE AND SCOPE

This document provides guidance to drinking water officers on the roles and responsibilities of stakeholders in the reduction of lead in drinking water at the tap.

This document also provides guidance and tools for:

- Screening communities to identify those with increased risk of corrosive water;
- assessing typical lead concentrations in drinking water at the tap in communities;
- screening and assessing typical lead concentrations of water in schools, day cares and other buildings; and
- possible mitigation strategies and examples of communication material.

This document does not address collecting or assessing human exposure data such as blood lead reporting, or assessment of broader human lead exposure beyond drinking water. It also focusses on lead corrosion only, and does not discuss other corrosion products including copper and iron, that can cause significant aesthetic and economic impacts if unchecked.

2. INTRO/BACKGROUND

Ingestion of lead can be hazardous to human health, especially for young children and infants, as they absorb lead more easily than adults and are more susceptible to its harmful effects. Even low level exposure may harm the intellectual development, behaviour, size and hearing of infants and children. Lead can also cross the placenta during pregnancy to affect the unborn child, and can be released into breast milk.

The degree of harm from lead exposure depends on a number of factors including the frequency, duration, and dose of the exposure(s) and individual susceptibility factors (e.g., age, previous exposure history, nutrition, and health). The degree of harm also depends on an individual's total exposure to lead from all sources in the environment – air, soil, dust, food, and water. Common sources of lead exposure for children are chips and particles of deteriorating lead paint found in house dust and soil. While drinking water is the second largest source of exposure when lead levels in water are above 5 μg/L, there is currently no evidence that drinking water in BC is a significant source of dietary lead intake. It is important to note that people often consume water from numerous sources throughout the day (i.e. workplaces, schools, homes, restaurants), thereby the lead concentration in water from any one source may only represent a small portion of total daily intake. Nonetheless, it is important to minimize lead intake from all sources as much as possible, and where Drinking Water Officers consider drinking water is at risk of having elevated concentrations of lead, take steps to reduce lead in drinking water to levels as low as is reasonably achievable.

Under the *Drinking Water Protection Act* (DWPA), drinking water supply systems in BC are responsible for monitoring water they deliver to verify it is within acceptable limits for lead and other metals. The Guidelines for Canadian Drinking Water Quality (GCDWQ) suggest a maximum acceptable concentration

(MAC) of total lead in drinking water of 10 micrograms per litre (µg/L) or 10 parts per billion (ppb). You may also see this guideline value written as 0.010 milligrams per litre (mg/L) or 0.010 parts per million (ppm).

Most drinking water supply systems in BC deliver water that has levels of lead well below 10 µg/L. Lead is usually not found in drinking water when it leaves the treatment plant. Instead lead tends to leach out of pipes and fixtures in buildings or homes, or service lines connecting homes to water mains[1]. The extent of leaching depends on the nature of the plumbing materials used, the corrosiveness of the water (i.e. the extent to which the water can cause a chemical reaction that will cause a deterioration in the material used in the pipes), and the length of time that the water is stagnant in the plumbing. The longer water remains in contact with leaded plumbing, the more opportunity there is for lead to leach into the water. As a result, older facilities with intermittent water use patterns and older plumbing materials, such as schools, child care facilities and office buildings, may have elevated levels of lead in their drinking water. The water sits in the pipes of these facilities for long periods (overnight, weekends, and holidays), which allows the leaching of lead to occur. If the water entering the building is corrosive, the lead will leach more quickly. Corrosive water may sometimes be described as “acidic” or “aggressive”.

Since 1989, the BC Building Code has restricted the lead content in components in the construction of potable water lines and fixtures. This restriction reduces the amount of lead available to react with corrosive water and lowers the risk of lead leaching into drinking water supplies. As a result, in buildings constructed on or before that time, there may be a greater probability of finding elevated lead levels in the water from service plumbing, especially if the corrosiveness of the water entering the building and the water use patterns in the building are conducive to lead leaching.

The quality and characteristics of the delivered water not only impact lead solubility and lead speciation (i.e., the chemical and mineral form of lead), they also impact the behaviour of pipe scales (i.e., a coating that forms inside of pipes) that contain lead. Physical disturbances or changes in water quality and flow velocity can cause lead particles found within pipe scales to become dislodged and released into drinking water. These lead particles can cause intermittent spikes in the lead concentrations found in drinking water. Screened aerators on kitchen taps may trap these particles and should be periodically cleaned.

Under the National Plumbing Code (NPC), all fittings must comply with the American Society of Mechanical Engineers (ASME) 112.18.1 / Canadian Standards Association (CSA) B125.1 standard for plumbing supply fittings. In 2012, these standards revised the requirement for "lead-free" components from 8% down to 0.25% lead as a weighted average with respect to the wetted surfaces of pipes, pipe fittings, plumbing fittings, and fixtures. This means that fixtures produced as late as 2012 could legally contain 8% lead – enough to cause an exceedance of the MAC on stagnant ("first flush") water samples.

Anecdote: A city in Northern BC was conducting a survey of lead content in the drinking water in their various facilities. In one new building, built in 2013, the lunchroom tap surprisingly failed its first-flush sample. The City responded by changing the tap to a newer model with an NSF certification. The retest for lead was lower, but again exceeded the MAC. Only when the shutoff valve was also replaced did the sink pass the first-flush lead test.

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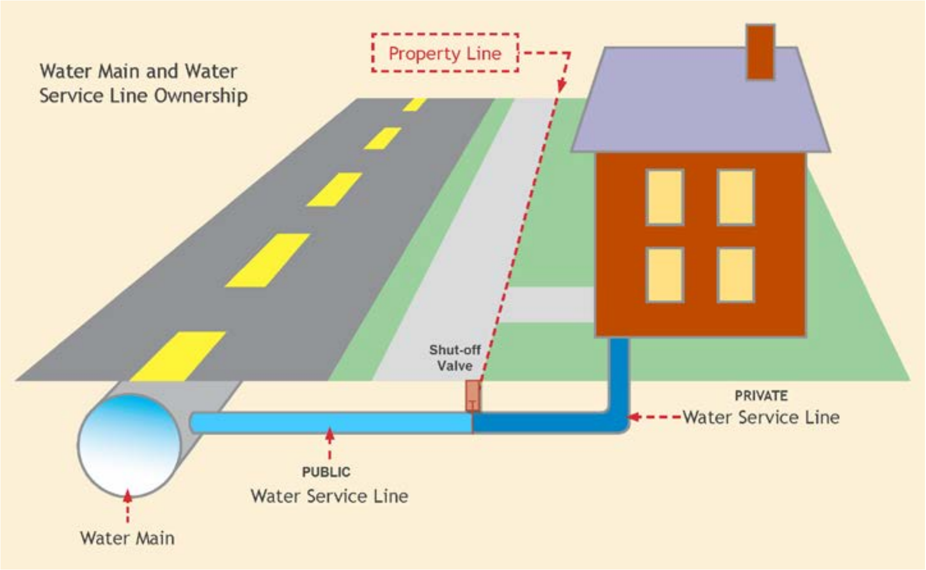
[1] Service lines connect individual buildings to the water supply system distribution main. Service line ownership is shared. The utility typically owns the portion up to the property line and the home or building owner owns the portion on their property. Before the 1960s, service lines were commonly made of lead in some communities.

3. ROLES AND RESPONSIBILITIES

The question of responsibility for lead in drinking water is unique in that water delivered by water suppliers may be potable at the point of delivery, but may have characteristics that make it susceptible to leaching lead and other metals from pipes, solder and fixtures after it is delivered to the property. This may result in significant portions of the community being affected or localized problem areas affecting some buildings or neighborhoods in a community but not others. The problems can also be localized within buildings, affecting only some taps depending on water use patterns, plumbing configurations and materials, and differences in plumbing fixtures.

The issue of who is responsible for lead in drinking water is complex given that lead in drinking water may come from the pipes and fixtures contained within private properties, or services lines. Water suppliers are not responsible for the maintenance or replacement of plumbing beyond service lines and other fixtures upstream of the curb stop where water is delivered, after which it becomes the responsibility of the property owner (see Figure 1). So while the water supplier may own the water supply system, property owners own the pipes and plumbing on their property. This shared ownership also means a shared responsibility to mitigate excessive lead concentrations found at the tap. Property owners are responsible for the condition of their building's plumbing and for taking any necessary remedial action to minimize lead exposure deriving from the plumbing and fixtures in their property, such as replacing leaded plumbing and fixtures, installing treatment devices to remove lead, or implementing a flushing program. Where the characteristics of the water (i.e., the corrosiveness) are expected to significantly contribute to leaching, the water supplier has the responsibility to take reasonable steps to mitigate likelihood of a hazard being associated with the water being delivered to the end user.

Figure 1: Water service line responsibilities (modified from: https://www.alexandriava.gov/uploadedImages/health/info/AlexandriaWaterService.jpg



Several statutes play a role in ensuring that drinking water does not pose a health risk for consumers. These include: the *Drinking Water Protection Act,* the *BC Plumbing and Building Code,* the *Public Health Act,* the *School Act* and the *Community Care and Assisted Living Act.* As these statutes apply concurrently, the overlap indicates a shared responsibility of all parties involved.

- The *Drinking Water Protection Act:*
    - Requires water suppliers to deliver potable water to customers. While the DWPA may not directly compel water suppliers to ensure potability beyond the point where it is delivered to the consumer, health authorities may impose conditions on permits that require water suppliers to take actions to reduce the likelihood that the water they deliver contributes to a drinking water health hazard.
- The BC Building Code:
    - Speaks to plumbing standards within buildings. However, this statute is only applied at the time of construction and many buildings constructed prior to 1989 can be assumed to be at an increased risk for lead leaching from plumbing under certain water conditions.
- The *School Act* and the *Community Care and Assisted Living Act* (Child Care Licensing Regulation):
    - These Acts protect children in schools and in licensed child day care facilities. Medical Health Officers may act as School Health Officers under the *School Act* and may conduct inspections, and where necessary impose requirements for the construction and/or operation of the facilities. Similarly, Licensing Officers (who are delegates of the Medical Health Officer) inspect child day care facilities, issue licences to operators of child care facilities, and where necessary impose requirements for the health, safety and well-being of children who attend child day care, the physical premises and/or operation of the facilities. Similarly, where there is reason to believe there are children at risk due to lead exposure in residential care facilities, action may also be warranted to assess and mitigate these situations.
- The *Public Health Act:*
    - Requires landlords to provide potable water to tenants. The *Public Health Act* may also be used as a legal tool where a lack of action by water suppliers, building owners, or others may contribute to a health hazard.

Successful reduction of lead in tap water depends on a multi-barrier approach with participation and actions of all parties as it is difficult to achieve lead reduction through centralized mitigation alone. The following table lays out high level expectations of roles and responsibilities of each stakeholder in this process. More specific roles and responsibilities related to each stakeholder are discussed below.

Table 1. Stakeholder Responsibility for Lead in Drinking Water

Responsibility	***Responsible Stakeholders***		
	Drinking Water Supply systems	***Schools/Day cares***	***Private buildings***
Screening & Prioritizing	*HA* + Water supplier*	*HA + SD + IS + CF*	*Building owner*
Planning to Test	*HA + Water supplier*	*HA + SD + IS + CF*	*Building owner*
Testing	*Water supplier* *Building owner***	*SD + IS + CF*	*Building owner*
Interpretation	*HA*	*HA*	*HA upon request*
Planning to Mitigate	*Water supplier + HA review & permitting*	*SD + IS + CF + HA review*	*Building owner*
Implementing Mitigation	*Water supplier*	*SD + IS +CF*	*Building owner*
Verification of Mitigation	*Water supplier + HA review*	*SD +IS +CF + HA review*	*Building owner*
Communication/ Education	*Water Supplier (system specific)* *HA (community level)*	*SD + IS +CF (facility specific)* *HA (community level)*	*Building owner (building specific)* *HA (community level)*

** HA- Health Authorities; SD – School Districts; IS – Independent Schools; CF – Care Facilities*
***As lead testing is done at the tap, building owners are key participants in testing programs*

3.A ROLES AND RESPONSIBILITIES OF HEALTH AUTHORITIES

The high level roles of drinking water officers (DWO), medical health officers (MHO), environmental health officers (EHO), public health engineers (PHE) and licensing officers (LO) are to:

- Screen communities to identify those likely to have lead issues, and for those identified;
- work with water suppliers to determine if elevated lead concentrations in community tap water pose an unacceptable risk to end users, and where there is an unacceptable risk; and
- advocate for, or mandate the evaluation and mitigation of lead risks by all stakeholders through appropriate and reasonably achievable mitigation measures.

In communities likely to have lead issues due to corrosion concerns, PHEs and DWOs may need to determine with water suppliers whether concerns are best addressed through centralized mitigation measures at the water supply (e.g., pH and alkalinity adjustment or the addition of corrosion inhibitors at treatment), decentralized measures by users (e.g., flushing, point-of-use treatment devices, leaded plumbing replacement, etc.), or by a combination of both.

The role of the health authority in evaluating and mitigating the risk of lead in a community should include actively working with all stakeholders to ensure they are aware of risks and of the actions they should take to evaluate and reduce risks. Where necessary, health authorities may also need to take progressive enforcement actions with regulated facilities. The priority of any enforcement action should be directed towards large community water systems where the corrosiveness of the water supply contributes to excessive lead levels known to exist in public and private buildings.

As infants and children are more susceptible to health effects from lead, schools and care facilities where children may be exposed to elevated lead concentrations in drinking water should be the focus of health authority efforts. Health authorities should include evaluation of risks for lead in drinking water as part of their engagement with schools and child day care facilities and re-assess the frequency of monitoring in areas where lead has been found to be a problem. Drinking water officers should work with licensing officers to introduce testing for lead and ensure appropriate mitigation measures are in place as part of inspections and licensing requirements for child day care facilities.

Details of specific roles and responsibilities of health authorities in relation to stakeholders are outlined below. Technical information on assessing risks and sampling are in the appendices of this document.

3.B ROLES AND RESPONSIBILITIES OF WATER SUPPLIERS

The *Drinking Water Protection Act* requires water suppliers to deliver potable water to users, but does not directly compel water suppliers to ensure potability after delivery to customers. However, where it is probable that the nature of the water is likely to pose a potential health risk to users after delivery, the DWO may be justified in requiring the water supplier, through conditions on the operating permit, to take steps to assess whether corrosivity of the water, and/or resulting water lead concentrations in buildings presents a risk to the population, and if necessary, to take steps to reduce risks.

To assess corrosion risks in community water supplies, water suppliers, in collaboration with the local health authority, should develop plans to conduct surveys, tests, inventories or studies to:

- Screen water for indicators of corrosivity;
- survey the prevalence of lead service lines in communities;
- survey the prevalence of buildings with plumbing and fixtures with elevated lead content; and
- implement testing, including surveys of representative samples taken at consumers' taps to evaluate impact of the corrosivity of the water supply in the community.

Results of assessment programs should be reviewed with health authorities. Where the corrosive nature of water quality is determined to contribute to lead exposure from interaction with plumbing at the community level, building owners and the water supplier may need to take steps to reduce risks as described later in the document. For water suppliers, these risk mitigation steps may be done informally through agreement, or may be formalized by the health authority through conditions on its operating permit.

Table 2. Health authority and water supplier roles

Health Authority	Water Supplier
• Liaise with water supplier and advise them as necessary to conduct community risk	• Liaise with health authority on the necessity to conduct a community risk assessment for

Health Authority	Water Supplier
assessment for corrosion and typical lead exposure. • If necessary, in consultation with the Water Supplier, place conditions on the operating permit, to ensure that an adequate assessment of population health risks from lead in drinking water is undertaken. • Provide direction and advice to water supplier on sampling protocols. • Interpret surveys and studies to advise water suppliers on the risks that the water supply system poses. • Advise water suppliers on public education messaging and provide information on risks. • Follow up on complaints or concerns regarding potential health hazards in the community. • Provide progressive enforcement to mitigate health hazards under the *Public Health Act* and/or DWPA.	corrosion. • Design and implement a residential testing strategy to evaluate lead exposure burden from drinking water in the community, if necessary. • Conduct sampling, tests and surveys in the community. • Report any potential health hazards associated with water supply to end users of water supplies related to the corrosivity of water. Provide messaging and information to the public regarding what is being done to mitigate hazards by the water supplier, and what the public can do to protect itself. • Minimize leaching impacts through planning and implementing corrosion control programs.

3.C ROLES AND RESPONSIBILITIES OF SCHOOL DISTRICTS AND INDEPENDENT SCHOOLS

Schools districts and independent schools are responsible for operating schools in a manner that does not adversely affect the health of their students. School districts and independent schools should work with heath authorities to establish a plan to identify where lead risks might occur, as well as to mitigate any identified risks. Details on developing a plan are found in Section 4.

Table 3: Health authority and water supplier roles relative roles of school districts, independent schools, health authorities, and the provincial government in determining risk and actions that should be taken to identify and reduce lead risks in schools.

School Districts / Independent Schools	Health Authority	Ministry of Health and Ministry of Education
• Inventory and characterize schools and identify whether they are on a community water supply or school district operated water supply. • Plan and carry out screening/testing programs in consultation with the health	• Work with water suppliers to identify where schools are at increased risk. • Assist school officials to develop plans to evaluate lead risks in schools. Provide advice on sampling protocols. • Interpret results and provide	• Provide policy and guideline direction. • The Minister of Health under the School Act can require the school medical officer to conduct inspections of schools and can require the

School Districts / Independent Schools	Health Authority	Ministry of Health and Ministry of Education
authority. • Plan and implement lead mitigation programs for school buildings. • Communicate risks to parents and students. • Send annual reminders to school maintenance staff regarding flushing or other mitigation measures that might be necessary. • Maintain records and report findings to HAs including a summary of the mitigation strategy that identifies flushing schedules and the locations being flushed.	information on mitigation options. • Review the effectiveness of mitigation options. • Advise school officials on risk messaging for the schools. • Engage with schools to verify lead mitigation programs are adhered to, and follow up on complaints or concerns. • Provide progressive enforcement where necessary if health hazard remains unabated.	MHO to provide a report.

3.D ROLES AND RESPONSIBILITIES OF LICENSED CHILD CARE FACILITIES

Licensed child care facilities are responsible for operating in a manner that will promote the health, safety and dignity of persons in care. Licensed child care facilities should work with heath authorities to evaluate lead risks in their facility, as well as mitigation planning to identify and mitigate the risks.

Table 4: Relative roles of licensed child care facilities and health authorities in determining the actions that should be taken to identify and reduce the risks of lead in drinking water.

Child Care Facilities	Health Authority	Ministry of Health and Director of Licensing
• Plan and carry out screening/testing programs in consultation with health authority where there is a risk of lead in drinking water. • Plan and implement lead mitigation programs for their facilities. • Communicate risks and mitigation steps to parents. May consider sharing with parents new to a facility upon child enrollment, and include in parents	• Provide education materials relating to lead in drinking water. Work with water suppliers to identify where conditions might exist that put facilities at increased risk. • Assist affected facilities to develop plans to evaluate lead risks. Provide advice on sampling protocols. Interpret results and provide information on mitigation options. • Review the effectiveness of mitigation options. • Work with child care facilities to	• Provide policy direction • Develop educational materials on lead in drinking water. • Recommend or require testing for lead in high risk child care facilities.

handbook. • Send annual reminders to staff regarding flushing, alternate sources of water, or other mitigation measures necessary.	develop messaging to users and their families on lead risks in the child care facilities. • Include lead education in inspections. Verify lead mitigation programs are adhered to and effective. Follow up on complaints or concerns regarding lead in child care facilities. • Provide progressive enforcement where necessary if health hazard remains unabated.	

3.E ROLES AND RESPONSIBILITIES OF THE OWNERS OF HOMES AND OTHER BUILDINGS

The BC Building Code provides plumbing standards within buildings; however this statute is only applied at the time of construction. As a result, it can be assumed that most homes and other buildings constructed or altered prior to the 1989 revisions of the BC Building Code have a higher risk of lead leaching into drinking water from their plumbing. Under the *Public Health Act*, the owners of these properties are responsible for ensuring that the plumbing does not create a drinking water health hazard for those who consume the water.

While there are no specific regulations that require lead to be tested and mitigated in individual homes and buildings, owners are required to provide tenants with potable water that is fit to drink without further treatment. Owners are responsible for testing their own water and taking mitigation steps (e.g. flushing, service line/plumbing fixture replacement), and health authorities may provide reference information on the best practices for doing so.

Table 5: Relative roles of building owners and health authorities in determining risk and actions that should be taken to identify and reduce the risks of lead in drinking water.

Building/Home Owners	**Health Authority**
• Provide potable water to rental units intended to be living accommodations. • Learn about the risks of corrosion from communications from the water supplier (system specific info) and/or the health authority (general info). • Plan and carry out testing on building water. • Provide information and communications to tenants and/or employees. • Develop and implement a mitigation strategy for lead in their buildings.	• Work with water suppliers to ensure that risks are communicated to users. • Provide information to the public on the risks of lead in drinking water, lead testing, the interpretation of test results, and mitigation options.

3.F ROLE OF PROVINCIAL GOVERNMENT

Ministry of Health is the main agency for provincial drinking water policy development. The Ministry will work with Health Canada, BC's health authorities, the Ministry of Education and other stakeholders to provide advice and policy on best practices for assessing lead risks from drinking water, to develop educational material, and to advocate for the reduction of lead exposure to the public from drinking water.

4. ASSESSMENT AND MITIGATION OF LEAD RISKS IN DRINKING WATER

4.A WATER SUPPLY SYSTEM/COMMUNITY LEVEL

EVALUATE AND PRIORITIZE

Screening water supply systems for high risk of corrosion:

Health authorities should work with water suppliers to screen water supply systems for characteristics that suggest potential corrosion risks, and/or the prevalence of buildings at risk. These systems may be prioritized for further investigation of the potential for unacceptable lead concentrations in water for consumers.

The chemistry of corrosivity is complex, typically involving many different factors (chemical, physical or microbiological), which can make it challenging to predict how it will impact leaching when it comes into contact with leaded components.

Many indexes such as the Langelier Saturation Index (LSI), the Ryzner Index, the Aggressiveness Index, the Momentary Excess and the Calcium Carbonate Precipitation Potential, were developed to assess the calcium carbonate–bicarbonate equilibrium, and were historically used as an indicator of the corrosivity of water. However, Health Canada's *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* and Ontario's *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems*, report significant empirical evidence contradicting the presumed connection between corrosion and the most common of the corrosion indices, the Langelier Index. The American Water Works Association Research Foundation recommends that the use of corrosion indices for corrosion control practices be abandoned. Because of these limitations, these authorities recommend lead and/or other metal sampling at the tap as the most reliable indicator of corrosive water. This is critical, because corrosivity of the water is under control of the water supplier, whereas the lead content in the plumbing is largely under control of the building/home owner. Because the most reliable indicator of corrosive water is actual corrosion as detected in sampling at the tap, water suppliers should not conclude that their water is not corrosive until that is confirmed by sampling inside buildings and homes.

This being said, the chemistry of the water in water supply systems can be proactively evaluated for risk factors that indicate a higher probability that it will be corrosive. Water supplies with one or more of the following water chemistry characteristics should be *prioritized* for further evaluation of potential lead risks from corrosion of plumbing in the community:

- Lower pH (<7)
- Low alkalinity (<30 mg/L)
- Low hardness, i.e., "soft water" (<60 mg/L as calcium carbonate $CaCO_3$)[2]

Other drinking water quality parameters that might impact corrosivity may also be considered such as: higher temperatures, fluctuations in free chlorine residual, chloramines, chloride, sulphate, natural organic matter (NOM), oxidation-reduction potential (ORP), and chloride-sulphate mass ratio (CSMR) (see Table 6).

Table 6. Water Quality Factors Affecting Corrosion.

Factor	**Effect**
pH	Low pH causes iron, lead, and copper corrode rapidly.
Alkalinity and Dissolved Inorganic Carbonate (DIC)	Neutralize strong acids and provide buffering capacity against a pH drop. Affect many reactions in corrosion chemistry.
Hardness	In combination with alkalinity, promote the formation of a protective passivating film.
Disinfectant Residual	Gaseous chlorine lowers pH. Higher chlorine residuals (2 mg/L) may cause protective lead scales.
Dissolved Oxygen	Increases corrosion of copper; effect on lead less certain.
Oxidation Reduction Potential, Redox Potential (ORP, Eh)	High ORP and high pH promote protective lead scales.
Ammonia	Interfere with the formation of passivating films. Oxidation of ammonia (nitrification) lowers alkalinity and pH, increasing corrosion.
Chloride and Sulphate	Chloride (Cl^-) and sulphate (SO_4^{2-}) cause dissolved metals to remain soluble. Increase the salinity (TDS) and electrical conductivity of water. High chloride-to-sulphate-mass ratios (CSMRs) increase corrosion rates for lead solder connected to copper pipe.
Salinity (TDS)	The higher the TDS, the higher the ionic strength and electrical conductivity.
Natural Colour and Organic Matter	May form a protective film and reduce corrosion. May react with the corrosion products to increase corrosion. Food for microorganisms growing in biofilms in the pipes.

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[2] According to Health Canada's Guideline Technical Document for Hardness, soft water can lead to corrosion of pipes. The degree to which this occurs is also a function of pH, alkalinity and dissolved oxygen content. According to the Water Research Centre, in water that is soft, corrosion occurs because of the lack of dissolved cations, such as calcium or magnesium in the water. In scale forming water (hard water), a precipitate or coating of calcium or magnesium carbonate forms on the inside of the piping called scale. This scale coating can inhibit the corrosion of the pipe by acting as a barrier, but it can also clog the pipe (i.e., incrustation). Health Canada recommends hardness levels between 80 and 100 mg/L (as $CaCO_3$), which are generally considered to provide an acceptable balance between corrosion and incrustation from scale. (Source: http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/water-hardness-durete-eau/index-eng.php)

Factor	Effect
Corrosion Indices	Langelier Saturation Index (LSI) measures calcium carbonate ($CaCO_3$) scale-forming tendency. LSI does not correlate well with actual corrosion, so LSI is less reliable than sampling at taps for corrosion products.
Temperature	For every 10°C rise in temperature, chemical reaction rates, including corrosion, typically tend to double.
Flow velocity	High velocity: increases the supply of dissolved oxygen; erodes pipe walls if abrasive suspended solids are present. Zero velocity: Stagnation may cause pitting and tuberculation, especially in iron pipes, as well as promoting biological growth
Microbiological	Microbiologically induced corrosion (MIC) ≡ localised high corrosion zones (pinholes) sheltered inside biofilms.
Orthophosphate	Corrosion inhibitor added to water to form a passivating film on the pipe surface.

Based on: ON (2009) Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems. Section 2.3 Water Quality Factors Affecting Corrosion.

To confirm whether corrosion is an issue for a community's water supply system, the most reliable approach is sampling surveys of lead at consumers' taps as described in Health Canada's *Guideline Technical Document on Corrosion Control*, and Appendix C of this document.

Health Authorities may also consider data from lead testing programs in schools, day cares or other buildings, which may serve as sentinel information for a community, and help flag the need to further investigate.

Where the initial screening of water chemistry (pH, alkalinity and softness) indicates increased risk factors for corrosive water, a survey of the prevalence of service connections and of the typical age and condition of buildings in the community can also help determine the magnitude of risk. This information can also be used in later steps to assist in determining where to focus lead sampling program from consumers' taps. Communities where a high proportion of buildings were constructed prior to 1989, that have not upgraded their plumbing to lower lead content are likely to be at the highest risk of having lead in their plumbing.

Large communities with older housing stock and buildings as well as a water supply with corrosive characteristics should be targeted for further sampling first. Additionally, communities where there has been a change in water source or water chemistry or treatment processes should also be flagged for testing.

TESTING AND EVALUATING RESULTS

Those drinking water systems identified as being at the highest risk by the screening step should develop and implement lead sampling programs conducted at consumers' taps. The objectives of these sampling programs are to:

- Determine whether community level lead mitigation measures are warranted to reduce corrosion;
- establish base lines to help evaluate the effectiveness of any mitigation measures that are adopted; and
- evaluate if the water typically consumed by customers exceeds the maximum acceptable concentration (MAC) level for lead set out in the *Guidelines for Canadian Drinking Water Quality*.

High level descriptions of sampling protocols for corrosion risks, as well as for determining whether concentrations of lead typically found in the community's water meets the *Guidelines for Canadian Drinking Water Quality* are outlined in Appendix C.

MITIGATION

Both centralized and decentralized mitigation measures can be taken to address concerns from lead at user's taps resulting from corrosive water. The most appropriate method will depend on a number of factors. In areas where the nature of the water supply itself is reasonably believed to contribute to a health risk from lead at users' taps, water suppliers should work with health authorities to determine feasible strategies for mitigating lead risk. Reducing risk will usually involve a combination of communicating how consumers can reduce their own risks as well as planning long term corrosion control strategies as follows:

1. Communicate the results of testing programs to consumers and inform them of the appropriate measures that they can take to reduce their exposure to lead. Corrective measures that consumers can take could include any or a combination of the following:
    - flushing the building plumbing system;
    - replacing their portion of the lead service line (if applicable);
    - replacing brass fittings or in-line devices (pre-2012);
    - using drinking water treatment devices certified to reduce lead; and
    - using an alternate water supply for drinking water or food preparation.[3]

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[3] Exposure through bathing and other household purposes is not a health hazard.

2. Implement appropriate corrective measures to control corrosion in the drinking water supply system. Results of sampling should be used to help determine the best corrective measures for the system, which may include any or a combination of the following:
    - replacing lead service lines;
    - adjusting drinking water pH and alkalinity;
    - adding corrosion inhibitors;
    - replacing brass fittings or in-line devices containing lead;
    - carrying out *ad hoc* or unidirectional flushing, swabbing, or pigging of water mains to reduce accumulated sediment and biofilms; and
    - maintaining a disinfectant residual to avoid reducing conditions and to control biofilms.

Corrosion control programs have been shown to significantly reduce leaching, but may not eliminate it. Careful consideration should be given to the potential effectiveness, potential unintended effects on water, public acceptance, and the cost of mitigation measures and programs to determine the most appropriate course of action to follow. Bench-scale and pilot testing should be carried out for any proposed change to distribution water chemistry. No matter what type of mitigation measures are employed, an evaluation of the effectiveness of the mitigation measures should be done after they are implemented. Community level assessment and mitigation steps are outlined in the flow chart set out in Appendix A.

4B. INDIVIDUAL BUILDINGS

EVALUATE AND PRIORITIZE

Owners and operators of buildings (particularly school boards and child care facilities), particularly those on water systems identified to be at risk from corrosive water, should evaluate their buildings for plumbing components that can leach lead into drinking water. The complexity of the evaluation may vary depending on whether the building in question is a single family home, a multi-family dwelling, an industrial/office building, a school, or a child care facility; however the overlying evaluation principles will be the same. [4]

Evaluations should include:

- Developing a plumbing profile for the building that identifies plumbing components such as service lines, pipes, solder or fixtures that contain lead, and inventories drinking fountains and other points of consumption that might contain lead or brass;

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[4] *For the purpose of this document:*
"buildings" includes private residences and private schools served by a community water system;and
"schools" and "facilities" mean those that are connected to an approved water supplier and are not themselves a water supplier under the DWPA. Schools and other facilities that are their own water supplier may need to also take on roles of water suppliers in this document.

- identifying potential problems and health hazards to users through screening tests and/or more comprehensive testing;
- maintain records and communicate plans and results with stakeholders; and
- taking routine, interim and permanent mitigation measures.

An example of school and child day care assessment and mitigation steps is outlined in the flow chart set out in Appendix B. The following publication from the Province of Ontario manual is an excellent reference for evaluating risks from their plumbing and identifying options to remedy any excess lead in facilities: (2009) A Manual for Operators of Schools, Private Schools and Day Nurseries with excess Lead in their Drinking Water: A resource guide on how to locate the source and remedy the problem [Available at: https://www.ontario.ca/document/manual-operators-schools-private-schools-and-day-nurseries-excess-lead-their-drinking-water].

TESTING AND EVALUATING RESULTS

For schools, licensed child care facilities and other buildings that have plumbing containing lead components, or where there is a lack of information about the plumbing that is in place, screening tests and/or more comprehensive testing programs should be planned and implemented in consultation with regional health authorities.

When testing water, it is important to determine the sampling objective, so that the appropriate sampling protocol is used. Sampling protocols differ depending on the desired objective: e.g. whether it is screening of schools for potential lead problems, identifying fixtures/sources of lead for replacement or to estimate health risk from exposure to lead. In order to provide meaningful results, multiple samples are needed. Health authorities can provide advice on what sampling method is appropriate and can help evaluate and interpret the results.

A high level description of how, when and where to test buildings is outlined in Appendix C. Health authorities can provide advice on how it should be applied to individual facilities, and can help evaluate and interpret the results against the guidelines.

Subsequent to initial screening and evaluation, schools and child care facilities should develop a plan for long term routine lead monitoring. Annual testing would be ideal, however risk-based decisions on frequency may be warranted from a resource perspective. In general, higher risk facilities where lead has been found as a problem may require more frequent testing than facilities where lead is not known to be an issue or risk. In BC, the Ministry of Education has developed policies for schools districts and independent school authorities regarding expectations for lead sampling, reporting and mitigation. These policies (see links below) require regular screening for lead in all schools. This guidance document serves as a guide on how to meet this testing requirement.

BC Ministry of Education (Sept 26, 2016) *Testing Lead Content in Drinking Water of School Facilities*

BC Ministry of Education (January 1, 2017) *Testing Lead Content in Drinking Water of Independent School Facilities*

MITIGATION

In buildings where the risk of exposure to lead in drinking water is determined to be unacceptable, mitigation measures should be taken. Owners should communicate results of evaluations, and identify what consumers can do to reduce exposure to lead in the short term, and what building owners can do to reduce exposure in the long term. In situations where the drinking water is at risk of elevated lead and testing to establish water quality has not yet been done, it would be prudent to err on the side of caution and adopt interim measures (flushing, bottled water) to reduce the risks associated with the presence of lead in drinking water while awaiting assessment results.

Options for reducing lead in buildings may include short and long term solutions such as:

- Educating the occupants of the building (e.g., teachers, day care providers, students) and other interested parties (e.g., parents, occupational health and safety committees) on the sampling results and the interim and long-term corrective measures that are being undertaken;
- flushing all water taps used for drinking water or food preparation at the start of each day or after periods of stagnation;
- providing an alternative water supply such as bottled water;
- installing point-of-use (POU) filtration units designed specifically to remove lead;
- installing corrosion control equipment at the point-of-entry (POE) into the building to adjust pH to reduce the likelihood of lead leaching into water (however complexity of maintenance may pose challenges in many situations);
- where lead sample results identify particulate vs dissolved lead, this may help decide whether it is better solved by filtration than conditioning for corrosion control;
- removing drinking water taps from service that contain unacceptable levels of lead;
- posting signs that identify “designated drinking water taps” (DDWTs) and "Do not drink" taps (non-DDWTs);
- replacing lead containing outlets, fixtures, fountains, pipes and fittings with low-lead alternatives;
- replacing old water lines and solder that might contain lead;
- working collaboratively with the water supplier to ensure that the water delivered to the building is not corrosive.

Evaluation of the effectiveness of mitigation measures should be done after they have been implemented, and at regular time intervals afterwards. No matter what type of mitigation measures are employed, re-sampling should be done to verify the effectiveness of the mitigation measures and to ensure that the concentration of lead falls below the GCDWQ maximum acceptable concentration.

COMMUNICATION

Users of drinking water systems and buildings need to know the risks that exist, if any, and what is being done to mitigate the risks. Users should be advised regularly on lead risks associated with their drinking water and the need for regular testing, and mitigation measures. Communication should be clear and transparent to avoid confusion and ensure the goals, message and actions are understood.

Simple handouts for the public and other stakeholders such as: Health Files https://www.healthlinkbc.ca/healthlinkbc-files/lead-drinking-water, as well as those specific to School testing, and daycares may be helpful in communicating key messages.

Table 7: Communication Expectations

Who and What?
Health Authorities
• General messaging about lead and health risks to the public • General technical medical questions • Audience: General public, media, water suppliers, school boards; operators of child care facilities
Water Suppliers
• What is known about water corrosivity • What the drinking water supply system is doing about it • What users need to do to protect themselves • Audience: users of the water supply system
School Boards, Child Care Facilities and Other Building Owners
• What assessments are being done • Results of the assessments • Mitigation measures being taken • Audience: building users, parents of children and students in care
How?
• Written and media communication: Targeted mail outs, flyers in water bills, media releases, annual reports, newsletters, e-mails, websites and social media • Face to face conversations: interviews, public events • Signage: Warning signs on taps. Where flushing is the mitigation measure of choice, signage should be posted by fountains warning users to flush until the water runs cold
When?
• Whenever new, reliable information is available • Prior to and after lead screening and testing programs • Reminders should be done regularly in problem areas

REFERENCES:

BC Centre for Disease Control. (2017) Managing risks to children's health from lead in drinking water in British Columbia's daycares and schools.

Deshommes et al. (2016) Evaluation of exposure to lead from drinking water in large buildings, *Water Research*; 99:46-55 [URL: http://dx.doi.org/10.1016/j.watres.2016.04.050]

Health Canada (2007) Water Talk: Minimizing Exposure to Lead from Drinking Water Distribution Systems [URL: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/lead-plomb-eng.php]

Health Canada (2015) Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – pH.

Health Canada (1979, reprinted 1995) Guidelines for Canadian Drinking Water Quality: Hardness

Health Canada (2009) Guidance on Controlling Corrosion in Drinking Water Distribution Systems. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No. H128-1/09-595E).

Health Canada (1992) Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Lead Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No. H128-1/09-595E).

Ontario Ministry of Environment (2009) A Manual for Operators of Schools, Private Schools and Day Nurseries with Excess Lead in the Drinking Water: A resource guide on how to locate the source and remedy the problem [URL: https://www.ontario.ca/document/manual-operators-schools-private-schools-and-day-nurseries-excess-lead-their-drinking-water]

Ontario Ministry of Environment and Climate Change (updated June 23, 2016) Guide for schools, private schools and day nurseries on flushing for lead: A guide to requirements for flushing and testing drinking water taps in schools, private schools and day nurseries. [URL: https://www.ontario.ca/page/guide-schools-private-schools-and-day-nurseries-flushing-and-testing-lead]

Ontario Ministry of Environment and Climate Change (2009) Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems [URL: https://archive.org/details/guidancedocument00snsn21738]

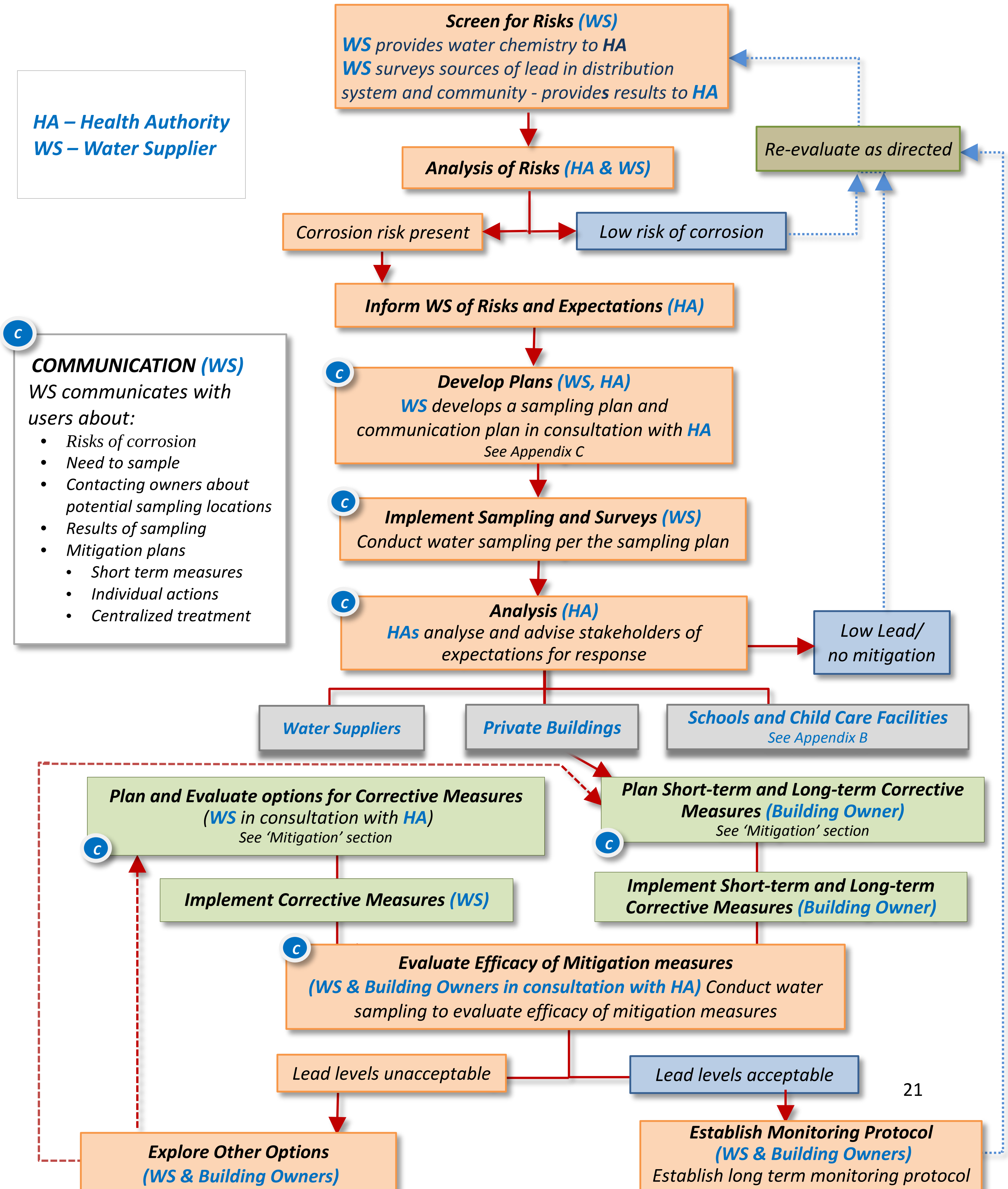
US EPA (Nov 9, 2015) Testing Schools and Child Care Centres for Lead in the Drinking Water [URL: https://www.epa.gov/dwreginfo/testing-schools-and-child-care-centers-lead-drinking-water]

US EPA (2005) 3Ts for Reducing Lead in Drinking Water in Child Care Facilities: Revised Guidance [URL: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20017JVA.txt]

US EPA (2006) 3Ts for Reducing Lead in Drinking Water in Schools: Revised Technical Guidance [URL: https://www.epa.gov/dwreginfo/lead-drinking-water-schools-and-child-care-facilities#3Ts]

Water Research Foundation / American Water Works Association (2015) Controlling Lead in Drinking Water; Web Report # 4409 [URL: http://www.waterrf.org/PublicReportLibrary/4409.pdf]

Appendix A – Process Flow for Evaluating Corrosion Risk in Water Supplies



HA – Health Authority
WS – Water Supplier

***Screen for Risks** (WS)*
WS provides water chemistry to HA
WS surveys sources of lead in distribution system and community - provides results to HA

Re-evaluate as directed

***Analysis of Risks** (HA & WS)*

Corrosion risk present

Low risk of corrosion

***Inform WS of Risks and Expectations** (HA)*

C

***COMMUNICATION** (WS)*
WS communicates with users about:

- *Risks of corrosion*
- *Need to sample*
- *Contacting owners about potential sampling locations*
- *Results of sampling*
- *Mitigation plans*
  - *Short term measures*
  - *Individual actions*
  - *Centralized treatment*

C

***Develop Plans** (WS, HA)*
WS develops a sampling plan and communication plan in consultation with HA
See Appendix C

C

***Implement Sampling and Surveys** (WS)*
Conduct water sampling per the sampling plan

C

***Analysis** (HA)*
HAs analyse and advise stakeholders of expectations for response

Low Lead/ no mitigation

Water Suppliers

Private Buildings

Schools and Child Care Facilities
See Appendix B

Plan and Evaluate options for Corrective Measures
(WS in consultation with HA)
See 'Mitigation' section

C

***Implement Corrective Measures** (WS)*

***Plan Short-term and Long-term Corrective Measures** (Building Owner)*
See 'Mitigation' section

C

***Implement Short-term and Long-term Corrective Measures** (Building Owner)*

C

Evaluate Efficacy of Mitigation measures
(WS & Building Owners in consultation with HA) Conduct water sampling to evaluate efficacy of mitigation measures

Lead levels unacceptable

Lead levels acceptable

Explore Other Options
(WS & Building Owners)

Establish Monitoring Protocol
(WS & Building Owners)
Establish long term monitoring protocol

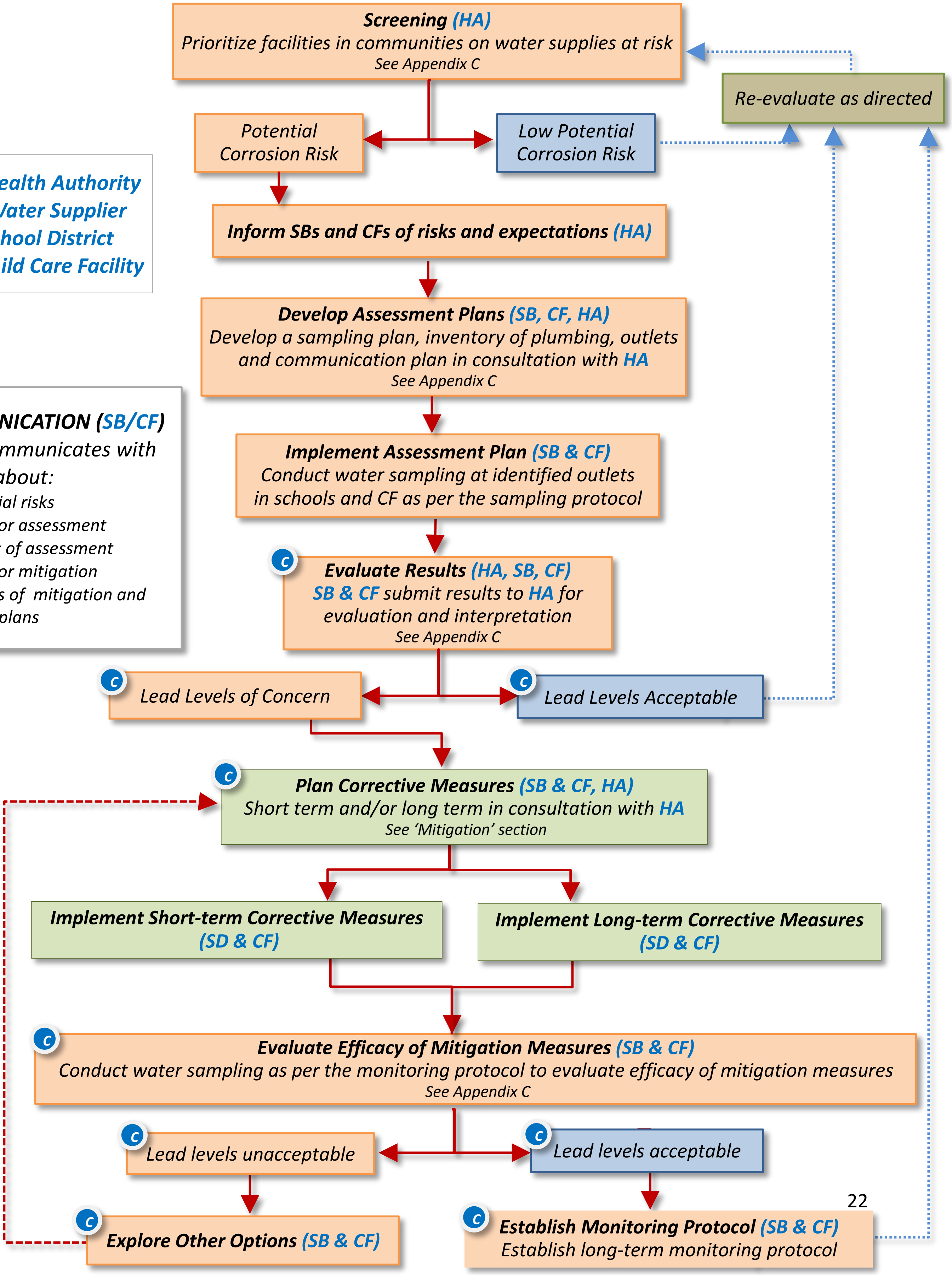
Appendix B - Processs Flow for Evaluating Lead in Schools and Child Care Facilities

HA – Health Authority
WS – Water Supplier
SD – School District
CF – Child Care Facility

C **COMMUNICATION (SB/CF)**

SB/CF communicates with parents about:

- *Potential risks*
- *Plans for assessment*
- *Results of assessment*
- *Plans for mitigation*
- *Success of mitigation and future plans*



***Screening** (HA)*
Prioritize facilities in communities on water supplies at risk
See Appendix C

Potential Corrosion Risk

Low Potential Corrosion Risk

Re-evaluate as directed

***Inform SBs and CFs of risks and expectations** (HA)*

***Develop Assessment Plans** (SB, CF, HA)*
Develop a sampling plan, inventory of plumbing, outlets and communication plan in consultation with HA
See Appendix C

***Implement Assessment Plan** (SB & CF)*
Conduct water sampling at identified outlets in schools and CF as per the sampling protocol

C ***Evaluate Results** (HA, SB, CF)*
SB & CF submit results to HA for evaluation and interpretation
See Appendix C

C *Lead Levels of Concern*

C *Lead Levels Acceptable*

C ***Plan Corrective Measures** (SB & CF, HA)*
Short term and/or long term in consultation with HA
See 'Mitigation' section

***Implement Short-term Corrective Measures** (SD & CF)*

***Implement Long-term Corrective Measures** (SD & CF)*

C ***Evaluate Efficacy of Mitigation Measures** (SB & CF)*
Conduct water sampling as per the monitoring protocol to evaluate efficacy of mitigation measures
See Appendix C

C *Lead levels unacceptable*

C *Lead levels acceptable*

C ***Explore Other Options** (SB & CF)*

C ***Establish Monitoring Protocol** (SB & CF)*
Establish long-term monitoring protocol

APPENDIX C - EVALUATING LEAD IN DRINKING WATER

Contents:

1. WHY ARE YOU SAMPLING?

The purpose of this appendix is to provide a reference of best practices for evaluating and sampling lead content in drinking water. As lead concentrations in drinking water vary both spatially and temporally, there are many sampling protocols that have been developed. Therefore consideration should be taken to choose the one that is the most appropriate for the situation.

Prior to embarking on a sampling program, the questions should be asked – what is the objective of sampling and what is it that one would like to demonstrate? Sampling protocols differ depending on the desired objective (e.g. identifying corrosive water, identifying fixtures and potential sources of lead in a building, and estimating if typically consumed lead concentrations in water meets guidelines). It is important that the selected protocol be appropriate to meet the desired objective.

1.1. EVALUATING IF CENTRALIZED WATER SYSTEM CORROSION CONTROL IS WARRANTED

Depending upon the drinking water supply system and the characteristics of the drinking water produced, it may be necessary to determine whether the drinking water is capable of causing downstream corrosion problems in buildings with leaded plumbing components. Sampling results can be used to make decisions on whether community water system level actions are needed, and to evaluate the effectiveness of corrosion control measures after they are implemented. (See Section 2.1)

1.2. EVALUATING SOURCES OF LEAD WITHIN A BUILDING

Where sources of lead are suspected in buildings, such as schools, child care facilities or other structures, testing should be done to determine if mitigation measures are warranted. This can range from simple screening for potential problems, to comprehensively testing to determine which specific taps/fixtures or other plumbing components within a building are contributors to lead. Results can be used to make decisions on whether building level actions are needed, and to evaluate the effectiveness of control measures after they have been implemented. (See Section 2.2)

1.3. EVALUATING WHETHER LEAD CONCENTRATIONS IN TYPICALLY CONSUMED TAP WATER POSE A HUMAN HEALTH RISK

The health advice and the Maximum Acceptable Concentration (MAC) for lead in the *Guidelines for Canadian Drinking Water Quality* is based on samples representing typical or average concentrations of lead consumed throughout the day, not best or worst case scenarios. To evaluate whether the guideline for lead is being met, typical lead concentrations in drinking water ingested by users (i.e. representative of normal use) need to be determined. This may be done in the context of a building such as a school, a residence, or an entire community. The results can be used to determine what messaging should be delivered to advise of potential health risks, action plans to mitigate the risks, and to determine if mitigation measures are successful after they have been implemented. (See section 2.3)

Once sampling objectives have been determined, careful planning should be done to get meaningful results, and to ensure that the sampling objectives are met.

2.0 SAMPLING PROTOCOLS:

2.1. TO EVALUATE IF CENTRALIZED WATER SYSTEM CORROSION CONTROL IS APPROPRIATE.

The purpose of this type of monitoring program is to identify drinking water supply systems in which corrosion is an issue, to allow decisions to be made as to whether corrective measures at the water supplier level are warranted, and to determine what measures are likely to be the most effective. These programs can also be used to assess the effectiveness of corrosion control programs after their implementation. Results of this type of protocol do not represent typical concentrations of the lead in drinking water ingested by consumers, therefore, results should not be used for the interpretation of health risks, nor whether the Maximum Acceptable Concentration (MAC) in the Guidelines for Canadian Drinking Water Quality (GCDWQ) is being met.

For the evaluation of the risk of corrosion, “Option 1 (two-tier protocol)” from page 4 of Health Canada’s *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* (GCCDWDS) is the preferred protocol. A second option, “Option 2 (lead service line residences)” described in the document can be used as an alternate where the two tier protocol is impractical. A brief overview of the protocol is described below; however, the original document should be referred to for the details.

Investigators will need to determine the number and location of monitoring sites. These sites should include taps within residences. To provide meaningful results, investigators will need to collect between 5 and 100 samples, depending on the size of the drinking water system (i.e., the number of people served). The recommended minimum number of sites to be monitored is shown in Table A. Sampling at individual sites is conducted as follows:

First Tier: Sample to establish whether the community water system has corrosion concerns.

- 6 hour stagnation, then collect 1L of water.
- If more than 10% of the sampled residential sites have a lead concentration greater than the action level of 15 µg/L, go to second tier. Note that this action level is different than the MAC for lead, as this is a measure of corrosion risk, not health risk.

Second Tier: For systems with corrosion concerns, this will provide detailed information about how lead is typically entering the drinking water, and will help plan mitigation measures that most appropriately target the sources found.

- Sampling is conducted at 10% of the sites sampled in Tier 1, specifically, the sites in which the highest lead concentrations were measured.
- Four consecutive 1L samples should be taken at a consumer’s cold drinking water tap after a 6 hour stagnation period. This will provide a detailed profile of the sources of lead from within each building (e.g., the faucet, plumbing (lead in solder, brass and bronze fittings, brass water meters, etc.) and the lead service line.
- Each sample should be analysed separately to determine where the highest lead concentrations come from.

Table A: Suggested minimum number of monitoring sites

System Size (number of people served)	**Number of Sites (annual Monitoring)**	**Number of Sites (reduced annual monitoring)**
>100 000	**100**	**50**
10 001-100 000	**60**	**30**
3 301-10 000	**40**	**20**
501-3 300	**20**	**10**
101-500	**10**	**5**
≤ 100	**5**	**5**

Adapted from USEPA (1991a)

Interpreting Results

Where the sampling program shows more than 10% of the sampled residential sites have a lead concentration greater than the action level of 15 µg/L the water supply system should consider mitigation programs. This may include any or all of those listed in section 4 of this Guideline. It is recommended that water supply systems considering mitigation options initiate the second tier to help pinpoint typical sources of lead (fixtures vs plumbing vs lead service lines), so that the most effective mitigation measures can be planned to target those sources.

2.2. SCREENING FOR AND LOCATING SOURCES OF LEAD WITHIN A NON-RESIDENTIAL BUILDING (INCLUDING SCHOOLS, DAY CARES)

This protocol is designed to locate specific lead sources within a building's plumbing and to help identify where and how to proceed with remedial actions. It provides details that help identify specific cold drinking water outlets that have elevated levels of lead following periods of water stagnation.

This is based on Section A.2.5. of Health Canada's *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* be used in conjunction with a systematic plan for lead sampling. While a brief overview of the sampling protocol is described briefly below, the original Health Canada document should be referred to for details.

2.2.1 - SCREENING FOR LEAD

- Survey and inventory the building to identify all locations in the building where drinking water is likely to be consumed.
- Take a First Draw (FD) 250ml sample from each location after an 8 hour stagnation period.
- In addition to those locations where drinking water is consumed, an additional fully flushed (FF) sample should be taken at a faucet near the water main to be representative of water from the water main.
- If lead concentration exceeds 20 µg/L (lead action level) at any of the monitoring locations, further investigation and remedial action is warranted. This may include short term measures such as flushing programs, and/or long term measures to find and replace source of lead in plumbing (see below).

2.2.2 – LOCATING SPECIFIC SOURCES OF LEAD IN THE PLUMBING FOR REMEDIATION

- To evaluate whether lead may come from other sources within the building, monitoring locations (above) exceeding 20 µg/L (lead action level) a subsequent 250 ml sample should be taken at those locations after an 8 hour stagnation period plus 30 seconds of flushing.
- Alternatively, while it may initially require more samples be taken, it may be more cost efficient for investigators to simply take a second sample at all sampling locations 30 seconds after taking the first sample.
- An analysis of results against plumbing plans for the building can be used to pinpoint sources of lead.

Interpreting Results

A comparison of the results can be used to help determine sources of lead, and to plan corrective actions. For example:

- Where the first samples do not exceed the lead action level – no further action would be required unless other samples in the building exceed the action level.
- Where the first samples exceed the lead action level, and subsequent samples do not, the fixture is the likely source of contamination and mitigation measures targeted at the fixture should be considered.
- Where the first and subsequent samples exceed the lead action level, mitigation measures targeted to the entire building should be considered.

Successful determination of lead sources within buildings is dependent on developing and implementing a systematic sampling plan to ensure meaningful results. Sampling plans should be tailored to specific situations. Ontario's Manual for Operators of Schools, Private Schools and Day Nurseries with Excess Lead in their Drinking Water published by the Ontario Ministry of the Environment and Climate Change provides an excellent resource for school and other buildings to locate the source of problems and mitigate them. This manual guides users through four key steps:

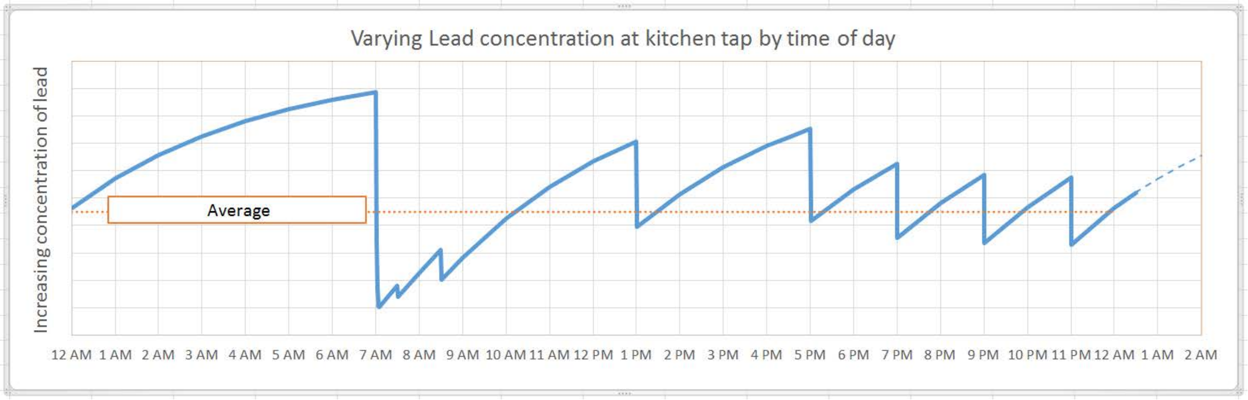
- Assessing plumbing;
- developing a sampling strategy;
- executing the sampling strategy and using the test results to remedy the problem; and
- taking routine, interim and permanent measures.

The manual may describe slightly different sampling protocols and action levels than this document, but its description of the processes for sampling still applies. The general process in this manual could also be applied to non-school settings.

Ideally, schools should be monitored at least once per year with consideration for reductions in the sampling frequency if monitoring shows that the results are acceptable. The BC Ministry of Education may recommend alternative frequencies, however the health authority should be consulted in order to help determine an appropriate health-based sampling frequency based on the data available. In circumstances where Ministry of Education lead sampling policies require testing at a frequency greater than what a DWO would typically recommend, the frequency set by the Ministry of Education's policy should be followed.

2.3 TO EVALUATE HEALTH RISKS:

The Maximum Acceptable Concentration (MAC) published in the *Guidelines for Canadian Drinking Water Quality (GCDWQ)* is intended to apply to the average concentration in the water consumed. This implies that when evaluating health risk, the sampling protocol should be designed to estimate the average or typical exposure to lead in drinking water not the worst possible case scenario. (See conceptual figure A below.)



As water that has remained stagnant in pipes is at highest risk for lead content, it would be expected that concentrations in plumbing will be highest in the morning, and drop over the day with use. Assessing whether or not typical concentrations consumed meet the GCDWQ should therefore be based on sampling at times and places where water is usually consumed, and not a worst or best case scenario.

The following describes specific approaches to estimate typical concentrations in different scenarios, including community risk, and risks with individual dwellings or larger buildings.

2.3.1 EVALUATING HEALTH RISK AT THE COMMUNITY LEVEL:

While it is relatively simple to sample lead concentrations in drinking water as it leaves the treatment plant, it is not representative of what is consumed by users as building plumbing can significantly impact lead content. To establish a typical concentration of lead being consumed by customers, a series of either Random Daytime Samples (RDT) or Thirty Minute Stagnation (30MS) samples should be taken at multiple points of consumption. These samples should be averaged. Details of the pros and cons of each method are discussed in part three of this document.

Sampling plan designs should consider:

- Producing reliable results typically requires 20 or more samples, taken at different consumer locations and at different times of year;
- choosing sampling points from consumer's taps that are balanced between public and private buildings;
- identifying homes with lead service lines for inclusion in the sampling program, as these are likely to have the highest lead concentrations;
- dividing larger distribution networks into neighbourhoods or zones of similar age and evaluating the risk of each community independently may be advisable in some areas; and
- taking samples of the water supplied to the distribution network to establish baselines of the lead concentration of water supplies.

After selection of the taps being sampled, either:

a) For RDT programs, the first 1 litre of water, from each tap is sampled without flushing at random times throughout the day, or

b) for 30MS programs, flush taps for 5 minutes, let stagnate for 30 minutes, then take two consecutive 1-litre samples.

Interpretation

Results should be averaged to determine a typical value for evaluation against the MAC set in the GCDWQ of 10 µg/L. Individual samples that exceed the MAC should not be cause for community concern, however further investigation of the cause might be warranted. Where averaged samples exceed the MAC, the Health Authority should be engaged with the water supplier to further investigate and plan mitigation options.

2.3.2 EVALUATING HEALTH RISKS IN INDIVIDUAL DWELLINGS:

Homeowners, operators of child care facilities in residential settings or occupants of dwellings with older plumbing may wish to investigate whether drinking water from their home meets the requirements of the GCDWQ. This scenario provides a challenge as it is unlikely that a series of samples will be taken and averaged to produce “typical” results. Where only one sample is practical to be taken, a 30MS sample should be done as it is the most reproducible for post mitigation evaluation, and can be done at any time of the day.

Interpretation

Where possible, multiple samples should be taken and averaged, and results evaluated against the MAC of 10 µg/L in the GCDWQ. Where the MAC is exceeded, further investigation should be done to determine the source of lead and/or the mitigation measures that can be implemented.

2.3.3 EVALUATING HEALTH RISKS IN SCHOOLS AND OTHER LARGER BUILDINGS:

The purpose is to determine if water typically consumed by students in schools or occupants/residents of larger buildings are likely to be at levels that exceed the GCDWQ. This may be done after screening (See Section 2.3). If screening does not show exceedance of action levels, further sampling and calculation of the MAC is likely not warranted. As school plumbing tends to be complex in use patterns, age, and variability, there is typically no single sentinel site that can be established for most schools, thereby requiring the sampling of every drinking water location. Large buildings face similar challenges.

A RDT sampling protocol is recommended to capture typical exposures, including potential exposure to particulate lead. This should be conducted by sampling at all drinking water fountains and cold water taps where water is used for drinking or food preparation. Samples should be taken:

- At random times throughout the school day;
- preferably taken between May and September as leaching increases with higher water temperatures; and
- two consecutive 125 mL samples should be collected at each fountain or tap without a stagnation period and without prior flushing. Note: smaller samples are taken as it can provide valuable data for find and fix options if needed at a later date.

Interpreting Results

Results from a sampling program should be calculated by averaging the results from at least two samples and averaging sampling locations within a building. Averages should not exceed the MAC for lead that is set out in the GCDWQ.

Those schools and buildings with indicators of lead problems should undertake further screening and mitigation as per section 2.3 below. Taking two 125ml samples is preferable to taking a 1L sample as it can help determine if the fixture or the plumbing system is the problem by providing valuable data for further investigation and for determining mitigation options.

3.0.0 DEFINITIONS

3.1.1 RANDOM DAYTIME SAMPLING (RDT):

Purpose: To capture typical exposures at residential sites, assess health risk, and set priorities.

A sample is taken at a random time during a working day directly from the tap in a property without previous flushing. The stagnation of water in a distribution system influences the concentration of lead in a random manner. Health Canada recommends taking a 1L samples for sampling programs conducted at the community level. For schools and other large buildings, Health Canada recommends taking two 125ml samples be taken as the data from smaller volumes can provide valuable data for identifying and mitigating problem fixtures and areas within buildings.

RDT sampling is relatively inexpensive and convenient (per sample), but needs to be repeated numerous times to provide confidence in the results. Results are close to typical use when averaged over many samples. RDT sampling is better suited for determining system wide health risks than for individual sites. It requires 2-5 times more samples that 30MS sampling to provide statistically significant results.

3.1.2 THIRTY MINUTE STAGNATION (30MS):

Purpose: To capture typical exposures at residential sites, assess health risk, and set priorities.

A typical 30MS sampling protocol is to flush a tap for 5 minutes, then allow water to stand for 30 minutes. Two consecutive 1L samples are then taken and the results of the two samples are averaged.

30MS samples are more reproducible than RDT samples, and may be the most appropriate for single samples estimating lead risk in individual dwellings. Using two consecutive samples allows the estimation of the relative contribution of the fixture to the lead concentration. 30MS sampling is time consuming and may underestimate typical exposure to lead in drinking water.

3.1.4. FIRST DRAW (FD)

Purpose: To capture the highest levels of lead using long stagnation times.

During the stagnation period no water should be drawn from any outlet within the property (this includes the flushing of toilets). If any water is drawn during the stagnation period the result will be invalid.

- 6-8hr stagnation period then the collection of a 250 mL or 1L sample.

First draw gives the “worst case scenario”. This may also be useful in conjunction with flushed samples to help determine if a specific fixture is contributing lead to the water. This protocol is not appropriate for assessing health risk based on average exposure to lead in drinking water, unless it confirms samples are below thresholds of concern.

3.1.5. FULLY FLUSHED (FF)

Purpose: To determine lead levels in plumbing after complete flushing of the system, or to infer lead levels from water mains.

Samples are taken after prolonged flushing of the tap in a premise in such way that the stagnation of water in the domestic distribution system does not influence the concentration of lead in the drinking water. In practice a sample is taken after flushing at least three plumbing volumes, a prescribed time, or after an observed temperature drop.

While fully flushed samples provide an indication of lead concentrations in systems that are under heavy use, they are not suitable for assessing average exposure to lead in drinking water, as they are likely to underestimate typical lead exposure. Calculating pipe volumes, flow rates and flushing times may be challenging for some larger buildings with complex plumbing systems.

4.0 REFERENCES

Health Canada (2009) Guidance on Controlling Corrosion in Drinking Water Distribution Systems. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No. H128-1/09-595E).

Health Canada (1992) Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Lead Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No. H128-1/09-595E).

Ontario (2009) A Manual for Operators of Schools, Private Schools and Day Nurseries with Excess Lead in their Drinking Water, Queens Printer for Ontario, (Toronto, Ontario)

European Commission, (2009) Guidance on sampling and monitoring for lead in Drinking Water, European Commission Joint Research Centre, Ispra (VA) Italy.

UK Drinking Water Inspectorate, DWI PR14 Guidance – Lead in Drinking Water, 2013.
http://www.dwi.gov.uk/stakeholders/price-review-process/PR14-guidance-lead.pdf

UK Drinking Water Inspectorate, Lead in Drinking Water January 2010,
http://www.dwi.gov.uk/consumers/advice-leaflets/lead.pdf

APPENDIX D: GUIDANCE ON FLUSHING FOR MITIGATION

One option for mitigation of lead risks from drinking water in schools, licensed child care facilities, or other buildings is to implement a flushing program. The intention of flushing is to run the tap water until the water from the water main in the street or the water supply from within the well reaches the taps. This has been shown to significantly reduce lead levels in drinking water at the tap. However, the degree to which flushing helps reduce lead levels in drinking water can vary, depending upon the age and condition of a facility's plumbing and the corrosiveness of the water. Regardless of these limitations, flushing is still the quickest and easiest measure to reduce high lead levels in drinking water, especially when contamination is localized in a small area or in a small building.

CIRCUMSTANCES THAT INDICATE IMPLEMENTING A FLUSHING PROGRAM

Where assessment and/or water sampling of a facility has identified risks for elevated lead in water mitigation actions should be taken. These circumstances include:

- Results of testing for lead in water (see appendix C) exceed the Maximum Acceptable Concentration in the *Guidelines for Canadian Drinking Water Quality or* action levels;
- any part of the plumbing was installed before January 1, 1990 that has not been assessed for lead content, and/or there is no sampling history for the last 24 months;
- it is recommended by the Regional Health Authority.

Mitigation should include implementing a flushing program until permanent measures can be taken to reduce the lead or until testing confirms that lead levels are within acceptable limits. Any additional flushing requirements will be determined by the results of the facility's plumbing profile and risk assessment in consultation with the local Environmental Health Officer.

WHEN TO FLUSH:

- Flushing should be conducted daily when the facility or part of the facility is open.
- Flushing should be completed before the facility opens for the day. Where a facility is open for 24 hours on that day (e.g., a building housing student residences within a school property), flushing should be completed as early in the day as possible.

WHERE AND HOW TO FLUSH:

- First, turn on the cold water for at least five minutes at the last tap on each branch or each run of pipe in the plumbing that serves a drinking water tap that is commonly used to provide water for consumption. In many cases, depending on the plumbing configuration, it may be necessary to flush the plumbing for a longer period of time. The actual amount of time that will be needed depends on the type of tap, diameter of pipes, and its location within the building plumbing (i.e. distance from the water main in the street or the distance to the water supply well). For best results, the volume of the plumbing and the flow rate at the tap should be calculated, and the flushing time should be adjusted accordingly – See **Calculating how long to flush** below.

- Then, turn on the cold water for at least 10 seconds at every drinking water fountain and every tap that is commonly used to provide drinking water for human consumption.
- Additional recommendations for flushing specific types of non-end-of-run outlets include:
    - For drinking water fountains without refrigeration units, the water should run for at least 15 seconds, or until the water is cold.
    - For drinking water fountains with refrigeration units, the water should run for at least 15 minutes. If it is not feasible to flush for such a long time, these outlets should be replaced with lead-free, NSF-approved devices.
    - For all kitchen faucets and other faucets where water may be used for drinking (including bathroom faucets where it is possible to obtain cold water), the water should run for at least 10 seconds or until the water is cold.
- Be careful not to flush too many taps at once. This could dislodge sediments that might create further lead problems, or could reduce pressure in the system below safe levels. If the flow from drinking water outlets is reduced noticeably during flushing, too many taps are probably being turned on at once.

CALCULATING HOW LONG TO FLUSH:

The amount of time it will take to fully flush a building's plumbing will vary depending on the diameter of the water supply pipe and the water flow rate during flushing. Some of the ways to determine how long to flush include:

- Calculating the pipe volume, in litres, between the outlet and the location in the plumbing being flushed using the formula: 3.14 x pipe radius^2 x pipe length (i.e., $\pi r^2 l$);
- measuring the outlet flow rate in litres per minute;
- dividing the pipe volume in litres by the outlet flow rate in litres per minute.

The following table and information from the 2016 Copper Tube Handbook[5] can assist in calculations.

Table B: Pipe Volume (per unit of pipe length) for different diameters of copper pipe

Pipe diameter	Volume of tube (litres per meter of length) Type L Copper
9.53 (3/8)	0.0938
12.70 (1/2)	0.1505
15.88 (5/8)	0.2248
19.05 (3/4)	0.3122
25.40 (1)	0.5323
31.75 (1 ¼)	0.8129
38.10 (1 ½)	1.1520
50.80 (2)	1.9974
63.50 (2 ½)	3.0751
76.20 (3)	4.3943

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[5] Copper Development Association Inc.(2016) *Copper Tube Handbook: Industry Standard Guide for the Design and Installation of Copper Piping Systems*; CDA Publication A4015-14/16, NY

ESTABLISHING DUE DILIGENCE – RECORDING AND REPORTING:

- Keep written records of the date and time of every required flushing and the name of the person who performed the flushing. If auto flushers are used, record the name of the person who verified that the automatic flushing took place. Records for auto flushers need to be completed based on the frequency set out in the manufacturer's instructions or at least once a month if no instructions are available.
- Keep the written record on file and available for review by an Environmental Health Officer.

ADDITIONAL INFORMATION:

- It is not required to flush any tap or drinking water fountain in a part of a building that is not in use by children or staff during the day as well as in private student residences or in a public washroom (e.g., in a shopping mall).
- If a tap or drinking water fountain has an aerator, the aerator should not be removed when flushing.
- If a tap or drinking water fountain has an individual filter or other water treatment device, the filter should be bypassed when flushing if this can be done easily. A filter or treatment device is not required to be bypassed if it would require removing or dismantling the device to do so.
- To save water, thoroughly flush several designated drinking water outlets daily while taking all others temporarily out of service. Collect the water being flushed and use it for non-consumptive purposes.

REFERENCES:

Copper Development Association Inc.(2016) *Copper Tube Handbook: Industry Standard Guide for the Design and Installation of Copper Piping Systems*; CDA Publication A4015-14/16, NY

Ontario Ministry of the Environment and Climate Change (updated June 23, 2016) *Guide for schools, private schools and day nurseries on flushing for lead: A guide on the requirements for flushing and testing drinking water taps in schools, private schools and day nurseries* [Available at: https://www.ontario.ca/page/guide-schools-private-schools-and-day-nurseries-flushing-and-testing-lead]

Ontario Ministry of the Environment (2009) *A Manual for Operators of Schools, Private Schools and Day Nurseries with Excess Lead in their Drinking Water: A resource guide on how to locate the source and remedy the problem* [Available at: https://www.ontario.ca/document/manual-operators-schools-private-schools-and-day-nurseries-excess-lead-their-drinking-water]

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Copper in Drinking Water

Guideline Technical Document for Public Consultation

Prepared by the Federal-Provincial-Territorial
Committee on Drinking Water

Consultation period ends
May 25, 2018

Canada

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March 2018

Copper in Drinking Water

Purpose of consultation

The Federal-Provincial-Territorial Committee on Drinking Water (CDW) has assessed the available information on copper with the intent of updating the current drinking water guideline and guideline technical document on copper in drinking water. The purpose of this consultation is to solicit comments on the proposed guideline, on the approach used for its development and on the potential economic costs of implementing it, as well as to determine the availability of additional exposure data.

The existing guideline on copper, last updated in 1992, established an aesthetic objective of ≤1.0 mg/L, to ensure palatability and to minimize staining of laundry and plumbing fixtures. This new updated document proposes a health-based maximum acceptable concentration (MAC) of 2 mg/L for copper in drinking water. The proposed MAC is considered to be protective of both short-term effects (i.e., gastro-intestinal effects) as well as longer-term effects (including potential effects in the liver and kidneys). The document is based on currently available scientific studies and approaches, taking into consideration the mode of action. It provides exposure information as well as sampling considerations, analytical methods and treatment technologies for copper in drinking water. The document also proposes an aesthetic objective (AO) of 1 mg/L, based on taste and staining considerations.

The CDW has requested that the guideline technical document on copper in drinking water be made available to the public and open for comment. Comments are appreciated, with accompanying rationale, where required. Comments can be sent to the CDW Secretariat via email at water_eau@hc-sc.gc.ca. If this is not feasible, comments may be sent by mail to the CDW Secretariat, Water and Air Quality Bureau, Health Canada, 3rd Floor, 269 Laurier Avenue West, A.L. 4903D, Ottawa, Ontario K1A 0K9. All comments must be received before May 25, 2018.

Comments received as part of this consultation will be shared with the appropriate CDW member, along with the name and affiliation of their author. Authors who do not want their name and affiliation shared with their CDW member should provide a statement to this effect along with their comments.

It should be noted that this guideline technical document on copper in drinking water will be revised following evaluation of comments received, and a drinking water guideline will be established, if required. This document should be considered as a draft for comment only.

March 2018

Copper

Part I. Overview and Application

1.0 Proposed guideline

A maximum acceptable concentration (MAC) of 2 mg/L (2000 µg/L) is proposed for total copper in drinking water, based on a sample of water taken at the tap. An aesthetic objective (AO) of 1 mg/L (1000 µg/L) is also proposed for total copper in drinking water.

2.0 Executive summary

Copper is present in tap water principally as a result of leaching from copper-containing components of distribution and plumbing systems. Copper has been, and continues to be, broadly used in drinking water applications, including in household pipes and in fittings.

This guideline technical document reviews and assesses all identified health risks associated with copper in drinking water. It assesses new studies and approaches and takes into consideration the availability of appropriate treatment technology in order to propose a maximum acceptable concentration that is protective of human health, measurable and achievable by both municipal and residential scale treatment technologies. Based on this review, the proposed guidelines for copper in drinking water are a maximum acceptable concentration of 2 mg/L (2000 µg/L) and an aesthetic objective of 1 mg/L (1000 µg/L).

During its fall 2016 meeting, the Federal-Provincial-Territorial Committee on Drinking Water reviewed the guideline technical document on copper and gave approval for this document to undergo public consultation.

2.1 Health effects

Copper is an essential element in humans. Copper deficiency may cause several health effects, but is not expected to be a concern in Canada, based on copper intake from food. The U.S. National Academy of Medicine (formerly called the Institute of Medicine) has established recommended daily allowances of 900 µg/day for adults and 340–890 µg/day for children, as well as tolerable upper intake levels of 10,000 µg/day for adults, and between 1,000 and 8,000 µg/day for children.

International agencies have determined that the data available on copper are not sufficient to classify it with respect to carcinogenicity. Short-term exposure to copper may result in effects in the gastrointestinal tract (nausea, pain and vomiting, diarrhea). Long-term effects are less well documented; current evidence indicates that, in the general population, chronic exposure to very high levels of copper may lead to effects in the liver and kidney. The proposed MAC was developed based on bottle-fed infants (aged 0 to 6 months) and is considered to be protective of all health effects, both short-term and longer-term.

2.2 Aesthetic considerations

The presence of copper can affect the taste of the water and cause the staining of laundry and plumbing fixtures at levels below the proposed MAC. Although there are no adverse effects associated with such levels, they will affect the acceptability of the water by consumers.

Although the proposed AO for copper in drinking water is 1 mg/L (1000 µg/L), some individuals can readily perceive copper at levels below the AO. Nevertheless, corrosion control practices should target the MAC and not the elimination of aesthetic concerns as this could jeopardize other water quality priorities such as lead control. Utilities may choose to use the AO to trigger a site-specific or localised water quality/corrosion investigation.

2.3 Exposure

Copper occurs naturally in the Earth's crust, either in mineral deposits or, less frequently, as a metal. Copper can enter water sources from natural processes, such as soil weathering, and human activities such as agriculture, mining and manufacturing. The National Plumbing Code of Canada considers copper to be an acceptable material for service lines and plumbing systems. Consequently, copper in drinking water can also result from the corrosion of copper-containing pipes and fittings in distribution and plumbing systems, depending on the chemistry of the water.

Canadians can be exposed to copper through food, drinking water, air, soil and consumer products. Although the most significant source of copper intake is food for the general population, the bioavailability of copper in drinking water may be greater than that in food. Based on the physical and chemical properties of copper, inhalation and dermal absorption of copper are not expected from exposure to drinking water.

2.4 Analysis and treatment

The establishment of a drinking water guideline must take into consideration the ability to measure the contaminant. There are several methods available for the analysis of total copper in drinking water. Based on the capacity of commercial laboratories in Canada, analytical methods are available to reliably measure total copper in drinking water below the proposed MAC. These methods should include sample preparation to ensure that they are able to detect both dissolved and particulate copper.

Copper levels in source water are typically very low. Although there are treatment technologies that can remove copper efficiently at the treatment plant, municipal treatment is not generally an effective strategy. This is because copper is an acceptable material for service lines and plumbing systems. However, in certain water qualities, copper may be released into drinking water from pipes, service lines and brass fittings. The treatment approach for copper is generally focused on corrosion control through approaches such as water quality adjustments and the use of corrosion inhibitors.

As the primary source of copper in drinking water is the leaching from plumbing and distribution system components, drinking water treatment devices offer an effective option at the residential level, although their use should not be considered to be a permanent solution. There are a number of certified residential treatment devices available that can remove copper from drinking water to below the proposed MAC.

3.0 Application of the guideline

Note: Specific guidance related to the implementation of drinking water guidelines should be obtained from the appropriate drinking water authority in the affected jurisdiction.

The proposed MAC for copper is established to be protective of both short-term gastrointestinal effects and longer-term effects in bottle fed infants as well as in the general population. Considering that copper levels at the consumer's tap may be significantly higher than levels at the treatment plant or in the distribution system, strategies to reduce exposure to copper will need to focus on controlling corrosion within the distribution and plumbing systems. The water quality factors that have the greatest effect on copper corrosion are pH and alkalinity. Dissolved oxygen and/or chlorine residual/oxidants are also important considerations for copper. Copper monitoring should focus on areas known or likely to have new copper piping and where water quality conditions are potentially corrosive (e.g., low pH, dead ends, low or high alkalinity waters) and in consecutive systems.

An exceedance of the proposed MAC should be investigated and followed by the appropriate corrective actions to reduce the copper levels below the MAC. These actions include, but are not limited to, resampling, public education and corrosion control measures. However, these actions should be based on an assessment of the cause of the exceedance using appropriate protocols, such as those found in *Guidance on Controlling Corrosion in Drinking Water Distribution Systems*.

3.1 Monitoring

Sampling protocols will differ, depending on the desired objective (i.e., identifying sources of copper, controlling corrosion, assessing compliance, estimating exposure to copper). As monitoring of copper at the tap can be done using different sampling protocols, it is important that the selected protocol be appropriate to meet the desired objective. It is important to note that although the analysis of metals can be undertaken from the same sample bottle, sample sites for copper and lead differ. As such, copper results from lead sampling sites are unlikely to properly identify areas with copper issues.

The objective of sampling protocols in this document is to monitor for typical community exposure to total copper to determine whether there are concerns about human health effects. Compliance monitoring should be conducted at the consumer’s tap and focus on areas known or likely to have new copper pipe installations and should include areas or zones (geographical areas within which the quality of drinking water is considered approximately uniform) supplied by potentially corrosive water (e.g., low pH, low or high alkalinity). Specifically, priority should be given to sites known to have new copper plumbing or when the water supply has a pH < 7, with or without disinfection or oxidation processes and alkalinity < 25 mg $CaCO_3$/L, or pH >7 and alkalinity >200 mg $CaCO_3$/L with disinfection or oxidation processes, regardless of the age of copper.

The addition of corrosion inhibitors can prevent the formation of stable malachite scales or displace sorbed oxyanions (e.g., copper) from distribution system piping. A water system using orthophosphate treatment for corrosion control having a PO_4 residual less than 3.3 mg PO_4/L, should also monitor for copper. Daycare facilities should also be prioritized for monitoring to ensure that the most sensitive population (i.e., infants) is captured. Sampling should be conducted at least once per year, with the number of sites to be monitored determined based on the size of the drinking water system and the type of building.The frequency may be reduced if no failures have occurred in a defined period as determined by the regulator, or if water quality conditions are not corrosive to copper.

Part II. Science and Technical Considerations

4.0 Identity, use and sources in the environment

4.1 Chemical and physical properties

Copper (Cu, CAS Registry No.7440-50-8) is a transition element that naturally occurs in four oxidation states: elemental copper metal (Cu(0) or Cu^0), cuprous (monovalent)ion (Cu(I) or Cu^+), cupric (divalent)ion (Cu(II) or Cu^{2+}) and rarely trivalent copper ion (Cu(III) or Cu^{3+}). Copper has two stable (^{63}Cu and ^{65}Cu) and 27 less stable-isotopes (Turnlund et al., 1998; Riedel, 2008; EFSA, 2015). Copper metal has a reddish-brown color, an atomic mass of 63.55 Da, a density of 8.92 g/cm^3 and a vaporization point of 2350°C (Georgopoulos et al., 2001; Kiaune and Singhasemanon, 2011; Ellingsen et al., 2015). In the sections below, “total copper” will be used when referring to all of the major oxidation states. However, “copper” will be used when referring to both Cu(I) and Cu(II), which cycle from one to the other (see section 9.1), are soluble, bioavailable, and considered the most relevant from a toxicological standpoint (see sections 4.3, 8 and 9.3); otherwise, the specific form will be used.

4.2 Sources and uses

With an average concentration of 50 ppm in the Earth’s crust, copper occurs in several primary mineral deposits, mostly as sulphide ores (the most abundant being chalcopyrite, and chalcocite) and less frequently in its metallic form (CCME, 1999; Mauceri and Mishra, 2014). In general, weathering of these primary mineral deposits liberates secondary forms of copper including copper carbonate ores (e.g., malachite and azurite) and copper oxide ores (e.g., cuprite) (CCME, 1999; ATSDR, 2004; Ellingsen et al., 2007; Riedel, 2008; Mauceri and Mishra, 2014). In addition, anthropogenic activities like mining, municipal and industrial wastes management, agriculture (e.g., pesticides), and water treatment (e.g., copper sulphate pentahydrate in algaecides) can generate localized copper deposits and increase levels in the neighborhood (ATSDR, 2004; Mauceri and Mishra, 2014). Thus, copper can enter water sources from natural processes (e.g., soil weathering), human activities (e.g., agricultural runoffs), or from the corrosion of pipes/fittings in water distribution systems; the latter depends on water chemistry (e.g., low pH, high temperature, reduced hardness) (WHO, 1998; NRC, 2000; Ellingsen et al., 2007).

In Canada, the mining industry has produced 580,082; 652,595 and 695,513 tonnes of total copper in 2012, 2013 and 2014, respectively (British Geological Survey, 2016). Owing to its malleability, conductivity, alloying potential and resistance to corrosion and wear, copper metal is used in many products, such as pipes, paint pigments, antifouling agents, refinery oils, and in construction materials such as flashing electronic components, tubes, sheets, and rods for roofing (ATSDR, 2004; WHO, 2011; Stewart et al., 2012; Gaetke et al., 2014; Ellingsen et al., 2015). As a component of bronze and brass, it is used in marine equipment, cooking utensils, coins, to name a few. Copper nanoparticles are increasing in use for example in antimicrobial products such as biomedical and surgical devices (Ingle et al., 2014), or in copper nanowires (Yang et al., 2014). In addition, total copper is used by the health industry as a component of birth control pills, intrauterine devices (IUDs), dental amalgam, anti-microbial/bacterial agents, vitamin and mineral supplements, and by the food industry as a colouring agent (Barceloux, 1999; Grass et al., 2011; Park et al., 2012; Stewart et al., 2012; Shaligram and Campbell, 2013). Finally, copper is used as an active ingredient in pesticides (fungicides, algaecides, and antimicrobials). There are currently nine copper compounds (e.g., cuprous oxide, copper sulphate, copper carbonate) registered as pesticides, for use in combination with other active ingredients, in Canada (Health Canada, 2009a).

Copper is present in tap water principally as a result of dissolution or leaching (i.e., corrosion) from components of distribution and plumbing systems that contain copper, particularly from the extensive use of copper pipes in household plumbing. In addition, fittings or service connections to homes and brass fittings may also represent a source of copper (Schock and Neff, 1988; Kimbrough, 2001, 2007, 2009). Copper leaching will vary with the types of alloys used and the manufacturing and fabrication processes (Lytle and Schock, 1996, 2000; Oliphant and Schock, 1996; Dudi et al., 2005). Several factors can influence copper corrosion, including the age of the piping and the water quality characteristics in the system. These factors are discussed in greater detail in section 7.2.

Copper release may result in blue water, which can stain bathroom fixtures and hair and may be caused by the presence of particulate copper. It is more difficult to determine the cause of particulate copper corrosion, but it is thought to primarily be the result of microbiological, chemical, or physical factors, or some combination of factors that also result in pitting corrosion and/or pipe failure (Edwards et al. 2000; Bremer et al. 2001; Arnold et al., 2012). The most significant home plumbing failures that occur as a result of internal corrosion are copper pitting and pinhole leaks. Pitting corrosion is not a well understood cause of copper release, but it can cause significant damage to copper plumbing, leading to leaks that can also cause substantial damage to homes and result in mould growth (Scardina et al., 2008). Pitting can occur relatively rapidly (a few months to years) after installation in cold water plumbing; whereas pitting generally takes many years (typically more than 8 years) to perforate pipe walls in hot water systems (Ferguson et al., 1996).

4.3 Environmental fate

In the environment, copper metal and Cu (I) are unstable. Conversely, Cu(II) is more stable and the most abundant and frequently encountered species in the environment, including water and biological systems (Georgopoulos et al., 2001; Ellingsen et al., 2007; Riedel, 2008; Shike, 2009; Kiaune and Singhasemanon, 2011; Omur-Ozbek and Dietrich, 2011; Gaetke et al., 2014; Ellingsen et al., 2015). Hence, in general, surface oxidation leads to copper(I) oxide or hydroxide; but, due to its instability, Cu(I) is frequently oxidized to Cu(II) (WHO, 2004). Cu(II) is subject to redox reactions and tends to be hydrated. The hydrated Cu(II) ion rarely occurs free, but usually adsorbs to particulate matter or a variety of dissolved (inorganic and organic) compounds such as hydrated metal oxides (including those of iron, aluminium and manganese), polyvalent organic anions and humic acids (WHO, 1996, 2004; IPCS, 1998).

In the air, copper is mainly removed from the atmosphere by wet deposition (rain and snow), followed by gravitational settling and dry deposition (Kieber et al., 2004; WHO, 2004). In soil, copper strongly adsorbs to particles and has low mobility, with greatest retention at neutral pH (Health Canada, 2009a). Applied copper usually persists in topsoil, accumulating in upper layers (≈15 cm) (CCME, 1999; Kiaune and Singhasemanon, 2011). Its fate and availability in soils depend on many soil features: soil types (high mobility in sand vs. clays), pH (acidity and high reductive capacity favor release from oxide complexes), cation exchange capacity, water content, organic/inorganic matter content, redox potential, and the presence of oxides (e.g., of iron, manganese, aluminum) and clay (IPCS, 1998; Kiaune and Singhasemanon, 2011). Also, copper does not bioaccumulate, hydrolyze or breakdown in soil (Health Canada, 2009a).

In water, copper speciation is complex and influenced by many factors such as water source (e.g., Cu(II) is less bioavailable in hard water than in soft water), water chemistry (i.e., alkalinity, ionic strength, dissolved oxygen, pH and redox potential), sediments-water clays interaction (pH-dependent), presence of complexing (inorganic and organic) ligands and suspended particulate matter and carbon (WHO, 2004; Cuppett et al., 2006; Kiaune and Singhasemanon, 2011). The formation of Cu(I) and Cu(II)complexes can impact the solubility, color, and taste of water. Thus, when dissolved, Cu(I) is colourless while most Cu(II)-compounds impart a light blue-green colour and a metallic, bitter taste to drinking water (Georgopoulos et al., 2001; Cuppett et al., 2006; Omur-Ozbek and Dietrich, 2011). In raw water, copper primarily occurs as complexed Cu(II) and to a lesser extent as precipitated Cu(II) particles (Cu(II)-particulate matter), assuming typical pH values and oxidation-reduction potentials (Lide, 1993). The primary copper-complexing ligands are dissolved molecules such as organic (e.g., dissolved organic carbon or matter) and inorganic species. On one hand, copper-organic complexes and copper-particulate matter compounds usually precipitate, rendering them non-bioavailable (Kiaune and Singhasemanon, 2011). On the other hand, inorganic ligands commonly form Cu(II) and Cu(I) complexes, alongside the ubiquitous copper hydroxo complexes; the latter, however, mostly precipitate (commonly at pH 6.5–12) as copper hydroxide (Cuppett et al., 2006). Thus the further dissolution of the remaining copper complexes and the relative stability of Cu(II) as compared to Cu(I) makes free Cu(II) the most prevalent species in drinking water (Cuppett et al., 2006; Kiaune and Singhasemanon, 2011; Omur-Ozbek and Dietrich, 2011). Therefore, the main focus of this document will be on dissolved copper.

4.4 Aesthetic characteristics

Copper in water can be detected through taste or visual inspection (i.e., colouration). Taste thresholds for copper have ranged from 0.0035 to > 5 mg/L (Zacarias et al., 2001; Omur-Ozbek and Dietrich, 2011) and 0.4–0.8 mg/L (Cuppett et al., 2006); reported taste threshold values vary significantly due to different sensory test methods used, the concentrations of the metal tested, the type of water used, and the type of data analysis performed. The aesthetic properties of copper are affected by solubility, with soluble copper being more readily tasted than the particulate form (Cuppett et al., 2006). However, both Cu(I) and Cu(II) ions are equally detectable producing a weak bitter and salty taste and an astringent mouth feel (Omur-Ozbek and Dietrich, 2011). Omur-Ozbek and Dietrich (2011) estimated that 79% of the population would be able to taste copper at a concentration of 2 mg/L, while 72% would be able to taste it at 1 mg/L. The visual detection of copper in water is a function of light path through the water, deposited particles and the concentration of copper in water (Edwards et al., 2000). For example, 0.3 mg/L would be visible in a white bathtub at a distance of approximately 460 mm (18 inches) (typical observation distance), but 3 mg/L of copper would need to be present for the copper particulate to be noticeable in a glass of water.

5.0 Exposure

Canadians can be exposed to total copper via food, drinking water, air, soil and consumer products. For the general population, food is the major source of exposure (more than 90% of dietary intake), followed by drinking water (less than 10% of dietary intake) and copper-containing supplements (WHO, 2004; Sadhra et al., 2007; Cockell et al., 2008; de Romana et al., 2011; Shaligram and Campbell, 2013; Mauceri and Mishra, 2014; EFSA, 2015). However, drinking water can be a significant source of exposure if distributed through corroded pipes, especially in the case of infants fed formula (fortified, non-soy-based) reconstituted with water from such sources (Cockell et al., 2008; Chambers et al., 2010). Copper speciation in water differs from that in food (NRC, 2000) and this can influence its solubility and bioavailability. In fact, in food, copper is covalently bound to macromolecules (IOM, 2001; OEHHA, 2008; Ceko et al., 2014). In contrast, copper occurs free or complexed with ligands in drinking water. Thus, copper in drinking water can readily reach the bloodstream, bypassing the liver processing. Consequently, the bioavailability of copper in drinking water ingested in a fasted state is considered greater than that in food (OEHHA, 2008; Mauceri and Mishra, 2014; Ellingsen et al., 2015).

5.1 Food

The Canadian Total Diet Study (TDS) is a Health Canada initiative that measures the dietary concentrations of different chemicals in food and uses these data to estimate dietary intakes for different age–sex groups of the Canadian population (Health Canada, 2009b). Based on the TDS, the average intakes of dietary copper were estimated between 1993 and 2007 for Canadians of all age groups in 7 cities (Montreal, Ottawa, St John’s, Vancouver, Winnipeg, Toronto, and Halifax). These estimates (µg/kg bodyweight [bw] per day) were 40–91 for 0–6 months old, 36–57 for 6 months–4 years old, 36–48 for 5–11 years old, 19–35 for 12–19 years old, and 13–32 for 20 years old and above. Based on copper intake for male and female 20+ years of age, an adult Canadian weighing 70 kg would have a dietary exposure to copper of 910–2,240 µg/day.

Based on the data collected as part of the TDS conducted between 1993 and 2007, copper concentrations in common food items vary in Canada, with the highest concentrations being food in organ meats (offal) such as liver and kidney. Lower copper levels are found in milk (25–70 µg/kg) , while infant milk formulas have concentrations of 650–850 µg/L, and human breast milk was reported to have 200–300 µg/L (Lonnerdal, 1998; Bauerly et al., 2005). The World Health Organization (WHO) and the Food and Agricultural Organization (FAO) recommended a minimum of 35 µg Cu/100 kcal formula (liquid or powder) intended to be marketed in order to comply with normal nutritional requirements of infants. They also acknowledged that levels adjustment may be needed in regions with high copper levels (FAO and WHO, 2011).

Even if the copper content of human breast milk is lower than that of formula, this form of copper is highly bioavailable (Lonnerdal, 1996, 1998; Bauerly et al., 2005). In contrast, phytates (zinc and copper chelators found at high levels in soy-based infant formula) and soy proteins in infant formula reduce copper bioavailability (Gibson, 1994; NRC, 2000; IOM, 2001; WHO, 2004; EFSA, 2006, 2009; Stern et al., 2007; OEHHA, 2008; Collins and Klevay, 2011).

5.2 Water

Exposure to copper in drinking water can be properly assessed only by monitoring copper levels at the tap. This is because copper is present in tap water principally as a result of dissolution (corrosion) from components of distribution and household plumbing systems that contain copper. However, the concentration of copper is less variable both across a system and within an individual site (Kirmeyer et al., 1994; Schock et al., 1995), making the assessment of copper exposure from drinking water much less challenging than for lead. Monitoring of copper at the tap can be done using different sampling protocols; the selection of an appropriate protocol must take into consideration the desired objective, such as identifying sources of copper, effectively controlling corrosion or estimating exposure to copper.

5.2.1 Canadian exposure to copper from drinking water

Generally, across the provinces and territories, median copper levels at the tap were low (below 1 mg/L); however there are cases where high levels of copper release have been observed.

In Prince Edward Island, dissolved copper (filtered through a 0.45 µm filter prior to sample preservation) was measured in ground water, municipal central water supply plants, private central water systems, and private wells and stand-alone system. Data from 2013–2015 were analyzed. For municipal central water supply plants, 48% of samples were below the detection limit (0.005 mg/L), and for the samples above the detection limit (n=117), the median dissolved copper level was 0.03 mg/L, with a maximum reported value of 0.9 mg/L. For municipal central water supplies, the 95th percentile was 0.12 mg/L, and the 97th percentile was 0.19 mg/L. In private central water systems, 67% of samples were below the detection limit, and for those samples above the detection limit (n=13), the median dissolved copper level was 0.013 mg/L, with a maximum reported value of 0.044 mg/L. For private wells, and stand-alone systems, 27% of samples were below the detection limit, and for those samples above the detection limit (n=2798), the median dissolved copper level was 0.017 mg/L, with a maximum reported value of 1.8 mg/L

In Newfoundland, for the 62 source water samples taken in 2013–2014, all were found to be above the detection limit, and the median total copper level was 0.0020 mg/L, with a range of 0.001–0.073 mg/L. For source water samples, the 95th percentile was 0.031 mg/L, and the 97th percentile was 0.033 mg/L. For the 1968 tap water samples reported from 2013–2014, 97% were above the detection limit. For the tap water samples above the detection limit (n=1905), the median total copper level was 0.035 mg/L, with a range of 0.001–2.5 mg/L. For tap water samples, the 95th percentile was 0.4 mg/L and the 97th percentile was 0.49 mg/L.

In Nova Scotia, for the 845 municipal treated water samples reported from 2005-2012, 73% of the total copper were above the detection limit of 0.002 mg/L. For the treated water samples above the detection limit, the median total copper level was 0.014 mg/L, with a range of 0.002–0.490 mg/L. The treated water samples 95th percentile was 0.12 mg/L, and the 97th percentile was 0.17 mg/L.

In New Brunswick, for copper samples from 2010–2015 the detection limit ranged from 0.000026 mg/L to 0.0004 mg/L. Samples are prepared by nitric acid preservation, and analyzed for dissolved plus dilute acid labile trace copper, which is approximate to a total copper sample. For raw water, 71% of total copper samples were below the detection limit; for samples above the detection limit (n=367) the median copper level was 0.006 mg/L with a maximum of 8.3 mg/L. For water treatment plant samples, all the total copper samples were above the detection limit (n=17), with a median of 0.029 mg/L and a maximum of 0.11 mg/L. For water treatment plant samples, the 95th percentile was 0.083 mg/L, and the 97th percentile was 0.094 mg/L. For the distribution system samples, 20% were below the detection limit; for samples above the detection limit (n=1129), the median copper level was 0.021 mg/L with a maximum of 3.1 mg/L. For distribution system samples, the 95th percentile was 0. 48 mg/L, and the 97th percentile was 0.63 mg/L.

In Quebec, copper sampling is conducted at the tap following a five minute flush. Of the 17,863 reported total copper samples from 2012–2015, 12.5% were below the detection limit (0.001–0.01 mg/L), and 119 samples (0.7%) exceeded 1.0 mg/L. The median total copper concentration was 0.028 mg/L, and the maximum value detected was 15 mg/L.

In Manitoba, total copper samples from 2009–2015 were analysed, and the detection limit was reported as 0.001 mg/L. For raw water, 6% of samples were below the detection limit, and for those samples above the detection limit (n=969), the median copper level was 0.003 mg/L, with a maximum of 0.94 mg/L. For raw water samples, the total copper 95th percentile was 0.03 mg/L, and the 97th percentile was 0.05 mg/L. For distributed water, all of the samples were above the detection limit, and the median copper level was 0.016 mg/L with a maximum reported level of 0.193 mg/L and minimum reported level of 0.002 mg/L (n=9). For distributed water samples, the 95th percentile was 0.133 mg/L, and the 97th percentile was 0.157 mg/L. For treated drinking water, 2% of the samples were below the detection limit, and for those samples above the detection limit (n=1026), the median copper level was 0.009 mg/L with a maximum of 0.8 mg/L. For treated water samples, the 95th percentile was 0.12 mg/L, and the 97th percentile was 0.19 mg/L. For untreated drinking water, 6% of the total copper samples were below the detection limit, and for those samples above the detection limit (n=165) the median copper level was 0.005 mg/L with a maximum of 0.62 mg/L. For disinfected drinking water samples, the 95th percentile was 0.08 mg/L, and the 97th percentile was 0.13 mg/L.

In Saskatchewan, of the 2423 total copper samples taken from distribution sites in 2005–2015, 90% were above the detection limit, with a median of 0.012 mg/L, and a range of 0.002–3.9 mg/L. The 95th percentile was 0.12 mg/L and the 97th percentile was 0.18 mg/L.

In Alberta, for dissolved copper samples from 2010-2015 the detection limit ranged from 0.002–0.003 mg/L. For raw water/entering the water treatment plant samples 43% were below the detection limit, and the median copper level was 0.005 mg/L with a maximum of 0.025 mg/L for those samples above the detection limit (n=131). For samples taken exiting the water treatment plant, 94% were below the detection limit, and the median copper level was 0.003 mg/L with a maximum of 0.17 mg/L for those samples above the detection limit (n=9). For water leaving the treatment plant, the 95th percentile was 0.105 mg/L, and the 97th percentile was 0.131 mg/L. For distribution system samples, 82% of samples were below the detection limit, and the median copper level was 0.004 mg/L, with a maximum of 0.147 mg/L for those samples above the detection limit (n=50). For distribution system samples, the 95th percentile was 0.047 mg/L, and the 97th percentile was 0.096 mg/L.

In British Columbia, for total copper samples from 2010–2015, 11% were below the detection limit (0.0002–0.005 mg/L). For those samples above the detection limit (n=473), the median copper level was 0.0077 mg/L, with a maximum reported value of 0.549 mg/L. The 95th percentile was 0.0824 mg/L, and the 97th percentile was 0.13 mg/L.

In the Yukon, samples from 2012–2015 taken from 20 communities were examined, and 19% of raw water and 10% of treated water total copper samples were below the detection limit (0.001–0.002 mg/L). For raw water samples above the detection limit (n=51), the median total copper level was 0.0029 mg/L, with a maximum reported value of 0.13 mg/L. For raw water samples, the total copper 95th percentile was 0.054 mg/L, and the 97th percentile was 0.09 mg/L. For treated water samples above the detection limit (n=26), the median total copper level was 0.003 mg/L, with a maximum reported value of 0.0712 mg/L. For treated water samples, the total copper 95th percentile was 0.067 mg/L, and the 97th percentile was 0.07 mg/L.

High Canadian household tap water copper levels have also been documented in the literature. In a 1985 study found that 50% of rural Nova Scotia homes had copper levels exceeding 1 mg/L. The 55 homes surveyed were all served by private wells in three different areas of bedrock (granite, quartzite, and limestone). The authors did not find the Langelier, Ryznar, or Aggressiveness indexes, chloride to sulphate mass ratio (CSMR), alkalinity, or pH to be good predictors of corrosion. They also noted that from house to house, there was a large degree of variation of metal (copper, lead, zinc) mobilization (Maessen et al., 1985).

5.2.2 Sampling to assess copper exposure from drinking water

Sampling protocols will differ, depending on the desired objective (i.e., identifying sources of copper, controlling corrosion, assessing compliance, estimating exposure to copper). As monitoring of copper at the tap can be done using different sampling protocols, it is important that the selected protocol be appropriate to meet the desired objective. Monitoring for typical exposure to total copper should be conducted at the consumer's tap, with priority given to identifying homes with new copper plumbing or supplied with water having low or unstable pH or situated near dead ends, as these are likely to have the highest copper concentrations. Daycare facilities should also be prioritized for monitoring, to ensure that the most sensitive population (i.e., bottle-fed infants) is captured. Sampling should be conducted at least once per year, with the number of sites to be monitored determined based on the size of the drinking water system and the water quality characteristics.

5.3 Air

The Canadian National Air Pollution Surveillance Program reported copper concentrations in fine ($PM_{2.5}$) particulates in 2014 (Environment Canada, 2014). 75.2% of samples exceeded the detection limit of 0.28–0.85 ng/m^3, 14 samples were above 50 ng/m^3 and 7 were above 100 ng/m^3. The mean was 3.4 ng/m^3, the median was 1.2 ng/m^3, the 75th percentile was 2.4 ng/m^3, and the maximum was 430.3 ng/m^3. Similar results were observed in a Health Canada study of indoor and outdoor air (n=3,000 sites in Edmonton, Halifax, Ottawa, Sault-Saint-Marie, and Windsor), where average concentrations of 2.9 ng/m^3 and medians < 2 ng/m^3 were reported (Health Canada, 2015). Indoor airborne copper concentrations of 8.2 ng/m^3 (range of 3.8–17.8) and 11.4 ng/m^3 (range of 3.9–56.9) were reported in10 Canadian rural and urban homes ($PM_{2.5}$ filter), respectively (Rasmussen et al., 2006). Copper was shown to be mainly associated with the organic phase of house dust, increasing its bioavailability (Rasmussen et al., 2008). Based on these low concentrations of copper in ambient air, intake from air would be negligible compared with that from other media.

5.4 Consumer products

Canadian quantitative estimates of total copper exposure from consumer products are rather scarce. However, copper compounds, e.g., copper(II) acetate, carbonate, chloride, sulfate, are part of various medicinal products available in Canada, and can be consumed in oral natural therapy formulae at maximum doses of 0.7 mg/day for children 1–3 years of age, up to 8 mg/day for adults ≥ 19 years of age (Health Canada, 2007). The use of copper IUDs may also result in daily exposure of about 80 µg copper and less, with decreasing levels after the first few weeks from insertion (IPCS, 1998; Gaetke et al., 2014; Ellingsen et al., 2015). Although amalgams have been pointed out as a source of copper, exposure from this source is considered minimal (IPCS, 1998).

5.5 Soil

Copper distribution in rocks and soil varies as a reflection of the mineralogy of parent material and proximity to anthropogenic sources. Total copper mean concentration in Canada was estimated at 20 mg/kg soil (range: 2–100 mg/kg), with lower levels in the Canadian Shield (11 mg/kg) and higher levels in the Cordilleran region (46 mg/kg) (CCME, 1999). Levels of 41–65 mg/kg were reported in Ontario parklands, 25 mg/kg in western Manitoba, and 17–19 mg/kg in rural Alberta. Street dusts in Halifax had levels of 87 mg/kg. Copper was measured in garden soil (geometric mean [GM]: 12.3 mg/kg; 95th percentile: 19.4 mg/kg), house dust (GM: 170.7 mg/kg; 95th percentile: 489.0 mg/kg), and street dust (GM: 38.1 mg/kg; 95th percentile: 236.2 mg/kg) from 50, 48 and 45 residences in Ottawa, respectively (Rasmussen et al., 2001). Copper is used as a dietary supplement for farmed animals (Nicholson et al., 1999; Xiong et al., 2010) with some of the copper absorbed by the animal and the remainder excreted. The concentration of copper in manure has been reported in a study in China as 699.6 mg Cu/kg (pigs); 31.8 mg Cu/kg (cattle); 81.8 mg Cu/kg (chickens) and; 66.85 mg Cu/kg (sheep). In a study in England and Wales, 360 mg Cu/kg was found in pig manure, 80 mg Cu/kg in poultry manure and 50 mg Cu/kg in cattle manure. In a Canadian study examining run-off from manure compost windrows (containing a mixture of cattle manure and barley straw), the copper concentration in the compost ranged from 49 to 55 mg Cu/kg (Larney et al., 2014). Run-off from the manure was measured periodically over a 224 day period. On day 18 (first measurement), the copper concentration ranged from 0.3 to 0.62 mg/L. The copper concentration in run-off peaked at 0.78 mg/L on day 26. As the compost matured, the copper concentration significantly declined, and the copper concentration had decreased by 67% between days 26 and 40.

5.6 Blood and urine levels in the Canadian population

Copper levels in the blood and urine of Canadians are available from the Canadian Health Measures Survey (cycle 2) conducted by Statistics Canada, Health Canada and the Public Health Agency of Canada. As part of this cross-sectional study, health data and biological specimens were collected at 257 sites from 6,070 Canadians aged 3–79 years, distributed among six age groups (3–5, 6–11, 12–19, 20–39, 40–59 and 60–79 years). The geometric mean for whole blood copper concentration was 900 µg/L (95% confidence interval [CI] = 900–910 µg/L; *n* = 6,070), and the geometric mean for urinary copper concentration was 10 µg/L (95% CI = 10–11 µg/L; *n* = 6,311), for the total Canadian population aged 3–79 years (Health Canada, 2013).

A study conducted by the Government of the Northwest Territories and Health Canada between 1994 and 1999 found that the geometric mean for maternal and umbilical cord plasma copper concentrations for 523 women from arctic Canada was 2.1 mg/L (Butler Walker et al., 2006). Levels did not differ between ethnic groups.

5.7 Multi-route exposure

Based on the physical and chemical properties of copper, drinking water exposure through the dermal and inhalation routes is likely negligible. Exposure to copper in vapors while showering is not expected since it is non-volatile, and no reports on copper absorption by inhalation were found. Although the generation of mists during showering could allow for inhalation of copper in aerosol form, the typical multi-route assessment, which measures inhalation exposure to volatile chemicals from showering and bathing, would not accurately represent copper aerosols inhaled during a showering event. There is little information on the dermal absorption of copper; however, bathing and showering are not expected to be significant sources of exposure, as indicated in a risk assessment of dissolved trace metals in drinking water (Karim, 2011). As a result, dermal and inhalation exposure during showering and bathing are unlikely to contribute significantly to the total exposure to copper through drinking water.

6.0 Analytical methods

The United States Environmental Protection Agency (U.S. EPA) has several approved methods for measuring copper in drinking water:

- EPA 200.5 Rev 4.2 (U.S. EPA, 2003a)
- EPA 200.7 Rev 4.4 (U.S. EPA, 1994a)
- EPA 200.8 Rev 5.4 (U.S. EPA, 1994b)
- EPA 200.9 Rev 2.2 (U.S. EPA, 1994c)
- ASTM D1688-95A, ASTM D1688-02A, ASTM D1688-07A, D1688-12A (ASTM, 1995, 2002, 2007, 2012).
- ASTM D1688-95C, ASTM D1688-02C, ASTM D1688-07C, D1688-12C (ASTM, 1995, 2002, 2007, 2012).
- Hach 8026, Hach 10272 (Hach, 2014, 2016)
- SM 3111B (1992, 1995, 2005, 2012) and the online version of SM3111B (1999) (APHA et al., 1992, 1995, 1999, 2005, 2012)
- SM 3113B (1992, 1995, 2005, 2012) (APHA et al., 1992, 1995, 1999, 2004, 2005, 2010, 2012)
- SM 3120 B (1992, 1995, 1998, 2005, 2012) and the online version of SM 3120B (1999) (APHA et al., 1992, 1995, 1999, 2005, 2012).

The method detection limits (MDLs) for the methods listed above range between 0.02 and 500 µg/L. It should be noted, however, that MDLs are dependent on the sample matrix, instrumentation and selected operating conditions and will also vary between individual laboratories. In selecting an analytical method, consideration should be given to the water matrix to minimize the effect of interfering agents by using the prescribed sample pre-treatment or mitigation steps can help eliminate or decrease the effects of interfering agents.

ASTM D1688A, ASTMD1688C, EPA Rev 2.2, SM 3111B, SM 3113B are all atomic absorption based methods. The light source is specific to each element measured, as each metal has a characteristic absorption wavelength (APHA et al., 2012). ASTM D1688 uses an atomic absorption direct method, with a method range of 0.5–5 mg/L (ASTM, 1995, 2002, 2007, 2012); whereas ASTM D1688C uses an atomic absorption graphite furnace method, with a method range of 5–100 µg/L (ASTM, 1995, 2002, 2007, 2012). EPA 200.9 Rev 2.2 uses a graphite furnace atomic absorption method, with a method detection limit of 0.7 µg/L (U.S. EPA, 1994c). SM 3111B (1992, 1995, 2005, 2012) and the online version of SM 3111B (1999) use a flame atomic absorption spectrometry method, with an instrument detection limit of 0.01 mg/L (APHA et al., 1992, 1995, 1999, 2005, 2012). SM 3113B (1992, 1995, 2005, 2012) and the online version of SM 3113B (1999, 2004, 2010) use an electrothermal atomic absorption spectrometry method with an estimated detection level of 0.7 µg/L with an optimum concentration range of 5–100 µg/L (APHA et al., 1992, 1995, 1999, 2004, 2005, 2010, 2012). Flame atomic absorption is subject to several interferences primarily chemical interferences, where there is a lack of absorption by atoms because they are bound in molecules or they ionize in the flame. The electrothermal/graphite furnace method generally has detection levels 20 to 1000 times lower than flame based methods as a result of increased atom density within the furnace (APHA et al., 2012). However, the electrothermal/graphite furnace method is also subject to more interferences, including spectral, matrix and memory interferences (U.S. EPA, 1994c) and may require increased analysis time compared to flame based methods (APHA et al., 2012).

EPA 200.7 Rev 4.4 uses an inductively coupled plasma atomic emission spectroscopy (ICP-AES) method, with a method detection limit of 0.003 mg/L (U.S. EPA, 1994a). EPA 200.5 Rev 4.2 uses an axially viewed ICP-AES method, with a method detection limit of 0.3 µg/L and a calculated reporting limit of 0.7 µg/L (U.S. EPA, 2003a). EPA 200.8 Rev 5.4 uses an inductively coupled plasma mass spectroscopy (ICP-MS) method, with a method detection limit of 0.5 µg/L in scanning mode and 0.02 µg/L in selective ion monitoring mode (U.S. EPA, 1994b). SM 3120 B (1992, 1995, 1998, 2005, 2012) and the online version of SM 3120B (1999) use an inductively coupled plasma method, with an estimated detection level of 6 µg/L (APHA et al., 1992, 1995, 1999, 2005, 2012). Sources of interference can include matrix effects and isobaric elemental and polyatomic ion interferences. Generally, for both ICP-AES and ICP-MS methods, the presence of high dissolved solids in a sample may interfere with ion transmission, and interferences can occur when dissolved solids exceed 0.2% (w/v) (U.S. EPA, 1994b; APHA et al., 2012).

Determination of copper by the colorimetric methods Hach 8026 and 10272 rely on the complexation of Cu(I) with bicinchoninic acid. Hach 8026 has a method range of 0.04–5 mg/L (Hach, 2014), and Hach 10272 has a method detection limit of 0.06 mg/L (Hach, 2016). In the colorimetric method, the Cu(II) is chemically reduced to Cu(I), and the concentration is determined through spectrophotometry at 560 nm. There are a number of interfering agents for Hach 8026 (Al^{3+}, CN^-, Fe^{3+}, Ag^+, hardness, $pH \leq 2$) and Hach 10272 (CN^-, Ag^+, $pH \leq 2$) that can be mitigated through the use of a chelating agent or a prescribed pH adjustment.

The current practical quantitation limit (PQL) is 0.05 mg/L (U.S. EPA, 2009). In the second-six year review of existing national primary drinking water regulations, the U.S. EPA indicated that although the laboratory passing rate was high, there were insufficient or inconclusive performance evaluation and proficiency testing data for copper to justify lowering the PQL (U.S. EPA, 2009).

6.1 Sample preparation

The concentration of copper is much less variable than the concentration of lead, both across a system and within an individual site (Kirmeyer et al., 1994; Schock et al., 1995), making the analysis of total copper generally easier. Sample preparation to ensure that both the particulate and dissolved fractions of copper are capable of being detected is best practice, especially for diagnostic purposes. Generally, all methods listed above follow the same preservation steps, including the use of 0.15% nitric acid, a 16-hour holding time and the addition of hydrochloric acid for hot digestion when the sample turbidity is above 1 nephelometric turbidity unit (NTU). The standard acid preservation ($pH < 2$) has been shown to quantify total copper in water samples (U.S. EPA, 1994b; APHA et al., 2012). However, similarly to lead and other metals, when particles of copper are present in a sample, they may not be well dispersed and may settle to the bottom of the sampling bottle, resulting in turbidity below 1 NTU. As such, the current protocol may underestimate total copper in drinking water when particulate copper is present and best practice for the preservation step should be considered. Increasing the nitric acid strength to 2% for the preservation step may result in better recovery for most forms of particulate copper as has been observed with lead particulates (Haas et al., 2013; Triantafyllidou et al., 2013; Clark et al., 2014).

Best practice leading to a better estimation of total metals include ensuring that no aliquot or volume transfers occur prior to preservation or analysis, *in situ* sample preservation where feasible, maintaining a minimum holding time of 16 hours after preservation, thoroughly mixing the sample prior to analysis and taking the aliquot directly from the original sample bottle

(Cartier et al., 2013; Haas et al., 2013; Triantafyllidou et al., 2013). It is important to note that the addition of 2% nitric acid should be undertaken by qualified personnel and using appropriate precautions. To this end, if sampling is conducted by homeowners, the sample should only be acidified and held upon arrival at the laboratory.

7.0 Treatment technology

7.1 Municipal scale

Historically, copper release has been considered an aesthetic nuisance in the case of blue water or a financial nuisance in the case of pipe failure attributed to pitting corrosion/pinhole leaks. Copper levels in source water are typically very low, and copper is generally introduced into drinking water after it leaves the treatment plant. The treatment approach for copper is generally focused on corrosion control. The approaches used for corrosion control include water quality adjustments (e.g., pH, alkalinity) and the use of corrosion inhibitors. The selection of an appropriate strategy for minimizing copper at the tap and, thus copper exposure, will depend on many factors including the characteristics of the raw water supply and the type of corrosion (Health Canada, 2009c). Utilities should undertake pilot-scale or pipe rig studies to understand how water quality changes to control copper will affect various chemical constituents in the treated water (e.g., iron and manganese) as well as materials in the distribution system (e.g., scale stability, lead-bearing components).

Site-specific investigations can be a useful tool when copper exceedances are limited an individual building or neighbourhood. An investigation of a widespread and rapid copper plumbing failure (2 months after installation) in a German hospital, Fischer et al. (1992) found evidence of both uniform and pitting corrosion in copper pipes. Biofilm was also found layered between corrosion products and implicated as a contributing factor to copper release. The authors also found that the areas that experienced greater corrosion were in intensively branched, horizontal sections of the pipe network that experienced long stagnation times. Arnold et al. (2012) conducted a site-specific investigation at a newly built U.S. school where copper release exceeded 6 mg/L and blue water was observed. Through targeted investigations, a practical long-term treatment strategy (removal of natural organic matter [NOM]) was identified for the school.

7.1.1 Treatment considerations

Although copper levels in source water tend to be low, conventional water treatment technologies have been demonstrated both at the bench/pilot-scale as well as full scale to remove copper. Stover and Kincannon (1983) conducted bench/pilot scales treatability studies using raw groundwater (pH 6). pH adjustments using lime decreased copper from 0.1 mg/L to < 0.001 mg/L (at pH 9.1 and 9.9) and 0.008 (at pH 11.3). Activated carbon adsorption was shown to also decrease copper from 0.1 mg/L to < 0 .001 mg/L (Stover and Kincannon, 1983). A survey of the performance of twelve water treatment plants in Colorado and California also provided some evidence of copper removal from source water (average influent concentration of 0.03 mg/L) through microstrainer (14%) , clarifier (26%) and filtration (37%) steps, for an overall removal of 49% (Zemansky, 1974). A comparison of three granular activated carbon (GAC) filter media was conducted in a river water supplied water treatment plant in Southern Poland. The water treatment plant consisted of two parallel treatment trains prior to the GAC filters consisting of either pre-ozonation, coagulation, flocculation, sedimentation and rapid sand filtration; or pre-ozonation, coagulation, clarification/flocculation, rapid sand filtration and ozonation. The GAC filters were followed by storage where final disinfection occurred. The water entering the GAC filters was pH 6.8, 0.2 NTU. The authors found that the copper concentration increased by 130-253% on the Chemviron F-300 filter media and by 1965% on the Norit ROW 08 filter media over the course of the first year of operation (influent concentration not reported). On the third filter media (WG-12), adsorption of copper was irregular and some desorption (release) of copper was observed. (Dabioch et al., 2013). For public water systems, the U.S. EPA has identified point-of-use (POU) ion exchange (using cationic resins) and reverse osmosis (RO) as small systems (i.e., serving fewer than 10 000 people) compliance technologies for copper removal (U.S. EPA, 1998). These technologies are also relevant for residential-scale treatment (see section 7.). The alkalinity of finished water is affected by the use of the reverse osmosis process. This process removes sodium, sulphate, chloride, calcium and bicarbonate ions and results in finished water that is corrosive (Taylor and Wiesner, 1999). This underlines the importance of process adjustments such as addition of a base and aeration of the permeate stream to recover alkalinity prior to distribution.

7.1.2 Distribution system considerations

The National Plumbing Code of Canada (NPC) allows copper as an acceptable material for service lines and plumbing systems (NRCC, 2010), without respect to water quality. All provinces and territories use the NPC as the basis for their plumbing regulations. However, in certain water qualities, both soluble and particulate copper may be released into drinking water from copper plumbing pipes, copper service lines and copper in brass fittings used in both home plumbing systems and in distribution mains, to levels exceeding the proposed MAC.

7.2 Factors affecting uniform copper corrosion

Schock and Lytle (2011) report that for general uniform copper corrosion and copper release, the most important variables are pH, alkalinity, redox potential (ORP) and plumbing age. Several other factors can also influence uniform copper corrosion including the stagnation time of the water and flow in pipes, temperature and other water quality conditions as well as NOM and biofilms.

7.2.1 pH

The effect of pH on the solubility of the corrosion products formed during the corrosion process is often the key to understanding the concentration of metals at the tap. Typically, distributed water with higher pH decreases the solubility of the corrosion products formed in the distribution system. Copper corrosion increases rapidly as the pH drops below 6; in addition, uniform corrosion rates can be high at low pH values (below about pH 7), causing metal thinning. At higher pH values (above about pH 8), copper corrosion problems are almost always associated with non-uniform or pitting corrosion processes (Edwards et al., 1994a; Ferguson et al., 1996). Edwards et al. (1994b) found that for new copper surfaces exposed to simple solutions that contained bicarbonate, chloride, nitrate, perchlorate or sulphate, increasing the pH from 5.5 to 7.0, roughly halved corrosion rates, but that further increases in pH yielded only subtle changes. The prediction of copper levels in drinking water relies on the solubility and physical properties of the Cu(II) oxide, hydroxide and basic carbonate solids that comprise most scales in copper water systems (Schock et al., 1995). In the Cu(II) hydroxide model of Schock et al. (1995), a decrease in copper solubility with higher pH is evident. Above a pH of approximately 9.5, an upturn in solubility is predicted, caused by carbonate and hydroxide complexes increasing the solubility of Cu(II) hydroxide. Copper solids also age much more rapidly, transforming to much less soluble Cu(II) hydroxide phases, at higher pH and higher temperatures (Hidmi et Edwards, 1999). Copper solubility was found to be high in cold, high-alkalinity and high-sulphate groundwater up to about pH 7.9 (Edwards et al., 1994a).

7.2.2 Alkalinity

Alkalinity is a measure of the capacity of the water to neutralize acids and serves to control the buffer intensity of most water systems. Therefore, a minimum amount of alkalinity is necessary to provide a stable pH throughout the distribution system for corrosion control. Alkalinity is influenced by the presence of the conjugate bases of inorganic carbon ($HCO^{3-}$and $CO3^{2-}$), organic acids and OH^{-} ion and is expressed in mg $CaCO_3$/L (Edzwald and Tobiason, 2011). Alkalinity is generally used interchangeably with dissolved inorganic carbon (DIC). The relationship between alkalinity, pH and cuprosolvency is complex, with the form of the controlling copper solid playing a critical role. Hard, high alkalinity groundwaters are particularly aggressive toward copper materials (Schock and Lytle, 2011). For example, copper releases of 1.4 – 2.4 mg/L were observed in high alkalinity (273 $CaCO_3$ mg/L) and pH 7.4 water from tap water samples from relatively new copper plumbing (< 6 years old) in large buildings. The addition of orthophosphate at 3mg/L was sufficient to decrease copper release to below 1.3 mg/L (Grace et al., 2012). Similarly, Schock and Fox (2001) found that in a high alkalinity (280 mg $CaCO_3$/L), pH 7.3 water, the 90th percentile copper levels exceeded 1.63 mg/L. Edwards et al., (1999) found that a combination of low pH (< 7.8) and high alkalinity (> 74 mg $CaCO_3$/L) produced the worst-case 90th-percentile copper levels (Edwards et al., 1999). Laboratory and utility experience have demonstrated that copper corrosion releases are worse at higher alkalinity (Edwards et al., 1994b, 1996; Schock et al., 1995; Ferguson et al., 1996; Broo et al., 1998). These effects are likely due to the formation of soluble Cu(II) bicarbonate and carbonate complexes (Schock et al., 1995; Edwards et al., 1996) and in certain waters such as those that do not form insoluble malachite scale (Arnold et al., 2012). Both carbonate complexation and pH have a strong effect of on copper solubility in relatively new plumbing systems. Low alkalinity (< 25 mg $CaCO_3$/L) also proved to be problematic under utility experience (Schock et al., 1995). For high-alkalinity waters, the only practical solutions to reduced cuprosolvency are lime softening, removal of bicarbonate or addition of rather large amounts of orthophosphate (U.S. EPA, 2003b). Lower copper concentrations can be associated with higher alkalinity when the formation of the less soluble malachite and tenorite has been favoured (Schock et al., 1995; Edwards et al., 2002).

7.2.3 Redox potential

The importance of redox potential (ORP) lies mostly in defining the conditions under which Cu(II) ions are formed (i.e., high oxidizing potential). At lower redox potentials, copper will not be subject to corrosion or the formation of highly insoluble copper(I) oxide or hydroxide solids will occur, resulting in extremely low copper levels in the water (Schock et al., 1995; Ferguson et al., 1996). Many untreated groundwaters of neutral pH and high alkalinity fall into this category.

The rate of release of copper into the water is influences by the level of oxidizing agents in the system, especially free chlorine. Even low levels (i.e., 0.2 mg/L) affect the oxidation and corrosion rate (Schock and Lytle, 2011). Reiber (1989) has shown that the chlorine effect is much more important than dissolved oxygen in normal drinking water situations.

Hypochlorous acid is the predominant form of free chlorine below pH 7.5 in drinking water and the dominant oxidant on the copper surface (Atlas et al., 1982; Reiber, 1987, 1989;

Hong and Macauley, 1998). Free chlorine residual was shown to increase the copper corrosion rate at lower pH (Atlas et al., 1982; Reiber, 1989). Conversely, free chlorine residual was shown to decrease the copper corrosion rate at pH 9.3 (Edwards and Ferguson, 1993; Edwards et al., 1999). However, Schock et al. (1995) concluded that free chlorine species would affect the equilibrium solubility of copper by stabilizing copper (II) solid phases, which results in a substantially higher level of copper release. The authors did not observe any direct effects of free chlorine on copper (II) solubility other than the change in valence state and, hence, the indirect change in potential of cuprosolvency.

Sometimes, copper levels in water that has been stagnant in the plumbing system can increase for as many as 48 to 72 hours, especially in relatively rare cases of blue water (Edwards et al., 2000). For this reason, an overnight standing sample is not necessarily representative of a worst-case scenario for exposure to copper (Schock et al., 1995). Conversely, the depletion of oxidants may decrease copper levels (Edwards et al., 1996; Schock and Lytle, 2011). The introduction of oxidative processes such as those for iron or manganese removal, or the initiation of disinfection after low-ORP conditions, could increase, decrease or have no effect on copper concentration depending on the circumstances.

Limited information has been reported in the literature about the effect of other disinfectants on copper. A bench-scale study by Rahman et al. (2007) examined the effect of three disinfectants (chlorine, chlorine dioxide, and chloramines) under two pH (7.2 and 8.5) and alkalinity (10 or 100 mg $CaCO_3$/L) conditions. The authors found that there was no significant difference in dissolved copper release for the disinfectant-free control compared to any of the disinfectants used in the study. Generally, the study found that the application of disinfectant lowered the copper release, with the lowest total copper release found under the pH 8.5, 10 mg $CaCO_3$/L and 1.0 mg Cl_2/L conditions. The authors suggested that the lower biomass (not assessed in the study) might explain part of the benefit to disinfectant, and that the long stagnation period (72 h) would result in low chlorine residuals. The authors also suggested that in the case of chlorine dioxide the presence of chlorite (a by-product) may have acted as a corrosion inhibitor.

Boyd et al. (2010) studied the effects of changing disinfectants from free chlorine to chloramines and vice versa on leaching rates of metals and concentrations of metals from lead, brass, and copper components in the distribution system. Local tap water was used and water quality parameters (disinfectant residual, pH, alkalinity, and orthophosphate concentration) were monitored and maintained. The authors conducted pipe loop testing using new copper tubing and bronze piping (as a surrogate for standard brass) with different galvanic couplings (copper-bronze, lead-bronze, and lead-copper couplings). Copper concentrations in unpassivated copper and bronze pipe loops were sensitive to free chlorine and chloramines but the effects were transient and not related to a specific disinfectant. A study assessed the leaching potential for several components tested under NSF/ANSI Standard 61 protocols with both chlorinated and chloraminated water. The study also tested these components using 28 waters (chlorinated and chloraminated) collected from utilities throughout the U.S. These utilities were also surveyed on copper and lead release issues. The authors found that neither chlorine nor chloramine was a dominant factor towards the leaching of copper under the test conditions for both the synthetic and utility waters. This mirrored the results from the utility survey that indicated few problems with copper (and lead) release when chloramines were used for secondary disinfection (Sandvig et al., 2012).

7.2.4 Pipe age and copper solubility

Copper release into the drinking water largely depends on the type of scale formed within the plumbing system and whether they are relatively thin and adherent films of corrosion products such as copper(I) oxide (cuprite, Cu_2O), copper(II) oxide (tenorite, CuO), or copper carbonate (malachite, $Cu_2(OH)_2CO_3$) (Schock and Lytle, 2011). It can be assumed that at a given age, a corrosion product governs the release of copper into the drinking water. In uniform corrosion, solubility is highest for Cu(I) hydroxide [$Cu(OH)_2$] and lowest for tenorite [CuO] and malachite [$Cu_2(OH)_2CO_3$] (Schock et al., 1995). Similarly, Lagos et al. (2001) observed a linear relationship between pipe age and mean dissolved copper concentration in water. The more stable scales (malachite and tenorite) were also found to be the oldest and the least stable scale (langite), the youngest. Copper concentrations continue to decrease with the increasing age of plumbing materials, even after 10 or 20 years of service, when tenorite or malachite scales tend to predominate (Sharrett et al., 1982; Neuman, 1995; Edwards and McNeill, 2002). Sulphate and phosphate can decrease copper concentrations by forming bronchantite and copper(II) phosphate in the short term but, in the long term, they may prevent the formation of the stable tenorite and malachite scales (Edwards et al., 2002; Schock and Sandvig, 2009; Arnold et al., 2012).

7.2.5 Stagnation time, water age and flow

Long copper pipe of small diameter produces the greatest concentrations of copper upon stagnation (Kuch and Wagner, 1983; Ferguson et al., 1996). Copper behaviour is complex with respect to the stagnation of the water. Copper levels will initially increase upon stagnation of the water, but can subsequently decrease or increase, depending on the oxidant levels. Lytle and Schock (2000) showed that copper levels increased rapidly with the stagnation time of the water, but only until dissolved oxygen (DO) fell below 1 mg/L, after which they dropped significantly. Sorg et al. (1999) also observed that in softened water, copper concentrations increased to maximum levels of 4.4 and 6.8 mg/L after about 20–25 h of standing time, then dropped to 0.5 mg/L after 72–92 h. Peak concentrations corresponded to the time when the DO was reduced to 1 mg/L or less. In non-softened water, the maximum was reached in less than 8 h, because the DO decreased more rapidly in the pipe loop exposed to non-softened water. Typically, water in a conventional home has a water age of 1 day compared to green buildings, where water age has been found to range from 2.7 days (net-zero energy house), 8 days (in a LEED-Gold healthcare facility) and 1–6 months (net-zero office) (Rhoads et al., 2016). Increased water age has been associated with deterioration of water quality (loss of disinfectant residual, pH decrease) (Masters et al., 2015) as well as increases in microbial population (Masters et al., 2015; Rhoads et al., 2016) and could increase the propensity of water towards copper corrosion. As green building technology becomes more prevalent, consideration should be made for the implications of increased water age on water quality and corrosion.

High flow velocities can sometimes be associated with erosion corrosion or the mechanical removal of the protective scale (impingement attack) in copper pipes. Water flowing at high velocity, combined with corrosive water quality, can rapidly deteriorate pipe materials. For example, the combination of high Cl_2, continuous flow velocity with low-pH and high-alkalinity is extremely aggressive toward copper (Sarver et al., 2011; Schock and Lytle, 2011).

7.2.6 Temperature

No simple relationship exists between temperature and corrosion processes, because temperature influences several water quality parameters, such as dissolved oxygen solubility, solution viscosity, diffusion rates, activity coefficients, enthalpies of reactions, compound solubility, oxidation rates and biological activities (McNeill and Edwards, 2002). These parameters, in turn, influence the corrosion rate, the properties of the scales formed and the leaching of materials into the distribution system. In hot water systems of building plumbing, a high water temperature (>60°C), in the presence of high flow velocity, is a factor in erosion corrosion (Ferguson et al., 1996). In a survey of the release of copper corrosion by-products into the drinking water of high-rise buildings and single-family homes in the Greater Vancouver Regional District, Singh and Mavinic (1991) noted that copper concentrations in water run through cold water taps were typically one-third of copper concentrations in water run through hot water taps. A laboratory experiment that compared copper release at 4, 20, 24 and 60°C in a soft, low alkalinity water showed higher copper release at 60°C, but little difference in copper release between 4°C and 24°C (Boulay and Edwards, 2001). However, copper hydroxide solubility was shown to decrease with increasing temperature (Edwards et al., 1996; Hidmi and Edwards, 1999). In a survey of 365 utilities under the U.S. EPA Lead and Copper Rule, no significant trend between temperature and copper levels was found (Dodrill and Edwards, 1995).

7.2.7 Chloride and sulphate

Chloride has traditionally been reported to be aggressive towards copper but has been found to be less detrimental for cuprosolvency than originally expected (Edwards et al., 1994b). High concentrations of chloride (71 mg/L) were shown to reduce the rate of copper corrosion at pH 7–8 (Edwards et al., 1994a, 1994b, 1996; Broo et al., 1997, 1999). Edwards and McNeill (2002) suggested that this dichotomy might be reconciled when long-term effects are considered instead of short-term effects: chloride increases copper corrosion rates over the short term. However, with aging, the copper surface becomes well protected by the corrosion products formed. Sulphate is a strong corrosion catalyst implicated in the pitting corrosion of copper (Schock, 1990; Edwards et al., 1994b; Ferguson et al., 1996; Berghult et al., 1999). Although sulphate was shown to decrease concentrations of copper in new copper materials, it was found that high sulphate concentrations resulted in higher copper levels in the experimental water once the copper material had aged (i.e., transitioned from copper(II) hydroxide to CuO) (Edwards et al., 2002). The authors concluded that this was due to the ability of sulphate to prevent the formation of the more stable and less soluble malachite and tenorite scales, supporting the hypothesis of Schock et al. (1995) that aqueous sulphate complexes are not likely to significantly influence cuprosolvency in potable water.

7.2.8 Natural organic matter

Research in copper plumbing pitting has indicated that some NOM may alleviate the propensity of a water to cause pitting attacks by promoting the formation of more protective scales (Campbell, 1954a, 1954b, 1971; Campbell and Turner, 1983; Edwards et al., 1994a; Korshin et al., 1996; Edwards and Sprague, 2001). However, NOM contains strong complexing groups and has been shown to increase the solubility of copper corrosion products (Korshin et al., 1996; Rehring and Edwards, 1996; Broo et al., 1998, 1999; Berghult et al., 1999, 2001; Edwards et al., 1999; Boulay and Edwards, 2001; Edwards and Sprague, 2001). Nevertheless, the significance of NOM to cuprosolvency relative to competing ligands has not been conclusively determined (Schock et al., 1995; Ferguson et al., 1996). A study found that NOM initially promoted pitting under certain narrow water quality and NOM concentration ranges. However, over long periods of time, a reduction in pitting at the higher NOM concentrations was observed (Korshin et al., 1996). Generally, the study concluded that NOM interacts with the copper through sorption, increasing the rate of copper leaching and the dispersion of the corrosion scales.

Mechanistic work by Edwards and Sprague (2001) elucidated some of the complex and apparently contradictory effects of NOM on copper. NOM was shown to contribute to copper by-product release through complexation and/or colloid mobilisation. NOM can interfere with pipe ageing through promoting the formation of highly soluble copper(II) hydroxide, copper carbonate and copper-NOM complex formation and thus, prevent the formation of the more stable solid, malachite. Conversely, NOM can serve as a food source for bacteria, which in turn consumes dissolved oxygen, triggering re-deposition of copper onto the pipe in the presence of a suitable catalyst (e.g. chloride). In practice, Arnold et al. (2012) demonstrated, at the bench-scale, that NOM removal was a practical and effective method to decrease copper release in a school experiencing blue-water issues. NOM removal increased dissolved oxygen (and the corrosion rate) and subsequently increased scale formation. The authors suggested that in the absence of NOM, the corrosion rate increased, accelerating the natural ageing process. Visual inspection of the copper pipes revealed a blue-green solid, which is associated with the stable crystalline solid, malachite.

7.2.9 Microbiologically influenced corrosion

Microbiologically influenced corrosion (MIC) results from a reaction between the pipe material and organisms, their metabolic by-products, or both (Schock and Lytle, 2011). Microbial activity can affect pH, metal solubility, and the oxidation-reduction potential of the surrounding microenvironment. Biofilms are surface associated communities of bacteria and their interaction with copper surfaces is complex. Bacteria can interact with the surface in physically, metabolically, or as storage reservoir for released metals. As biofilms form on the surface, corrosive microenvironments can form, for example, the area under the biofilm becomes oxygen deprived (anaerobic) and can act as an anode to the neighbouring metallic surface (cathode), thereby driving a localised corrosion event (Javaherdashti, 2008). Acidic metabolic products can also create local pH decreases (Little et al., 1991) and create bulk water pH decreases (Davidson et al., 1996). Bacteria in a biofilm produce sticky exopolymeric substances (EPS) that tend to have a negative charge, providing a binding site for positively charged metals ions (Qin-qin et al., 2012). Specifically, biofilm has been shown to act as a reservoir for released copper (Davidson et al., 1996; Lehtola et al., 2006; Qin-qin et al., 2012; Payne et al., 2016), representing another potential source of copper exposure in a biofilm detachment event.

There have been several bench-scale studies, as well as autopsies of corroded copper plumbing, that have indicated a significant role for bacteria and biofilm in cuprosolvency. Dutkiewicz and Fallowfield (1998) found that copper exposed to *Agrobacterium* sp., isolated from a copper pipe biofilm found in Adelaide, Australia, increased copper release compared to a sterile control. In an Australian study, *Sphingomonas* spp. and *Acidovorax* sp. have been identified as species associated with corroding copper surfaces, and a species of *Acidovorax* has been observed to accumulate copper when grown in a laboratory setting on a copper-containing food source (Critchley et al., 2004). Conversely, other bacteria, *Stenotrophomonas maltophilia*, were observed to have protective effects on copper, which the authors hypothesized could be a result of the binding of the chloride ions to the EPS (Critchley et al., 2003).

Copper has antimicrobial properties (Grass et al., 2011), and in drinking water delayed biofilm formation on copper pipes has been observed when compared to polyethylene pipes. Although after 200 days there was a significant decrease in virus numbers on copper pipe biofilm, there was no significant difference in microbial numbers (Lehtola et al., 2004). Biofilms have also been implied as causative or contributing agents to both blue water events (Arens et al., 1996; Critchley et al., 2004) and pitting corrosion (Fischer et al., 1992; Reyes et al., 2008; Burleigh et al., 2014).

7.3 Blue water events

Copper dissolution can cause blue or green water events and are frequently characterized by a fine dispersion of copper corrosion products. Particulate copper appears light blue as a copper hydroxide and black as copper sulphide. Visual perception of a blue water issue is challenging as the coloured water can be flushed away through the first flush of a toilet or tap. The distance of the observer from the coloured water also affects the perception, with 0.3 mg/L visible at the typical observation distance from a bathtub, but 3 mg/L would need to present for the copper particulate to be noticeable in a glass of water (Edwards et al., 2000).

No single cause has been identified for blue water events; they are thought to result from a combination of microbial activity and certain water quality conditions. Critchley et al. (2004) successfully induced blue water in a laboratory setting by inoculating copper pipe rigs with non-sterile copper corrosion extracts, although the water used was not representative of drinking water. The authors noted a nine week lag time before blue water was apparent suggesting that there is an initial establishment phase to initiate this type of corrosion. Previously, Arens et al. (1996) investigated a blue water event in recently commissioned copper pipes. MIC was suspected as the causative agent and Arens et al. (1996) found that various food sources (e.g., sealing putty) increased microbial activity and copper release. Arnold et al. (2012) also reported blue water and elevated copper (>6 mg/L) in new copper plumbing, in a high alkalinity (200 mg $CaCO_3$/L), pH 7.15-7.4 water. NOM removal provided long-term copper stability through accelerated pipe ageing.

7.4 Brass alloys

Brasses are, basically, alloys of copper and zinc, with other minor constituents, such as lead. Brass dezincification is thought to be a either a selective leaching of zinc or a multi-stage process through which zinc and copper are leached through uniform corrosion and copper is redeposited, creating a net effect of zinc leaching and both mechanisms leave behind a porous weakened copper surface (Lytle and Schock, 1996; Sarver et al., 2011). Zinc oxide corrosion products can build-up forming a “meringue” structure that restricts flow, which can subsequently cause leaks and bursts. Brasses are particularly vulnerable to dezincification in low alkalinity, high chloride water (Sarver et al., 2011). Ideally, brass used in premise plumbing should be low zinc to help make the brass dezincification resistant. However, it should also be noted that in cross-linked polyethylene (PEX) plumbing systems, higher zinc content brass (yellow brass) fittings are frequently used. There have been widespread plumbing failures associated with PEX and dezincification of brass fittings documented in North America (U.S. District Court, 2011; Ontario Superior Court of Justice, 2011; Superior Court Province of Quebec, 2011). In addition to the financial ramifications of brass corrosion, other metals are also released, including copper. Lytle and Schock (1996) demonstrated that the composition of the brass alloy was a significant factor in the amount of copper released and that small changes in pH were a strong influence on copper release. A pH 8.5 and 7, with red brasses (low zinc) released more copper than yellow brasses (high zinc) and some red brasses released similar copper levels as pure copper. Brasses at pH 7 released more copper than at pH 8.5. It should also be noted that at pH 7, the copper releases were more sporadic. In practice brass can represent a significant source of copper release. A cluster of Southern California homes with all plastic plumbing, brass fittings were the major source of copper release with medians ranging from 85-185 µg/L over the course of three sampling events.

7.5 Pitting corrosion

Pitting corrosion is a form of non-uniform corrosion in all types of copper pipe and tubing and can ultimately lead to pinhole leaks, a costly plumbing failure (Scardina et al., 2008). Pitting corrosion can occur where a localised corrosion cell forms as a result of several mechanisms such as a differential in pH or oxygen on the pipe surface. In the localised corrosion cell, the cathodic area is protected, and the anodic area is oxidized, electrons are release, and copper is depleted, creating a pit. The pit can ultimately breach the wall of the copper, creating a small pinhole. If unfavorable water quality conditions occur prior to the formation of the protective scale, then a serious pitting corrosion may occur (Schock and Lytle, 2011). The causal pit initiation mechanism could be a result of one or a combination of several factors including surface imperfections, carbon residues from manufacturing, soldering flux, unfavourable water quality or microbiological activity. There are certain water quality, microbiological and flow conditions that appear to induce or propagate pits and include: waters with high pH, low alkalinity, the presence of chloride (Lytle and Schock, 2008; Lytle and Nadagouda, 2010) and sulphides (Jacobs et al., 1998; Jacobs and Edwards, 2000); chlorine, high pH, low alkalinity (Sarver et al., 2011); the presence of some biofilms (Fischer et al., 1992; Reyes et al., 2008; Burleigh et al., 2014); pipe configuration (Fisher et al., 1992) and high water velocity (Custalow, 2009). Lytle and Schock (2011) describe the three types of copper pitting (based on chemistry and physical features): cold-water (type I), hot-water (type II) and soft-water (type III) as well as conditions typically associated with each type. It is important to note that sulphate and chloride are typically associated in one way or another to all forms of pitting although the relative importance of chloride versus sulfate in copper pitting corrosion is still a subject of debate (Schock and Lytle, 2011).

In bench-scale experiments, the addition of 3 mg PO_4/L or increasing DIC to 50 mg/L (from 5–25 mg/L) was effective in preventing pit initiation at pH 9 (Lytle and Schock, 2008). It has been theorised that phosphate may displace other anions from the anode and compete for binding sites with Cu^{2+} to form a relatively stable scale and that alkalinity decreases pit initiation by either, limiting pH differentials on the surface or by forming copper carbonates and decreasing precipitation on the surface. Ha and Scully (2013) suggested that phosphate (as Na_2HPO_4) addition inhibits pit initiation through increasing passivation and suppressing the dissolution of copper. Lytle and Nadagouda (2010) analysed the elemental composition of copper pits taken from in-home plumbing and found that chloride was concentrated in the floor of the pits as well as in cracks or imperfections near the surface, suggesting that chloride plays an important role in the propagation of pits. Although the presence of chloride has been demonstrated to play a fundamental role in pit initiation, Edwards et al (1994a) hypothesized that given longer exposures (with greater scale formation) that chloride could potentially have a protective effect. Sulphides have been shown to be significant factors in inducing copper corrosion and have been associated with pitting at pH 9.2 (Jacobs and Edwards, 2000).

Burleigh et al. (2014) evaluated copper pitting in copper tubing from multiple cold water lines in Santa Fe, New Mexico and found evidence of Actinobacteria deep inside the pits. The authors suggested that Actinobacteria role in copper pitting could be through either the excretion of an acidic metabolic product or using copper as an energy source (Burleigh et al., 2014). Reyes et al (2008) compared two communities in Chile, one rural (pH 6.2, $CaCO_3$ = 63 mg/L, no chlorine) and one urban (pH = 6.9, $CaCO_3$ = 98 mg/L, chlorinated), and although the two communities had similar water quality they had different stagnant copper levels. The rural homes had stagnant copper levels of 5 mg/L compared to the urban homes where stagnant copper levels were 0.4 mg/L. When investigating the copper release in rural homes, the authors found that only one quarter of the copper release could be attributed to water quality factors and the microbiological component was suspected as another causal agent of copper release. In the rural homes pipes with biofilm, surface pitting was observed; whereas in the absence of bacterial biofilms no pitting was observed. High water velocity have also been demonstrated to increase pitting in high pH chlorinated waters (Custalow, 2009) and are likely a result of the continuous resupply of oxidants to the cathodic regions of a localised corrosion cell (Sarver et al., 2011). Leaking pipes present an additional health risk as they could lead to mould growth (Scardina et al., 2008), affecting indoor air quality (Health Canada, 2016).

7.6 Impact of treatment and/or water quality changes on copper release

Distribution system deposits and corrosion scales lie in delicate balance with the aqueous environment and utilities should be aware that changes in water quality can affect the stability of distribution system scale. Some treatment technologies can increase copper in drinking water by changing water quality parameters that impact copper release. Changing water treatment to address one issue, could inadvertently negatively impact another water treatment objective. For example, switching from a sulphate to chloride containing coagulant has been shown to increase CSMR and exacerbate lead release in premise plumbing material (Edwards and Triantafyllidou, 2010).

In the anion exchange process, when removing contaminants such as uranium, freshly regenerated ion exchange resin removes bicarbonate ions. This causes reductions in pH and total alkalinity during the initial 100 bed volumes (BVs) of a run and may require raising the pH of the treated water at the beginning of a run to avoid corrosion (Clifford, 1999; Wang et al., 2010; Clifford et al., 2011). Similarly, frequent regeneration of an ion exchange resin can have an impact on corrosion. In a case study in Maine, frequent regeneration of the ion exchange resin was required to reduce the levels of uranium in the waste stream (residuals). This resulted in a significant and continual decrease of pH and subsequent leaching of copper and lead into the drinking water (Lowry, 2009, 2010). Since reverse osmosis (RO) continually and completely removes alkalinity in water, it will continually lower the pH of treated water and increase its corrosivity. Therefore, the product water pH must be adjusted to avoid corrosion issues in the distribution system such as the leaching of lead and copper (Schock and Lytle, 2011; U.S. EPA, 2012). Additionally, changing from lime softening, which balances hardness and alkalinity with a high pH, to ion exchange softening can leave a high alkalinity, which is corrosive to copper (Schock and Lytle, 2011).

Similarly changes to finished water to address corrosion concerns can cause other unintended changes in the distribution system. For example, raising pH in finished water to greater than 9 in order to decrease copper release from premise plumbing, would precipitate dissolved manganese in the treated water, which could lead to unwanted aesthetic issues.

Additionally, it is important to consider that distribution system deposits are susceptible to changes in water quality. Distribution system deposits are comprised of the underlying corroded material (e.g. cast iron) as well as the accumulated trace inorganics that have accumulated over the service life of the water main. Friedman et al. (2010) found that trace inorganic contaminants (including barium lead nickel, vanadium, arsenic, radium, chromium and uranium) had accumulated in manganese deposits in distribution systems. Gerke et al. (2016) reported copper accumulation in both chlorinated and chloraminated distribution system manganese deposits. The stability of deposited inorganics is dependent upon maintaining stable water quality conditions (e.g., pH, ORP, corrosion control), as well as avoiding the uncontrolled blending of source water (ground and surface), and the uncontrolled blending of chlorinated and chloraminated water (Friedman et al., 2010).

Before changing water quality to achieve a new treatment goal, such as corrosion control, utilities should undertake pilot-scale studies to understand how a proposed water quality amendment will affect various components of their distribution system.

7.7 Mitigation of copper release

The selection of a mitigation strategy for copper should take into consideration other metals present since different strategies, including water quality adjustments, may impact various metals differently. The use of test pipe-rigs under site specific water quality conditions is recommended, as the testing process can be helpful in selecting an effective corrosion control strategy and aid in anticipating unintended impacts. Generally, the level of trace metals increases upon stagnation of the water but may vary according to water quality. For example, in standing water in plumbing systems where oxidants are present, copper levels can increase for up to 48 to 72 hours. As such, flushing the water present in the plumbing system can significantly reduce the levels of copper and is, therefore, considered a mitigation strategy. However, flushing the cold water tap may not be sufficient to reduce the levels of copper (Singh and Mavinic, 1991; Murphy, 1993; Barn et al., 2014). Periodic flushing throughout the day and extensive flushing following long stagnation periods (vacation periods, weekends) may therefore be advisable to provide suitable water quality throughout the day.

Reducing exposure to copper can also be achieved, as an interim measure, by the use of drinking water treatment devices. It must be noted that in situations where high levels of copper occur, drinking water treatment devices may have reduced capacity and require more frequent replacement of the filter.

7.7.1 Alkalinity and pH

Copper solubility is strongly influenced by both alkalinity (through carbonate complexation) and pH, for relatively new plumbing systems (Edwards et al., 1994b; Dodrill and Edwards, 1995). However, it was also noted that high alkalinity groundwaters are aggressive toward copper materials (Schock et al., 1995; Vik et al., 1996; Schock and Lytle, 2011).

The adjustment of pH at the water treatment plant is the most common method used for reducing corrosion in drinking water distribution systems and leaching of contaminants, such as copper, in the distributed water. Raising the pH is an effective method for reducing copper corrosion and thus, minimizing copper levels in drinking water. Generally, uniform corrosion of copper is best controlled at pH > 7, depending on alkalinity (Schock and Lytle, 2011). Treatment chemicals used for adjusting pH include caustic soda, potash, lime and sulfuric acid. Minimal pH adjustment can also be achieved using CO_2, with either sodium carbonate (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$); however, this combination primarily adjusts alkalinity. Aeration is a non-chemical treatment method that introduces air in the water, removing CO_2 and resulting in a pH increase. Another method of adjusting pH is the use of limestone contactors: water flows through a bed of crushed limestone, dissolving the limestone and causing the pH (as well as alkalinity and calcium level) to increase. These last two methods offer less precise control of the pH adjustment. A combination of lime or caustic soda and carbon dioxide offers more precise control, as it allows the pH and alkalinity of the water to be independently adjusted (Schock, 1999).

Alkalinity, in combination with pH, serves to control the buffer intensity of most water systems. Therefore, sufficient alkalinity is necessary to provide a stable pH throughout the distribution system for corrosion control of copper (and other metals such as lead). Alkalinity can improve the buffering capacity at a given pH. Raising or lowering the pH can substantially increase the buffering capacity of the water as seen in buffer intensity plots developed by Schock and Lytle (2011). This was demonstrated in practice by Clement et al. (1998) in a field study in Concord, New Hampshire, where minor adjustments in pH and alkalinity resulted in greater pH stability in the distribution system and improved corrosion control. In very low alkalinity waters, adjustment of the alkalinity can be achieved by adding carbonate ion with either Na_2CO_3 or $NaHCO_3$. As stated previously, these chemicals are also used to adjust pH because they also contribute carbonate (CO_3^{2-}) or bicarbonate (HCO_3^-) ions. It is important to note that the number of carbonate ions available is a complex function of pH, temperature, and other water quality parameters (Schock, 1999).

7.7.2 Addition of corrosion inhibitors

Phosphate- and silicate-based corrosion inhibitors are typically used for corrosion control in drinking water. The most commonly used inhibitors are phosphate corrosion inhibitors with or without zinc, which include orthophosphate or polyphosphate (typically, blended polyphosphates). Silicate corrosion inhibitors (i.e. sodium silicates) have also been used for corrosion control. The success of corrosion inhibitors is often based on pilot- or bench-scale testing and depends on both the water quality and the conditions prevailing in the distribution system. The effectiveness of corrosion inhibitors is largely dependent on maintaining a residual of the inhibitor throughout the distribution system and on the pH and alkalinity of the water. Measuring the concentration of inhibitors within the distribution system is part of good corrosion control practice. Generally, direct correlations between the residual concentration of inhibitors in the distribution system and the levels of metals, including copper at the tap are not possible.

Health Canada recommends that water utilities choose drinking water additives, such as corrosion inhibitors, that have been certified as conforming to the applicable NSF/ANSI health-based standard. Phosphate- and silicate-based corrosion inhibitors are included in NSF/ANSI Standard 60, Drinking Water Treatment Chemicals—Health Effects (NSF International, 2015a). These standards have been designed to safeguard drinking water by ensuring that additives meet minimum health effects requirements and thus are safe for use in drinking water.

7.7.2.1 Phosphate-based inhibitors

Orthophosphate and zinc orthophosphate are the inhibitors most often reported in the literature as being successful in reducing copper levels in drinking water (Bancroft, 1988; Reiber, 1989; Boffardi, 1993; Johnson et al., 1993; Dodrill and Edwards, 1995; Rezania and Anderl, 1995, 1997; Schock et al., 1995; Boireau et al., 1997; MacQuarrie et al., 1997; Churchill et al., 2000; Schock and Fox, 2001; Becker, 2002; Dudi, 2004; Kirmeyer et al., 2004). Orthophosphate is generally used for lead control when pH control or pH and alkalinity adjustment are not sufficient to control corrosion (Vik et al., 1996), and the effects on copper are secondary considerations.

Some authors have reported that the use of orthophosphate may reduce copper levels in the short term, but that in the long term the formation of more stable scales such as malachite and tenorite may be prevented (Schock and Clement, 1998; Edwards et al., 2001; Cantor et al., 2003; Schock and Sandvig, 2009). There is evidence that ineffective treatment for copper with phosphate was successful when higher dosages were applied or when pH and orthophosphate dosages were optimized (Schock et al., 1996; Schock and Fox, 2001). Schock and Fox (2001) demonstrated successful copper control in high-alkalinity water with orthophosphate when pH and alkalinity adjustments were not successful. Similarly, Grace et al. (2012) found that orthophosphate dosed at 3 mg/L effectively decreased copper levels below 1.3 mg/L from 1.4-2.4 mg/L in a high alkalinity (273 mg/L) neutral pH (7.4) water. Bench-scale results also indicated that a pH increase to 8.4 may also have been successful; however due to the high alkalinity of the water this option was not selected over concerns of calcium carbonate deposition on distribution system components (Grace et al., 2012).

A survey of 365 water utilities under the U.S. EPA Lead and Copper Rule also revealed that utilities using orthophosphate had significantly lower copper levels only when pH was below 7.8 and alkalinity was below 74 mg $CaCO_3$/L as (Dodrill and Edwards, 1995). Limited data are available on the impact of polyphosphate on copper solubility. Generally, polyphosphates increase the corrosion rate of copper (Vik et al., 1996). In a case study, Cantor et al. (2000) reported that the use of a polyphosphate blend, at one of the three utilities studied, increased copper levels at the tap. In a copper pipe rig study, Edwards et al. (2002) reported that although polyphosphate generally reduced soluble copper concentrations, they also significantly increased them at pH 7.2 and alkalinity of 300 mg $CaCO_3$/L since polyphosphates hinder the formation of the more stable malachite scales.

McNeill and Edwards (2004) used bench-scale experiments to compare the performance of orthophosphate, polyphosphate and zinc orthophosphate. Orthophosphate addition (1 mg/L) was associated with decreased soluble copper release, although no difference was observed for particulate release compared to the control. Polyphosphate addition (1 mg/L) decreased soluble copper release compared to orthophosphate, but increased particulate copper release. Zinc orthophosphate addition decreased soluble copper release but increased particulate copper release, compared to orthophosphate, except at pH 9.5. Additionally, particulate copper release increased with pipe age in zinc orthophosphate treated copper pipes. The comparison of phosphate corrosion inhibitors highlights the importance of using site-specific water quality as well as pilot testing and/or pipe rigs in selecting an appropriate corrosion inhibitor for a given water system. It should also be noted that phosphate can decrease copper concentrations by forming copper(II) phosphate but may also prevent the formation of the more stable tenorite and malachite scales (Edwards et al., 2002; Arnold et al., 2012).

7.7.2.2 Silicate-based inhibitors

Only limited data are available on the impact of sodium silicate on copper solubility. As sodium silicate is a basic compound, it is always associated with an increase in pH, making it difficult to attribute reductions in copper concentrations to sodium silicate alone when an increase in pH may also result in a decrease in copper concentrations. A study conducted by Schock (2005) in a medium-sized utility was able to solve problems from iron in source water as well as lead and copper leaching in the plumbing system. The problems were solved simultaneously through the addition of sodium silicate with chlorination. Sodium silicate was added to the three wells that contained elevated levels of iron and manganese and that serviced homes containing lead service lines. A fourth well required only chlorination and pH adjustment with sodium hydroxide. At the three wells, an initial silicate dose of 25–30 mg/L increased the pH from 6.3 to 7.5 and immediately resulted in 55% and 87% reductions in lead and copper levels, respectively. An increase in the silicate dose to 45–55 mg/L increased the pH to 7.5 and resulted in an even greater reduction in the lead and copper levels (0.002 mg/L and 0.27 mg/L, respectively).

Lintereur et al. (2011) compared three different sodium silicate dosages (3 mg/L, 6 mg/L, and 12 mg/L) and found that sodium silicate decreased copper release compared to the control (i.e., no treatment) and pH increase control. The decrease appeared to be dose dependant, with the lowest copper releases observed at the highest doses of sodium silicate. Additionally, scale analysis revealed a silicate-copper scale on coupons retrieved from the silicate treated systems, providing evidence that a silicate scale is at least partly responsible for the inhibitory action of sodium silicates. Woszczynski et al. (2015) found that sodium silicates (18 mg-Si/L, pH 7.3 and pH 6.3) did not control copper when compared to treatment by phosphate (0.8 mg-PO_4/L, pH 7.3). The authors noted that silicate performance was affected by pH and suggested that water quality conditions could affect sodium silicate performance

7.7.3 Mitigation of blue water events

Blue water remains a poorly understood phenomenon, and there is limited guidance on its management. Short term management strategies include identified heat-shock (> 60ºC) (Arens et al., 1996) or a one-time super chlorination Edwards et al. (2000), although the blue water could reoccur. Arnold et al. (2012) found that NOM removal through GAC provided a practical long-term solution for a blue water issue.

Sequestering agents, such as polyphosphate, will mask the copper release, improving the aesthetic quality without decreasing copper levels and may, in some cases, increase copper levels. Cantor et al. (2000) reported on an incident in Wisconsin, where polyphosphates were used to sequester iron in one of three communities with a hard, high alkalinity groundwater. Subsequent to this treatment, copper related illness were reported to and confirmed by the Wisconsin Department of Health and Family Services (Knobeloch et al., 1994). The highest copper levels (up to 5 mg/L) were found in new and newly remodeled homes and the levels decreased over time once polyphosphate was no longer dosed (Cantor et al., 2000). Generally, the use of sequestering agents is not recommended for mitigating copper release.

7.7.4 Mitigation of copper pitting and dezincification

Given the variety of water quality, microbiological and flow condition factors that can affect the propensity towards copper pitting, utilities should consider using the tools such as those found in Sarver et al. (2011). These tools help utilities avoid or mitigate copper pitting and address key water quality changes including the removal of NOM, phosphate, silicate as well as waters with chlorine, high pH or low alkalinity. In addition, utilities should conduct pilot-testing to evaluate their particular water quality and any proposed or potential changes to water quality to both diagnose a problem and to identify workable solutions (Lytle and Schock, 2008; Lytle et al., 2012). A low-cost pipe-loop system is described in Lytle et al. (2012) and could serve as an evaluative tool for utilities.

The water quality conditions associated with a tendency towards dezincification are not as clearly characterized when compared to the copper pitting phenomenon. However, high alkalinity low chloride water is associated with decreased dezincification (Sarver et al., 2011). Lytle and Schock (1996) found that orthophosphate did not provide a clear benefit at pH 7 and 8.5 although they suggested that orthophosphate might be more effective for copper leaching from brass at pH 6.5 (Lytle and Schock, 1996). Sarver et al. (2011) suggested that utilities determine the aggressiveness of their particular water quality towards brass alloys and communicate this information to stakeholders (consumers and developers), and encourage the use of dezincification resistant brass alloys.

7.8 Impact of copper ions on lead release

Copper has also been observed to play a role in lead release in downstream plumbing. Clark et al. (2015) observed copper deposition onto lead surfaces in certain water conditions significantly increased lead release. The copper deposits were hypothesized to act as small galvanic connections on the lead surface. The solubility of copper directly correlated to copper deposition and release of lead. Based on bench-scale experiments, Hu et al. (2012) deduced that between 37- 92% of the Cu^{2+} in chloraminated water and 62-91% of Cu^{2+} in chlorinated water accumulated on new lead pipe under stagnation conditions. Copper deposition was also observed to be affected by flow and stagnant conditions, as lead release was greatest from the chlorinated system under flow-through conditions; whereas lead release was greatest from the chloraminated system under stagnant conditions. Although, the specific water quality and flow conditions that exacerbate the effects of copper deposition still require further investigation, the role of copper deposition on lead release could be a significant consideration when upstream copper tubing is followed by lead bearing materials, such as in the case of partial lead service line replacements.

7.9 Residential scale

It is not generally recommended that drinking water treatment devices be used to provide additional treatment to municipally treated water. However, as the primary source of copper in drinking water is the leaching from plumbing and distribution system components, a private residential drinking water treatment device is the best option for reducing copper concentrations in drinking water at the tap. However, the use of such devices should not be considered to be a permanent solution.

Before a treatment device is installed, the water should be tested to determine general water chemistry and to verify the concentration of copper. Periodic testing by an accredited laboratory should be conducted on both the water entering the treatment device and the finished water to verify that the treatment device is effective. Products that use adsorption technology can lose removal capacity through usage and time and need to be maintained and/or replaced. Consumers should verify the expected longevity of the adsorption media in their treatment device as per the manufacturer’s recommendations and service the device when required.

Health Canada does not recommend specific brands of drinking water treatment devices, but it strongly recommends that consumers use devices that have been certified by an accredited certification body as meeting the appropriate NSF/ANSI drinking water treatment unit standard(s). These standards have been designed to safeguard drinking water by helping to ensure the material safety and performance of products that come into contact with drinking water. Certification organizations provide assurance that a product conforms to applicable standards and must be accredited by the Standards Council of Canada (SCC). In Canada, the following organizations have been accredited by the SCC to certify drinking water devices and materials as meeting NSF/ANSI standards (SCC, 2016):

- CSA Group (www.csagroup.org);
- NSF International (www.nsf.org);
- Water Quality Association (www.wqa.org);
- UL LLC (www.ul.com);
- Bureau de normalisation du Québec (www.bnq.qc.ca – available in French only);
- Truesdail Laboratories (www.truesdail.com); and
- International Association of Plumbing & Mechanical Officials (www.iapmo.org).

An up-to-date list of accredited certification organizations can be obtained directly from the SCC (2016).

Drinking water treatment devices can be installed at the faucet (POU) or at the location where water enters the home (point-of-entry or POE) in residential settings to reduce contaminant concentrations. POU systems are preferred for the removal of copper, as copper levels may increase in the plumbing system and because exposure to the contaminants from drinking water is a concern only if the contaminants are ingested (i.e., inhalation and dermal absorption are not significant routes of exposure). As such, POU treatment devices installed at individual drinking water taps are considered to be the best approach to reduce concentrations to safe levels immediately before consumption or for preparation of food or beverages.

A number of certified residential treatment devices are available that can remove copper from drinking water to below the proposed MAC of 2 mg/L. Adsorption (i.e., carbon block/resin), RO and distillation technologies are effective treatment technologies at the residential scale for the removal of copper at the tap. Certified residential treatment devices using adsorption, RO and distillation are currently available for the reduction of copper in drinking water.

For a drinking water treatment device to be certified to NSF/ANSI Standard 53 (Drinking Water Treatment Units—Health Effects) for the removal of copper, the device must be capable of reducing an influent copper concentration of 3 mg/L to a maximum final (effluent) copper concentration of less than 1.3 mg/L (NSF/ANSI, 2015b). Treatment devices that are certified to remove copper under NSF/ANSI Standard 53 are generally based on activated carbon adsorption technology.

RO systems certified to NSF/ANSI Standard 58 (Reverse Osmosis Drinking Water Treatment Systems) may also be certified for the reduction of copper to achieve a final concentration below 1.3 mg/L (NSF/ANSI, 2015c). RO systems certified to this standard are intended for POU installation only. This is because water treated by an RO system may be corrosive to internal plumbing components. RO requires larger quantities of influent water to obtain the required volume of drinking water, because these systems reject part of the influent water. A consumer may need to pretreat the influent water to reduce fouling and extend the service life of the membrane.

Distillation systems certified to NSF/ANSI Standard 62 (Drinking Water Distillation Systems) can also be certified for the reduction of copper to achieve a final concentration below1.3 mg/L (NSF/ANSI, 2015d). Distillation systems that would be certified to this standard are also intended for POU installation, for the same reasons described above. The distillation process is effective for the reduction of copper, but requires an electrical energy input.

Health Canada strongly recommends that any components used in these treatment systems be certified to NSF/ANSI Standard 61- Drinking Water System Components Health Effects (NSF/ANSI, 2016a) and NSF/ANSI Standard 372 – Drinking Water Systems Components Lead Content (NSF/ANSI, 2016b).

8.0 Toxicokinetics

The toxicokinetics, storage and handling of copper are regulated by homeostatic mechanisms (Petris et al., 1996; Peña et al., 1999).

8.1 Absorption

In humans, dietary Cu(II) is mainly absorbed from the upper gastrointestinal (GI) tract after oral exposure, with maximum absorption occurring within1-3 hours of exposure (Linder, 1991; Lonnerdal, 1996; Tapiero et al., 2003; Stern et al., 2007; Shike, 2009; Corkins, 2011).

Studies on copper absorption in humans are limited; mean absorption rates of 50–55% (range, 12–60%) have been reported for normal copper intakes (0.6–1.6 mg/day) from mixed diets, as was a theoretical maximum absorptive capacity of 63–75% (Turnlund et al., 1989; Wapnir, 1998; NRC, 2000; Tapiero et al., 2003; Turnlund et al., 2005; Klevay, 2010; Collins and Klevay, 2011; EFSA, 2015; Ellingsen et al., 2015). However, with typical diets in developed countries, copper absorption is considered to average 30–40% (Wapnir, 1998). Dietary Cu(II) absorption is modulated by several factors, including an individual's copper status and intake, age, the amount of metal in the GI tract, the valence state, and the presence of other dietary factors or (essential and nonessential) competing metals (Turnlund et al., 1989; Wapnir, 1998; NRC, 2000; EFSA, 2006; Stern et al., 2007; van den Berghe and Klomp, 2009; Stern, 2010; Collins and Klevay, 2011; de Romana et al., 2011; Gaetke et al., 2014). Although limited, human studies using different methodologies (e.g., fecal copper excretion, ^{65}Cu retention) have demonstrated that absorption rates vary inversely with dietary copper intake. More specifically, absorption rates higher than 50% have been reported with copper intakes below 1 mg/day whereas absorption rates less than 20% have been reported with copper intakes above 5 mg/day(Turnlund et al., 1989, 1998; Stern et al., 2007). In contrast, copper retention (or balance) increases with increasing dietary intakes.). For example, an increase in copper retention from 0.06 mg/day when dietary intake was 1.6 mg/day to 0.67 mg/day with dietary intake of 7.8 mg/day was reported. However, the amount retained decreases with time, suggesting restoration of normal balance over time (Turnlund et al., 2005).

The solubility of Cu(II) complexes influences their bioavailabilities (OEHHA, 2008; Mauceri and Mishra, 2014; EFSA, 2015). This was observed in a study by Lind and Glynn (1999) in which high levels of Cu(II) were measured in the blood of rats given copper in deionized water as compared to rats given a fulvic acid mixture in infant formula. Furthermore, developmental stage has been reported to influence Cu(II) absorption, with higher intestinal absorption anticipated in neonates (Lonnerdal, 1998; Bauerly et al., 2005; Collins and Klevay, 2011). This may be explained by immature digestive and homeostatic copper mechanisms (WHO, 2004; Araya et al., 2005a; Collins and Klevay, 2011). Finally, it has been suggested that Cu(II) absorption increases during pregnancy and cancer (Tapiero et al., 2003).

8.2 Distribution

Upon release from the GI tract, Cu(II) is immediately bound to either albumin, transcuprein, or low-molecular weight molecules (e.g., peptides and amino acids, especially histidine) before it reaches the hepatic portal circulation (Linder, 1991; IPCS, 1998; Linder, 2002; Talcott, 2013; Ellingsen et al., 2015). During this first pass, around 40% of copper is taken up by the liver (Gaetke et al., 2014; Pal, 2014; EFSA, 2015). Cu(II) then reaches the post-hepatic circulation bound to ceruloplasmin (Cp) for distribution throughout the body. Hence, under human physiological conditions, plasma copper is usually viewed in two pools, one covalently bound to Cp (about 75-98% of plasma copper) and the remainder (about 7% or less), also known as 'free copper', which is loosely bound to albumin and low-molecular weight molecules (IPCS, 1998; Bradberry, 2007; Montes et al., 2014; Ellingsen et al., 2015). Cp is a ferroxidase synthesized and bound to copper within the liver, for the delivery of the nutrient to peripheral tissues (OEHHA, 2008; Shike, 2009; Montes et al., 2014). Consequently, increases in copper and Cp parallel one another (Turnlund et al., 2004). Moreover, Cp is an acute phase protein that levels and activity can be increased by hormone replacement therapy (e.g., oral contraceptives, steroid hormones), response to several physiological alterations (e.g., inflammation, some non-specific diseases, some cancers, pregnancy and other hormonal perturbations) and smoking

(Kehoe et al., 2000; Turnlund et al., 2004; Shike, 2009; Collins and Klevay, 2011). There is a well-documented sex difference in Cp levels and activity with women exhibiting higher levels (Kehoe et al., 2000).

"Free copper" mostly includes free Cu(I) and Cu(II) and, to a lesser extent, complexes of these ions with labile ligands, in body fluids (Donnelly et al., 2007). In addition, 'free copper' constitutes the bulk of the exchangeable copper pool in blood plasma and (presumably) interstitial fluid which levels have been estimated around 2×10^{-16} M or 43±30 mg (Linder, 2001; Harvey et al., 2005). Its levels are tightly controlled by homeostatic mechanisms (IOM, 2001; Bertinato and L'Abbe, 2004; Cockell et al., 2008; Collins and Klevay, 2011) and very low within cells (Rae et al., 1999; Rosenzweig, 2001; Prohaska, 2008; Boal and Rosenzweig, 2009; Kaplan and Lutsenko, 2009; Brewer, 2010). Some of these mechanisms are materialized by: transporters such as ATP7A, ATP7B(Kim et al., 2008; Qian et al., 2012; Montes et al., 2014), storage proteins such as metallothionein (Tapia et al., 2004) and chaperones such as copper chaperone for superoxide dismutase (SOD), cytochrome c oxidase copper chaperone (COX17) and ATOX1 (Shike, 2009; Bertinato et al., 2010; Boveris et al., 2012; Talcott, 2013).

Thus, copper is distributed to all tissues (including the liver) as Cu(II)-Cp bound and a volume of distribution of 1.95L/kg has been estimated in healthy individuals (OEHHA, 2008; Shike, 2009; Montes et al., 2014). The average total body content of copper is about 110 mg (range, 50-150 mg) (Turnlund et al., 2005), with approximately 50% being found in muscle and bone; however, its highest concentrations are found in the liver (about 40µg/g dry weight or 8-10% of the body's total content) and the brain (about 5 µg/g) (Prohaska, 1990; Turnlund, 1998; Gaggelli et al., 2006; Gurusamy and Davidson, 2007; Madsen and Gitlin, 2007; Collins and Klevay, 2011; Kumar et al., 2015). It is noteworthy that in humans of all ages, there are documented sex differences in plasma copper levels. Women, particularly those taking estrogens, have higher plasma levels (Ellingsen et al., 2015). In humans, fetal copper levels increase during gestation, reaching their maximum around the third trimester (13-1,218 µg/g wet weight), then decline with age (Zlotkin et al., 1995; Lonnerdal, 1996; Bauerly et al., 2005; Michaluk and Kochman, 2007). Quantitative estimates of copper in infant livers are quite variable. Hepatic levels above 90% of the total body copper (4–5 mg/kg bw) have been reported for neonates (WHO, 1996). In contrast, in one study, neonatal levels similar to adults were reported, while in another, neonatal to adult ratios as high as 16:1were suggested (EFSA, 2015 and references therein).

8.3 Metabolism

Copper metabolism involves all the processes implicated during its absorption, distribution, biotransformation and utilization by cells within the body. The intestines and liver are the key metabolic organs and steps within each of them could be considered as pre-systemic and post-systemic metabolism, respectively.

8.3.1 Pre-systemic metabolism

In mammals, ingested Cu(II)is first reduced to Cu(I) by enterocyte metalloreductases for either storage by metallothionein (MT), use by intestinal enzymes or blood absorption (by the transporter affected by Menkes disease). Upon leaving the gut, Cu(I) is reoxidized to Cu(II), bound to albumin, and then secreted into the portal circulation (Peña et al., 1999; Shike, 2009; Ellingsen et al., 2015).

8.3.2 Post-systemic metabolism

The liver plays a key role in storage, uptake regulation and biliary excretion (Talcott, 2013; Ellingsen et al., 2015). When Cu(II)-albumin enters hepatocytes, it is first reduced to Cu(I). The latter is further complexed by glutathione (GSH) before being incorporated as Cu(I)-GSH complex into either MT (for storage) or various copper chaperones. Later, these chaperones transfer copper to Cp or the numerous copper-requiring nascent apo-proteins within the hepatocytic cytoplasm and subcellular compartments. However, the most significant of these hepatic copper metabolism pathways is the transfer of copper from a chaperone to ATPase7B (the transporter affected in Wilson's disease) with further coupling to Cp. The Cu(II)-Cp complex is then either excreted into the bile or secreted into systemic circulation (IPCS, 1998; Roelofsen et al., 2000; Linder, 2002; Bradberry, 2007; de Romana et al., 2011; Boveris et al., 2012; Gitlin, 2014).

8.4 Elimination

In humans, absorbed copper is primarily excreted from the body by feces (up to 98% or ~2,500 µg/day), and, to a lesser extent, through urine, sweat, menses, and hair (Turnlund et al., 1990; Wijmenga and Klomp, 2004; Stern et al., 2007; Mauceri and Mishra, 2014). Biliary copper excretion accounts for almost all of the fecal copper and is proportional to dietary copper to some degree (Linder, 1991; Turnlund et al., 1998; Harvey et al., 2005; Stern et al., 2007). It represents the main mechanism of regulating total body copper (Scott and Turnlund, 1994; Turnlund, 1998; Miller et al., 2006; van den Berghe and Klomp, 2009). 12-days averaged daily fecal excretion of 100% (1.6 mg/day) and 91% (7.1 mg/day) have been reported in 9 men after 18-day exposure to low (1.6 mg/day) and high (7.8 mg/day) dietary intakes, respectively (Turnlund et al., 2005). It is noteworthy that, in contrast, intravenous infusion of 460 µg ^{63}Cu resulted in significantly higher ($p < 0.05$) excretion (46%) during high intakes than during low intakes (27%; standard error = 2.3) (Turnlund et al., 2005).

Quantitative estimates of urinary excretion are scarce. However, excretion increases with increasing intakes (Turnlund et al., 2004, 2005) and average levels lower than 3% are generally reported (WHO, 1996; Turnlund et al., 2004, 2005). Turnlund et al. (2004, 2005) reported average urinary excretion for 9 men of 26 µg/day and 20 µg/day (range, 18.5–30.9; standard error on the means = 3.3) during high (7.8 mg/day) and low (1.6 mg/day) intake period, respectively. Even if the authors didn't estimate daily losses in hair, they found significantly increased hair concentrations (mean ± standard deviation [SD]) during periods of high copper dietary intakes as compared to low intakes: from 9.2 ± 3.1 to 21.1 ± 5.9 µg/g hair (range, 3–40 µg/g hair), as measured on the 15th day of a 18-day exposure period (Turnlund et al., 2004, 2005). These levels were not significantly different between subjects (Turnlund et al., 2004). Linder (1991) has estimated a total daily excretion from hair, nails, skin, and sweat of 200 µg in adults. A half-life of 2–5 weeks was estimated for copper in healthy adults following oral administration (Ellingsen et al., 2007). Biliary excretion is limited in early life due to a poorly developed biliary transport system at the time of birth. Excretory losses of 50 µg/kg bw per day have been estimated for infants (Aggett, 1999).

9.0 Health effects

9.1 Effects in humans

9.1.1 Essentiality

Copper is an essential element. Its ability to cycle between the oxidized (Cu(II)) and reduced (Cu(I)) forms provides the catalytic properties of various metalloenzymes that are necessary for metabolism (e.g., of glucose) and cellular respiration (e.g., SOD, cytochrome c oxidase) (IOM, 2001; Bertinato and L'Abbe, 2004; Gitlin, 2014). Moreover, copper plays a role in many physiological processes including neurological, immunological, connective tissues formation, thermal regulation and erythropoiesis (Tapiero et al., 2003; Stern et al., 2007; Gambling et al., 2011).

Copper deficiency can lead to abnormalities of these systems; cases of copper deficiency have been reported in premature infants fed unfortified milk formulas, in severely malnourished infants with chronic diarrhea, and in patients receiving chronic parenteral nutrition without copper supplementation (IOM, 2001). Copper deficiency is characterized by anemia, leukopenia, neutropenia, neurological and bone abnormalities, among other symptoms. Deficiency is not expected in the Canadian population, as food is the main source of intake, and the Canadian TDS (Health Canada, 2011) shows that the population is meeting the recommended daily allowances (RDAs) established by the Institute of Medicine (IOM, 2001) and Health Canada (2010). The RDA is “the average daily intake level sufficient to meet the nutrient requirements of 97.5% of the apparently healthy population of a given sex and age” (de Romana et al., 2011). RDAs for copper have been established at 900 µg/day for adults (19–70+ year-old) of both genders and 340–890 µg/day for children (1 to ≤ 18 years old) (IOM, 2001; Health Canada, 2010). No RDA was established for infants, but adequate intakes of 200 µg/day for 0–6 month-olds and 220 µg per/day for 7–12 month-olds were established based on copper levels in human milk (200–250 µg/L).

Due to the potential for adverse health effects from ingestion of high amounts of copper, tolerable upper intake levels (ULs) have been estimated at 1,000 µg/day for 1–3 year-olds, 3,000 µg/day for 4–8 year-olds, 5,000 µg/day for 9–13 year-olds, 8,000 µg/day for 14–18 year-olds, 10,000 µg/day for those ≥19 year-olds, and 8,000–10,000 µg/day for pregnant and lactating women (IOM, 2001). The ULs were based on absence of liver or GI effects in a small and poorly detailed 12-week double-blind study of back-pain management in seven human adults (Pratt et al., 1985), indicating no adverse effects of diets contributing 10 mg/day of copper, as the gluconate salt.

9.1.2 Copper toxicity syndromes

Copper dyshomeostasis can cause adverse health effects including conditions resulting from inherited metabolic disorders such as Menkes’ disease (MKD) and Wilson’s disease (WD) (Cockell et al., 2008; Govindaraju et al., 2013; Gaetke et al., 2014; Jazvinscak Jembrek et al., 2014).

MKD, a rare X-linked recessive disorder, results from a mutation on the gene encoding ATP7A translocase. Symptoms in patients with MKD are consistent with those of a severe copper deficiency. Thus, MKD (and its milder variant occipital horn syndrome [OHS]) is characterized by reduced systemic Cu(II) absorption from the gut and blood-brain barrier, excessive copper accumulation in gut mucosa, low serum copper and Cp levels and low copper levels in liver and brain (NRC, 2000; Shike, 2009; Montes et al., 2014; Ellingsen et al., 2015).

Most MKD patients die during early childhood (within their first 10 years, usually before three years of age) while OHS patients may live longer (Kaler, 1998; Camakaris et al., 1999; Schaefer and Gitlin, 1999).

WD (an hepatolenticular degeneration) is a monogenic autosomal recessive disorder that results from one mutation, among over 500 identified, in the gene encoding ATP7B translocase (Harris and Gitlin, 1996; Schilsky, 1996; Shike, 2009; Boveris et al., 2012; Bandmann et al., 2015; Ellingsen et al., 2015; Kumar et al., 2015). WD is characterized by impaired biliary excretion of excess copper, deficient efflux of copper from cells, impaired ceruloplasmin synthesis, which results in copper accumulation in certain tissues (particularly the liver, brain and kidneys). Consequently, WD patients frequently experience liver failure (e.g., disease, cirrhosis) and a variety of neuropsychiatric/behavioral symptoms (Das and Ray, 2006; Machado et al., 2008; Shike, 2009; Montes et al., 2014).Usually, liver dysfunction occurs in the first decade of life and neurological dysfunction in the second (Ala et al., 2007). WD patients are normally under medical supervision. Heterozygous carriers of the defective WD gene have been speculated to be sensitive populations, but evidence for this, other than increased hepatic copper levels, is lacking (IPCS, 1998; NRC, 2000; WHO, 2004).

Other extremely rare but well documented childhood copper toxicosis conditions are: Indian childhood cirrhosis (ICC, a condition primarily affecting children under 5 years old), endemic Tyrolean infantile cirrhosis (TIC), and idiopathic copper toxicosis (ICT) (Madsen and Gitlin, 2007; Pal, 2014). These diseases are characterized by extremely high copper concentrations in the liver during early childhood, leading to liver enlargement, pericellular fibrosis, necrosis, and even death (Muller et al., 1996; Tanner, 1998; Johncilla and Mitchell, 2011). However, the etiology of these syndromes seems more complex, potentially involving, in addition to genetic components, environmental factors (e.g., very high copper intakes) (Olivares and Uauy, 1996; Scheinberg and Sternlieb, 1996; ATSDR, 2004; OEHHA, 2008; Shike, 2009; Ellingsen et al., 2007, 2015). Finally, individuals with glucose-6-phosphate dehydrogenase deficiencies may be sensitive to haemolytic anemia in response to copper overexposure (OEHHA, 2008).

9.1.3 Case reports

There are several reports of ingested copper poisoning with the main targets including the GI tract, liver, kidneys and haematopoietic/central nervous systems (IPCS, 1998; NRC, 2000).

During 1992 and 1993, the Wisconsin Division of Health investigated cases of gastrointestinal upsets thought to be related to copper in drinking water. They concluded that the symptoms occurred most frequently in infants and children and among residents of newly constructed or renovated homes (Knobeloch et al., 1994). In adults, anecdotal reports suggest that the immediate symptoms following the consumption of contaminated beverages or drinking water include a metallic taste and GI disruption (e.g., nausea and epigastric pain and vomiting combined, diarrhea), usually occurring like symptoms of food poisoning, within 15–60 minutes, and at concentrations as low as 3–4 mg Cu(II)/L drinking water. Nausea and vomiting (generally not persistent) are usually more common than diarrhea. Anorexia, headache, dizziness, hypotension and shock have also been reported. Delayed symptoms, at higher doses, include anemia, hemoglobinuria, jaundice, liver and renal failure, and even death. Histological findings upon autopsy include kidney lesions (e.g., glomeruli congestion, necrosis) and gastric mucosa erosions (Wyllie, 1957; Spitalny et al., 1984; Mehta et al., 1985; Gulliver, 1991; Araya et al., 2001). Rhabdomyolysis (muscle injury) has also been reported (Jantsch et al., 1984; Takeda et al., 2000).

In children, limited data indicate similar effects. Indeed, case reports have attributed adverse effects (e.g., diarrhea and weight loss) to levels ranging from 0.22 to 1.0 mg Cu(II)/L drinking water (Stenhammar, 1999) or 1.0 to 6.5 mg Cu(II)/L drinking water (Berg et al., 1981). Also, neonates and infants appear to be more sensitive due to their enhanced intestinal absorption and immature hepatobiliary system (Collins and Klevay, 2011).

Finally, there are few case reports of chronic exposure. According to the available data, chronic ingestion of excessive copper may cause GI effects in infants, and liver and renal failure in adults (O'Donohue et al., 1993, 1999; Stenhammar, 1999; Cech et al., 2006; Stern et al., 2007).

9.1.4 Short-term exposure

Gastrointestinal symptoms, usually defined in most studies as the occurrence of one or more outcome symptoms of nausea, epigastric pain, vomiting, or diarrhea, have been identified as primary effects from short-term exposure to ingested Cu(II). Nausea is the earliest (occurring within 15 minutes to one hour) and most frequent symptom and is transient (Pizarro et al., 1999a; Pizarro et al., 1999b; Araya et al., 2001; Olivares et al., 1998; 2001).

In a double-blind randomized prospective study consisting of sixty healthy Chilean women (15/group), acute GI effects from ingested copper were identified by (Pizarro et al., 1999b) following a two-week-exposure to drinking water with at least 3 mg Cu(II)/L (as copper sulphate). In this study, GI effects (nausea, abdominal pain, or vomiting) were significantly increased (overall $\chi^2 = 11.3$, $p<0.01$) but not diarrhea. Although thresholds for specific symptoms could not be derived, nausea was identified as a good indicator for the effects evaluation. Also, there was a range of sensitivity among subjects and most symptoms disappeared when the exposure ceased. Therefore, a lowest observed adverse effect level (LOAEL) of 3 mg Cu(II)/L based on nausea, abdominal pain, and vomiting combined can be identified from this study.

With nausea identified as the earliest symptom of GI effects, several efforts were conducted to estimate a dose threshold. Olivares et al. (2001) used a randomized, Latin square design to administer 0, 2, 4, 6, 8, 10, or 12 mg Cu(II)/L purified water or orange-flavored drink, as copper sulphate, to apparently healthy Chilean adults. In this study, the subjects (47–61/group) received, after an overnight fast, a fixed volume of 200 mL of the solution, during a 1-hour session, once per week, for a theoretical maximum of 12 weeks. This resulted in exposure dose of 0, 0.4, 0.8, 1.2, 1.6, 2 and 2.4 mg Cu(II), respectively. There were no age- or gender-related differences between the groups and no observed response up to 0.4 mg (= no observed adverse effect level [NOAEL] based on nausea). However, mild nausea shortly after ingestion was most frequently reported, starting at 0.8 mg Cu(II), then plateauing at 1.6–2.4 mg. The vomiting incidence, which first appeared at 1.2 mg, was low (11.5%), with a two-fold increase between 2 and 2.4 mg. The concomitant occurrence of nausea and vomiting was less frequent, with the highest incidence at 2.4 mg (12% of subjects). Diarrhea and abdominal cramps were rare within the range of concentrations studied. Because a range of sensitivity had been reported earlier (Pizarro et al., 1999b), the authors used a benchmark dose (BMD) approach to derive the lower bound on the 95% confidence interval (CI) on the drinking water concentration that would produce a response in 5% of the population ($BMDL_{05}$). The resulting $BMDL_{05}$ were 0.4 mg Cu(II) (2 mg/L) and 0.84 mg Cu(II) (4.2 mg/L) for apparent and confirmed cases of nausea, respectively. The $BMDL_{05}$ for apparent cases of nausea is very close to the NOAEL of 0.4 mg Cu(II) based on nausea; the LOAEL based on nausea was 0.8 mg Cu(II), which was also the NOAEL for vomiting.

The same group of investigators reported on a prospective, double-blind controlled multi-site (Chile, Northern Ireland and United States) phase I study in apparently healthy adult volunteers, also designed to determine the nausea threshold (Araya et al., 2001). After an overnight fast, subjects (179/group) were randomly given 0, 0.4, 0.8, 1.2, or 1.6 mg Cu(II) (as copper sulphate salt) in a bolus of 200 mL distilled-deionized water (equivalent to 0, 2, 4, 6, or 8 mg Cu(II)/L) once per week over five consecutive weeks. The results also suggested that women may be more sensitive. As copper dose increased, female subjects reported significantly more occurrences of nausea and GI symptoms than male subjects (odds relative to males, 2.66, $p < 0.004$; and 1.68, $p< 0.05$, respectively). Nausea, which was transient, was the most prevalent symptom (average prevalence = 27.3% among all subjects) and was frequently reported within the first fifteen minutes. Also, there was a clear dose-response to (1) combined positive GI symptoms (nausea, vomiting, diarrhea or abdominal pain) and (2) nausea alone. Statistically significant greater reporting of effects occurred at 1.2 and 1.6 mg Cu(II). Unlike abdominal pain and diarrhea, nausea and GI symptoms as a whole were strongly predicted by Cu(II) concentrations, with incidences significantly increasing ($P < 0.0001$) with increasing concentrations (odds of 0.66; 3.53, 7.67, and 17.15 for nausea and 0.87, 1.83, 3.54, and 7.29 for GI symptoms, for 2, 4, 6, and 8 mg/L, respectively; $p < 0.0001$). Both nausea and other GI symptoms were significantly increased ($p < 0.002$) at 1.2 mg Cu(II) but not at 0.8 mg Cu(II) (LOAEL and NOAEL, respectively). The performed dose-response modeling determined that the $BMDL_{05}$ for nausea alone was 0.7–0.8 mg Cu(II) (3.5–4 mg/L). The upper bound of this latter range is similar to the NOAEL of 0.8 mg based on nausea and other GI symptoms. Overall, the findings (nausea occurrence, no correlation with diarrhea and a LOAEL ≥ 3 mg Cu(II)/L) were consistent with that from Olivares et al. (2001) and Pizarro et al. (1999b).

The above phase I results from Araya et al. (2001), in which copper was delivered in distilled-deionized water, were confirmed in the phase II of this study (Araya et al., 2003a) in another multi-sites double-blind study in 269 adult women receiving Cu(II) sulphate in 200 mL bottled natural spring water, once per week, for 11consecutive weeks. In this study, a 3 × 3 two-way factorial design was used to administered to the subjects (58 to 73/site) 0.4, 0.8, 1.2 mg Cu(II) as the sulphate salt in 100, 150 and 200 mL of water. The 0 and 1.6 mg Cu(II) doses were added at the 200 mL level. It is worth noting here that, all the other short-term studies used a constant dosing volume of 200 mL. The results from (Araya et al., 2003a) showed that both the copper dose ($p = 0.0001$) and the volume of water ($p = 0.032$) significantly contribute to the nausea incidence. The latter increased with increase in copper dose, and decrease in water volume. In addition, a benchmark dose (BMD) analysis was performed for nausea incidence for the 200 mL bolus dose. The calculated BMD for a 10% response was 0.94 mg Cu(II) (4.8 mg/L; $p = 0.94$) and the corresponding $BMDL_{10}$ was 0.84 mg Cu(II) (4.2 mg/L). The $BMDL_{10}$ is very close to the NOAEL of 0.8 mg Cu (II) (4 mg/L); this NOAEL identified for women is also the same as the NOAEL based on nausea and other GI symptoms identified for both men and women in the phase I of the study by Araya et al. (2001).

Overall, from the above short-term studies, the lowest effect level identified is a $BMDL_{05}$ of 0.7 mg (or 3.5 mg/L) based on nausea alone and non-continuous exposure (Araya et al., 2001).

9.1.5 Long-term exposure

Chronic copper toxicity is usually observed in patients with Wilson's disease, hemochromatosis and infantile cirrhosis (Olivares et al., 1998; Mauceri and Mishra, 2014). While WD involves more than simple accumulation of copper, it is likely that some of the typical WD symptoms are related to long-term exposure to excessive copper (see section 9.1.2). However, the current evidence, mostly from mechanistic data, as well as limited case and clinical studies, indicates that in the general population, chronic exposure to very high levels, above those associated with GI illnesses, may lead to liver and renal damage (O'Donohue et al., 1993; IPCS, 1998; O'Donohue et al., 1999; Pizarro et al., 1999b; Stenhammar, 1999; Stern et al., 2007).

9.1.5.1 Gastrointestinal effects

Araya et al. (2004) conducted a randomized, double-blind, two-month-community-based study on 1365 apparently healthy adults (327 to 355/test group) receiving up to 6 mg Cu(II)/L. Copper-containing water was used for drinking and the preparation of other beverages (e.g., tea, coffee, infusions, and soups) and mean fluid consumption was 1.5 L/day. Unlike the previous findings from short-term exposure (Pizarro et al., 1999b; Araya et al., 2001, 2003a; Olivares et al., 2001), abdominal pain and nausea were most prevalent and symptoms reporting significantly decreased over time for both sexes, suggesting an adaptive response. However, more importantly, a LOAEL of 6 mg Cu(II) (4 mg/L) was identified in women, the most sensitive population. This LOAEL which was no longer valid by week 4, is similar to the $BMDL_{05}$ of 4 mg/L, based on nausea, identified previously for short-term exposure (Araya et al., 2001, 2003a; Olivares et al., 2001). Also, as with the short-term studies, the symptom risks were positively associated with copper concentration and the female sex, and negatively related to time. In fact, the risk of GI effects was significantly higher in female during the first week, but this was no longer the case by week 4. Overall, the authors found that Cu(II) concentration and dosing volume were the main determinants of the response, the applied dose and vehicle being less important.

A prospective study by Olivares et al. (1998) showed that infants who continuously received up to 31.48 µmol Cu(II)/L drinking water as copper sulphate (i.e., 2 mg/L) during the last nine months of their first year of life remained asymptomatic, grew normally, and did not present with significant increased risk of diarrhea when compared to those receiving less than 1.57 µmol Cu(II)/L (i.e., less than 0.1 mg/L). The main goal of this study was to verify the tolerance and safety of chronic exposure of infants to the previous provisional guideline value (WHO, 1993) for the general population. This placebo-controlled study randomly assigned 128 apparently healthy Chilean infants (3 months of age), from the same socioeconomic level and weighing more than 2 kg at birth, to receive, drinking water with either 1.57 µmol Cu(II)/L or 31.48 µmol Cu(II)/L, daily for 9 months. Breast-fed infants were exclusively breast-fed until at least 6 months of age and those given formula were partially or totally weaned from the breast by 3 months of age. More specifically, the 3-month olds infants were divided into four groups at the beginning of the study as follows: 1) group 1: formula-fed infants receiving 31.48 µmol Cu(II)/L (n = 56); 2) group 2: formula-fed infants receiving 1.57 µmol Cu(II)/L (n = 27); 3) group 3: breast-fed infants receiving 31.48 µmol Cu(II)/L (n = 24); and 4) group 4: breast-fed infants receiving 1.57 µmol Cu(II)/L water (n = 21). Mothers of breast-fed infants (groups 3 and 4) also received water with the corresponding Cu(II) levels. Thus, two litres of drinking water were prepared for consumption daily, by the mothers, either from a fresh copper sulphate-containing standard solution (0.8 g Cu (II)/L) for the exposed groups (1 and 3), or from an equivalent volume of placebo for the non-exposed groups (2 and 4). This placebo was not clearly defined except that it was organoleptically identical to the copper-based solution. The water for daily consumption was used for drinking, in preparation of meals, and in preparations (by dilution) of the powdered cow's milk and the powdered cow's milk-based formula. The latter was fortified with 7.87 µmol copper/L. Any additional water needed was prepared as per the same approach. Formula-fed infants started receiving solid food at 3 months of age whilst breast-fed infants began weaning and receiving unfortified cow's milk formula and solid food at 6 months of age. Although breast milk Cu(II) was not considered when calculating total intake, dietary copper from foods, milk formula and water used for meals and formula preparation was. During the study, a field worker visited each home weekly, recording water intake, GI, respiratory, and other illnesses, as recalled by mothers. Each infant also underwent monthly clinical and anthropometric evaluations. Overall, chronic ingestion of up to 31.48 µmol Cu/L by infants (in their formula [F], foods and drinking water), from three months to one year old, did not result in any acute or chronic effects. Specifically, there were no differences in morbidity episodes (i.e., diarrhea and respiratory infections) among the four studied groups, as indicated by the performed analyses. At 9 months, there was a significant difference in Cp activity between the Cu(II) exposed subjects (groups 1 and 3) as compared to the unexposed (groups 2 and 4) (350 ± 85 mg/L vs. 322 ± 75 mg/L; $F = 5.42$; $p = 0.02$), which was more pronounced in the breast-fed groups (groups 3 and 4). However, the overall copper status (based on serum copper levels, Cp protein levels or activity, erythrocyte Cu/Zn-SOD, erythrocyte metallothionein) of the infants did not significantly change at 6, 9, and 12 months of age. Also, no significant differences were found in the liver function (based on bilirubin, SGOT, serum glutamic pyruvic transaminase, and gamma glutamyl transferase [GGT]) among the infants at 6, 9, and 12 months of age. The authors reported the results for 3 time points (4 to 6 months, 6 to 9 months and 9 to 12 months). But as discussed earlier (section 9.1.3), infants are at increased risk of copper exposure during their first 6 months of life, when their hepatobiliary system is still immature. Since no toxic effect was reported for the entire studied period, results from the highest exposure window, months 4 to 6 (equivalent to a 4-month exposure), will be considered. According to the authors, for this exposure window, the corresponding figures for total daily intakes (mean ± SD) were: 318.7 ± 107.3 µg/kg bw per day (group 1); 122.7 ± 107.4 µg/kg bw per day (group 2); 52.2 ± 48.5 µg/kg bw per day (group 3); 37.8 ± 36.7 µg/kg bw per day (group 4).

9.1.5.2 Liver and renal effects

Liver toxicity from copper overexposure has mostly been studied and reported in sensitive populations (e.g., WD, childhood cirrhosis syndromes); however, there have been a few reports studying individuals from the general population. Indeed, a significant transient increase in liver enzyme activities (glutamic-oxaloacetic aminotransferase (GOT), glutamic-pyruvic transaminase (GPT) and gamma glutamyl transferase (GGT); ANOVA p-value < 0.01) was observed in a prospective controlled trial in apparently healthy Chilean adults (n = 87, with serum Cp levels below the 0.05 and above the 0.95 quantiles of the distribution curve) receiving 10 mg Cu(II)/day(0.17 mg/kg bw per day assuming an average 60-kg adult) (as sulphate salt) in capsules for 60 days (Araya et al., 2005b). However, not only were the results within normal clinical ranges, but the participants remained asymptomatic and the increased liver enzyme activities ceased one year after the termination of the study.

In a double-blind study by Pratt et al. (1985), there was no evidence of liver or GI effects in seven adult humans supplemented with 10 mg Cu/day (0.08 mg/kg bw twice a day) as gluconate salt in capsules for 12 weeks. Furthermore, no significant changes were reported in:(1) hair, serum and urine copper levels; (2) hematocrit, serum triglycerides and cholesterol; and (3) serum enzymes such as alkaline phosphatase (AP), GGT, GOT and lactate dehydrogenase (LDH).

A European multi-sites, double-blind, placebo-controlled, food-trial also found no association between liver function and copper supplementation (in sequence: 0.05 mg/kg bw per day as copper sulfate salt, and 0.12 mg/kg bw per day as copper amino acid chelates) for 6 weeks (O'Connor et al., 2003).

No significant changes in indicators of liver function (aspartate aminotransferase (AST), alanine aminotransferase (ALT), GGT) were observed in adults who ingested up to 6 mg Cu(II)/L (0.10 mg/kg bw per day for an average 60-kg adult) as the sulphate salt for two months (Araya et al., 2003b).

Long-term exposure of infants and young children to drinking water containing copper was not associated with a significant increase in the prevalence of liver disease (Fewtrell et al., 1996; Olivares et al., 1998; Zietz et al., 2003a).

9.1.5.3 Biochemical effects

In general, the results of studies that lasted less than 3 months showed that copper supplementation did not alter the indexes of its status. Thus, no significant changes in markers of copper status (serum, erythrocyte, and mononuclear cell copper concentrations; serum Cp; non-Cp-bound copper pool; SOD activity) were detected in healthy adults given either up to 6 mg Cu(II)/L as the sulphate (~ 0.20 mg/kg bw per day for 2 L water/day) (Araya et al., 2003b, 2004; Mendez et al., 2004), tablets of 10 mg/day (0.17 mg/kg bw per day) copper sulphate for two months (Mendez et al., 2004), or diet supplemented with up to 6 mg Cu(II)/day (0.09 mg/kg bw per day) as the sulphate salt or amino acid chelates (Kehoe et al., 2000; Turnlund et al., 2004). However, some changes observed after supplementation for a longer period of time may suggest an adverse effect of high copper intake. Thus, a study was conducted in 9 men to determine the long-term effects of high copper intake (Turnlund et al., 2004). After a 5-month supplementation with up to 7.8 mg Cu(II)/day (0.11 mg/kg bw per day for an average 70-kg adult), changes were observed in several function markers. Indeed, for the immune function, there were significant decreases ($p < 0.05$) in the percentage of circulating neutrophils, serum interleukin 2R, and the antibody titer against the Beijing strain of influenza. For the antioxidant defense, the urinary thiobarbituric acid reactive substances (TBARS), an indirect measure of oxidative damage, was significantly higher ($p < 0.05$). Additionally, small but significant changes were observed in some indexes of copper status (e.g., Cp activity and SOD activity), although concentrations of plasma copper and Cp did not change (Turnlund et al., 2004).

In conclusion, for exposure less than 3 months, the results were negative. Indeed, adults supplementation with up to 0.17 mg/kg bw per day did not significantly alter the indices of liver damage (O'Connor et al., 2003; Araya et al., 2005b) or copper status (Kehoe et al., 2000; Mendez et al., 2004; Turnlund et al., 2004); the same picture was observed after long-term exposure to drinking water with up to 0.2 mg/kg bw per day (Araya et al., 2003b; Araya et al., 2004; Mendez et al., 2004). However, for exposure above 5 months, the results suggest adverse effect of high copper intake over longer period of time (Turnlund et al., 2004). Therefore, given the paucity of chronic exposure studies, perhaps such data (Turnlund et al., 2004) and the symptoms experienced by WD patients could shed light on the types of adverse effects that might be expected from chronic copper overexposure.

9.1.5.4 Neurotoxicity

Copper-enzymes play an essential role in neurological functions. Multiple reviews have reported conflicting results on the association between copper exposure and neurodegenerative conditions such as Alzheimer’s disease (AD) and Parkinson’s disease (Bush et al., 2003; Squitti et al., 2006; Rivera-Mancia et al., 2010; Tiffany-Castiglioni et al., 2011; Montes et al., 2014; Pal et al., 2014). For example, two case-control studies in Italy have found that serum copper levels were significantly higher in AD patients compared to age or sex-matched controls (P-value < 0.001) and correlated with lower neuropsychological scores; however, the copper serum levels reported were within normal range (Squitti et al., 2002; Brenner, 2003). Also, senile plaques and neuropils of the amygdala of 9 AD patients were found to contain significantly higher levels of copper compared with neuropils of the amygdala of 5 control subjects (P-value < 0.05) (Lovell et al., 1998) and compared with non-plaque regions of 2 AD patients, However, copper levels also correlated with those of zinc (Miller et al., 2006).

Other studies have not supported the above results. For example, copper levels in cerebrospinal fluid and serum were not significantly different between Alzheimer's disease patients (n = 26) and matched controls (n = 28) (Molina et al., 1998). In another study, patients with lower plasma copper had a significantly poorer performance on the AD's Assessment Scale-cognitive subscale compared with patients with higher plasma copper(ANOVA p-value < 0.001; all patients (n = 32) had normal plasma copper levels) (Pajonk et al., 2005). Finally, higher levels of AD biomarkers were correlated with lower plasma copper levels among AD patients (Mann-Whitney p-value = 0.03, total n = 29) (Kessler et al., 2006).

In conclusion, from the above results, it appears that the specific role of copper in neurodegenerative diseases, which are multifactorial, remains unclear.

9.1.6 Carcinogenicity

Numerous epidemiological studies have investigated the association between copper status or intake, serum copper and various types of cancers. In general, the evidence of the carcinogenicity of copper is inconclusive and there is no clear or substantiated evidence of an aetiological role of the nutrient in the cancer development in humans.

A case-control study in France (Senesse et al., 2004) found an increase in the odds of colorectal cancer in the highest quartile of copper intake compared to the lowest quartile (odds ration [OR] = 2.4, 95% CI 1.3–4.6, p-value <0.01). Another case-control study nested within a large Dutch chronic diseases cohort (n > 10,000) found an increased risk of death from cancer (OR = 3.7, 95% CI 1.5–9.1) in participants with serum copper > 1.4 mg/L compared to 1.1–1.4 mg/L after adjusting for BMI, cholesterol, education and blood pressure; however, important cofactors were not adjusted for (Kok et al., 1988). Furthermore, a nested case-control study (n = 133 cases, 241 controls) of a worker cohort (n = 5,000) in Washington also found an increased risk of cancer in subjects with serum copper at 126–276 µg/dL compared with those having 43–92 µg/dL (OR = 2.4, 95% CI 1.1–5.1). However, according to the authors, the findings rather suggested that increased serum copper was a consequence of the disease state, i.e., cancer (Coates et al., 1989). Finally, a nested case-cohort study from a random sample of cases (n = 46) from a cohort of English women found an increased odds of breast cancer (OR 3.2, 95% CI 1.1–9.4) for women with plasma copper above 1.3 mg/L compared to 1.0–1.2 mg/L after adjusting for age, weight, and family history; however, there was no dose-response and other factors could explain the association (Overvad et al., 1993). Moreover, many case-control studies have not supported associations between copper intake or serum levels and the risk of breast or oesophageal cancers (Cavallo et al., 1991; Dabek et al., 1992; Prasad et al., 1992). Furthermore, no association between copper intake and lung cancer was observed in a retrospective cohort study (Mahabir et al., 2010). In a cohort study of associations between multiple antioxidants and cancers in women, the risks of non-Hodgkin's lymphoma, diffuse large B-cell lymphoma or follicular lymphoma were not increased in participants with higher copper intake (Thompson et al., 2010).

In conclusion, the results from the above studies are equivocal since (1) individual exposure was poorly characterized and (2) increased serum copper concentrations might be related to alterations in copper handling as a result of disease state (cancer in this case). In addition, as has been mentioned earlier, more than 90% of serum copper is normally bound to Cp. The latter is an acute phase protein whose levels increase during stress (see section 8.2).

9.1.7 Genotoxicity

In general, copper is not expected to be genotoxic with normal intakes. However, increases in genotoxicity and oxidative damage have been shown in patients suffering from copper dyshomeostasis conditions (NRC, 2000). For example, DNA damage was observed in hepatocytes from patients with Indian Childhood Cirrhosis, and this was postulated to result from excessive accumulation of copper in the nucleus, leading to the production of free radicals (Prasad et al., 1996). Also, bulky DNA adducts (vs. 8-hydroxydeoxyguanosine adducts) were observed in the livers of Wilson's disease patients (Carmichael et al., 1995). Moreover, a 6-week-double-blind crossover trial (n = 15–17) found no significant differences in leucocyte DNA damage (Comet assay) in participants supplemented with 3 mg/day copper sulphate or 3 or 6 mg/day copper glycine chelates compared with the placebos (*t-test* p-value > 0.05) (O'Connor et al., 2003).

9.1.8 Developmental and reproductive toxicity

There is no convincing evidence of reproductive or developmental toxicity in humans related to oral copper intake (IPCS, 1998; NRC, 2000; EFSA, 2006; Heinemann et al., 2015). However, it should be noted that women with untreated WD frequently experience spontaneous abortions (NRC, 2000).

9.2 Effects on experimental animals

Copper toxicity varies between animal and chemical species, and target organs are primarily those involved in the absorption and excretion of the metal (i.e., liver, kidneys, forestomach). Liver and kidney toxicities were the main endpoints reported in young rodents exposed to high copper doses for short/sub-chronic durations, and recoveries suggestive of physiological adaptations to high copper intake have been observed in rats (Haywood, 1980, 1985; Haywood and Loughran, 1985; Haywood et al., 1985a, 1985b; Fuentealba and Haywood, 1988; Fuentealba et al., 1989a, 1989b). Effects on the central nervous system have also been observed; however, the body of evidence for these effects is weak and inconclusive. Exposure to high levels of copper via drinking water appears to be more toxic than via the diet, and rats were generally more sensitive than mice. Copper salts, and particularly Cu(II) sulphate, were commonly used and the toxicity is attributed to the ionic form. No quality study of chronic duration was found.

9.2.1 Acute toxicity

Oral lethal doses (LD_{50}) of 15–1600 mg Cu/kg bw have been reported for different forms of copper across different species; for example, in rats, the LD_{50} is 120–300 mg/kg bw for Cu(II) sulphate and 15–90 mg/kg bw for Cu(II) chloride (Stern et al., 2007; OEHHA, 2008; Ellingsen et al., 2015). Death is usually preceded by bleeding of the stomach, cardiovascular dysfunctions, and paralysis (IPCS, 1998). The stomach being the primary site for the emetic response, vomiting is induced within a few minutes in Beagle and Mongrel dogs and ferrets exposed to aqueous solution of Cu(II) sulphate (WHO, 2004). Most studies using vomiting as an indicator may not have observed a response in mouse and rat at levels that might be comparable to those eliciting a response in other species; it is important to note, however, that rats and mice do not vomit (Horn et al., 2013). Soluble salts (e.g., Cu(II) sulphate) generally elicit greater responses than insoluble forms, and rodents were reported to be more sensitive than ferrets, sheep, dogs and cats (IPCS, 1998; WHO, 2004).

9.2.2 Short-term and sub-chronic toxicity

9.2.2.1 Liver effects

Liver inflammation (i.e., multifocal hepatitis, accumulation of macrophages, increased liver enzyme activity in the serum) and necrosis of hepatocytes have been observed in young (~6–10 weeks of age) and adults F344 rats of both sexes ingesting 1,500–16,000 ppm Cu(II) sulphate in feed for 2–18 weeks (Hebert et al., 1993; NTP, 1993; Fuentealba et al., 2000; Aburto et al., 2001). Effects were more pronounced in both male and young rats. Moreover, alterations in the integrity and size of lysosomes, endoplasmic reticulum, mitochondria, and nucleus have been observed in rats fed 1,500 mg Cu/kg feed for 16 weeks (Fuentealba and Haywood, 1988).

No evidence of copper toxicity or liver damage was observed in infant rhesus monkeys administered 6.6 mg Cu(II) sulphate/L (900 µg/kg bw per day, n = 5) until 5 months of age; however, increased number of Küpffer cells were observed in the liver, suggestive of inflammation (Araya et al., 2005a). Moreover, no clinical, biochemical, or histological evidence of liver damage were observed in newborn or adults capuchin monkeys (2 females, 2 males each) exposed for 36 months to, 5.5 mg and 7.5 mg Cu(II) gluconate/kg per day, respectively; however, an increase in inflammatory genes (e.g., HGF, TGFβ and NFκB) was found (Araya et al., 2012). Finally, no adverse effects were noted in Beagle dogs fed with Cu(II) gluconate at levels up to 8.4 mg/kg bw per day for 6 to 12 months, and the slight liver function changes observed at the highest dose were reversed after stopping the exposure (NRC, 2000).

9.2.2.2 Kidney effects

Increases in cytoplasmic protein droplets were observed in the renal convoluted tubules of male rats given water containing 300 ppm Cu(II) sulphate for 2 weeks (Hebert et al., 1993; NTP, 1993). Similar effects were observed in rats receiving feed with 2,000 ppm Cu(II) sulphate and more for 2–15 weeks (Haywood, 1980; Hebert et al., 1993; NTP, 1993). The effects were more pronounced in males.

9.2.2.3 Other effects

Hyperplasia and hyperkeratosis of the forestomach's limiting ridge mucosa were observed in both sexes of rats and mice at doses of 2,000 ppm Cu(II) sulphate and more in food for 2–13 weeks, with rats being more sensitive (Hebert et al., 1993; NTP, 1993).Symptoms varied from oedema and inflammation in the stroma to papilliferous ridge with expansions of the stromal core and the squamous mucosa in severely affected rats.

Bone marrow cell depletion, decreased spleen and bone marrow hematopoiesis, transient changes in haematological parameters, organ damages, and death have been observed in rats consuming high doses of copper (over 2,000 ppm) (NTP, 1993; Bertinato et al., 2010).

9.2.3 Carcinogenicity

Copper has not been shown to be carcinogenic in animals. Indeed, the limited available data does not suggest that copper or its salts are carcinogenic in animals with normal copper homeostasis. Specifically, the available data have several weaknesses that hinder any adequate assessment such as: 'dated studies, small group sizes, single oral-dose tested; limited extent of histopathological examination, inadequate reports' (NRC, 2000; EFSA, 2006; Abe et al., 2008; OEHHA, 2008). No chronic/cancer inhalation studies in animals were identified. However, the data for the Long-Evans cinnamon (LEC) rat, a model for Wilson disease, support the hypothesis that copper-induced cirrhosis can be an aetiological factor in hepatic cancer (NRC, 2000).

9.2.4 Genotoxicity

Although some positive responses have been observed in the Mutatox and SOS Chromotest assays (Codina et al., 1995), copper is generally not genotoxic. Moreover, microbial mutation assays with different copper salts were negative. Indeed, no mutations were induced by Cu(II) sulphate in the TA98, TA 100, TA102, TA1535 or TA1537 strains of *S. Typhimurium* (Moriya et al., 1983). Also, no mutations were induced by Cu(II) gluconate in the Ames test or by Cu(II) chloride in *E. coli* WP2 with or without microsomal activation (Wong, 1988; Hujita et al., 1998).

9.2.5 Neurotoxicity

There is some evidence for a relationship between copper exposure and neurotoxicity. For example, lower anti-oxidative activity and alterations in dopamine kinetics were observed in the brains of rats exposed to high levels of copper (1 g Cu/L, or 46 mg Cu/kg bw) via drinking water for 1–11 months (De Vries et al., 1986; Ozcelik and Uzun, 2009) and both alterations in amyloid-beta protein processing and learning impairment were observed in mouse and rabbit models of AD chronically exposed to copper (Sparks and Schreurs, 2003; Kitazawa et al., 2009). However, no increased neurological sensitivities were identified in LEC rats and in Bedlington terriers, genetic animal models for copper toxicosis (NRC, 2000; Pal et al., 2013), and no neurobehavioral manifestations were observed in rats exposed to 1 ppm Cu(II) sulphate in their drinking water for 6 weeks (Fujiwara et al., 2006)(Fujiwara et al., 2006). Hence, the results for neurotoxicity are equivocal and adverse effects were only observed following exposure to very high doses and/or with the use of animals with genetic anomalies.

9.2.6 Reproductive and developmental toxicity

Some studies have reported changes in testes, seminal vesicles, uteri and ovaries in rats, mice, and bank voles after exposure to high levels of copper (27–200 mg/kg bw per day) (EFSA, 2006; Roychoudhury et al., 2015). Despite that there were some reports of teratogenicity and feto-lethality following ingestion of copper at high doses (above 80–390 mg/kg bw), these outcomes were attributed to dam toxicity (IPCS, 1998; NRC, 2000; EFSA, 2006). Moreover, no adverse effects were reported for any of the reproductive parameters studied in rats and mice of either sex exposed to Cu(II) sulphate (up to 8,000 mg/kg of feed or 140 mg/kg bw) for 13 weeks (NTP, 1993).

9.3 Mode of action

Copper exerts its toxicity via two main pathways: The neuronal pathway in the case of GI effects, and the cellular toxicity pathway (especially oxidative stress) for the other adverse effects. In order to manifest toxic effects, copper must be in its free ionic form or free copper. The following sections briefly describe the proposed mode of action for copper-induced toxicity.

9.3.1 Gastrointestinal effects

Copper exerts its GI tract toxicity by direct irritation of the stomach, activating the release of serotonin by enterochromaffin cells (NRC, 2000; Bradberry, 2007; OEHHA, 2008). The mode of action of this neuromuscular response is a reflex mechanism mediated by the central nervous system. As part of a study involving several emetic agents, Bhandari and Andrews (1991) concluded that copper sulfate causes emesis through GI chemoreceptors in the vagal nerve afferents and that this process most likely involves activation of 5-hydroxytryptamine-4 receptors in some manner. These receptors are receptor subtypes that respond to serotonin. Serotonin can sensitize gastric mucosa parasympathetic nerve endings, activating the vomit centre in the brain. The latter mediates efferent signaling messages to the GI tract, initiating a response (OEHHA, 2008). Stomach infusion with copper sulphate solution resulted in vomiting in 7/9 ferrets as compared to 1/9 animals with duodenum infusion with similar solution (Makale and King, 1992). Dogs with severed vagus and sympathetic gastric nerves showed impaired emetic response (Fukui et al., 1994). The latter is modulated by many factors such as: individual sensitivity, copper form, and the nature of gastric content. Adaptation in the response has also been demonstrated (NRC, 2000). Since the GI responses of copper are related to portal of entry effects, the appropriate metric for risk assessment is the concentration.

9.3.2 Other adverse effects

Cellular toxicity is the main and most studied mode of action by which copper exerts its other adverse effects (Gaetke and Chow, 2003; Gaetke et al., 2014). Several mechanisms have been proposed to explain copper-induced cellular toxicity. However, oxidative damage to membranes and biological macromolecules is the most studied and consistent of them (Bremner, 1998; Gaetke and Chow, 2003; Jomova and Valko, 2011; Mauceri and Mishra, 2014). Free copper has been identified as the toxic moiety leading to oxidative stress (EFSA, 2006; Bertinato et al., 2010; Stern, 2010; Montes et al., 2014). Both Cu(I) and Cu(II) ions possess redox potential and can catalyze the production of reactive oxygen species (ROS), especially the hydroxyl radical ($OH^{\bullet}$). However, in order to exert its cytotoxicity, the Cu(II) ion must be reduced (e.g., by GSH or ascorbate) to the Cu(I) ion (EFSA, 2006; Bertinato et al., 2010; Stern, 2010; Formigari et al., 2013; Montes et al., 2014) which can catalyze the formation of $OH^{\bullet}$ from hydrogen peroxide (H_2O_2) via a Haber-Weiss driven Fenton reaction (Bremner, 1998; Bradberry, 2007; Bertinato et al., 2010; Stern, 2010; Formigari et al., 2013; Gaetke et al., 2014; Jazvinscak Jembrek et al., 2014; Montes et al., 2014). Indeed, copper-induced oxidative stress involves the formation of the extremely reactive hydroxyl radical ($OH^{\bullet}$) which is capable of initiating one of the three main cellular events most frequently reported (Gaetke et al., 2014; Jazvinscak Jembrek et al., 2014). The first event, the peroxidation of membrane lipids, is the consequence of a hydrogen abstraction from an unsaturated fatty acid by the hydroxyl radical, leading to a lipid radical. One consequence of this process is the breakdown of hepatic lysosome membranes (Burkitt, 2001; Letelier et al., 2010; Gaetke et al., 2014). The second key event, the oxidation of proteins, results from a hydrogen abstraction from an amino-bearing carbon by $OH^{\bullet}$, to form a carbon-centered protein radical. This leads to, for example, the deactivation of enzymes. The third key event, DNA damage, is the consequence of the DNA strands breaks and oxidation of bases by $OH^{\bullet}$, leading for example to mutations (Gaetke and Chow, 2003; Jomova and Valko, 2011; Gaetke et al., 2014). These key oxidation events can lead to inflammation and cell death (Yoshida et al., 1993; NRC, 2000; Jomova and Valko, 2011; Formigari et al., 2013; Gaetke et al., 2014)which potentially explain copper's toxic effects as well as the molecular and morphological alterations observed in the liver, kidney, brain, and red blood cells at high doses in animal studies(Eskici and Axelsen, 2012; Shaligram and Campbell, 2013; Jazvinscak Jembrek et al., 2014). Also, since copper-induced ROS is time and dose-dependent, this mode of action has long been proposed to explain the liver toxicity induced by the metal (Formigari et al., 2013). In addition, the current evidence suggests that the hepatic mitochondrion is an important target in copper-induced liver oxidative damage (Jiménez Del Río and Vélez-Pardo, 2004; EFSA, 2006; Kawakami et al., 2008; Paris et al., 2009; Tardito et al., 2011; Formigari et al., 2013; Gaetke et al., 2014).

Thus, data from experimental studies support the ROS-induced oxidative damage as the mode of action of copper toxicity. For example, lipid peroxidation, protein oxidation, decline in the mitochondrial membrane potential, and mitochondrial expulsion of cytochrome c, all preceding cell death, were reported following exposure to excess copper (Kumar et al., 2015). Also, rats fed high levels of dietary copper exhibited increased peroxidation of the mitochondrial membrane lipids as measured by increased levels of conjugated dienes and TBARS (Sokol et al., 1990). In addition, the formation of hydroxyl radical has been measured in bile of rats dosed with copper and ascorbic acid (Kadiiska et al., 1992).

Furthermore, neurotoxic endpoints observed at high doses could be explained by the production of ROS, such as release of a hydroxyl radical, a by-product of the monoamine oxidase metabolism (Eskici and Axelsen, 2012; Formigari et al., 2013; Govindaraju et al., 2013; Shaligram and Campbell, 2013; Zhao et al., 2013; Gaetke et al., 2014; Jazvinscak Jembrek et al., 2014; Montes et al., 2014). Also, the depletion of GSH reductase (which also depends on NADPH) and generation of hydroxyl radicals could also lead to haemolytic effects (IPCS, 1998; Grass et al., 2011). Furthermore, the methaemoglobinemia often observed in cases of acute copper poisoning may be a consequence of the direct oxidization of the haem iron from the ferrous (Fe^{2+}) to the ferric (Fe^{3+}) form by copper (IPCS, 1998; Bradberry, 2007).

Other modes of action such as the direct interaction of copper with essential macromolecules and the displacement of cofactors from metalloenzymes have also been proposed. Thus, being a component of many metalloenzymes, it is also likely that high concentrations of copper can affect proteins containing sulfhydryl groups by directly interacting with macromolecules (e.g., DNA, biological membranes, proteins, etc.). The irreversible and non-specific binding of copper to sulfhydryl groups can alter the structure of macromolecules (e.g., GSH, monooxygenases, etc.) and inactivate them. This mode of action has been proposed to explain the haemolytic anemia and methaemoglobinemia observed following acute copper sulphate poisoning. Copper can enter red blood cells, where it can bind to sulfhydryl groups and inactivate glucose-6-phosphate dehydrogenase, which is essential for generating NADPH, an intermediate in the electron transfer chain (Pamp et al., 2005).

10.0 Classification and assessment

The current data are insufficient to classify copper with respect to carcinogenicity. The U.S. EPA (1988) has classified copper in Group D, not classifiable with respect to its carcinogenic risk to humans. The International Agency for Research on Cancer has not classified copper and its soluble salt (e.g., sulphate, chloride) with respect to carcinogenicity.

10.1 Non-cancer risk assessment

Copper is an essential element involved in many biological processes (e.g., as a component of metalloenzymes), however, both copper deficiency and overexposure can result in adverse effects. As discussed in section 9.1.1, copper deficiency and overexposure are rare in healthy Canadians consuming a balanced diet since homeostatic mechanisms regulate nutrient levels (Health Canada, 2011).

The health effects from copper exposure may be influenced by the medium of exposure. Copper in food is subject to liver's first-pass effect which can potentially reduce the systemic dose; free copper, the toxic moiety of concern in drinking water, may not be subject to such an effect which may significantly increase the internal dose (Brewer, 2009, 2014).

The database of human studies on health effects associated with ingested copper is large and contains adequate data for determining an acceptable concentration in drinking water. In general, short-term exposures results in GI tract effects, usually observed at copper levels greater than 3 mg/L water (see sections 9.1.3 and 9.1.4). Also, when considering the current evidence (mainly from animal and mechanistic studies) it appears that the primary effect from chronic overexposure is metal accumulation in the liver and kidneys, potentially leading to structural and biochemical damage (Linder and Hazegh-Azam, 1996; IPCS, 1998; Tapiero et al., 2003; Cockell et al., 2008).

Several randomized controlled studies have investigated the adverse health effects of copper exposure, although mostly in adults; the results from these studies indicate that short-term oral exposure to copper in drinking water while in a fasted state leads to GI effects (usually nausea, epigastric pain and vomiting combined, and diarrhea), which although transient, are the most sensitive clinical endpoints (Pizarro et al., 1999b; Araya et al., 2001, 2003a; Olivares et al., 2001). Nausea was the most frequently reported symptom generally occurring within 15 minutes following exposure; diarrhea was less frequently reported within the range of studied doses and women appeared to be more sensitive. In addition, the observed GI effects were found to disappear when exposure ceased suggesting an adaptive response with time (Araya et al., 2004). Furthermore, the results indicate that the concentration of copper (i.e., the bolus dose in water on an empty stomach divided by the dosing volume) is the primary determinant of the incidence of nausea (Araya et al., 2001, 2003a) and thus, with support from the data on the mode of action, is considered as the most appropriate dose metric for risk assessment. It is noteworthy, however, that although the above studies (except Araya et al., 2004) were conducted for up to 12 weeks, the exposure was not continuous and copper was consistently administered via single bolus dosing (using tap or distilled-deionized water) for short time periods (i.e., once/week) which may not accurately reflect the typical chronic low-dose drinking water exposure.

Although the long-term exposure to copper has not been extensively studied, limited results suggest an effect of time. Indeed, available data from drinking water exposure of adults for less than 3 months confirmed the results from short-term exposure studies (Araya et al., 2004). However, the results from adult supplementation studies suggest adverse health effects following exposure to high levels intakes over longer periods of time (over 5 months; Turnlund et al., 2004).

Subgroups identified as being vulnerable to chronic copper overexposure are individuals with copper-metabolism-related genetic disorders (such as WD patients), individuals with glucose-6-phosphate dehydrogenase deficiencies, children with childhood cirrhosis syndromes (ICC, ICT and TIC), and infants (less than one year-old). Of these subgroups, infants are considered the most vulnerable since they are likely to have the highest exposure due to the immaturity of their hepatobiliary system and their higher rates of copper absorption.

A randomized prospective study by Olivares et al. (1998) investigated the effects of copper exposure in breast- and formula-fed infants (3 to 12 months old) who ingested drinking water with high (31.48 µmol Cu(II)/L or 2 mg/L) or low (less than 1.57 µmol Cu(II)/L or 0.1 mg/L) copper levels (as Cu (II) sulphate) for nine months via different means of consumption (e.g., food, formula, drinking water). Clinical and biochemical findings were recorded at six, nine and twelve months of age. Both over the course of the study and upon study termination, the subjects presented no acute (i.e., cases of diarrhea or respiratory symptom) or chronic (i.e., differences in markers of liver function) clinical effects following exposure to drinking water containing 2 mg/L of copper (corresponding to a mean ± SD daily intake of 318.7 ± 107.3µg/kg bw per day) when compared to controls.

The Olivares et al. (1998) study has been chosen as the critical study for deriving a proposed MAC since it was conducted in infants, involved continuous exposure to Cu(II) via drinking water for a longer period than studies in adults (usually up to three months), and took into account several temporal windows, including infants 4–6 months when the hepatobiliary system is still immature and gut absorption is greatest. Since formula-fed infants are expected to have the highest exposure to copper, the upper bound of the NOAEL, based on GI effects and liver function, for the formula-fed exposure sub-group (mean ± SD = 318.7 ± 107.3 µg/kg bw per day, experienced by 56 infants aged 4–6 months) was chosen as the point of departure; this upper bound dose (i.e., 426 µg/kg bw per day) represents the highest dose administered where no adverse effects were observed.

Although there are some uncertainties in the database for copper toxicity (including limited data on copper exposure in infants aged less than 6 months, limited data on the degree of variability in copper absorption among early age groups, as well as a lack of chronic exposure studies), the point of departure identified from Olivares et al. (1998) is considered conservative since no symptoms of copper toxicity were observed at this dose over the entire duration of the study (9 months); furthermore, due to the homeostatic regulation of copper absorption and excretion, the absorption of copper has been shown to decline as exposure to dietary copper increases (see section 8.1). As a result, an uncertainty factor accounting for database deficiencies is not warranted and thus 426 µg/kg bw per day is identified as the tolerable daily intake (TDI) for free copper.

A proposed MAC for total copper can be calculated as follows:

$$\begin{aligned} \text{MAC} &= \frac{426\ \mu\text{g/kg bw per day} \times 7\ \text{kg} \times 0.5}{0.75\ \text{L/day}} \\ &= 1988\ \mu\text{g/L} \\ &\approx 2000\ \mu\text{g/L}\ (2\ \text{mg/L}) \quad \text{[rounded]} \end{aligned}$$

where:

- 426 µg/kg bw per day is the TDI based on gastro-intestinal effects and liver function in formula-fed infants in the 9-month study by Olivares et al. (1998);
- 7 kg is the average body weight of an infant (0–6 months) (Health Canada, 1994);
- 0.5 is the allocation factor estimated for drinking water. Given that formula represents the total diet in non-breast fed infants for the first few months of life, both drinking water and formula represent the main sources of exposure and contributions from other sources are not expected to be significant for this age group (WHO, 1996). Thus allocating 50%

source contribution to drinking water is deemed appropriate since only two principal sources of exposure have been identified (Krishnan and Carrier, 2013) and the data for these exposure sources is highly variable; and
- 0.75 L/day is the estimated daily volume of tap water consumed by a bottle-fed infant in the 0–6 month age group (Health Canada, 1994).

The proposed MAC is considered to be protective of both short-term effects (i.e., GI effects) as well as longer-term effects (including potential effects in the liver and kidneys).

10.2 International considerations

This section presents drinking water guidelines and standards from other national and international organizations. Variations in theses limits can be attributed to the age of the assessments or to differing policies and approaches, including the choice of key study and the use of different consumption rates, body weights an allocation factors.

The WHO (1993) set a provisional health-based guideline value of 2 mg/L for copper in drinking water from a provisional maximum tolerable daily intake (PMTDI) of 0.5 mg/kg proposed by JECFA in 1982 and an allocation factor of 10% of the PMTDI to drinking water. The PMTDI was based on liver toxicity, observed in an industry-funded study in dog (Shanaman et al., 1972) and the guideline was deemed provisional due to the uncertainties related to copper toxicity in humans (WHO, 1996). However, from an assessment conducted in 2003, the WHO maintained the value of 2 mg/L stated that is was based ‘to be protective against acute GI effects of copper and provide an adequate margin of safety in population with normal copper homeostasis’ (WHO, 2011). In 2004, the guideline value of 2 mg/L was confirmed, but was no longer provisional based on (Olivares et al., 1998, 2001; Pizarro et al., 1999b, 2001; Araya et al., 20012003a; Zietz et al., 2003b).

The U.S. Environmental Protection Agency (U.S. EPA, 1991) has set the maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for copper in drinking water at 1.3 mg/L. The U.S. EPA’s MCLG for copper was based on adverse gastrointestinal tract effects following acute exposure and was derived from a case study of nurses who consumed an alcoholic beverage that was stored in copper containers (Wyllie, 1957). A secondary Maximum Contaminant Level (SMCL) for copper has been established at 1 mg/L based on aesthetic considerations (taste and blue/green staining). However, the U.S. EPA regulates levels of copper through the Lead and Copper Rule (U.S. EPA, 1991, 2000), a treatment based rule, which established an action level of 1.3 mg/L for copper in drinking water. Large water systems (with more than 50,000 connections), unless determined to be non-corrosive, are required to install “optimal corrosion control treatment” and meet specified water quality operating limits requirements. If the 90th percentile of copper concentrations in samples taken at customer taps at sites distributed with a specified prioritization (first-draw samples that have stagnated for at least 6 hours) exceeds the action level of 1.3 mg/L, the system must undertake a number of additional actions to control corrosion and provide public education. The number of sites, frequency of monitoring and scope of required actions vary with system size. Currently, a major revision of the Lead and Copper Rule is under way, but is not expected to be finalized until after 2017.

The California EPA (OEHHA, 2008) has developed a non-regulatory public health goal of 0.3 mg/L for copper in drinking water, based on infants as a sensitive population and is “believed adequate to protect against any adverse acute or chronic effects” from copper exposure. This goal was based on the absence of an adverse effect in the Olivares et al. (1998)

clinical study of infants exposed to copper in drinking water, and took into consideration “data from other studies on GI effects as the key endpoint” .

The Australian Drinking Water Guidelines has set two levels for copper: 1 mg/L for aesthetics to prevent taste and staining problems; and 2 mg/L to prevent health issues (NHMRC, 2011).

11.0 Rationale

Copper is an essential nutrient that occurs naturally in the Earth’s crust, either in mineral deposits or, less frequently, in its metallic form. The U.S National Academy of Medicine (formerly called the Institute of Medicine) has established both recommended daily intakes and tolerable upper intake levels for copper.

Copper is used in a wide range of products, including as a result of it being a component of bronze and brass, and is considered by the National Plumbing Code of Canada to be an acceptable material for service lines and plumbing systems. The main anthropogenic sources of copper in the environment include mining, agricultural run-off, waste management and water treatment.

Canadians are mainly exposed to copper through the ingestion of food, drinking water and nutritional supplements. International agencies have determined that the data available on copper are not sufficient to classify it with respect to carcinogenicity. Health effects can be associated with both copper deficiency, and to exposure to copper at levels much higher than the recommended daily intake. Copper deficiency is not considered to be a concern in Canada.

A maximum acceptable concentration (MAC) of 2 mg/L (2000 µg/L) is proposed for total copper in drinking water. The proposed MAC is considered to be protective of both short-term effects (i.e., GI effects) as well as longer-term effects (including potential effects in the liver and kidneys). The proposed MAC is achievable by available treatment technology and measurable by available analytical methods. However, because copper is generally found in drinking water as a result of leaching in the distribution and plumbing systems, strategies for reducing exposure to copper from drinking water should focus on corrosion control through approaches such as water quality adjustments and the use of corrosion inhibitors.

As part of its ongoing guideline review process, Health Canada will continue to monitor new research in this area and recommend any change to the guideline that it deems necessary.

12.0 References

Abe, M., Suzuki, N., Yoshida, M., Usuda, K., Furukawa, S., Juneja, L.R., Okubo, T. and Nakae, D. (2008). Possible carcinogenic risks of copper gluconate and their prevention by co-administered green tea catechins evaluated by a rat medium-term multi-organ carcinogenicity bioassay protocol. Food Chem.Toxicol., 46(5): 1760–1770.

Aburto, E.M., Cribb, A.E., Fuentealba, I.C., Ikede, B.O., Kibenge, F.S. and Markham, F. (2001). Morphological and biochemical assessment of the liver response to excess dietary copper in fischer 344 rats. Can. J. Vet. Res., 65(2): 97–103.

Aggett, P.J. (1999). An overview of the metabolism of copper. Eur. J. Med. Res. 4: 214–216. [As cited in EFSA, 2006].

Ala, A., Walker, A.P., Ashkan, K., Dooley, J.S. and Schilsky, M.L. (2007). Wilson's disease. The Lancet, 369(9559): 397–408.

APHA, AWWA and WEF (1992). Standard methods for the examination of water and wastewater. 18th edition supplement. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

APHA, AWWA and WEF (1995). Standard methods for the examination of water and wastewater. 19th edition. Association, American Water Works Association, and Water Environment Federation, Washington, DC.

APHA, AWWA and WEF (1999). Standard methods for the examination of water and wastewater. online. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

APHA, AWWA and WEF (2004). Standard methods for the examination of water and wastewater. online. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

APHA, AWWA and WEF (2005). Standard methods for the examination of water and wastewater. 21st edition. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

APHA, AWWA and WEF (2010). Standard methods for the examination of water and wastewater. online. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

APHA, AWWA and WEF (2012). Standard methods for the examination of water and wastewater. 22nd edition. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

Araya, M., McGoldrick, M.C., Klevay, L.M., Strain, J.J., Robson, P., Nielsen, F., Olivares, M., Pizarro, F., Johnson, L.A. and Poirier, K.A. (2001). Determination of an acute no-observed-adverse-effect level (NOAEL) for copper in water. Regul. Toxicol. Pharmacol., 34(2): 137–145.

Araya, M., Chen, B., Klevay, L.M., Strain, J.J., Johnson, L., Robson, P., Shi, W., Nielsen, F., Zhu, H., Olivares, M., Pizarro, F. and Haber, L.T. (2003a). Confirmation of an acute no-observed-adverse-effect and low-observed-adverse-effect level for copper in bottled drinking water in a multi-site international study. Regul. Toxicol. Pharmacol., 38(3): 389–399.

Araya, M., Olivares, M., Pizarro, F., Gonzalez, M., Speisky, H. and Uauy, R. (2003b). Gastrointestinal symptoms and blood indicators of copper load in apparently healthy adults undergoing controlled copper exposure. Am. J. Clin. Nutr., 77(3): 646–650.

Araya, M., Olivares, M., Pizarro, F., Llanos, A., Figueroa, G. and Uauy, R. (2004). Community-based randomized double-blind study of gastrointestinal effects and copper exposure in drinking water. Environ. Health Perspect., 112(10): 1068–1073.

Araya, M., Kelleher, S.L., Arredondo, M.A., Sierralta, W., Vial, M.T., Uauy, R. and Lonnerdal, B. (2005a). Effects of chronic copper exposure during early life in rhesus monkeys. Am. J. Clin. Nutr., 81(5): 1065–1071.

Araya, M., Olivares, M., Pizarro, F., Mendez, M.A., Gonzalez, M. and Uauy, R. (2005b). Supplementing copper at the upper level of the adult dietary recommended intake induces detectable but transient changes in healthy adults. J. Nutr., 135(10): 2367–2371.

Araya, M., Núñez, H., Pavez, L., Arredondo, M., Méndez, M., Cisternas, F., Pizarro, F., Sierralta, W., Uauy, R. and González, M. (2012). Administration of high doses of copper to capuchin monkeys does not cause liver damage but induces transcriptional activation of hepatic proliferative responses. J. Nutr., 142(2): 233–237.

Arens, P., Tuschewitzki, G-J., Follner, H., Jacobi, H., and Leuner, S. (1996). Experiments for stimulating microbiologically induced corrosion of copper pipes in a cold-water plumbing system. Materials and Corrosion, 47: 96–102.

Arnold, R.B., Griffin, A. and Edwards, M. (2012). Controlling copper corrosion in new construction by organic matter removal. J. Am. Water Works Assoc., 104(5): E310-E317.

ASTM (1995). ASTM D1688-95 Standard test methods for copper in water. ASTM International, West Conshohocken, Pennsylvania.

ASTM (2002). ASTM D1688-02 Standard test method for copper in water. ASTM International, West Conshohocken, Pennsylvania.

ASTM (2007). ASTM D1688-07 Standard test method for copper in water. ASTM International, West Conshohocken, Pennsylvania.

ASTM (2012). ASTM D1688-12 Standard test method for copper in water. ASTM International, West Conshohocken, Pennsylvania.

Atlas, D., Coombs, J. and Zajcek, O.T. (1982). The corrosion of copper by chlorinated drinking waters. Water Res., 16: 693–698.

ATSDR (2004). Toxicological profile for copper. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services. Public Health Service. Atlanta, Georgia.

Bancroft, D.A. (1988). Corrosion control program in Danvers, Massachusetts. J. N. Engl. Water Works Assoc., 102(3): 163–171.

Bandmann, O., Weiss, K.H. and Kaler, S.G. (2015). Wilson's disease and other neurological copper disorders. Lancet Neurol., 14(1): 103–113.

Barceloux, D.G. (1999). Copper. J. Toxicol. Clin. Toxicol., 37(2): 217–230.

Barn, P., Nicol, A.M., Struck, S., Dosanjh, S., Li, R. and Kosatsky, T. (2014). Investigating elevated copper and lead levels in school drinking water. Environ. Health Rev., 56(4): 96–102.

Bauerly, K.A., Kelleher, S.L. and Lonnerdal, B. (2005). Effects of copper supplementation on copper absorption, tissue distribution, and copper transporter expression in an infant rat model. Am. J. Physiol. Gastrointest. Liver Physiol., 288(5): G1007–14.

Becker, A. (2002). The effect of corrosion inhibitors in drinking water installations of copper. Mater. Corros., 53: 560–567.

Berg, R., Lundh, S., Jansonn, G. and Rappe, A. (1981). Copper contamination of drinking water as a cause of diarrhea in children. Halsovardskontakt 1:6-10. [as cited in OEHHA, 2008]

Berghult, B., Hedberg, T. and Broo, A.E. (1999). Drinking water distribution: corrosion control in Swedish municipalities. J. Water Supply Res. Technol. – Aqua, 48(2): 44–52.

Berghult, B., Broo, A.E. and Hedberg, T. (2001). Corrosion control measures in Sweden and the effect of succession order. Water Sci. Technol. Water Supply, 1(3): 47–58

Bertinato, J. and L'Abbe, M.R. (2004). Maintaining copper homeostasis: Regulation of copper-trafficking proteins in response to copper deficiency or overload. J. Nutr. Biochem., 15(6): 316–322.

Bertinato, J., Sherrard, L. and Plouffe, L.J. (2010). Decreased erythrocyte CCS content is a biomarker of copper overload in rats. Int. J. Mol. Sci., 11(7): 2624–2635.

Bhandari, P. and Andrews, P.L. (1991). Preliminary evidence for the involvement of the putative 5-HT4 receptor in zacopride- and copper sulphate-induced vomiting in the ferret. Eur. J. Pharmacol., 204(3): 273–280.

Boal, A.K. and Rosenzweig, A.C. (2009). Structural biology of copper trafficking. Chem. Rev., 109(10): 4760–4779.

Boffardi, B.P. (1993). The chemistry of polyphosphate. Mater. Perform., 8: 50–53

Boireau, A., Benezet-Toulze, M., Randon, G. and Cavard, J. (1997). Limitation de la solubilisation du plomb par ajout de produit filmogène. Transposition d'une étude sur pilote à un réseau réel. Tech. Sci. Meth. Gen. Urbain Gen. Rural, 92(5): 63–72.

Boulay, N. and Edwards, M. (2001). Role of temperature, chlorine, and organic matter in copper corrosion byproduct release in soft water. Water Res., 35(3): 683–690.

Boveris, A., Musacco-Sebio, R., Ferrarotti, N., Saporito-Magrina, C., Torti, H., Massot, F. and Repetto, M.G. (2012). The acute toxicity of iron and copper: Biomolecule oxidation and oxidative damage in rat liver. J. Inorg. Biochem., 116: 63–69.

Boyd, G.R., McFadden, M.S., Reiber, S.H., Sandvig, A.M., Korshin, G.V., Giani, R. and Frenkel, A.I. (2010). Effects of changing disinfectants on distribution system lead and copper release: Part 2—research results. Water Research Foundation, Denver, Colorado.

Bradberry, S. (2007). Copper. Poisoning part 2 of 3. Medicine, 35(11): 608.

Bremer, P., Webster, B.J. and Wells, D.B, (2001). Biocorrosion of copper in potable water. J. Am. Water Works Assoc., 93(8): 82–91.

Bremner, I. (1998). Manifestations of copper excess. Am. J. Clin. Nutr., 67(5 Suppl): 1069S-1073S.

Brenner, I.B. and Zander, A.T. (2000). Axially and radially viewed inductively coupled plasmas – a critical review. Spectrochimica Acta Part B: Atomic Spectroscopy, 55(8): 1195–1240.

Brenner, S. (2003). Elevation of serum copper levels in Alzheimer's disease. Neurology, 60(9): 1559; author 1559.

Brewer, G.J. (2009). The risks of copper toxicity contributing to cognitive decline in the aging population and to Alzheimer's disease. J. Am. Coll. Nutr., 28(3): 238–242.

Brewer, G.J. (2010). Copper toxicity in the general population. Clin. Neurophysiol., 121(4): 459-460.

Brewer, G.J. (2014). Alzheimer's disease causation by copper toxicity and treatment with zinc. Front. Aging Neurosci., 6: 92.

British Geological Survey (2016). World mineral production 2010-2014. Natural Environmental Research Council (NERC). ISBN 978-0-85272-856-7 (print version). ISBN 978-0-85272-857-4 (website version).

Broo, A.E., Berghult, B. and Hedberg, T. (1997). Copper corrosion in drinking water distribution systems—The influence of water quality. Corros. Sci., 39(6): 1119–1132.

Broo, A.E., Berghult, B. and Hedberg, T. (1998). Copper corrosion in water distribution systems—The influence of natural organic matter (NOM) on the solubility of copper corrosion products. Corros. Sci., 40(9): 1479–1489.

Broo, A.E., Berghult, B. and Hedberg, T. (1999). Drinking water distribution—The effect of natural organic matter (NOM) on the corrosion of iron and copper. Water Sci. Technol., 40(9): 17–24.

Burkitt, M.J. (2001). A critical overview of the chemistry of copper-dependent low density lipoprotein oxidation: Roles of lipid hydroperoxides, alpha-tocopherol, thiols, and ceruloplasmin. Arch. Biochem. Biophys., 394(1): 117–135.

Burleigh, T.D, Gierke, C.G., Fredy, N. and Boston, P.J. (2014). Copper tube pitting in Sante Fe municipal water caused by microbial induced corrosion. Materials, 7:4321–4334.

Bush, A.I., Masters, C.L. and Tanzi, R.E. (2003). Copper, beta-amyloid, and Alzheimer's disease: Tapping a sensitive connection. Proc. Natl. Acad. Sci. U. S. A., 100(20): 11193–11194.

Butler Walker, J., Houseman, J., Seddon, L., McMullen, E., Tofflemire, K., Mills, C., Corriveau, A., Weber, J., LeBlanc, A., Walker, M., Donaldson, S.G. and Van Oostdam, J. (2006). Maternal and umbilical cord blood levels of mercury, lead, cadmium, and essential trace elements in arctic Canada. Environ. Res., 100(3): 295–318.

Camakaris, J., Voskoboinik, I. and Mercer, J.F. (1999). Molecular mechanisms of copper homeostasis. Biochem. Biophys. Res. Commun., 261(2): 225–232.

Campbell, H.S. (1954a). The influence of the composition of supply waters, especially of traces of natural inhibitor on pitting corrosion of copper water pipes. Proc. Soc. Water Treat. Exam., 3: 100–117.

Campbell, H.S. (1954b). A natural inhibitor of pitting corrosion of copper in tap waters. J. Appl. Chem., 4: 633–647.

Campbell, H.S. (1971). Corrosion, water composition and water treatment. Proc. Soc. Water Treat. Exam., 20: 11–34.

Campbell, H.S. and Turner, M.E.D. (1983). The influence of trace organics on scale formation and corrosion. J. Inst. Water Eng. Sci., 37(1): 55–72.

Cantor, A.F., Denig-Chakroff, D., Vela, R.R., Oleinik, M.G. and Lynch, D.L. (2000). Use of polyphosphate in corrosion control. J. Am. Water Works Assoc., 92(2): 95–102.

Cantor, A.F., Park, J.K. and Vaiyavatjamai, P. (2003). Effect of chlorine on corrosion. J. Am. Water Works Assoc., 95(5): 112–123.

Carmichael, P.L., Hewer, A., Osborne, M.R., Strain, A.J. and Phillips, D.H. (1995). Detection of bulky DNA lesions in the liver of patients with Wilson’s disease and primary haemochromatosis. Mutat. Res., 326(2): 235–243.

Cartier, C., Doré, E., Laroche, L., Nour, S., Edwards, M. and Prévost, M. (2013). Impact of treatment on Pb release from full and partially replaced lead service lines (LSLs). Water Res., 47(2): 661–671.

Cavallo, F., Gerber, M., Marubini, E., Richardson, S., Barbieri, A., Costa, A., DeCarli, H. and Pujol, A. (1991). Zinc and copper in breast cancer: A joint study in Northern Italy and Southern France. Cancer, 67: 738–745. [as cited in IPCS, 1998].

CCME (1999). Copper. Canadian soil quality guidelines for the protection of environmental and human health. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment.

Cech, I., Smolensky, M.H., Afshar, M., Broyles, G., Barczyk, M., Burau, K. and Emery, R. (2006). Lead and copper in drinking water fountains--information for physicians. South. Med. J., 99(2): 137–142.

Ceko, M.J., Aitken, J.B. and Harris, H.H. (2014). Speciation of copper in a range of food types by X-ray absorption spectroscopy. Food Chem., 164: 50–54.

Chambers, A., Krewski, D., Birkett, N., Plunkett, L., Hertzberg, R., Danzeisen, R., Aggett, P.J., Starr, T.B., Baker, S., Dourson, M., Jones, P., Keen, C.L., Meek, B., Schoeny, R. and Slob, W. (2010). An exposure-response curve for copper excess and deficiency. J. Toxicol. Environ. Health B Crit. Rev., 13(7–8): 546–578.

Churchill, D.M., Mavinic, D.S., Neden, D.G. and MacQuarrie, D.M. (2000). The effect of zinc orthophosphate and pH–alkalinity adjustment on metal levels leached into drinking water. Can. J. Civil Eng., 27(6): 33–43.

Clark, B., Masters, S. and Edward, M. (2014). Profile sampling to characterize particulate lead risks in potable water. Environ. Sci. Technol., 48(12): 6836–6843. doi: 10.1021/es501342j

Clark, B., St. Clair, J. and Edwards, M. (2015). Copper deposition corrosion elevates lead release to potable water. J. Am. Water Works Assoc., 107(11): E627–E637.

Clement, J.A., Daly, W.J., Shorney, H.J., and Capuzzi, A.J., (1998). An innovative approach to understanding and improving distribution system water quality. In: Proceedings of the 1998 AWWA Water Quality Technology Conference, San Diego, CA. American Water Works Association, Denver, Colorado.

Clifford, D.A. (1999). Ion exchange and inorganic adsorption. Chapter 9 in: Letterman, R.D.(ed). Water quality and treatment: a handbook of community water supplies. 5th edition American Water Works Association. Denver, Colorado. McGraw-Hill, New York, New York.

Clifford, D., Sorg, T. and Ghurye, G. (2011). Ion exchange and adsorption of inorganic contaminants. Chapter 12 in: Edzwald, J.K. (ed.).Water quality and treatment: a handbook of community water supplies. 6th edition. American Water Works Association, Denver, Colorado. McGraw-Hill, New York, New York.

Coates, R.J., Weiss, N.S., Daling, J.R., Rettmer, R.L. and Warnick, G.R. (1989). Cancer risk in relation to serum copper levels. Cancer Res., 49(15): 4353–4356.

Cockell, K.A., Bertinato, J. and L'Abbe, M.R. (2008). Regulatory frameworks for copper considering chronic exposures of the population. Am. J. Clin. Nutr., 88(3): 863S–866S.

Codina, J.C., Perez-Torrente, C., Perez-Garcia, A., Cazorla, F.M. and de Vicente, A. (1995). Comparison of microbial tests for the detection of heavy metal genotoxicity. Arch. Environ. Contam. Toxicol., 29(2): 260–265.

Collins, J.F. and Klevay, L.M. (2011). Copper. Adv. Nutr., 2(6): 520–522.

Corkins, M.R. (2011). Copper metabolism and pediatric cholestasis. Curr. Opin. Clin. Nutr. Metab. Care, 14(6): 642–646.

Critchley, M.M., Cromar, N.J., McClure, N.C. and Fallowfield, H.J. (2003). The influence of the chemical composition of drinking water on cuprosolvency by biofilm bacteria. J. of Appl. Microbiol., 94:501–507.

Critchley, M., Pasetto, R. and O’Halloran, R.J. (2004). Microbiological influences in ‘blue water’ copper corrosion. J. of Appl. Microbiol., 97:590–597.

Cuppett, J.D., Duncan, S.E. and Dietrich, A.M. (2006). Evaluation of copper speciation and water quality factors that affect aqueous copper tasting response. Chem. Senses, 31(7): 689–697.

Custalow, B.D. (2009). Influences of water chemistry and flow conditions on non-uniform corrosion in copper tube. Virginia Polytechnic Institute and State University, Blacksburg, VA (Master’s thesis).

Dabek, J.T., Hyvonen-Dabek, M., Harkonen, M. and Adlercreutz, H. (1992). Evidence for increased non-ceruloplasmin copper in early-stage human breast cancer serum. Nutr Cancer, 17: 195–201. [as cited in IPCS, 1998].

Dabioch, M., Storek, R., Kita, A., Janoska, P., Pytlakowska, K., Zerzucha, P. and Sitko, R. (2013). A study on adsorption of metals by activated carbon I a large-scale(municipal) process of surface water purification. Central European Journal of Chemistry, 11(5):742–753.

Das, S.K. and Ray, K. (2006). Wilson's disease: An update. Nat. Clin. Pract. Neurol., 2(9): 482–493.

Davidson, D., Beheshti, B. and Mittelman, M.W. (1996). Effects of arthrobacter sp., acidovorax delafieldii, and bacillus megaterium colonisation on copper solvency in a laboratory setting. Biofouling, 9(4):279–292.

de Romana, D.L., Olivares, M., Uauy, R. and Araya, M. (2011). Risks and benefits of copper in light of new insights of copper homeostasis. J. Trace Elem. Med. Biol., 25(1): 3–13.

De Vries, D.J., Sewell, R.B. and Beart, P.M. (1986). Effects of copper on dopaminergic function in the rat corpus striatum. Exp. Neurol., 91(3): 546–558.

Dodrill, D.M. and Edwards, M. (1995). Corrosion control on the basis of utility experience. J. Am. Water Works Assoc., 87(7): 74–85.

Donnelly, P.S., Xiao, Z. and Wedd, A.G. (2007). Copper and Alzheimer's disease. Bioinorganic chemistry / biocatalysis and biotransformation. Curr. Opin. Chem. Biol., 11(2): 128–133.

Dudi, A. (2004). Galvanic corrosion of lead bearing plumbing devices. In: Reconsidering lead corrosion in drinking water: Product testing, direct chloramine attack and galvanic corrosion. Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, VA. pp. 69–105 (Master's Thesis).

Dudi, A., Schock, M., Murray, N. and Edwards, M. (2005). Lead leaching from inline brass devices: a critical evaluation of the existing standard. J. Am. Water Works Assoc., 97(8): 66–78.

Dutkiewicz, C. and Fallowfield, H. (1998). Assessment of microbial involvement in the elevation of copper levels in drinking water. J. Appl. Microbiol., 85:597-602.

Edwards, M. and Ferguson, J.F. (1993). Accelerated testing of copper corrosion. J. Am. Water Works Assoc., 85(10): 105–113.

Edwards, M. and McNeill, L.S. (2002). Effect of phosphate inhibitors on lead release from pipes. J. Am. Water Works Assoc., 94(1): 79–90.

Edwards, M. and Sprague, N. (2001). Organic matter and copper corrosion by-product release: a mechanistic study. Corros. Sci., 43(1): 1–18.

Edwards, M. and Triantafyllidou, S. (2010). Chloride-to-sulphate mass ratio and lead leaching to water. J. Am. Water Works Assoc., 99(7): 96–109.

Edwards, M., Ferguson, J.F. and Reiber, S.H. (1994a). The pitting corrosion of copper. J. Am. Water Works Assoc., 86(7): 74–90.

Edwards, M., Meyer, T.E. and Rehring, J.P. (1994b). Effect of selected anions on copper corrosion rates. J. Am. Water Works Assoc., 86(12): 73–81.

Edwards, M., Schock, M.R. and Meyer, T.E. (1996). Alkalinity, pH, and copper corrosion by-product release. J. Am. Water Works Assoc., 88(3): 81–94.

Edwards, M., Jacobs, S. and Dodrill, D.M. (1999). Desktop guidance for mitigating Pb and Cu corrosion by-products. J. Am. Water Works Assoc., 91(5): 66–77.

Edwards, M., Jacobs, S. and Taylor, R.J. (2000). The blue water phenomenon. J Am. Water Works Assoc., 92(7): 72–82.

Edwards, M., Powers, K., Hidmi, L. and Schock, M.R. (2001). The role of pipe ageing in copper corrosion by-product release. Water Sci. Tech., 1(3):25–32.

Edwards, M., Hidmi, L. and Gladwell, D. (2002). Phosphate inhibition of soluble copper corrosion by-product release. Corros. Sci., 44(5): 1057–1071.

Edzwald, J.K. and Tobiason, J.E. (2011). Chemical principles, source water composition, and watershed protection. Chapter 3 in: Water quality and treatment: A handbook on drinking water, 6th edition. Edzwald, J.K. (ed.). American Water Works Association, Denver, Colorado; McGraw-Hill, New York, New York.

EFSA (2006). Tolerable upper intake levels for vitamins and minerals. Scientific Committee on Food. Scientific panel on dietetic products, nutrition and allergies. European Food Safety Authority. ISBN: 92-9199-014-0.

EFSA (2009). Scientific opinion of the panel on food additives and nutrient sources added to food on copper(II) oxide as a source of copper added for nutritional purposes to food supplements following a request from the European commission. EFSA Journal, 1089:1–15.

EFSA (2015). EFSA NDA panel (EFSA panel on dietetic products, nutrition and allergies). scientific opinion on dietary reference values for copper. EFSA journal, 13(10): 4253, 51 pp.

Ellingsen, D.G., Horn, N. and Aaseth, J. (2007). Chapter 26 - essential metals: Assessing risks from deficiency and toxicity. In: Handbook on the toxicology of metals. Nordberg, G.F., Fowler, B.A., Nordberg, M. and Friberg, L.T. (eds.). 3rd. Academy Press, San Diego, pp. 163–176.

Ellingsen, D.G., Møller, L.B. and Aaseth, J. (2015). Chapter 35 - copper. In: Handbook on the toxicology of metals (fourth edition). Nordberg, G.F.N.A.F. (ed.). 3rd edition. Academic Press, San Diego, California. pp. 765–786.

Environment Canada (2014). National air pollution surveillance network (NAPS) monitoring results: NAPS quality assured data products.

Eskici, G. and Axelsen, P.H. (2012). Copper and oxidative stress in the pathogenesis of Alzheimer's disease. Biochemistry, 51(32): 6289–6311.

FAO and WHO (2011). Standard for infant formula and formulas for special medical purposes intended for infants. CODEX STAN 72-1981. formerly CAC/RS 72-1972. Adopted as a Worldwide Standard in 1981. Amendment: 1983, 1985, 1987, 2011 and 2015. Revision: 2007. Codex Alimentarius. Food and Agriculture Organization of the United Nations. World Health Organization.

Ferguson, J.F., Franqué, O.V. and Schock, M.R. (1996). Corrosion of copper in potable water systems. In: Internal corrosion of water distribution systems. 2nd edition. American Water Works Association Research Foundation and DVGW Technologiezentrum Wasser. Denver, Colorado. pp. 231–268.

Fewtrell, L., Kay, D., Jones, F., Baker, A. and Mowat, A. (1996). Copper in drinking water--an investigation into possible health effects. Public Health, 110(3): 175–177.

Fischer, W., Paradies, H.H., Wagner, D. and Hänβel, I. (1992). Copper deterioration in a water distribution system of a county hospital in Germany caused by microbially induced corrosion- I. Description of the problem. Werkstoffe und Korrosion, 43:56–62.

Formigari, A., Gregianin, E. and Irato, P. (2013). The effect of zinc and the role of p53 in copper-induced cellular stress responses. J. Appl. Toxicol., 33(7): 527–536.

Friedman, M.J., Hill, A.S., Reiber, S.H., Valentine, R.L., Larsen, G., Young, A., Korshin, G.V. and Peng, C-Y. (2010). Assessment of inorganics accumulation in drinking water system scales and sediments. Water Research Foundation and United States Environmental Protection Agency. Denver, Colorado.

Fuentealba, I. and Haywood, S. (1988). Cellular mechanisms of toxicity and tolerance in the copper-loaded rat. I. ultrastructural changes in the liver. Liver, 8(6): 372–380.

Fuentealba, I., Haywood, S. and Foster, J. (1989a). Cellular mechanisms of toxicity and tolerance in the copper-loaded rat. II. pathogenesis of copper toxicity in the liver. Exp. Mol. Pathol., 50(1): 26–37.

Fuentealba, I.C., Haywood, S. and Foster, J. (1989b). Cellular mechanisms of toxicity and tolerance in the copper-loaded rat. III. ultrastructural changes and copper localization in the kidney. Br. J. Exp. Pathol., 70(5): 543–556.

Fuentealba, I.C., Mullins, J.E., Aburto, E.M., Lau, J.C. and Cherian, G.M. (2000). Effect of age and sex on liver damage due to excess dietary copper in fischer 344 rats. J. Toxicol. Clin. Toxicol., 38(7): 709–717.

Fujiwara, N., Iso, H., Kitanaka, N., Kitanaka, J., Eguchi, H., Ookawara, T., Ozawa, K., Shimoda, S., Yoshihara, D., Takemura, M. and Suzuki, K. (2006). Effects of copper metabolism on neurological functions in wistar and Wilson’s disease model rats. Biochem. Biophys. Res. Commun., 349(3): 1079–1086.

Fukui, H., Yamamoto, M., Sasaki, S. and Sato, S. (1994). Possible involvement of peripheral 5-HT4 receptors in copper sulfate-induced vomiting in dogs. Eur. J. Pharmacol., 257(1–2): 47–52.

Gaetke, L.M. and Chow, C.K. (2003). Copper toxicity, oxidative stress, and antioxidant nutrients. Toxicology, 189(1–2): 147–163.

Gaetke, L.M., Chow-Johnson, H.S. and Chow, C.K. (2014). Copper: Toxicological relevance and mechanisms. Arch. Toxicol., 88(11): 1929–1938.

Gaggelli, E., Kozlowski, H., Valensin, D. and Valensin, G. (2006). Copper homeostasis and neurodegenerative disorders (Alzheimer's, prion, and Parkinson’s diseases and amyotrophic lateral sclerosis). Chem. Rev., 106(6): 1995–2044.

Gambling, L., Kennedy, C. and McArdle, H.J. (2011). Iron and copper in fetal development. Semin. Cell Dev. Biol., 22(6): 637–644.

Georgopoulos, P.G., Roy, A., Yonone-Lioy, M.J., Opiekun, R.E. and Lioy, P.J. (2001). Environmental copper: Its dynamics and human exposure issues. J. Toxicol. Environ. Health B Crit. Rev., 4(4): 341–394.

Gerke, T.L., Little, B.J. and Maynard, B. (2016). Manganese deposition in drinking water distribution systems. Science of the Total Environment, 541:184–193.

Gibson, R.S. (1994). Content and bioavailability of trace elements in vegetarian diets. Am. J. Clin. Nutr., 59(5 Suppl): 1223S–1232S.

Gitlin, J.D. (2014). Copper homeostasis: Specialized functions of the late secretory pathway. Dev. Cell., 29(6): 631–632.

Govindaraju, M., Shekar, H.S., Sateesha, S.B., Vasudeva Raju, P., Sambasiva Rao, K.R., Rao, K.S.J. and Rajamma, A.J. (2013). Copper interactions with DNA of chromatin and its role in neurodegenerative disorders. J. Pharm. Anal., 3(5): 354–359.

Grace, S., Lytle, D.A. and Goltz, M.N. (2012). Control of new copper corrosion in high-alkalinity drinking water. J. Am. Water Works Assoc. 104(1), E15–E25.

Grass, G., Rensing, C. and Solioz, M. (2011). Metallic copper as an antimicrobial surface. Appl. Env. Microbiol., 77(5): 1541–1547.

Gulliver, J.M. (1991). A fatal copper sulfate poisoning. J. Anal. Toxicol., 15(6): 341–342.

Gurusamy, K. and Davidson, B.R. (2007). Trace element concentration in metastatic liver disease – A systematic review. J. Trace Elem. Med. Biol., 21(3): 169–177.

Ha, H.M. and Scully, J.R. (2013). Effects of phosphate on pit stabilization and propagation in copper in synthetic potable waters. Corrosion, 69(7): 703–718.

Haas, C., Koch, L., Kelty, K., Lytle, D. and Triantafyllidou, S. (2013). Effectiveness of the preservation protocol within the Environmental Protection Agency (EPA) Method 200.8 for soluble and particulate lead recovery in drinking water. U.S. Environmental Protection Agency, Washington, D.C. (EPA/600/R-13/222).

Hach (2014). Hach 8026 (CuVer2). Bicinchoninate Method. 9th Edition. Hach Company, Loveland, Colorado.

Hach (2016). Hach 10272 Copper Bicinchoninate Method. 5th Edition. Hach Company, Loveland, Colorado.

Harris, Z.L. and Gitlin, J.D. (1996). Genetic and molecular basis for copper toxicity. Am. J. Clin. Nutr., 63(5): 836S–841S.

Harvey, L.J., Dainty, J.R., Hollands, W.J., Bull, V.J., Beattie, J.H., Venelinov, T.I., Hoogewerff, J.A., Davies, I.M. and Fairweather-Tait, S.J. (2005). Use of mathematical modeling to study copper metabolism in humans. Am. J. Clin. Nutr, 81(4): 807–813.

Haywood, S. (1980). The effect of excess dietary copper on the liver and kidney of the male rat. J. Comp. Pathol., 90(2): 217–232.

Haywood, S. (1985). Copper toxicosis and tolerance in the rat: I. Changes in copper content of the liver and kidney. J. Pathol., 145(2): 149–158.

Haywood, S. and Loughran, M. (1985). Copper toxicosis and tolerance in the rat: II. Tolerance--a liver protective adaptation. Liver, 5(5): 267–275.

Haywood, S., Loughran, M. and Batt, R.M. (1985a). Copper toxicosis and tolerance in the rat: III. Intracellular localization of copper in the liver and kidney. Exp. Mol. Pathol., 43(2): 209–219.

Haywood, S., Trafford, J. and Loughran, M. (1985b). Copper toxicosis and tolerance in the rat: IV. Renal tubular excretion of copper. Br. J. Exp. Pathol., 66(6): 699–707.

Health Canada (1994). Human health assessment for priority substances. Canadian Environmental Protection Act. Available at: www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/contaminants/approach/approach-eng.pdf

Health Canada (2007). Copper. Natural Health Products Ingredients Database, Natural Health Products Directorate, Ottawa, Ontario.

Health Canada (2009a). Copper pesticides. Proposed re-evaluation decision. Pest Management Regulatory Agency. PRVD 2009-04.

Health Canada (2009b). Canadian total diet study. Health Products and Food Branch, Health Canada, Ottawa, Ontario. Available at: www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/canadian-total-diet-study.html.

Health Canada (2009c). Guidance on controlling corrosion in drinking water distribution systems. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario

Health Canada (2010). Dietary reference intakes tables. Health Products and Food Branch. Available at: www.hc-sc.gc.ca/fn-an/nutrition/reference/table/index-eng.php

Health Canada (2011). Average dietary intakes (µg/kg bw/day) of trace elements for Canadians in different age/sex groups for total diet study from 1993 to 1996. Available at: www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/canadian-total-diet-study/dietary-intakes-contaminants-other-chemicals-different-sex-groups-canadians/average-dietary-intakes-day-trace-elements-canadians-different-sex-groups-total-diet-study-1993-1996.html

Health Canada (2013). Second report on human biomonitoring of environmental chemicals in Canada. Available at: www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/environmental-contaminants/second-report-human-biomonitoring-environmental-chemicals-canada-health-canada-2013.html

Health Canada (2015). Personal communication with T. Shin. Healthy Environments and Consumer Safety Branch.

Health Canada (2016). Residential indoor air quality guideline: moulds . Available at: http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/mould-moisissure/alt/mould-moisissures-eng.pdf.

Hebert, C.D., Elwell, M.R., Travlos, G.S., Fitz, C.J. and Bucher, J.R. (1993). Subchronic toxicity of cupric sulfate administered in drinking water and feed to rats and mice. Fundam. Appl. Toxicol., 21(4): 461–475.

Heinemann, K., Reed, S., Moehner, S. and Do Minh, T. (2015). Risk of uterine perforation with levonorgestrel-releasing and copper intrauterine devices in the European active surveillance study on intrauterine devices. Contraception, 91(4): 274–279.

Hidmi, L. and Edwards, M. (1999). Role of temperature and pH in Cu(OH)2 solubility. Environ. Sci. Technol., 33(15): 2607–2610.

Hong, P.K.A. and Macauley, Y. (1998). Corrosion and leaching of copper tubing exposed to chlorinated drinking water. Water Air Soil Pollut., 108(3–4): 457–471.

Horn, C.C., Kimball, B.A., Wang, H., Kaus, J., Dienel, S., Nagy, A., Gathright, G.R., Yates, B.J. and Andrews,P.L. (2013). Why can't rodents vomit? A comparative behavioral, anatomical, and physiological study. PLoS One, 8(4): 1–16.

Hu, J., Gan, F., Triantafyllidou, S., Nguyen, C.K. and Edwards, M.A. (2012). Copper-induced metal release from lead pipe in drinking water. Corrosion, 68(11):1037–1048.

Hujita, H., Nakano, M. and Sasaki, M. (1998). Mutagenicity of food additives in the Ames Salmonella/microsome assay. Tokyo Metropolitan Research Laboratory of Public Health Annual Reports, 39, pp. 343–350. [cited in Abe et al., 2008].

Ingle, A.P., Duran, N. and Rai, M. (2014). Bioactivity, mechanism of action, and cytotoxicity of copper-based nanoparticles: A review. Appl. Microbiol. Biotechnol., 98(3): 1001–1009.

IOM (2001). Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Food and Nutrition Board, Institute of Medicine. National Academy Press, Washington, DC, USA, 797 pp.

IPCS (1998). Environmental Health Criteria 200: Copper. International Programme on Chemical Safety. World Health Organization, Geneva.

Jacobs, S. and Edwards, M. (2000). Sulfide scale catalysis of copper corrosion. Wat. Res., 34(10): 2798–2808

Jacobs, S., Reiber, S. and Edwards, M. (1998). Sulfide-induced copper corrosion, J. Am. Water Works Assoc., 90(7): 62–73.

Jantsch, W., Kulig, K. and Rumack, B.H. (1984). Massive copper sulfate ingestion resulting in hepatotoxicity. J. Toxicol. Clin. Toxicol., 22(6): 585–588.

Javaherdashti, R. (2008). Chapter 4: Microbiologically influenced corrosion (MIC). In: Microbiologically Influenced Corrosion. 1st edition. Springer-Verlag London Limited.

Jazvinscak Jembrek, M., Vlainic, J., Radovanovic, V., Erhardt, J. and Orsolic, N. (2014). Effects of copper overload in P19 neurons: Impairment of glutathione redox homeostasis and crosstalk between caspase and calpain protease systems in ROS-induced apoptosis. Biometals, 27(6): 1303–1322.

Jiménez Del Río, M. and Vélez-Pardo, C. (2004). Transition metal-induced apoptosis in lymphocytes via hydroxyl radical generation, mitochondria dysfunction, and caspase-3 activation: An in vitro model for neurodegeneration. Arch. Med. Res., 35(3): 185–193.

Johncilla, M. and Mitchell, K.A. (2011). Pathology of the liver in copper overload. Semin. Liver Dis., 31(3): 239–244.

Johnson , B., Yorton, R., Tran, T. and Kim, J. (1993). Evaluation of corrosion control alternatives to meet the Lead and Copper Rule for eastern Massachusetts. J. N. Engl. Water Works Assoc., 107(3): 24–45.

Jomova, K. and Valko, M. (2011). Advances in metal-induced oxidative stress and human disease. Toxicology, 283(2–3): 65–87.

Kadiiska, M.B., Hanna, P.M., Hernandez, L. and Mason, R.P. (1992). In vivo evidence of hydroxyl radical formation after acute copper and ascorbic acid intake: Electron spin resonance spin-trapping investigation. Mol. Pharmacol., 42(4): 723–729.

Kaler, S.G. (1998). Metabolic and molecular bases of Menkes disease and occipital horn syndrome. Pediatr. Dev. Pathol., 1(1): 85–98.

Kaplan, J.H. and Lutsenko, S. (2009). Copper transport in mammalian cells: Special care for a metal with special needs. J. Biol. Chem., 284(38): 25461–25465.

Karim, Z. (2011). Risk assessment of dissolved trace metals in drinking water of Karachi, Pakistan. Bull. Environ. Contam. Toxicol., 86(6): 676–678.

Kawakami, M., Inagawa, R., Hosokawa, T., Saito, T. and Kurasaki, M. (2008). Mechanism of apoptosis induced by copper in PC12 cells. Food Chem. Toxicol., 46(6): 2157–2164.

Kehoe, C.A., Turley, E., Bonham, M.P., O'Connor, J.M., McKeown, A., Faughnan, M.S., Coulter, J.S., Gilmore, W.S., Howard, A.N. and Strain, J.J. (2000). Response of putative indices of copper status to copper supplementation in human subjects. Br. J. Nutr., 84(2): 151–156.

Kirmeyer, G., Sandvig, A.M., Pierson, G.L. and Neff, C.H. (1994). Development of a pipe loop protocol for lead control. Water Research Foundation, Denver, Colorado. Awwa Research Foundation Report #90650.

Kessler, H., Pajonk, F.G., Meisser, P., Schneider-Axmann, T., Hoffmann, K.H., Supprian, T., Herrmann, W., Obeid, R., Multhaup, G., Falkai, P. and Bayer, T.A. (2006). Cerebrospinal fluid diagnostic markers correlate with lower plasma copper and ceruloplasmin in patients with Alzheimer's disease. J. Neural Transm. (Vienna), 113(11): 1763–1769.

Kiaune, L. and Singhasemanon, N. (2011). Pesticidal copper (I) oxide: Environmental fate and aquatic toxicity. In: Reviews of environmental contamination and toxicology. volume 213. chap.1. Whitacre, D.M. (ed.). Springer, pp. 1–26.

Kieber, R.J., Skrabal, S.A., Smith, C. and Willey, J.D. (2004). Redox speciation of copper in rainwater: Temporal variability and atmospheric deposition. Environ. Sci. Technol., 38(13): 3587–3594.

Kim, B.E., Nevitt, T. and Thiele, D.J. (2008). Mechanisms for copper acquisition, distribution and regulation. Nat. Chem. Biol., 4(3): 176–185.

Kimbrough, D.E. (2001). Brass corrosion and the LCR monitoring program. J. Am. Water Works Assoc., 93(2): 81–91.

Kimbrough, D.E. (2007). Brass corrosion as a source of lead and copper in traditional and all-plastic distribution systems. J. Am. Water Works Assoc., 99(8): 70–76.

Kimbrough, D.E. (2009). Source identification of copper, lead, nickel, and zinc loading in wastewater reclamation plant influents from corrosion of brass in plumbing fixtures. Environmental Pollution, 157:1310–1316.

Kirmeyer, G., Murphy, B., Sandvig, A., Korshin, G., Shaha, B., Fabbricino, M. and Burlingame, G. (2004). Post-optimization lead and copper control monitoring strategies. Awwa Research Foundation, Denver, Colorado.

Kitazawa, M., Cheng, D. and Laferla, F.M. (2009). Chronic copper exposure exacerbates both amyloid and tau pathology and selectively dysregulates cdk5 in a mouse model of AD. J. Neurochem., 108(6): 1550–1560.

Klevay, L.M. (2010). Copper. In: Encyclopedia of dietary supplements. pp. 175–184.

Knobeloch, L., Ziarnik, M., Howard, J., Theis, B., Farmer, D., Anerson, H. and Proctor, M. (1994). Gastrointestinal upsets associated with ingestion of copper-contaminated water. Env. Health Persp. 102(11):958–961.

Kok, F.J., Van Duijn, C.M., Hofman, A., Van der Voet, G.B., De Wolff, F.A., Paays, C.H. and Valkenburg, H.A. (1988). Serum copper and zinc and the risk of death from cancer and cardiovascular disease. Am. J. Epidemiol., 128(2): 352–359.

Korshin, G.V., Pery, S.A.L. and Ferguson, J.F. (1996). Influence of NOM on copper corrosion. J. Am. Water Works Assoc., 88(7): 36–47.

Krishnan, K., Carrier, R. (2013). The use of exposure source allocation factor in the risk assessment of drinking-water contaminants. J. Toxicol. Environ. Health B Crit. Rev., 16(1):39–51.

Kuch, A. and Wagner, I. (1983). A mass transfer model to describe lead concentrations in drinking water. Water Supply, 17(10): 1330–1307.

Kumar, V., Kalita, J., Misra, U.K. and Bora, H.K. (2015). A study of dose response and organ susceptibility of copper toxicity in a rat model. J. Trace Elem. Med. Biol., 29: 269–274.

Larney, F.J., Olson, A.F., Miller, J.J. and Tovell, B.C. (2014). Soluble salts, copper, zinc and solids constituents in surface runoff from cattle manure compost windrows. Can. J. Soil Sci., 94:515–527.

Lagos, G.E., Cuadrado, C.A. and Letelier, V. (2001). Aging of copper pipes by drinking water. J. Am. Water Works Assoc. 93(11): 94–103.

Lehtola, M.J., Miettinen, I.T., Keinänen, Kekki, T.K., Laine, O., Hirvonen, A., Vartiainen, T. and Martikainen, P.J. (2004). Microbiology, chemistry and biofilm development in a pilot drinking water distribution system with copper and plastic pipes. Water Research, 38: 3769–3779.

Lehtola, M.J., Laxander, M., Miettinen, I.T., Hirvonen, A., Vartiainen, T. and Martikainen, (2006). The effects of changing water flow velocity on the formation of biofilms and water quality in pilot distribution system consisting of copper or polyethylene pipes. Water Research, 40:2151–2160.

Letelier, M.E., Sanchez-Jofre, S., Peredo-Silva, L., Cortes-Troncoso, J. and Aracena-Parks, P. (2010). Mechanisms underlying iron and copper ions toxicity in biological systems: Pro-oxidant activity and protein-binding effects. Chem. Biol. Interact., 188(1): 220–227.

Lide, D.R. (1993). CRC Handbook of Chemistry and Physics, 73rd ed. CRC Press, Boca Raton, Florida.

Lind, Y. and Glynn, A.W. (1999). Intestinal absorption of copper from drinking water containing fulvic acids and an infant formula mixture studied in a suckling rat model. Biometals, 12(2): 181–187.

Linder, M.C. (1991). Biochemistry of copper. Plenum Press, New York, New York.

Linder, M.C. (2001). Copper and genomic stability in mammals. Mutat. Res., 475(1–2): 141–152.

Linder, M.C. (2002). Biochemistry and molecular biology of copper in mammals. Handbook of Copper Pharmacology and Toxicology. Edited by Massaro, E.J. and Totowa, N.J. Humana Press, 3–32.

Linder, M.C. and Hazegh-Azam, M. (1996). Copper biochemistry and molecular biology. Am. J. Clin. Nutr., 63(5): 797S–811S.

Lintereur, P.A., Duranceau, S.J. and Taylor, J.S. (2011). Sodium silicate impacts on copper release in a potable water comprised of ground, surface and desalted sea water supplies. Desalination and Water Treatment, 30:348–360.

Little, B., Wagner, P. and Mansfeld, F. (1991). Microbially influence corrosion of metals and alloys. International Materials Reviews, 36(6):253–272.

Lonnerdal, B. (1996). Bioavailability of copper. Am. J. Clin. Nutr., 63(5): 821S–829S.

Lonnerdal, B. (1998). Copper nutrition during infancy and childhood. Am. J. Clin. Nutr., 67(5 Suppl): 1046S–1053S.

Lovell, M.A., Robertson, J.D., Teesdale, W.J., Campbell, J.L. and Markesbery, W.R. (1998). Copper, iron and zinc in Alzheimer's disease senile plaques. J.Neurol.Sci., 158(1): 47–52.

Lowry, J. (2009). Lakhurst Acres, ME: Compliance issues engineering problems and solutions. U.S. EPA Sixth annual drinking water workshop: Small drinking water system challenges and solutions. August 4-6. Cincinnati, Ohio.

Lowry, J., (2010). Corrosion control with air stripping. American water work association. Inorganic contaminants workshop, Denver, Colorado.

Lytle, D.A. and Nadagouda, M.N. (2010). A comprehensive investigation of copper pitting corrosion in a drinking water distribution system. Corrosion Science, 52:1927–1938.

Lytle, D.A. and Schock, M.R. (1996). Stagnation time, composition, pH, and orthophosphate effects on metal leaching from brass. Office of Research and Development. U.S. EPA, Cincinnati, OH. EPA.600.R-96.103

Lytle, D.A. and Schock, M.R. (2000). Impact of stagnation time on metal dissolution from plumbing materials in drinking water Journal of Water Supply Research and Technology-AQUA, 49(5):243–257.

Lytle, D.A. and Schock, M.R. (2008). Pitting corrosion of copper in waters with high pH and low alkalinity. J. Am Water Works Assoc., 100(3): 115–129.

Lytle, D.A., Williams, D. and White, C. (2012). A simple approach to assessing copper pitting corrosion tendencies and developing control strategies. J Water Supply: Research and Technology – AQUA, 63(3): 164–175.

Machado, A.A., Deguti, M.M., Genschel, J., Cancado, E.L., Bochow, B., Schmidt, H. and Barbosa, E.R. (2008). Neurological manifestations and ATP7B mutations in Wilson's disease. Parkinsonism Relat. Disord., 14(3): 246–249.

MacQuarrie, D.M., Mavinic, D.S. and Neden, D.G. (1997). Greater Vancouver Water District drinking water corrosion inhibitor testing. Can. J. Civil Eng., 24(1): 34–52.

Madsen, E. and Gitlin, J.D. (2007). Copper and iron disorders of the brain. Annu. Rev. Neurosci., 30: 317–337.

Maessen, O., Freedman, B. and McCurdy, R. (1985). Metal mobilization in home well water systems in Nova Scotia. J. Am. Water Works Assoc., 77(6):73–80.

Mahabir, S., Forman, M.R., Dong, Y.Q., Park, Y., Hollenbeck, A. and Schatzkin, A. (2010). Mineral intake and lung cancer risk in the NIH-American association of retired persons diet and health study. Cancer Epidemiol. Biomarkers Prev., 19(8): 1976–1983.

Makale, M.T. and King, G.L. (1992). Surgical and pharmacological dissociation of cardiovascular and emetic responses to intragastric CuSO4. Am. J. Physiol., 263(2 Pt 2): R284–291.

Masters, S., Wang, H., Pruden, A. and Edwards, M.A. (2015). Redox gradients in distribution systems influence water quality, corrosion, and microbial ecology. Water Research, 68:140–149.

Mauceri, C. and Mishra, S. (2014). Copper. Chapter 18 in: Health effects of metals and related substances in drinking water. Ferrante, M., Conti, O.,G., Rasic-Milutinovic, Z. and Jovanovic, D. (eds.). IWA Publishing, Alliance House, London, UK, pp. 50–52.

McNeill, L.S. and Edwards, M. (2002). Phosphate inhibitor use at U.S. utilities. J. Am. Water Works Assoc., 94(7): 57–63.

McNeill, L.S. and Edwards, M. (2004). Importance of Pb and Cu particulate species for corrosion control. J. Environ. Eng., 130(2):136–144.

Mehta, A., Patney, N.L., Bhati, D.P. and Singh, S.P. (1985). Copper sulphate poisoning--its impact on kidneys. J. Indian Med. Assoc., 83(4): 108–110.

Mendez, M.A., Araya, M., Olivares, M., Pizarro, F. and Gonzalez, M. (2004). Sex and ceruloplasmin modulate the response to copper exposure in healthy individuals. Environ. Health Perspect., 112(17): 1654–1657.

Michaluk, A. and Kochman, K. (2007). Involvement of copper in female reproduction. Reprod. Biol., 7(3): 193–205.

Miller, L.M., Wang, Q., Telivala, T.P., Smith, R.J., Lanzirotti, A. and Miklossy, J. (2006). Synchrotron-based infrared and X-ray imaging shows focalized accumulation of cu and zn co-localized with beta-amyloid deposits in Alzheimer's disease. J. Struct. Biol., 155(1): 30–37.

Molina, J.A., Jimenez-Jimenez, F.J., Aguilar, M.V., Meseguer, I., Mateos-Vega, C.J., Gonzalez-Munoz, M.J., de Bustos, F., Porta, J., Orti-Pareja, M., Zurdo, M., Barrios, E. and Martinez-Para, M.C. (1998). Cerebrospinal fluid levels of transition metals in patients with Alzheimer's disease. J. Neural Transm. (Vienna), 105(4–5): 479–488.

Montes, S., Rivera-Mancia, S., Diaz-Ruiz, A., Tristan-Lopez, L. and Rios, C. (2014). Copper and copper proteins in Parkinson’s disease. Oxid. Med. Cell. Longev., 2014: 147251.

Moriya, M., Ohta, T., Watanabe, K., Miyazawa, T., Kato, K. and Shirasu, Y. (1983). Further mutagenicity studies on pesticides in bacterial reversion assay systems. Mutat. Res., 116(3–4): 185–216.

Muller, T., Feichtinger, H., Berger, H. and Muller, W. (1996). Endemic Tyrolean infantile cirrhosis: An ecogenetic disorder. Lancet, 347(9005): 877–880.

Murphy, E.A. (1993). Effectiveness of flushing on reducing lead and copper levels in school drinking water. Environ. Health Perspect., 101(3): 240–241.

Neuman, W.E. (1995). AWWC experience with zinc orthophosphate treatment. J. N. Engl. Water Works Assoc., 109: 57–60.

Nicholson, F.A., Chambers, B.J., Williams, J.R. and Unwin, R.J. (1999). Heavy metal contents of livestock feeds and animal manures in England and Wales. Biores. Tech., 70:23–31.

NHMRC (2011). Australian drinking water guidelines. Paper 6: National water quality management strategy. Version 3.1, updated march 2015. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra. ISBN online: 1864965118.

NRC (2000). Copper in drinking water. National Research Council. National Academy Press. Washington, DC.

NRCC (2010). National Plumbing Code. National Research Council of Canada, Ottawa, Ontario.

NSF International (2015a). NSF/ANSI Standard 60: Drinking water treatment chemicals—health effects. NSF International, Ann Arbor, Michigan.

NSF International (2015b). NSF/ANSI Standard 53: Drinking water treatments units—Health effects. NSF International, Ann Arbor, Michigan.

NSF International (2015c). NSF/ANSI Standard 58: Reverse osmosis drinking water treatment systems. NSF International, Ann Arbor, Michigan.

NSF International (2015d). NSF/ANSI Standard 62: Drinking water distillation systems. NSF International, Ann Arbor, Michigan.

NSF International (2016a). NSF/ANSI Standard 61: Drinking water system components—health effects. NSF International, Ann Arbor, Michigan.

NSF International (2016b). NSF/ANSI Standard 372: Drinking water system components—lead content. NSF International, Ann Arbor, Michigan.

NTP (1993). NTP Technical report on toxicity studies of cupric sulfate (CAS No. 7758-99-8) administered in drinking water and feed to F344/N rats and B6C3F1 mice. National Toxicology Program, National Institute of Health. Report No. 29 .

O'Connor, J.M., Bonham, M.P., Turley, E., McKeown, A., McKelvey-Martin, V.J., Gilmore, W.S. and Strain, J.J. (2003). Copper supplementation has no effect on markers of DNA damage and liver function in healthy adults (FOODCUE project). Ann. Nutr. Metab., 47(5): 201–206.

O'Donohue, J., Reid, M.A., Varghese, A., Portmann, B. and Williams, R. (1993). Micronodular cirrhosis and acute liver failure due to chronic copper self-intoxication. Eur. J. Gastroenterol. Hepatol., 5: 561–562.

O'Donohue, J., Reid, M., Varghese, A., Portmann, B. and Williams, R. (1999). A case of adult chronic copper self-intoxication resulting in cirrhosis. Eur. J. Med. Res., 4(6): 252.

OEHHA (2008). Public Health Goal for Copper in Drinking Water. Office of Environmental Health Hazard Assessment (OEHHA). California Environmental Protection Agency. Available at: https://oehha.ca.gov/media/downloads/water/chemicals/phg/copperphg020808_0.pdf

Oliphant, R.J. and Schock, M.R. (1996). Chapter 6: Copper alloys and solders. In: Internal corrosion of water distribution systems. 2nd edition. American Water Works Association Research Foundation and DVGW-Technologiezentrum Wasser, Denver, Colorado. pp.269–312.

Olivares, M. and Uauy, R. (1996). Copper as an essential nutrient. Am. J. Clin. Nutr., 63(5): 791S–796S.

Olivares, M., Pizarro, F., Speisky, H., Lonnerdal, B. and Uauy, R. (1998). Copper in infant nutrition: Safety of world health organization provisional guideline value for copper content of drinking water. J. Pediatr. Gastroenterol. Nutr., 26(3): 251–257.

Olivares, M., Araya, M., Pizarro, F. and Uauy, R. (2001). Nausea threshold in apparently healthy individuals who drink fluids containing graded concentrations of copper. Regul. Toxicol. Pharmacol., 33(3): 271–275.

Omur-Ozbek, P. and Dietrich, A.M. (2011). Retronasal perception and flavour thresholds of iron and copper in drinking water. J. Water. Health., 9(1): 1–9.

Ontario Superior Court of Justice. (2011) . Nicholas Rosati and Anthony Bellissimo and IPEX USA LLC and IPEX Inc. Proceeding Under the Class Proceedings Act, 1992. CV-09-13459. November 29, 2011.

Overvad, K., Wang, D.Y., Olsen, J., Allen, D.S., Thorling, E.B., Bulbrook, R.D. and Hayward, J.L. (1993). Copper in human mammary carcinogenesis: A case-cohort study. Am. J. Epidemiol., 137(4): 409–414.

Ozcelik, D. and Uzun, H. (2009). Copper intoxication; antioxidant defenses and oxidative damage in rat brain. Biol. Trace Elem. Res., 127(1): 45–52.

Pajonk, F.G., Kessler, H., Supprian, T., Hamzei, P., Bach, D., Schweickhardt, J., Herrmann, W., Obeid, R., Simons, A., Falkai, P., Multhaup, G. and Bayer, T.A. (2005). Cognitive decline correlates with low plasma concentrations of copper in patients with mild to moderate Alzheimer's disease. J. Alzheimer's Dis., 8(1): 23–27.

Pal, A. (2014). Copper toxicity induced hepatocerebral and neurodegenerative diseases: An urgent need for prognostic biomarkers. Neurotoxicology, 40: 97–101.

Pal, A., Badyal, R.K., Vasishta, R.K., Attri, S.V., Thapa, B.R. and Prasad, R. (2013). Biochemical, histological, and memory impairment effects of chronic copper toxicity: A model for non-Wilsonian brain copper toxicosis in wistar rat. Biol. Trace Elem. Res., 153(1–3): 257–268.

Pal, A., Jayamani, J. and Prasad, R. (2014). An urgent need to reassess the safe levels of copper in the drinking water: Lessons from studies on healthy animals harboring no genetic deficits. Neurotoxicology, 44: 58–60.

Pamp, K., Bramey, T., Kirsch, M., De Groot, H. and Petrat, F. (2005). NAD(H) enhances the cu(II)-mediated inactivation of lactate dehydrogenase by increasing the accessibility of sulfhydryl groups. Free Radic. Res., 39(1): 31–40.

Paris, I., Perez-Pastene, C., Couve, E., Caviedes, P., Ledoux, S. and Segura-Aguilar, J. (2009). Copper dopamine complex induces mitochondrial autophagy preceding caspase-independent apoptotic cell death. J. Biol. Chem., 284(20): 13306–13315.

Park, H.J., Nguyen, T.T., Yoon, J. and Lee, C. (2012). Role of reactive oxygen species in *Escherichia coli* inactivation by cupric ion. Environ. Sci. Technol., 46(20): 11299–11304.

Payne, S.J., Piorkowski, G.S., Truelstrup Hansen, L. and Gagnon, G.A. (2016). Impact of zinc orthophosphate on simulated drinking water biofilms influenced by lead and copper, J. Environ.. Eng., 142(2).

Peña, M.M.O., Lee, J. and Thiele, D.J. (1999). A delicate balance: Homeostatic control of copper uptake and distribution. The Journal of Nutrition, 129(7): 1251–1260.

Petris, M.J., Mercer, J.F., Culvenor, J.G., Lockhart, P., Gleeson, P.A. and Camakaris, J. (1996). Ligand-regulated transport of the Menkes copper P-type ATPase efflux pump from the Golgi apparatus to the plasma membrane: A novel mechanism of regulated trafficking. EMBO J., 15(22): 6084–6095.

Pizarro, F., Olivares, M., Gidi, V. and Araya, M. (1999a). The gastrointestinal tract and acute effects of copper in drinking water and beverages. Rev. Environ. Health, 14(4): 231–238.

Pizarro, F., Olivares, M., Uauy, R., Contreras, P., Rebelo, A. and Gidi, V. (1999b). Acute gastrointestinal effects of graded levels of copper in drinking water. Environ. Health Perspect., 107(2): 117–121.

Pizarro, F., Olivares, M., Araya, M., Gidi, V. and Uauy, R. (2001). Gastrointestinal effects associated with soluble and insoluble copper in drinking water. Environ. Health Perspect., 109(9): 949–952.

Prasad, M.P.R., Krishna, T.P., Pasricha, S., Krishnaswamy, K. and Quereshi, M.A. (1992). Esophageal cancer and diet a case-control study. Nutr. Cancer, 18: 85–93. [as cited in IPCS, 1998].

Prasad, R., Kaur, G., Nath, R. and Walia, B.N. (1996). Molecular basis of pathophysiology of Indian childhood cirrhosis: Role of nuclear copper accumulation in liver. Mol. Cell. Biochem., 156(1): 25–30.

Pratt, W.B., Omdahl, J.L. and Sorenson, J.R. (1985). Lack of effects of copper gluconate supplementation. Am. J. Clin. Nutr., 42(4): 681–682.

Prohaska, J.R. (1990). Development of copper deficiency in neonatal mice. J. Nutr. Biochem., 1(8): 415–419.

Prohaska, J.R. (2008). Role of copper transporters in copper homeostasis. Am. J. Clin. Nutr., 88(3): 826S–829S.

Qian, Y., Zheng, Y., Taylor, R. and Tiffany-Castiglioni, E. (2012). Involvement of the molecular chaperone Hspa5 in copper homeostasis in astrocytes. Brain Res., 1447: 9–19.

Qin-qin, T., Zhi-rong, L., Ying, D. and Xin-xing, Z. (2012). Biosorption properties of extracellular polymeric substances towards Zn (II) and Cu (II). Desalination and Water Treatment, 45(1–3): 40–47.

Rae, T.D., Schmidt, P.J., Pufahl, R.A., Culotta, V.C. and O'Halloran, T.V. (1999). Undetectable intracellular free copper: The requirement of a copper chaperone for superoxide dismutase. Science, 284(5415): 805–808.

Rahman, S., McDonald, B.C. and Gagnon, G.A. (2007). Impact of secondary disinfectants on copper corrosion under stagnation conditions. Journal of Environmental Engineering, 133(2): 180–185.

Rasmussen, P.E., Beauchemin, S., Nugent, M., Dugandzic, R., Lanouette, M. and Chénier, M. (2008). Influence of matrix composition on the bioaccessibility of copper, zinc, and nickel in urban residential dust and soil. Hum. Ecol. Risk Assess. 14(2): 351–371.

Rasmussen, P.E., Dugandzic, R., Hassan, N., Murimboh, J. and Grégoire, D.C. (2006). Challenges in quantifying airborne metal concentrations in residential environments. Can. J. Anal. Sci. Spectrosc., 51(1): 2–8.

Rasmussen, P.E., Subramanian, K.S. and Jessiman, B.J. (2001). A multi-element profile of housedust in relation to exterior dust and soils in the city of Ottawa, Canada. Sci. Total Environ., 267(1–3): 125–140.

Rehring, J.P. and Edwards, M. (1996). Copper corrosion in potable water systems: impacts of natural organic matter and water treatment processes. Corrosion, 52(4): 301–317.

Reiber, S.H. (1989). Copper plumbing surfaces: an electrochemical study. J. Am. Water Works Assoc., 87(7): 114.

Reiber, S., Poulsam, S., Perry, S.A.L., Edwards, M.A., Patel, S. and Dodrill, D.M. (1997). A general framework for corrosion control based on utility experience, AWWA Research Foundation and American Water Works Association, Denver, Colorado.

Reyes, A., Letelier, M.V., De la Igledia, R., González, B., Lagos, G. (2008). Microbiologically induced corrosion of copper pipes in low-pH water. International Biodeterioration & Biodegradation, 61:135–141.

Rezania, L.W. and Anderl, W.H. (1995). Copper corrosion and iron removal plants. The Minnesota experience. In: Proceedings of the 1995 AWWA Water Quality Technology Conference, New Orleans, LA. American Water Works Association, Denver, Colorado.

Rezania, L.W. and Anderl, W.H. (1997). Corrosion control for high DIC groundwater phosphate or bust. In: Proceedings of the 1997 AWWA Annual Conference, Atlanta, GA. American Water Works Association, Denver, Colorado.

Rhoads, W.J., Pruden, A., and Edwards, M.A. (2016). Survey of green building water systems reveals elevated water age and water quality concerns. Environmental Science Water Research & Technology, 2:164–173.

Riedel, G.F. (2008). Copper. In: Encyclopedia of ecology. volume 1 A-C. Jorgensen, S.E. and Fath, B.D. (eds.). pp. 778–783.

Rivera-Mancia, S., Perez-Neri, I., Rios, C., Tristan-Lopez, L., Rivera-Espinosa, L. and Montes, S. (2010). The transition metals copper and iron in neurodegenerative diseases. Chem. Biol. Interact., 186(2): 184–199.

Roelofsen, H., Wolters, H., Van Luyn, M.J.A., Miura, N., Kuipers, F. and Vonk, R.J. (2000). Copper-induced apical trafficking of ATP7B in polarized hepatoma cells provides a mechanism for biliary copper excretion. Gastroenterology, 119(3): 782–793.

Rosenzweig, A.C. (2001). Copper delivery by metallochaperone proteins. Acc. Chem. Res., 34(2): 119–128.

Roychoudhury, S., Nath, S., Massanyi, P., Stawarz, R., Kacaniova, M. and Kolesarova, A. (2015). Copper induced changes in reproductive functions: Review of in vivo and in vitro effects. Physiol. Res., 65(1):11–22.

Sadhra, S.S., Wheatley, A.D. and Cross, H.J. (2007). Dietary exposure to copper in the European union and its assessment for EU regulatory risk assessment. Sci. Total Environ., 374(2–3): 223–234.

Sandvig, A., Martel, K., Beggs, K., Jaffe Murray, A., Greiner, P., Kneen, K., McLellan, C., Bennet, D. and Terrell, J. (2012). Is NSF 61 relevant for chloraminating utilities? Water Research Foundation, Denver, Colorado (Water Research Foundation Project No. 4243).

Sarver, E., Zhang, Y. and Edwards, M. (2011). Copper pitting and brass dezincification: chemical and physical effects. Water Research Foundation, Denver, Colorado.

Scardina, P., Edwards, M., Bosch, D.J., Loganathan, G.V. and Dwyer, S.K. (2008). Assessment of non-uniform corrosion in copper piping. Water Research Foundation, Denver, Colorado.

Schaefer, M. and Gitlin, J.D. (1999). Genetic disorders of membrane transport. IV. Wilson's disease and Menkes disease. Am. J. Physiol., 276(2 Pt 1): G311–G314.

Scheinberg, I.H. and Sternlieb, I. (1996). Wilson disease and idiopathic copper toxicosis. Am. J. Clin. Nutr., 63(5): 842S–845S.

Schilsky, M.L. (1996). Wilson disease: Genetic basis of copper toxicity and natural history. Semin. Liver Dis., 16(1): 83–95.

Schock, M.R. (1990). Causes of temporal variability of lead in domestic plumbing systems. Environ. Monit. Assess., 15(1): 59–82.

Schock, M.R. (1999). Chapter 17: Internal corrosion and deposition control. In: Letterman, R.D. (ed.), Water quality and treatment: a handbook on drinking water. 5th edition. McGraw Hill and American Water Works Association, Denver, Colorado. pp. 87–88.

Schock, M.R. (2005). Distribution systems as reservoirs and reactors for inorganic contaminants. In: Distribution system water quality challenges in the 21st century: a strategic guide. American Water Works Association, Denver, Colorado.

Schock, M.R. and Clement, J.A. (1998). Lead and copper control with non-zinc orthophosphate. J. N. Engl. Water Works Assoc., 112(1): 20–33

Schock, M.R. and Fox, J.C. (2001). Solving copper corrosion problems while maintaining lead control in a high alkalinity water using orthophosphate. In: Proceedings of the 2001 AWWA Annual Conference, Washington, DC. American Water Works Association, Denver, Colorado.

Schock, M.R. and Lytle, D. (2011). Chapter 20: Internal corrosion and deposition control. In: J.K. Edzwald (ed.), Water quality and treatment: a handbook on drinking water. 6th edition. McGraw Hill and American Water Works Association, Denver, Colorado.

Schock, M.R. and Neff, C.H. (1988). Trace metal contamination from brass fittings. J. Am. Water Works Assoc., 80(11): 47–56.

Schock, M.R. and Sandvig, A.M. (2009). Long-term effects of orthophosphate treatment on copper concentration. J. Am. Water Works Assoc., 101(7): 71–82.

Schock, M.R., Lytle, D.A. and Clement, J.A. (1995). Effect of pH, DIC, orthophosphate, and sulfate on drinking water cuprosolvency. U.S. Environmental Protection Agency, Cincinnati, OH (Report No. EPA/600/R-95/085).

Schock, M.R., Wagner, I. and Oliphant, R.J. (1996). Corrosion and solubility of lead in drinking water. In: Internal corrosion of water distribution systems. 2nd edition. American Water Works Association Research Foundation and DVGW Technologiezentrum Wasser, Denver, Colorado. pp. 131–230.

Scott, K.C. and Turnlund, J.R. (1994). A compartmental model of zinc metabolism in adult men used to study effects of three levels of dietary copper. Am. J. Physiol., 267(1 Pt 1): E165–173.

Senesse, P., Meance, S., Cottet, V., Faivre, J. and Boutron-Ruault, M. (2004). High dietary iron and copper and risk of colorectal cancer: A case-control study in burgundy, France. Nutr. Cancer, 49(1): 66–71.

Shaligram, S. and Campbell, A. (2013). Toxicity of copper salts is dependent on solubility profile and cell type tested. Toxicol. in Vitro., 27(2): 844–851.

Shanaman et al. (1972). [as cited by WHO,1993].

Sharrett, A.R., Carter, A.P., Orheim, R.M. and Feinleib, M. (1982). Daily intake of lead, cadmium, copper, and zinc from drinking water: the Seattle study of trace metal exposure. Environ. Res., 28: 456–475.

Shike, M. (2009). Copper in parenteral nutrition. Gastroenterology, 137(5 Suppl): S13–S17.

Singh, I. and Mavinic, D.S. (1991). Significance of building and plumbing specifics on trace metal concentrations in drinking water. Can. J. Civil Eng., 18(6): 893–903.

Sokol, R.J., Devereaux, M., Mierau, G.W., Hambidge, K.M. and Shikes, R.H. (1990). Oxidant injury to hepatic mitochondrial lipids in rats with dietary copper overload. Modification by vitamin E deficiency. Gastroenterology, 99(4):1061–1071.

Sorg, T.J., Schock, M.R. and Lytle, D.A. (1999). Ion exchange softening: effects on metal concentrations. J. Am. Water Works Assoc., 91(8): 85–97.

Sparks, D.L. and Schreurs, B.G. (2003). Trace amounts of copper in water induce beta-amyloid plaques and learning deficits in a rabbit model of Alzheimer's disease. Proc. Natl. Acad. Sci. U. S. A., 100(19): 11065–11069.

Spitalny, K.C., Brondum, J., Vogt, R.L., Sargent, H.E. and Kappel, S. (1984). Drinking-water-induced copper intoxication in a Vermont family. Pediatrics, 74(6): 1103–1106.

Squitti, R., Lupoi, D., Pasqualetti, P., Dal Forno, G., Vernieri, F., Chiovenda, P., Rossi, L., Cortesi, M., Cassetta, E. and Rossini, P.M. (2002). Elevation of serum copper levels in Alzheimer's disease. Neurology, 59(8): 1153–1161.

Squitti, R., Barbati, G., Rossi, L., Ventriglia, M., Dal Forno, G., Cesaretti, S., Moffa, F., Caridi, I., Cassetta, E., Pasqualetti, P., Calabrese, L., Lupoi, D. and Rossini, P.M. (2006). Excess of nonceruloplasmin serum copper in AD correlates with MMSE, CSF [beta]-amyloid, and h-tau. Neurology, 67(1): 76–82.

SCC (2016). Standards Council of Canada. Available at: www.scc.ca.

Stenhammar, L. (1999). Diarrhoea following contamination of drinking water with copper. Eur. J. Med. Res., 4(6): 217–218.

Stern, B.R. (2010). Essentiality and toxicity in copper health risk assessment: Overview, update and regulatory considerations. J. Toxicol. Environ. Health A, 73(2): 114–127.

Stern, B.R., Solioz, M., Krewski, D., Aggett, P., Aw, T.C., Baker, S., Crump, K., Dourson, M., Haber, L., Hertzberg, R., Keen, C., Meek, B., Rudenko, L., Schoeny, R., Slob, W. and Starr, T. (2007). Copper and human health: Biochemistry, genetics, and strategies for modeling dose-response relationships. J. Toxicol. Environ. Health B Crit. Rev., 10(3): 157–222.

Stewart, J.H., Macintosh, D., Allen, J. and McCarthy, J. (2012). Chapter 11 - germanium, tin, and copper. In: Patty's toxicology, sixth edition. volume 1, Bingham, E. and Cohrssen, B. (eds.). John Wiley & Sons, Inc., pp. 355–380.

Stover, E.L. and Kincannon, D.F. (1983). Contaminated groundwater treatability- a case study. J. Am. Water Works Assoc., 75(6): 292–298.

Superior Court, Province of Quebec (2011). Karen Cooke and Terry Cooke and Coopérative d'Habitation Lézarts and Stéphane Morissette v. Ipex Inv. Judgment on a motion for approval of a settlement Article 1025 of the Code of Civil Procedure. No. 200-06-000121-098. District of Quebec City. December 9.

Takeda, T., Yukioka, T. and Shimazaki, S. (2000). Cupric sulfate intoxication with rhabdomyolysis, treated with chelating agents and blood purification. Intern. Med., 39(3): 253–255.

Talcott, P.A. (2013). Copper. Chapter 41 in: Small animal toxicology. Peterson, M. E., Talcott, P.A. (eds.), 3rd ed.

Tanner, M.S. (1998). Role of copper in Indian childhood cirrhosis. Am. J. Clin. Nutr., 67(5 Suppl): 1074S–1081S.

Tapia, L., Gonzalez-Aguero, M., Cisternas, M.F., Suazo, M., Cambiazo, V., Uauy, R. and Gonzalez, M. (2004). Metallothionein is crucial for safe intracellular copper storage and cell survival at normal and supra-physiological exposure levels. Biochem. J., 378(Pt 2): 617–624.

Tapiero, H., Townsend, D.M. and Tew, K.D. (2003). Trace elements in human physiology and pathology. copper. Biomed. Pharmacother., 57(9): 386–398.

Tardito, S., Bassanetti, I., Bignardi, C., Elviri, L., Tegoni, M., Mucchino, C., Bussolati, O., Franchi-Gazzola, R. and Marchio, L. (2011). Copper binding agents acting as copper ionophores lead to caspase inhibition and paraptotic cell death in human cancer cells. J. Am. Chem. Soc., 133(16): 6235–6242.

Taylor, J.S. and Wiesner, M. (1999). Membranes. Chapter 11 in: Letterman, R.D.(ed). Water quality and treatment: a handbook of community water supplies, 5th edition American Water Works Association. Denver, Colorado. McGraw-Hill, New York, New York.

Thompson, C.A., Habermann, T.M., Wang, A.H., Vierkant, R.A., Folsom, A.R., Ross, J.A. and Cerhan, J.R. (2010). Antioxidant intake from fruits, vegetables and other sources and risk of non-Hodgkin's lymphoma: The Iowa women's health study. Int. J. Cancer, 126(4): 992–1003.

Tiffany-Castiglioni, E., Hong, S. and Qian, Y. (2011). Copper handling by astrocytes: Insights into neurodegenerative diseases. Int. J. Dev. Neurosci., 29(8): 811–818.

Triantafyllidou, S., Nguyen, K., Zhang, Y. and Edwards, M. (2013). Lead (Pb) quantification in potable water samples: implications for regulatory compliance and assessment of human exposure. Environ. Monit. Assess., 185: 1355–1365. doi: 10.1007/s10661-012-2637-6

Turnlund, J.R. (1998). Human whole-body copper metabolism. Am. J. Clin. Nutr., 67(5 Suppl): 960S–964S.

Turnlund, J.R., Keyes, W.R., Anderson, H.L. and Acord, L.L. (1989). Copper absorption and retention in young men at three levels of dietary copper by use of the stable isotope 65Cu. Am. J. Clin. Nutr., 49(5): 870–878.

Turnlund, J.R., Keen, C.L. and Smith, R.G. (1990). Copper status and urinary and salivary copper in young men at three levels of dietary copper. Am. J. Clin. Nutr., 51(4): 658–664.

Turnlund, J.R., Keyes, W.R., Peiffer, G.L. and Scott, K.C. (1998). Copper absorption, excretion, and retention by young men consuming low dietary copper determined by using the stable isotope 65Cu. Am. J. Clin. Nutr., 67(6): 1219–1225.

Turnlund, J.R., Jacob, R.A., Keen, C.L., Strain, J.J., Kelley, D.S., Domek, J.M., Keyes, W.R., Ensunsa, J.L., Lykkesfeldt, J. and Coulter, J. (2004). Long-term high copper intake: Effects on indexes of copper status, antioxidant status, and immune function in young men. Am. J. Clin. Nutr., 79(6): 1037–1044.

Turnlund, J.R., Keyes, W.R., Kim, S.K. and Domek, J.M. (2005). Long-term high copper intake: Effects on copper absorption, retention, and homeostasis in men. Am. J. Clin. Nutr., 81(4): 822–828.

U.S. EPA (1988). Chemical assessment summary for copper; CASRN 7440-50-8.. Integrated Risk Information System (IRIS). National Center for Environmental Assessment. U.S. Environmental Protection Agency.

U.S. EPA (1991). Maximum contaminant level goals and national primary drinking water regulation for lead and copper; final rule. U.S. Environmental Protection Agency. Fed Reg 56 (110): 26460–26464. June.

U.S. EPA (1994a). Method 200.9 rev. 2.2 determination of trace elements by stabilized temperature graphite furnace atomic absorption. Environmental Monitoring Systems Laboratory, Office of Research and Development, Cincinnati, Ohio.

U.S. EPA (1994b). Method 200.8 rev 5.4 determination of trace elements in waters and wastes by inductively coupled plasma - mass spectrometry. Environmental Monitoring Systems Laboratory, Office of Research and Development, Cincinnati, Ohio.

U.S. EPA (1994c). Method 200.7 rev. 4.4 determination of metals and trace elements in water and wastes by inductively coupled plasma-atomic emission spectrometry. Environmental Monitoring Systems Laboratory, Ofice of Research and Development, Cincinnati, Ohio.

U.S. EPA (1998). Small system compliance technology list for the non-microbial contaminants regulated before 1996. Office of Water, U.S. Environmental Protection Agency, Washington, DC. (EPA 815-R-98-002).

U.S. EPA (2000). 40 CFR Parts 141 and 142, National Primary Drinking Water Regulations for Lead and Copper; Final Rules. U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA (2003a). Method 200.5 rev 4.2 determination of trace elements in drinking water by axially viewed inductively coupled plasma-atomic energy emission spectrometry. National Exposure Research Laboratory, Office of Research and Development, Cincinnati, Ohio.

U.S. EPA (2003b). Revised guidance manual for selecting lead and copper control strategies. U.S. Environmental Protection Agency, Washington, DC. (Report No. EPA-816-R-03-001).

U.S. EPA (2009). National Primary Drinking Water Regulations. U.S. Environmental Protection Agency, Washington, DC. Available at: www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants

U.S. EPA (2012). Radionuclides in drinking water, compliance options: Treatment technology descriptions. U.S. Environmental Protection Agency. Available at: http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm

U.S. District Court (2011). Order certifying class for settlement and approving class action settlement. Case no. 09-MD-2098. In re: Kitec Plumbing system products liability litigation.. Northern District of Texas, Dallas Division.. November.

van den Berghe, P.V. and Klomp, L.W. (2009). New developments in the regulation of intestinal copper absorption. Nutr. Rev., 67(11): 658-672.

Vik, E.A., Ryder, R.A., Wagner, I. and Ferguson, J.F. (1996). Mitigation of corrosion effects. In: Internal corrosion of water distribution systems. 2nd edition. American Water Works Association Research Foundation and DVGW Technologiezentrum Wasser, Denver, Colorado. pp. 389–444.

Wapnir, R.A. (1998). Copper absorption and bioavailability. Am. J. Clin. Nutr., 67(5 Suppl): 1054S–1060S.

WHO (1993). Guidelines for drinking-water quality. World Health Organization, Geneva, Switzerland. 2nd edition.

WHO (1996). Guidelines for drinking-water quality, 2nd ed. Volume 2: Health criteria and other supporting information. World Health Organization, Geneva, Switzerland, pp. 219–226.

WHO (1998). Guidelines for drinking-water quality, 2nd ed. Addendum to volume 2: Health criteria and other supporting information. World Health Organization, Geneva, Switzerland.

WHO (2004). Copper in drinking-water. background document for development of WHO guidelines for drinking-water quality. World Health Organization, Geneva, Switzerland.

WHO (2011). Guidelines for drinking-water quality, 4th ed. World Health Organization, Geneva, Switzerland. ISBN 978 92 4 154815 1.

Wijmenga, C. and Klomp, L.W. (2004). Molecular regulation of copper excretion in the liver. Proc. Nutr. Soc., 63(1): 31–39.

Wong, P.K. (1988). Mutagenicity of heavy metals. Bull. Environ. Contam. Toxicol., 40(4): 597–603.

Woszczynski, M., Bergese, J., Payne, S.J. and Gagnon, G.A. (2015). Comparison of sodium silicate and phosphate for controlling lead release from copper pipe rigs. Canadian Journal of Civil Engineering, 42: 953–959.

Wyllie, J. (1957). Copper poisoning at a cocktail party. Am. J. Publ. Health, 47: 617.

Xiong, X., Yanxia, L., Wei, L., Chunye, L., Wei, H. and Ming, Y. (2010). Copper content in animal manures and potential risk of soil copper pollution with animal manure use in agriculture. Resour. Conserv. Recy., 54:985–990.

Yang, H.J., He, S.Y. and Tuan, H.Y. (2014). Self-seeded growth of five-fold twinned copper nanowires: Mechanistic study, characterization, and SERS applications. Langmuir, 30(2): 602–610.

Yoshida, Y., Furuta, S. and Niki, E. (1993). Effects of metal chelating agents on the oxidation of lipids induced by copper and iron. Biochim. Biophys. Acta, 1210(1): 81–88.

Zacarias, I., Yanez, C.G., Araya, M., Oraka, C., Olivares, M. and Uauy, R. (2001). Determination of the taste threshold of copper in water. Chem. Senses, 26(1): 85–89.

Zemansky, G.M. (1974). Removal of trace metals during conventional water treatment. J. Am. Water Works Assoc. 66(10), 606–609.

Zhao, L., Wang, J., Wang, Y. and Fa, X. (2013). Apigenin attenuates copper-mediated β-amyloid neurotoxicity through antioxidation, mitochondrion protection and MAPK signal inactivation in an AD cell model. Brain Res., 1492: 33–45.

Zietz, B.P., de Vergara, J.D. and Dunkelberg, H. (2003a). Copper concentrations in tap water and possible effects on infant's health--results of a study in Lower Saxony, Germany. Environ. Res., 92(2): 129–138.

Zietz, B.P., Dieter, H.H., Lakomek, M., Schneider, H., Kessler-Gaedtke, B. and Dunkelberg, H. (2003b). Epidemiological investigation on chronic copper toxicity to children exposed via the public drinking water supply. Sci. Total Environ., 302(1–3): 127–144.

Zlotkin, S.H., Atkinson, S. and Lockitch, G. (1995). Trace elements in nutrition for premature infants. Clin. Perinatol., 22(1): 223–240.

Appendix A: List of Acronyms

AD	Alzheimer's disease
ANSI	American National Standards Institute
AO	aesthetic objective
BMD	benchmark dose
$BMDL_{05}$	95% lower confidence limit on the benchmark dose for a 5% change in effect
$BMDL_{10}$	95% lower confidence limit on the benchmark dose for a 10% change in effect
bw	body weight
CAS	Chemical Abstracts Service
Cp	caeruloplasmin
Cu	copper
CSMR	chloride to sulphate mass ratio
Cu(I)	cuprous ion
Cu(II)	cupric ion
DIC	dissolved inorganic carbonate
DNA	deoxyribonucleic acid
DO	dissolved oxygen
EPA	Environmental Protection Agency (U.S.)
EPS	exopolymeric substances
GAC	granular activated carbon
GGT	gamma glutamyl transferase
GI	gastrointestinal
GM	geometric mean
GOT	glutamic-oxaloacetic aminotransferase
ICT	idiopathic copper toxicosis
IUDs	intrauterine devices
LOAEL	lowest observed adverse effect level
MAC	maximum acceptable concentration
MT	metallothionein
MDL	method detection limit
MIC	microbiologically influenced corrosion
MKD	Menkes' disease
NOAEL	no observed adverse effect level
NOM	natural organic matter
NPC	National Plumbing Code of Canada
NSF	NSF International
NTU	nephelometric turbidity unit
OHS	occipital horn syndrome
ORP	redox potential
PEX	cross-linked polyethylene
POU	point of use (device)
PQL	practical quantitation limit
RDA	recommended daily allowance
RO	reverse osmosis
SD	standard deviation
SOD	superoxide dismutase

TBARS	thiobarbituric acid reactive substances
TDS	total diet study
TIC	Tyrolean infantile cirrhosis
WD	Wilson’s disease
WHO	World Health Organization

Appendix B: Provincial and territorial anticipated impacts

Please note that this information is not available in both official languages because the source of the information is not subject to the Official Languages Act.

Prince Edward Island

Based on available data, no impact is anticipated.

Newfoundland and Labrador

The Province of Newfoundland and Labrador is responsible for extensive monitoring for inorganic parameters including copper in the province. Copper monitoring is conducted semi-annually for all public water supplies in the province, and quarterly for populations larger than 5,000. pH in the province is typically low and below the guideline of 6.5–8.5. There are typically greater than 300 pH exceedances in the province annually. As discussed in the technical document, the low pH in the province causes issues with corrosion and can affects the copper concentration levels in drinking water.

There are 4 communities that may not meet the new proposed MAC of 2.0 mg/L. There are currently 16 communities that occasionally exceed the existing AO of 1.0 mg/L. There could be a moderate cost of implementing the proposed guideline for copper in Newfoundland and Labrador. Due to naturally low pH issues experienced by many water systems in the province, prevention of corrosion in household plumbing will require some communities to install pH adjustment systems or upgrade their existing pH adjustment systems to maintain appropriate pH levels within the distribution system. Water pH in some communities is so low, that even with treatment, it would be difficult to dose enough chemical to meet both pH and copper guidelines. Due to this, new treatment systems and/or significant upgrades may be required to a number of existing systems. The province will continue to monitor for copper and pH at the current frequency, and to assist communities in ensuring their pH adjustment systems are working effectively to increase pH levels and keep corrosion control measures in place.

Nova Scotia

Health Canada proposes to establish a maximum acceptable concentration (MAC) of 2 mg/L for total copper in drinking water while maintaining the existing aesthetic objective of 1 mg/L.

Available data suggests that utilities will not be impacted as a result of the proposed reduction; however, this data represents flushed samples collected from the distribution system and is not representative of total copper concentrations at the customer’s tap. Existing data prevents an accurate determination of the true impact. The widespread use of copper in plumbing and distribution system components coupled with the lack of enforceable corrosion control program requirements likely result in consumer exposures to copper that are above the concentrations currently reported by utilities.

For Nova Scotia, the revised guideline will require the development and enforcement of copper sampling protocols in addition to clear requirements for corrosion control programs. This will likely result in challenges for the utilities and the Inspection, Compliance, and Enforcement Division of Nova Scotia Environment. Specific challenges are likely to include: lack of willing participants; access for sample collection; and increased costs for laboratory analysis.

New Brunswick

New Brunswick is supportive of a copper guideline that is protective of public health. Based on historical drinking water quality results for both regulated municipal and crown systems, as well as private wells, there is no evidence that this guideline will cause any significant immediate impacts. However, copper is not a regulated parameter in New Brunswick as there is no health based guideline. For the most part, water quality data for regulated drinking water systems has been obtained from samples and taken at the same time and location as other Inorganic parameters as part of regular compliance monitoring. The true impact of this guideline will not be known until sampling and monitoring protocols and approaches are updated to align with the recommendations of the guideline.

Quebec

Au Québec, de 2012 à 2015, 17 863 analyses de cuivre ont été réalisées dans le cadre du Règlement sur la qualité de l’eau potable, dans l’eau d’un total de 3049 réseaux de distribution. Les responsables de tous les réseaux assujettis au Règlement doivent réaliser annuellement le contrôle du cuivre dans l’eau potable distribuée. Durant la période de 2012 à 2015, 119 (0,7 %) des analyses réalisées ont présenté un résultat supérieur à la norme québécoise pour le cuivre dans l’eau potable établie à 1,0 mg/L, pour 70 réseaux de distribution distincts (2 %). La concentration maximale mesurée a atteint 15 mg/L. La révision proposée de la recommandation sur le cuivre dans l’eau potable n’aurait pas d’impact pour les réseaux de distribution du Québec étant donné que la norme québécoise est plus sévère que la concentration maximale acceptable proposée dans le document.

Ontario

The proposed *Guideline for Canadian Drinking Water Quality* for copper of 2 mg/L and an aesthetic objective of 1 mg/L will have minimal impact in Ontario. Ontario currently has an aesthetic objective of 1 mg/L for copper. The health guideline value for copper will be appropriate to assess the health impacts of the occasional exceedance of the aesthetic objective for copper.

Manitoba

A review of available public and semi-public water system data does not provide a clear picture of potential impacts of the proposed change to the Canadian guideline for copper in drinking water from an aesthetic objective of ≤ 1 mg/L to a maximum acceptable concentration (MAC) of 2 mg/L and an aesthetic objective of 1 mg/L. Manitoba water systems have historically been monitoring for metals, including copper, at water treatment plants. The proposed guideline requires that copper samples be drawn at the consumer’s tap, which takes into consideration the effects of the main distribution system and individual home plumbing systems. Sampling at the consumer’s tap would represent a significant change for Manitoba water systems. This would likely be the most significant impact from a cost perspective as well.

Saskatchewan

The Water Security Agency (WSA) has reviewed the proposed guideline document for copper in drinking water and agrees with the proposed MAC of 2 mg/L and aesthetic objective of 1 mg/L for total copper in drinking water. Drinking water data of 3512 samples collected in the last 10 years (2006 to present) from the distribution systems of municipalities regulated by the

WSA showed that total copper levels exceeded the proposed MAC and aesthetic objective in only 8 sampling locations or distribution systems of communities in the province. The WSA notes that copper in drinking water mainly results from the corrosion of copper containing pipes and fittings in the distribution and plumbing systems and based on the chemistry of water. An analysis of total copper levels in source water in the database showed that the copper levels are very low/insignificant to cause any exceedances in finished water. Some of the municipalities in Saskatchewan continue to replace the aged service lines and plumbing systems, and others have some form of replacement programs including providing an incentive to home owners to replace their aged service lines from the curb stop to the building entry. The WSA follows the corrosion control guidance document of Health Canada in dealing with exceedances of parameters such as copper and lead in the distribution system and encourages the waterworks owner to replace the service lines where related exceedances occur. The communities regulated by the WSA continue to monitor copper levels in the distribution systems as per monitoring requirements specified in the provincial document “Municipal Drinking Water Quality Monitoring Guidelines - EPB 202” and in accordance with operational permit conditions. Since studies showed that many of the water treatment systems including conventional water treatment filtration systems are effective in removing copper, and since these type of treatment systems are in existence and/or are being increasingly adopted for use in WTPs in the province the WSA believes and expects that the new standard for Total Copper will have a minimal or no impacts including cost to municipal and other regulated waterworks in the province. The WSA will also work with the affected municipalities in the province to have an improved monitoring of pH/ or alkalinity levels at the water treatment plant and the use of corrosion inhibitors, if necessary so as to minimize the copper level in the distribution system.

Alberta

Based on available data, no impact is anticipated.

British Columbia

The proposed change to the copper guidelines to maintain the aesthetic objective (AO) at 1.0 mg/L as well as the addition of a maximum acceptable concentration (MAC) of 2.0 mg/L based on studies citing an association between long term exposure to copper and liver and kidney effects is anticipated to have some notable shifts in how copper in drinking water is measured. Similar to lead, a notable impact of the new MAC will be the shift in focus from centralized sampling to point of consumption based programs. Sampling of buildings, particularly high risk institutions such as schools and daycares, will remain a cost pressure. Questions of whether this is responsibility of water suppliers or building owners will be raised.

Given that the data on water concentrations reported in section 5.2 shows very few exceedances of the MAC, it is anticipated the proposed change in the guideline will have little impact on the water delivered by water supply systems. However, as leaching from fixtures within individual buildings is likely the most significant contributor to copper concentration in water, it is therefore difficult to anticipate copper concentrations delivered at individual taps, as this will vary from building to building, depending on plumbing, and system to system, depending on how corrosive water is.

The proposed addition of a maximum acceptable concentration will also mean significantly different messaging from what health officials have historically given regarding copper. It will also require the need for clear and meaningful advice to those that have been consuming water sources that exceed the proposed MAC, who have previously been told that elevated copper is merely an aesthetic concern.

Yukon

It is not possible to quantify the impact of the proposed technical document and MAC for copper at this point in time for Yukon. The Yukon drinking water regulatory framework is primarily focused on water treatment and provision of safe drinking water as it leaves the water treatment plant to the distribution system. Provisions of the Drinking Water Regulation specify specific monitoring requirements for raw and treated water (at the point of water leaving the plant). While there is a requirement for monitoring of free chlorine, total coliforms and *E.coli* within the distribution system, there are currently no specific requirements for routine monitoring of other parameters.

Environmental Health Services (EHS) regulatory mandate extends to curb stop for large public drinking water systems. Routine compliance monitoring and regulatory requirements for large public drinking water system owners beyond this point is not within the current mandate. Further policy development would be needed to incorporate testing at the tap. Currently all Yukon large public drinking water systems meet the proposed MAC for copper entering the distribution system. EHS will be doing policy development in terms of monitoring of the distribution system for copper and other metals over the next few months.

Northwest Territories

No impact paragraph has been provided by the territory.

Nunavut

No impact paragraph has been provided by the territory.

WHISTLER

REPORT | ADMINISTRATIVE REPORT TO COUNCIL

PRESENTED:	May 8, 2018	**REPORT:**	18-060
FROM:	Infrastructure Services	**FILE:**	534
SUBJECT:	WHISTLER TRANSIT SYSTEM: ANNUAL OPERATING AGREEMENT (AOA) 2018/2019 AND TRANSIT MANAGEMENT ADVISORY COMMITTEE (TMAC) UPDATE		

COMMENT/RECOMMENDATION FROM THE CHIEF ADMINISTRATIVE OFFICER

That the recommendation of the General Manager of Infrastructure Services be endorsed.

RECOMMENDATION

That Council authorize the Mayor and Municipal Clerk to execute the "2018-2019 Whistler Annual Operating Agreement" for the period April 1, 2018 through March 31, 2019 attached as Appendix "A" to Administrative Report to Council No. 18-060.

REFERENCES

Appendix "A" – 2018-2019 Whistler Annual Operating Agreement (AOA)
Appendix "B" – Term Sheet

PURPOSE OF REPORT

The purpose of this report is to seek Council approval to execute the annual operating agreement (AOA), attached as Appendix "A", between British Columbia (BC) Transit and the Resort Municipality of Whistler for the operation of the Whistler Transit System from April 1, 2018 to March 31, 2019 as well as provide a brief update on the 2018 Transit Management Advisory Committee (TMAC) workplan.

DISCUSSION

Background

The Whistler Transit System is operated by a partnership between BC Transit, the Resort Municipality of Whistler (RMOW) and the contracted operating company, Whistler Transit Ltd. (a wholly owned subsidiary of Pacific Western Transportation) through the BC Transit Regional Transit Systems program. The Whistler transit system Annual Operating Agreement (AOA), attached as Appendix "A", formalizes the partnership between BC Transit and the local government from April 1 through March 31 annually. It establishes the projected budget for the local Whistler Transit System, as summarized in Appendix "B", as well as defines hours of operation, revenues, costs, leasing payments, and BC Transit's financial contribution for the defined term.

2018/2019 Annual Operating Agreement (AOA) Highlights

This 2018/2019 AOA is for 66,100 annual service hours up from 64,250 in 2017/2018. Included in this AOA is the first phase (1,850 hours of the 6,500) of the authorized 2018/2019 expansion hours that were outlined and presented to Council at the July 4, 2017 Council meeting when the Expansion Memorandum of Understanding (MOU) 2018-2021 was endorsed. The second phase of the expansion is currently being planned for inclusion in the 2018/2019 winter schedule and will be brought back to Council as an AOA amendment once the scheduling process has been finalized.

This AOA also includes budget changes related to the introduction of the compressed natural gas (CNG) buses such as a significant reduction in fuel cost but an increase in Property Maintenance costs related to hydro and fueling station operations and maintenance. Also, related to the new CNG fleet is Whistler's share of the Public Transit Infrastructure Fund (PTIF) budget credit administered by BC Transit.

As Whistler is schedule to go live with the SmartBus – Real Time project (branded as NextBus) during the 2018/2019 AOA, six months of costs and budget credits related to hardware and software have been included in the AOA's Schedule C-Budget.

Finally, BC Transit has included Winter Extra Customer Service hours in this AOA. RMOW staff are concerned that these costs were included in the base AOA budget. The initial intention of the Winter Extra Customer Service Hours was to have Customer Service staff operating Twitter and answering the phone during winter peak AM and PM travel times as well as winter weekends and holidays since the Whistler Transit System vehicles were not yet equipped with real-time bus information. This was being done as a temporary operations measure until the system would be equipped with real-time technology. 2018/2019 is a transition year when NextBus is being implemented on Whistler Transit buses, therefore, staff feel it is premature to require the winter extended customer service hours from the operating company as part of the base level of service. Staff and BC Transit are continuing discussions on this and will report back to Council on the results when the 2018/2019 AOA Amendment 1 is presented later this year.

Transit Management Advisory Committee (TMAC) Update

The Transit Management Advisory Committee (TMAC) has been tasked by Council to provide advice on the operations of the Whistler Transit System. The members of TMAC are BC Transit staff, Whistler Transit Ltd (the operating company) staff, RMOW staff and a member of Council who is also Chair of the Committee.

TMAC's main tasks for 2017 were to participate in the Sea to Sky Corridor Regional Transit Study which was published in October 2017, oversee the 1-Valley Connector Review which was presented to Council on July 18, 2017 and implement the recommendations as part of the 2017/2018 winter schedule.

In 2017, TMAC also worked with the Transportation Advisory Group (TAG) providing recommendations on transit actions that could be delivered in 2017 as well as implementing the Whistler Transit System actions included in the approved 2017 Transportation Action Plan. These actions were:

- Reduced fares
- Expanded family travel program
- Expanded free summer service
- Expanded early winter service levels with additional buses running on Saturdays, Sunday and American Thanksgiving weekend.

TMAC 2018 Workplan

2018 will be another busy year of planning and implementing the approved expansion of 6,500 annual hours and three vehicles as well as pre-planning for the potential 2,500 annual hours expansion for both 2019/2020 and 2020/2021. TMAC has been reviewing the successes and issues that arose this past winter with the change from Routes 1-2-3 to the Route 20s and 30s. The change has generally been positive, however, as with any new routing and schedule design, there will be issues in the field.

As discussed previously in this report, over 1,800 of the expansion hours have been used in the spring/summer/fall schedule. TMAC is in the process of planning the reminder of the expansion. The majority of the remaining 4,700 hours will be used for winter 2018/2019. TMAC is also exploring what expansions and changes are needed for the new base service in spring/summer/fall including piloting the 10-Valley Express as directed by Council at the July 18, 2017 Regular Meeting of Council when the following motion was passed:

> ***That** Council direct staff to work with the Ministry of Transportation and Infrastructure, BC Transit and the operating company (Whistler Transit Ltd.) to conduct a pilot program of the proposed Route 10 Valley Express prior to full implementation.*

Last fall, RMOW staff in partnership with BC Transit staff submitted applications for additional transit stops on Highway 99 to the Ministry of Transportation and Infrastructure (MOTI) as part of the Highway Minor Betterment Program. These highway stops are aimed at servicing a new 10-Valley Express route as well as a future regional/interregional transit system. MOTI staff are currently reviewing the applications.

BC Transit has revised the proposal for the Route 10-Valley Express. The goal of this route is to serve destinations outside of Whistler Village. The revised plan was reviewed by TMAC at their last meeting on April 24, 2018. TMAC is recommending that this updated proposal be reviewed by the community and especially the potential users (employees in Rainbow Plaza, Nesters Mall, Whistler Creekside and Function Junction). BC Transit is preparing an on-line survey to receive feedback on the proposed service design and schedule. Depending on the results of the survey and continued discussions with MOTI, the new routes could either be pilot this fall or in 2019.

Finally, TMAC is also working with BC Transit on the implementation of the NextBus technology in Whistler with a go-live date schedule for this summer.

WHISTLER 2020 ANALYSIS

W2020 Strategy	TOWARD Descriptions of success that resolution moves us toward	Comments
Transportation	The transportation systems to, from and within the resort community are accessible and offer affordable travel options. The transportation system efficiently meets both the short and long-term needs of all users. The convenience and seamlessness of the preferred transportation system to, from and within Whistler ensures usage rates continue to rise.	Transportation congestion to, from, and within Whistler is an issue both in the winter and in the summer. Transportation infrastructure and policy affect almost all parts of the resort community. The Transportation Advisory Group, which is composed of a group of diverse stakeholders including BC Transit, has been reviewing the current issues as well as data collected related to the current issues and has recommended implementation of short and medium-term actions. The reduction in the cost of monthly transit and expanded

Resident Affordability	Residents have access to affordable goods and services that meet their needs.	service were both recommended actions for 2017 to help move Whistler toward the goal of improving transportation for everyone – residents, employees and visitors.
Partnership	Partners work together to achieve mutual benefit. Whistler partners and stakeholder work tighter to effectively and efficiently achieve Whistler 2020 and partner objectives.	The transit service in Whistler (provided in partnership with BC Transit and the operator – Whistler Transit Ltd.) provides a reliable, affordable transportation option for travel within Whistler. TMAC continues to work closely with TAG. The 2018 Whistler transit system is based on the recommendations of the 2017 1-Valley Connector Review as well as the TAG 2017 Transportation Action Plan.
Finance	The long-term consequences of decisions are carefully considered. Whistler lives within its financial means	The 2018 transit budget continues to include additional revenue associated with leasing of six covered parking stalls at the transit facility to a third party. BC Transit is exploring options to expand revenue by leasing underused space at the facility to third parties. The 2018 transit budget also includes contributions from the CTI fund as per the TAG 2017 Transportation Action Plan.
Energy	The energy system is continuously moving towards a state whereby a build-up of emissions and waste into air, land and water is eliminated.	In 2018, BC Transit has converted Whistler's bus fleet from diesel to Compressed Natural Gas.

The Whistler Transit System Annual Operating Agreement (AOA) 2018/2019 and Transit Management Advisory Committee (TMAC) Update do not move our community away from the adopted Whistler2020 Descriptions of Success.

OTHER POLICY CONSIDERATIONS

The base level of service and expansions that have been included in the 2018/2019 Annual Operating Agreement for the Whistler Transit System are guided by the Sea to Sky Transit Future Plan (December 2015) the 1-Valley Connector Review (July 2017) and existing Official Community Plan as well as the TAG Vision, Goals, short-term and medium-term Transportation Action Plan.

BUDGET CONSIDERATIONS

The Whistler Transit AOA costs from April 1, 2018 to March 31, 2019 are summarized in Appendix B – Term Sheet and are accommodated in the 2018 RMOW budget for transit service. January, February and March 2019 costs will be included in the 2019 annual municipal transit operating budget. BC Transit's fiscal year starts on April 1st, while the municipality's is January 1st, so there is a difference between the municipal annual budget and the AOA budget summarized in the attached term sheet (Appendix "B").

It is also important to note that the Community Transportation Initiative (CTI) Fund created from Day Lots 1-5 parking fees contributes to approved 2017/2018 Transportation Actions such as offsetting a portion of the anticipated reduction in farebox revenue from the reduced price of the monthly passes, the expanded Family Travel Program and the new Spirit Transit Pass, as well as the municipal share of costs associated with the expansion hours and vehicles to the Whistler Transit System approved on June 6, 2017 as part of the Whistler 2017 Transportation Action Plan outlined in Administrative Report to Council No. 17-062. This funding from the CTIF has been approved by the Day Lot Operating Committee.

COMMUNITY ENGAGEMENT AND CONSULTATION

Both the Transportation Advisory Group and BC Transit have been in involved in extensive public engagements in 2016 and 2017 to assist in developing the Whistler 2017 Transportation Action Plan, the Sea-to-Sky Transit Future Plan, the Sea-to-Sky Regional Transit Study and the 1-Valley Connector Review. Through these processes, staff heard from a large portion of the Whistler community indicating that more transit buses are needed year round to improve the base level of service.

The transit system also receives on-going customer comments and suggestions in person, on the phone, through social media (Twitter and Facebook) and through the BC Transit website Customer Feedback form found at: www.bctransit.com/whistler/contact. These comments and suggestions are reviewed immediately and seasonally to refine the system.

BC Transit staff are also scheduled to start public consultation on the revised proposal for piloting a new Route 10-Valley Express service in May with the goal of providing an implementation recommendation to TMAC in early summer.

SUMMARY

The BC Transit proposed Annual Operating Agreement (AOA) from April 1, 2018 through March 31, 2019 attached as Appendix A establishes the projected budget for the local Whistler Transit System, as summarized in Appendix B, as well as defines hours of operation, revenues, costs, leasing costs, and BC Transit's financial contribution for the defined term. The RMOW's funding obligation contained within this AOA is accommodated within the approved 2018 municipal budget.

The Transit Management Advisory Committee worked with the Transportation Advisory Group to implement the 2017 Transportation Action Plan transit actions and are continuing to work toward delivering on the medium term (2018-2019) actions.

Council is requested to authorize Mayor and Clerk to execute, the Whistler 2018/2019 AOA from April 1, 2018 to March 31, 2019.

Respectfully submitted,

Emma DalSanto
TRANSPORTATION DEMAND MANAGEMENT COORDINATOR
for
James Hallisey, P. Eng.
GENERAL MANAGER OF INFRASTRUCTURE SERVICES

APPENDIX A

Whistler

ANNUAL OPERATING AGREEMENT

between

THE RESORT MUNICIPALITY OF WHISTLER

and

BRITISH COLUMBIA TRANSIT

Effective
April 1, 2018

INFORMATION CONTAINED IN THIS AGREEMENT IS SUBJECT TO THE FREEDOM OF INFORMATION AND PROTECTION OF PRIVACY ACT. CONSULT WITH THE AUTHORITY PRIOR TO RELEASING INFORMATION TO INDIVIDUALS OR COMPANIES OTHER THAN THOSE WHO ARE PARTY TO THIS AGREEMENT.

ANNUAL OPERATING AGREEMENT

BETWEEN:

THE RESORT MUNICIPALITY OF WHISTLER

(the "Municipality")

AND:

BRITISH COLUMBIA TRANSIT

(the "Authority")

WHEREAS the Authority is authorized to contract for transit services for the purpose of providing and maintaining those services and facilities necessary for the establishment, maintenance and operation of a public passenger transportation system in the Transit Service Area;

WHEREAS the Municipality is authorized to enter into one or more agreements with the Authority for transit services in the Transit Service Area;

WHEREAS the parties hereto have entered into a Transit Service Agreement which sets out the general rights and responsibilities of the parties hereto;

WHEREAS the Municipality and the Authority are authorized to share in the costs for the provision of a Public Passenger Transportation System pursuant to the *British Columbia Transit Act*;

AND WHEREAS the parties hereto wish to enter into an Annual Operating Agreement which sets out, together with the Transit Service Agreement, the specific terms and conditions for the Public Passenger Transportation System for the upcoming term.

NOW THEREFORE THIS AGREEMENT WITNESSETH that in consideration of the premises and of the covenants hereinafter contained, the parties covenant and agree with each other as follows:

Contents

SECTION 1: DEFINITIONS

Unless agreed otherwise in the Annual Operating Agreement, the definitions set out in the Transit Service Agreement shall apply to this Annual Operating Agreement including:

a) "Annual Operating Agreement" shall mean this Annual Operating Agreement and any Annual Operating Agreement Amendments negotiated and entered into by the parties subsequent hereto;
b) "Transit Service Agreement" shall mean the Transit Service Agreement between the parties to this Annual Operating Agreement, including any amendments made thereto;

SECTION 2: INCORPORATION OF SCHEDULES

All schedules to this agreement are incorporated into the agreement, and form part of the agreement.

SECTION 3: INCORPORATION OF TRANSIT SERVICE AGREEMENT

Upon execution, this Annual Operating Agreement shall be deemed integrated into the Transit Service Agreement and thereafter the Transit Service Agreement and Annual Operating Agreement shall be read together as a single integrated document and shall be deemed to be the Annual Operating Agreement for the purposes of the *British Columbia Transit Act*, as amended from time to time.

SECTION 4: TERM AND RENEWAL

a) The parties agree that the effective date of this agreement is to be April 1, 2018 whether or not the agreements have been fully executed by the necessary parties. Once this agreement and the associated Transit Service Agreement are duly executed, this agreement will replace all provisions in the existing Transit Service Agreement and Master Operating Agreement with respect to the rights and obligations as between the Authority and the Municipality.
b) Upon commencement in accordance with Section 4(a) of this agreement, the term of this agreement shall be to March 31, 2019 except as otherwise provided herein. It is acknowledged by the parties that in the event of termination or non-renewal of the Annual Operating Agreement, the Transit Service Agreement shall likewise be so terminated or not renewed, as the case may be.
c) Either party may terminate this agreement as follows:
    a. Cancellation by the Authority: In the event that the Authority decides to terminate this Agreement for any reason whatsoever, the Authority shall provide at least one hundred and eighty (180) days prior written notice. Such notice to be provided in accordance with Section 10.
    b. Cancellation by the Municipality: In the event that the Municipality decides to terminate this Transit Service Agreement for any reason whatsoever, and by extension the Annual Operating Agreement, the Municipality shall provide at least one hundred and eighty (180) days prior written notice. Such notice to be provided in accordance with Section 10.

SECTION 5: FREEDOM OF INFORMATION AND PROTECTION OF PRIVACY ACT

This Agreement and the parties hereto are subject to the provisions of the *Freedom Of Information And Protection Of Privacy Act* ("FOIPPA"). Any information developed in the performance of this Agreement, or any personal information obtained, collected, stored pursuant to this Agreement, including database information, shall be deemed confidential and subject to the provisions of the FOIPPA including the handling, storage, access and security of such information. Confidential information shall not be disclosed to any third party except as expressly permitted by the Authority or pursuant to the requirements of the FOIPPA.

SECTION 6: SETTLEMENT OF DISPUTES

In the event of any dispute arising between or among the parties as to their respective rights and obligations under this Agreement, or in the event of a breach of this Agreement, the parties agree to use their best efforts to find resolution through a mediated settlement. However, in the event that mediation is not successful in finding a resolution satisfactory to all parties involved, any party shall be entitled to give to the other notice of such dispute and to request arbitration thereof; and the parties may, with respect to the particular matter then in dispute, agree to submit the same to a single arbitrator in accordance with the applicable statutes of the Province of British Columbia.

SECTION 7: MISCELLANEOUS PROVISIONS

a) Amendment: This agreement may only be amended in writing signed by the Municipality and the Authority and specifying the effective date of the amendment.
b) Assignment: This Agreement shall not be assignable without prior written consent of the parties.
c) Enurement: This Agreement shall be binding upon and enure to the benefit of the parties hereto and their respective successors.
d) Operating Reserve Fund: In accordance with OIC 594, in fiscal year 2015/16, BC Transit established a Reserve Fund to record, for each local government, the contributions that BC Transit has received but has not yet earned.
    a. BC Transit will invoice and collect on monthly Municipal invoices based on budgeted Eligible Expenses.
    b. Any expenditure of monies from the Reserve Fund will only be credited towards Eligible Expenses for the location for which it was collected.
    c. Eligible Expenses are comprised of the following costs of providing Public Passenger Transportation Systems:
        i. *For Conventional Transit Service:*
            1. the operating costs incurred in providing Conventional Transit Service excluding interest and amortization;
            2. the amount of any operating lease costs incurred by BC Transit for Conventional Transit Services;
            3. the amount of the municipal administration charge not exceeding 2% of the direct operating costs payable under an Annual Operating Agreement;
            4. an amount of the annual operating costs of BC Transit not exceeding 8% of the direct operating costs payable under an Annual Operating Agreement;
        ii. *For Custom Transit Service:*
            1. the operating costs incurred in providing Custom Transit Service excluding interest and amortization, but including the amount paid by BC Transit to redeem taxi saver coupons issued under the Taxi Saver Program after deducting from that amount the amount realized from the sale of those coupons;
            2. the amount of any operating lease costs incurred by BC Transit for Custom Transit Service;

        3. the amount of the municipal administration charge not exceeding 2% of the direct operating costs payable under an Annual Operating Agreement; and,
        4. an amount of the annual operating costs of BC Transit not exceeding 8% of the direct operating costs payable under an Annual Operating Agreement;
    d. Eligible Expenses exclude the costs of providing third-party 100%-funded services; and,
    e. BC Transit will provide an annual statement of account of the reserves received and utilized, including any interest earned for each local government.

e) The parties agree that this agreement is in substantial compliance with all relevant legislative requirements to establish the rights and obligations of the parties as set out in the *British Columbia Transit Act*.

SECTION 8: GOVERNING LAW

This Agreement is governed by and shall be construed in accordance with the laws of the Province of British Columbia, with respect to those matters within provincial jurisdiction, and in accordance with the laws of Canada with respect to those matters within the jurisdiction of the government of Canada.

SECTION 9: COUNTERPARTS

This contract and any amendment hereto may be executed in counterparts, each of which shall be deemed to be an original and all of which shall be considered to be one and the same contract. A signed facsimile or pdf copy of this contract, or any amendment, shall be effective and valid proof of execution and delivery.

SECTION 10: NOTICES AND COMMUNICATIONS

All notices, claims and communications required or permitted to be given hereunder shall be in writing and shall be sufficiently given if personally delivered to a designated officer of the parties hereto to whom it is addressed or if mailed by prepaid registered mail to the Authority at:

BRITISH COLUMBIA TRANSIT
c/o President & CEO
P.O. Box 610
520 Gorge Road East
Victoria, British Columbia V8W 2P3

and to the Municipality at:

THE RESORT MUNICIPALITY OF WHISTLER
c/o General Manager Infrastructure Services
4325 Blackcomb Way
Whistler, BC V0N 1B4

and, if so mailed, shall be deemed to have been received five (5) days following the date of such mailing.

IN WITNESS WHEREOF, the parties have hereunto set their hand this ___ day of _________, 2018.

THE RESORT MUNICIPALITY OF WHISTLER

____

____

BRITISH COLUMBIA TRANSIT

____
CHIEF OPERATING OFFICER

____
CHIEF FINANCIAL OFFICER

SCHEDULE "A": TARIFF AND FARES

WHISTLER CONVENTIONAL TRANSIT

a) **Fare Free Zone:**
A fare free zone will be comprised of the Village Shuttle route. This route includes passengers boarding and alighting at Gondola Transit Exchange, Blackcomb Way, Village Gate Boulevard, Northlands Boulevard, Lorimer Road (east of Highway 99), Spearhead Road and Painted Cliff Road. Any passengers travelling onto or west of Highway 99 pay regular fare.

b) **Single Cash Fares:**

i)	Adult	$2.50
ii)	Concession	$2.50
iii)	Child 5 years and under	Free (when accompanied by an adult)
iv)	Accessible Transit Attendant	Free

d) **Prepaid fares**

Effective July 1, 2017

	Adult	**Concession**
1 Day pass	$7.00	$7.00
Book of 10 Tickets	$22.50	$18.00
Monthly Pass	$50.00	$40.00
6 Month Pass	$270.00	$216.00
12 Month Pass	$510.00	$410.00

d) BC Bus Pass valid for the current calendar year and available through the Ministry of Housing and Social Development.

e) CNIB Pass available from the local office of the CNIB.

f) BC Transit Employee Bus Pass

SCHEDULE "B": SERVICE SPECIFICATIONS

Whistler Conventional

Transit Service Area: The boundaries of the Whistler Transit Service Area shall be the corporate boundaries of the Resort Municipality of Whistler.

Annual Service Level: for Whistler Conventional shall be **66,100** Revenue Service Hours.

Exception Days annually for the Whistler Conventional are:

Exception Days	**Service Level**
Easter Monday	Sunday Service
Victoria Day	Sunday Service
Canada Day	Sunday Service
BC Day	Sunday Service
Labour Day	Sunday Service
Thanksgiving Day	Sunday Service
Remembrance Day	Sunday Service
Christmas Day	Sunday Service
Boxing Day	Sunday Service
New Years Day	Sunday Service
Family Day (2019)	Sunday Service

SCHEDULE “C”: BUDGET

Whistler Conventional Transit

	Base Budget 2018/2019
Total Revenue	$2,859,115
Total Direct Operating Costs	$7,827,969
Total Operating Costs	$9,453,353
Total Costs (including Local Government Share of Lease Fees)	$11,142,263
Net Local Government Share of Costs	**$3,712,818**

APPENDIX B

TERM SHEET: APRIL 1, 2018 to March 31, 2019
WHISTLER ANNUAL OPERATING AGREEMENT

Parties: BC Transit and the
Resort Municipality of Whistler

Term: April 1, 2018 to March 31, 2019 for the Whistler Transit System.

Description: This agreement establishes the level of transit service, costs and maintenance of the Whistler Transit System. In particular, costs such as the variable hourly rate and the cost per kilometre are specified by the agreement.

Costs: The total maximum annual cost of the Whistler Transit System will be $11,142,263. The BC Transit contribution will be $4,570,330*. The total budgeted system revenue and local administration/operating credit are $2,859,115 resulting in a net municipal share of costs of $3,712,818.

*Does not include BC Transit share of Lease Fees

WHISTLER

REPORT | ADMINISTRATIVE REPORT TO COUNCIL

PRESENTED: May 8, 2018 **REPORT:** 18-059
FROM: Infrastructure Services **FILE:** 546
SUBJECT: TRANSPORTATION ACTION PLAN WINTER 2017/2018 MONITORING RESULTS AND TRANSPORTATION ADVISORY GROUP (TAG) RECOMMENDATIONS

COMMENT/RECOMMENDATION FROM THE CHIEF ADMINISTRATIVE OFFICER

That the recommendation of the General Manager of Infrastructure Services be endorsed.

RECOMMENDATION

That Council direct staff to publish the Transportation Action Plan Winter 2017/2018 Monitoring Results Report on the municipal website when finalized;

That Council receive and endorse the Transportation Advisory Group (TAG) recommendations from the March 15, 2018 TAG Workshop; and

That Council direct staff to work with Transportation Advisory Group members and partners to start implementing TAG recommended next steps as described in Administrative Report to Council 18-059.

REFERENCES

Appendix "A" – Draft Minutes of the Transportation Advisory Group (TAG) Workshop 14 – March 15, 2018.

PURPOSE OF REPORT

The purpose of this Report is to inform Council of the results of the 2017/2018 winter monitoring program as well as the new recommendations from the Transportation Advisory Group (TAG) for summer 2018.

DISCUSSION

Background

Drdul Community Transportation Planning has been contracted to monitor parking and traffic within Whistler to evaluate the success of the Whistler 2017 Transportation Action Plan and offer recommendations regarding refinement of the plan as well as recommendations to Transportation Advisory Group (TAG) for potential long-term actions.

The Action Plan was developed in response to increasing issues affecting transportation to, from and within Whistler. With a larger permanent population and increasing numbers of visitors to Whistler, transportation challenges of parking availability and traffic congestion were starting to affect Whistler's reputation. To identify the best strategies and actions to address these pressing issues, municipal council reactivated the Transportation Advisory Group to provide advice and recommendations on the development of a Transportation Action Plan. The full history of development of the 2017 short-term and the 2018-2019 medium-term transportation action plans is outlined in the February 20, 2018 Administrative Report to Council No. 18-018. Both the short-term and medium-term Transportation Action Plans have been developed using a consensus model guided by TAG's vision for transportation:

> *"Whistler's Transportation System efficiently and affordably moves people and products to, from and within Whistler while delivering a high quality experience and minimizing impacts on natural areas".*

Often, when two potential options were available, TAG chose the option that was most consistent with the other parts of the Transportation Action Plan and provided a reasonable option for everyone – residents, employees and visitors. TAG also adopted the general parking management goal of 10% to 15% availability during a regular business day as a guide to ensure a more positive customer experience. This balances the need to maximize use of parking with the need for customers to find spaces when they want to park, avoiding congestion and frustration.

The Transportation Action Plan Summer 2017 Monitoring Results were presented to council at the September 17, 2017 regular meeting of Council and the full report is published on the municipal website.

2017/2018 Winter Parking, Traffic and Transit Key Findings

Key findings from the winter monitoring program are summarized below:

- Overall, occupancy in the Village surface parking and of Day Lots 1-5 remained at or below the target 85% and 90% occupancy levels respectively at all times on five of six survey days and only reached 91% (1% over the target) in the Day Lots for three hours on the peak day. This is a significant improvement from winter 2016 when occupancy levels were much higher and reached 107%.
- Lots 1 through 3 were full at peak times every day, while Lots 4 and 5 had ample capacity. The key reason for the disparity between occupancy levels appears to be the number of monthly passes in use.
- Carpool parking passes were introduced in December 2017 (valid in Day Lots 4 and 5 only) allowing residents and employees to attach up to four license plates to a single pass (only one vehicle can be used at a time). Over 200 passes were sold over the winter, but only 16 passes accounting for a total of 38 people in "real" carpools were in use at any given time. The majority of carpool passes appear to be "convenience" carpools, with different vehicles all registered to the same household.
- Overtime parking continues to be a problem in some Village lots and on Blackcomb Way.
- The free parking at Creekside was well-used this winter with occupancies reaching 100% on three of the six survey days, very different from winter 2016 when occupancy almost reached 100% on only one of three survey days.
- Private lots have varying availability with daytime occupancies ranging from 39% to 96%, indicating that parking is available most days in most publically-accessible private lots in the Village.
- Commercial bus parking was permitted in Day Lot 4 over the winter in an area with a capacity of up to 12 buses, and a maximum of eight buses was observed on three of the six survey days.
- Average daily traffic volumes on Highway 99 at the Brio traffic counter during winter 2017/2018 were similar to the previous two record high winters.

- A comparison of traffic volumes at Function Junction and Brio both in July 2017 and January 2018 compared to July 2016 and January 2017 indicated fewer local trips in both July 2017 and January 2018 following implementation of the Transportation Action Plan as compared with the previous year. Both in summer and winter, there were approximately 1,000 more vehicles per day entering the community at Function Junction and being accommodated in the existing roadways and parking lots.
- Preliminary local transit ridership reports indicate that ridership in for winter (December, January, February and March) 2017/2018 was up by approximately 10% over winter 2016/2017.

TAG Recommended Next Steps

On March 15, 2018, the Transportation Advisory Group (TAG) met to continue working toward the Long-Term Transportation Action Plan and to finalize the recommended criteria for the Day Lot Operating Committee to use as a guideline when authorizing spending from the Community Transportation Initiative Fund going forward. The first part of the March 15th TAG workshop focused on a review of the primary results of the Official Community Plan Visioning session on March 5, 2018 as well as the winter 2017/2018 parking actions and the results of the 2017 Improving Parking Availability Strategy. TAG discussed the preliminary winter results, the consultant’s recommendations, as well as correspondence received from the public regarding on-street parking in neighbourhoods. Using all this information, TAG recommends the following next steps:

1. Install parking meters on Blackcomb Way with the same pricing as Main Street as outlined in the 2017 Transportation Action Plan.
2. Keep Commercial Bus Parking in Day Lot 4 and charge by the hour to a daily maximum during peak season. Complimentary staging in Day Lot 4 will only be considered for the bus companies that lease one of the four reserved bays in Gateway Loop.
3. Continue monitoring on-street parking in neighbourhoods adjacent to the Village and throughout the Valley.
4. More work needs to be done on pricing monthly passes before any new passes are introduced for Day Lots 1-3, either to supplement or replace the current monthly passes. If a 20-time pass is implemented, pricing for each day of the pass should be no less than 50% of the price for daily passes.
5. Ensure that the electronic and paper maps showing parking in Whistler are complete and accurate.
6. Proceed with a pilot project to display parking availability at the Conference Centre underground lot.
7. The following recommended purpose, goals, criteria and other information be forwarded to the Day Lot Operating Committee to help guide the allocation of Community Transportation Initiative Funds (CTIF) going forward.

   CTIF Purpose*:*
   Provide a funding mechanism to support preferred transportation initiatives that benefit the resort community.

   CTIF Goals*:*
   - Improve affordability
   - Improve transportation (including experience) for residents and visitors
   - Increase transit frequency and reliability
   - Reduce congestion
   - Create transportation choice
   - Solve more than one issue
   - Address year-round transportation challenges

- Promote and supports preferred modes of transportation
- Reduce environmental impact.

CTIF Criteria:
- Simple to administer
- Cost-effective (use is monitored)
- Flexible, depending on resort needs
- Ensure long-term viability of CTI fund
- Scaleable
- Minimal requirement/costs for communications.

Additional information required to make a decision on a proposed initiative
- Monitoring process
- Incremental benefits
- Cost (and compared to overall budget/other initiatives)
- Whether other funding opportunities have been explored
- Is not a core transportation service of RMOW or Whistler Blackcomb/Vail Resorts.

Staff Review

Staff have reviewed TAG's recommendations and determined that they can be accommodated in the 2018 work plans. Staff are working with the Day Lot Operating Committee and the current parking technology providers to see if an appropriate Whistler 20-time parking pass product can be developed for launch in winter 2018/2019.

The final Transportation Action Plan Winter 2017/2018 Monitoring Results report will be posted on-line at www.whistler.ca/MovingWhistler with all the 2016 and 2017 transportation reports and presentations.

WHISTLER 2020 ANALYSIS

W2020 Strategy	TOWARD Descriptions of success that resolution moves us toward	Comments
Transportation	Transportation preferences and options are developed, promoted and supported so that inter-community mobility minimizes the negative impacts of traditional modes of travel. Residents, businesses and visitors are increasingly aware of the importance and benefits of preferred transportation choices.	Transportation congestion to, from and within Whistler is an issue both in the winter and in the summer. Transportation infrastructure and policy affect almost all parts of the resort community. The Transportation Advisory Group, which is a composed of a group of diverse stakeholders, has been reviewing the current issues as well as data collected related the current issues
Partnership	Partners work together to achieve mutual benefit. Partners meaningfully engage stakeholders and practice "good governance" guided by Whistler's Partnership Principles.	

Economic	Effective partnerships with government and tourism organizations support economic health. The Whistler community shares resources and works together to compete in the destination resort market. Whistler is an integral part of the region's economy and works collaboratively with stakeholders.	and has started implementing recommended actions. The review of the Transportation Action Plan Winter 2017/2018 Monitoring Results and consequent recommended next steps including the recommended Community Transportation Initiative Fund (CTIF) purpose, goal and criteria move the community toward the Whistler 2020 Vision and Descriptions of Success as well as Transportation Action Plan's goal to continue improve transportation for everyone – residents, employees and visitors.
Finance	The long-term consequences of decisions are carefully considered. Whistler lives within its financial means	
Visitor Experience	Communications, travel and services are accessible, seamless and convenient at all phases of visitors' trips, from prior to departure until after returning home.	
Learning	Learning opportunities foster collaboration, trust and community engagement and build the community's capacity for achieving Whistler's vision of success and sustainability for future generations.	
Resident Affordability	Residents have access to affordable goods and services that meet their needs.	

Transportation Action Plan Winter 2017/2018 Monitoring Results and Transportation Advisory Group (TAG) recommendations do not move our community away from the adopted Whistler2020 Descriptions of Success.

OTHER POLICY CONSIDERATIONS

The recommended next steps are consistent with the policies in the existing Official Community Plan as well as the Transportation Advisory Group (TAG) Vision and Goals.

BUDGET CONSIDERATIONS

The 2018 – 2022 Five-Year Financial Plan includes a capital budget of $120,000 to support TAG studies and initiatives in 2018. It is anticipated that these recommended actions will fit within the exiting 2018 budgets. The revenues to be collected from the Commercial Bus Parking are intended to be revenue neutral and invested back into operations management and facilities for commercial bus operations.

Transit improvements directly related to the approved Transportation Action Plan will continue to be funded from parking revenue from Day Lots 1 to 5 through the Community Transportation Initiatives (CTI) Fund. Staff are continuing to work with the Day Lot Operating Committee (Whistler-Blackcomb and RMOW representatives) which has agreed in principle to the recommended Transportation Action Plan and are refining the budget for the 2018 and 2019 recommended actions to be funded by the CTIF.

COMMUNITY ENGAGEMENT AND CONSULTATION

The Transportation Action Plan has been developed through an open process involving the Transportation Advisory Group working through materials and potential actions and bringing forward potential ideas and actions to the community through surveys, the Transportation Forum in January 2017, the November 2017 Community Forum, the March 2018 OCP Visioning Forum and many presentations to Council and to stakeholders. All material related to the forums and TAG's work are posted on www.whistler.ca/MovingWhistler .

SUMMARY

The Whistler Transportation Action Plan was developed over the course of two years, involving expertise from the Transportation Advisory Group (TAG) members and RMOW staff, transportation studies undertaken by Drdul Community Transportation Planning, and input from the community through a forum and on-line surveys. Monitoring the results of the actions is an important component of implementing and refining the actions. The Transportation Action Plan was successful both in the summer 2017 and winter of 2017/2018. The results presented above indicate that parking availability in the Village was improved as compared with previous winters, there were fewer automobiles on the highway that started and ended their trips in Whistler and local transit ridership increased. These results demonstrate progress towards the TAG's vision that Whistler's transportation system efficiently and affordably moves people and products to, from and within Whistler while delivering a high quality experience and minimizing impacts on natural areas.

The Transportation Advisory Group's recommended next steps presented in this Report are intended to continue to alleviate the highway and parking congestion issues. The full details of the winter 2017/2018 monitoring program will be published on the Municipal website.

Respectfully submitted,

Emma DalSanto
TRANSPORTATION DEMAND MANAGEMENT COORDINATOR
for
James Hallisey, P. Eng.
GENERAL MANAGER OF INFRASTRUCTURE SERVICES

APPENDIX A

WHISTLER

File 546

MINUTES

DRAFT

TRANSPORTATION ADVISORY GROUP (TAG) WORKSHOP 14
THURSDAY, March 15, 2018 STARTING AT 9:05 A.M.

In the Meeting Room Flute – Resort Municipality of Whistler
4325 Blackcomb Way, Whistler, BC, V0N 1B4

PRESENT:
Chair – Mayor, N. Wilhelm-Morden
RMOW Councillor, C. Jewett
RMOW Councillor, S. Anderson
RMOW – CAO, M. Furey
Citizen-at-Large, B. Murray
Citizen-at-Large, J. Sobieniak
Citizen-at-Large, C. Doak
Whistler Blackcomb – VP Information Technology, M. Sedgwick
Tourism Whistler – VP Market Development & Sales, K. Goodwin
Whistler Chamber of Commerce – GM, The Whistler Experience, M. Facundo
MOTI – Operations Manager, Howe Sound & Sunshine Coast, D. Legault (*by phone)*
BC Transit – Senior Planner, L. Megenbir
RMOW – General Manager Infrastructure Services, J. Hallisey
RMOW – GM of Resort Experience, J. Jansen
RMOW – TDM Planner & Recording Secretary, E. DalSanto

GUESTS:
Whistler Blackcomb – Director of Community & Government Relations, S. McCullough
Whistler Blackcomb – Manager Maintenance Planning, M. King
RMOW – Bylaw Supervisor, L. DeBou

FACILITATOR:
Whistler Centre for Sustainability – Executive Director, C. Ho

REGRETS:
Citizen-at-Large, S. Pass
BC Transit, Senior Regional Transit Manager, L. Trotter

ADOPTION OF AGENDA

AGENDA

Moved by C. Jewett
Seconded by B. Murray
That the Transportation Advisory Group (TAG) adopt the agenda of Thursday, March 15, 2018 as circulated. CARRIED

ADOPTION OF MINUTES

Moved by C. Jewett
Seconded by B. Murray
That the Transportation Advisory Group (TAG) adoption of the Minutes of Monday, January 8, 2018 TAG workshops as circulated. CARRIED

PRESENTATIONS/DELEGATIONS

Updates and Discussion of Transportation Actions:

R. Drdul has been hired to monitor the results of the 2017/2018 Transportation Action Plan. Detailed parking and traffic surveys took place on weekends in January and February. Data continues to be collected into April. The final report will be completed in late spring.

Staff updated TAG on the preliminary results of the winter 2017/2018 monitoring program.

- Average daily traffic counts on Highway 99 at Brio are tracking slightly lower than 2017 and 2016 but higher than 2015
- Number of vehicles entering Whistler at Function Junction are higher than in 2017 but trips starting and ending in Whistler are lower than in 2017
- Ridership on the Whistler transit system is higher than last winter
- Day Lots 1-5 are at or below 90% occupancy target
  - Day Lots 4 and 5 had 10% and 70% availability, respectively, on all survey days.
  - Day Lots 1-3 were above the 90% occupancy target on all survey days
- Many vehicles in Day Lots 1–3 due to monthly passes
- Overtime parking in Village lots and on Blackcomb Way
- Creekside underground parkade is full most days
- Whistler Blackcomb will share occupancies in Day Lots 6, 7 and 8
- Private lots have limited availability
- The majority of Lot 4 and 5 carpool passes are “convenience carpools” consisting of two vehicles from the same address
- On-street parking counts have been and continue to be conducted in neighbourhood in Brio, Whistler Cay and White Gold. The average number of vehicles parked in these locations during off-peak season was higher than peak season.

TAG discussed the primary winter results, the consultant’s recommendations as well as J. Wood’s letter regarding on-street parking in neighbourhoods circulated with the agenda package. TAG recommends the following next steps:

1. Install parking meters on Blackcomb Way with the same pricing as Main Street as outlined in the 2017 Transportation Action Plan.
2. Keep Commercial Bus Parking in Day Lot 4 and charge by the hour to a daily maximum during peak season. Complimentary staging in Day Lot 4 will only be considered for the bus companies that lease one of the four reserved bays in Gateway Loop.
3. Continue monitoring on-street parking in neighbourhoods adjacent to the Village and throughout the Valley.
4. More work needs to be done on pricing monthly passes before any new passes are introduced for Day Lots 1-3, either to supplement or replace the current monthly pass. If a 20-time pass is implemented, pricing for each day of the pass should be no less than 50% of the price for daily passes.
5. Ensure that the electronic and paper maps showing parking in Whistler are complete and accurate.
6. Proceed with a pilot project to display parking availability at the Conference Centre underground lot.

D. Legault and L. DeBou left at 10:00 a.m.

Confirming CTIF Goals and Criteria Confirming CTIF Criteria and Desired outcomes

Community Transportation Initiative Fund (CTIF) Criteria
C. Ho summarized the results of the CTIF Exercise initiated at the January 2018 workshop and completed by TAG members electronically. She then facilitated finalizing resulting revisions to the draft Goals and Criteria. Listed below are the recommended purpose, goals, criteria and other information to help guide the Day Lot Operating Committee on the allocation of Community Transportation Initiative Funds.

***CTIF Purpose**:*
Provide a funding mechanism to support preferred transportation initiatives that benefit the resort community.

***CTIF Goals**:*

- Improve affordability
- Improve transportation (including experience) for residents and visitors
- Increase transit frequency and reliability
- Reduce congestion
- Create transportation choice
- Solve more than one issue
- Address year-round transportation challenges
- Promote and supports preferred modes of transportation
- Reduce environmental impact

***CTIF Criteria**:*

- Simple to administer
- Cost-effective (use is monitored)
- Flexible, depending on resort needs
- Ensure long-term viability of CTI fund
- Scaleable
- Minimal requirement/costs for communications

Additional information required to make a decision on a proposed initiative

- Monitoring process
- Incremental benefits
- Cost (and compared to overall budget/other initiatives)
- Whether other funding opportunities has been explored
- Is not a core transportation service of RMOW or Whistler Blackcomb/Vail Resorts
-

Break

10:15 a.m. to 10:25 a.m.

Highway Capacity Update
MoTI has initiated the study to look at increasing capacity on Highway 99 from Function to Lorimer Road. A draft report should be circulated this summer.
J. Hallisey presented the result of the report prepared by the Parson's group to address what it would take to improve Highway 99 capacity through regional transit between Metro Vancouver and Whistler. The model illustrated that 150 trips would need to be diverted from cars to transit in the peak hour between Horseshoe Bay and Squamish and 100 trips would need to be diverted from cars to transit between Squamish and Whistler. The technical memo was circulated to TAG as part of the agenda package.

2018 Official Community Plan (OCP) Refresh

Discussion of TAG and Official Community Plan (OCP) Vision and Goals

The 2018 Whistler OCP refresh project involves taking the 2011 OCP (see Official Community Plan Adoption Bylaw No. 1983, 2011), which was adopted May 7, 2013 as the starting point and updating it based on the current realities, studies, strategies and initiatives over the past five years.

Staff reviewed the input from the March 5, 2018 OCP Community Visioning Session and reorganized the Transportation policies in Chapter 9 under the eight TAG goals.

C. Ho facilitated an exercise to review the review and revise the transportation policies.

M. Sedgwick left at 10:50 a.m.

ACTION: Staff will revise the Transportation policies based on the feedback and circulate a revised draft of objectives and policies for a special TAG Working Group meeting on March 22 from 2:30 – 4:00 p.m. focused on completing the OCP transportation policy review.

M. Facundo left at 11:30 a.m.

Correspondence

Letter from J. Wood regarding restrictions to parking in neighbourhoods

ACTION: Staff will respond to J. Wood informing him of the preliminary results of the 2107/2018 monitoring program and the expanded monitoring that will take place this spring and early summer.

Letter from A. MacConnachie regarding parking for Fire Fighters

This letter was received and discussed by TAG at the June 15, 2017 workshop. It was forwarded to RMOW staff. This letter was recirculated in this agenda package as the minutes from June 15, 2017 did not reflect the discussion as the Correspondence section of the Minutes were missed.

N. Wilhem-Morden received a response from the Ministry of Transportation and Infrastructure that there are no plans to add additional barriers on Highway 99 between Whistler and Metro Vancouver and that the Ministry has invested in variable speed signs between Whistler and Squamish to encourage safer driving behaviours.

Communications Task Team Update and Discussion

The task team is reviewing summer messaging and will update materials to include messaging related to progress on Regional Transit, how parking fees (CTIFs) are being used to create other transportation options for residents, employees and visitors.

OTHER BUSINESS/UPDATES

The next two TAG workshops will be scheduled in April/May and June/July2018. Staff will explore inviting a speaker such as Gord Price or Gord Lovegrove to present on innovative transportation initiatives, and to open up the talk to the community.

ADJOURNMENT

Moved by S. Anderson
That Transportation Advisory Group (TAG) adjourn the March 15, 2018 TAG workshop at 12:01p.m.

CARRIED

CHAIR: N. Wilhelm-Morden

RECORDING SECRETARY: E. DalSanto

REPORT | ADMINISTRATIVE REPORT TO COUNCIL

PRESENTED:	May 8, 2018	**REPORT:**	18-058
FROM:	Resort Experience	**FILE:**	RZ1143
SUBJECT:	RZ1143 – 1501 ALTA LAKE ROAD (PRISM LANDS) AMENITY ZONING		

COMMENT/RECOMMENDATION FROM THE CHIEF ADMINISTRATIVE OFFICER

That the recommendation of the General Manager of Resort Experience be endorsed.

RECOMMENDATION

That Council consider giving first and second readings to “Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018”; and

That Council authorize staff to schedule a Public Hearing for “Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018”; and further

That Council direct staff to advise the applicant that before consideration of adoption of “Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018”, the following matters shall be completed to the satisfaction of the General Manager of Resort Experience:

1. The applicant is to assume responsibility for any hazardous trees that are located on the lands to be transferred to the municipality, which may impact the proposed development. The applicant must conduct a hazardous tree assessment and an appropriate mechanism put in place to insure any identified hazards are addressed prior to the lands being transferred to municipality; and further
2. Registration of a Section 219 development covenant in favour of the Resort Municipality of Whistler (“RMOW”) requiring development on the five estate lots to:
    a) achieve a minimum of BC Energy Step Code 3;
    b) meet the FireSmart BC Guidelines, or sprinkler buildings and meet the exterior building recommendations of the FireSmart BC Guidelines; and
    c) maintain a minimum of 20 per cent undisturbed land, ensure no development in the three small wetlands, retain a minimum 5 metre vegetated buffer around the three small wetlands, and require that site servicing, road and driveway works be monitored by a qualified environmental monitor.

REFERENCES

Location:	1501 Alta Lake Road
Legal Description:	District Lot 3361, Group 1, NWD, Except Firstly: Part in Reference Plan 1066 Secondly: Part on Plan 14962, Thirdly: Part on Plan 17731, Fourthly: Part on Plan 22573, Fifthly: Part on Highway Plan 119
Owners:	Prism Properties Inc.
Current Zoning:	RS-E1 (Residential Single Estate One)
Appendices:	“A” – Location Map “B” – Proposed Subdivision and Zoning Summary

PURPOSE OF REPORT

The purpose of this Report is to present "Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018" for Council consideration of first and second readings. The proposed Bylaw will amend the zoning for the Prism lands located at 1501 Alta Lake Road to create a new zone with amenity provisions that would permit the development of five estate lots provided the owner first dedicate 99 acres of land to the RMOW.

DISCUSSION

Background

The Prism Lands property is comprised of one 108 acre parcel of land located at 1501 Alta Lake Road as shown in Appendix "A".

The Prism Lands are currently zoned RS-E1 (Residential Single Estate One). For this zone the permitted uses are detached dwelling, auxiliary residential dwelling unit, auxiliary buildings and auxiliary uses, and park and playground. The minimum parcel area is 40 hectares or approximately 100 acres, and the maximum permitted gross floor area of a detached dwelling is 465 square metres. Under the existing RS-E1 Zone the 108 acre property would be permitted one detached dwelling.

The property owners have sought to increase the development potential of the property and have proposed a plan whereby they would be able to subdivide and develop four additional residential estate lots and dedicate the remainder of the land to the RMOW for municipal purposes. There would be five residential estate lots in total clustered on nine acres and the remaining 99 acres (98 acres for park, 1 acre for employee housing) would be transferred to the RMOW (see Appendix "B").

The 99 acres of land to be dedicated to the RMOW is considered to have significant value for municipal purposes. These purposes include:

- parks, open space and trails;
- protection of ecologically sensitive Millar Creek wetlands;
- wildfire protection;
- securing a legal right of way for an existing municipal sewer main line;
- securing public access for existing trails and securing land for a future valley trail connection to Function Junction from Alta Lake Road; and
- one acre of land for employee housing to be combined to an existing adjacent 2-acre site owned by the RMOW and located at 1451 Alta Lake Road, to assist 1451 Alta Lake Road to help realize its existing development potential of 3,050 square metres of gross floor area for employee housing.

On October 17, 2017 Council authorized further review and processing of Rezoning Application RZ1143 and directed staff to prepare a zoning amendment bylaw that would create new site specific zoning for the Prism Lands.

Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018

"Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018" will rezone the subject lands from RS-E1 to RS-E8, a new site specific zone the intent of which is to provide for low density detached dwelling residential use with greater density of development permitted as a condition of the provision of amenities and land for affordable housing.

The proposed bylaw describes the sequence and timing of how the land in the RS-E8 Zone is to be subdivided such that the municipality is transferred 99 acres of the land and the owner retains 9 acres. Specifically, the land in the RS-E8 Zone may be subdivided only as follows, and only in the following sequence:

(a) to create three parcels comprising a 98-acre parcel (the “Park Parcel”), a 1-acre parcel (the “Employee Housing Parcel”), and a 9-acre parcel (the “Estate Lot Parcel”) as illustrated in Figure 1 – Key Plan of initial subdivision, each of which parcels must have an area no more than 5% greater than and no more than 5% less than the stated areas: and

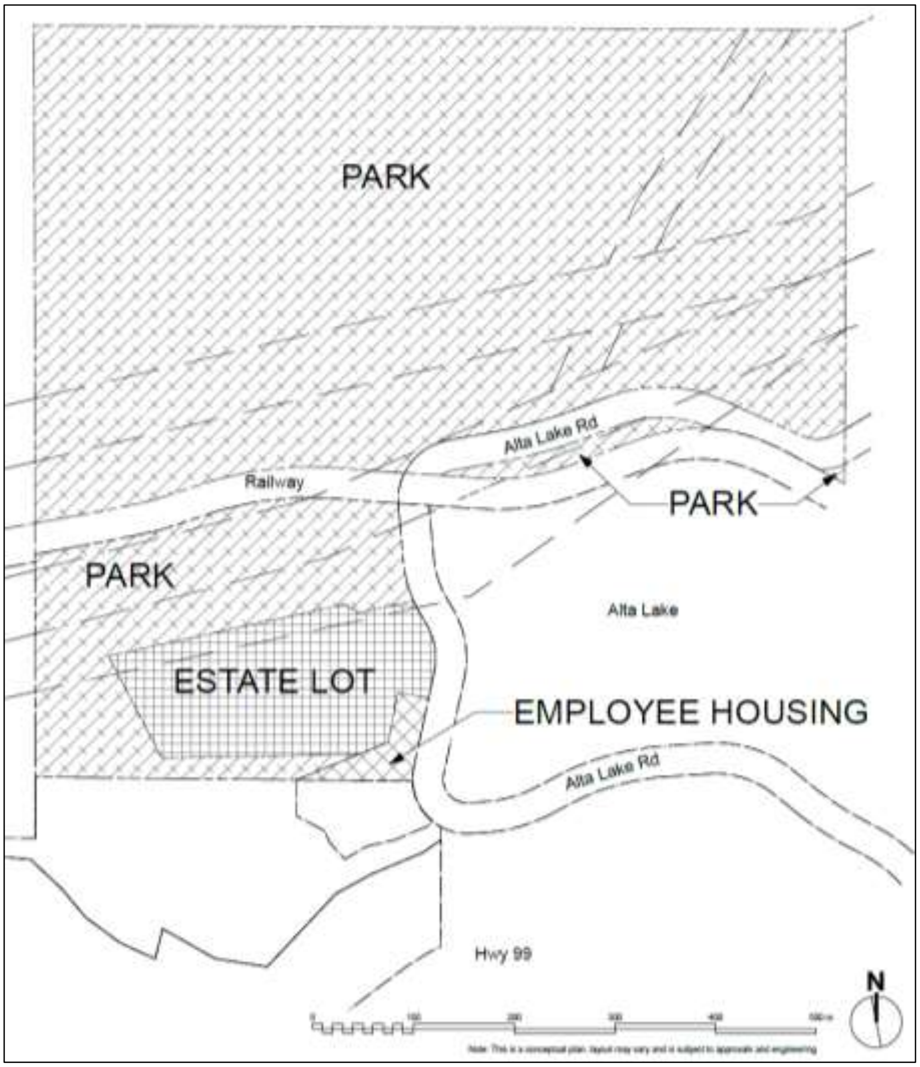


Figure 1 - Key Plan of initial subdivision

(b) to create from the Estate Lot Parcel the five parcels illustrated in Figure 2 – Key Plan of five-lot residential subdivision. The subdivision may vary from the layout in the Key Plan but not to create any number of parcels greater than five or any lot with an area that varies by more than 5% from the area stated on the Key Plan:

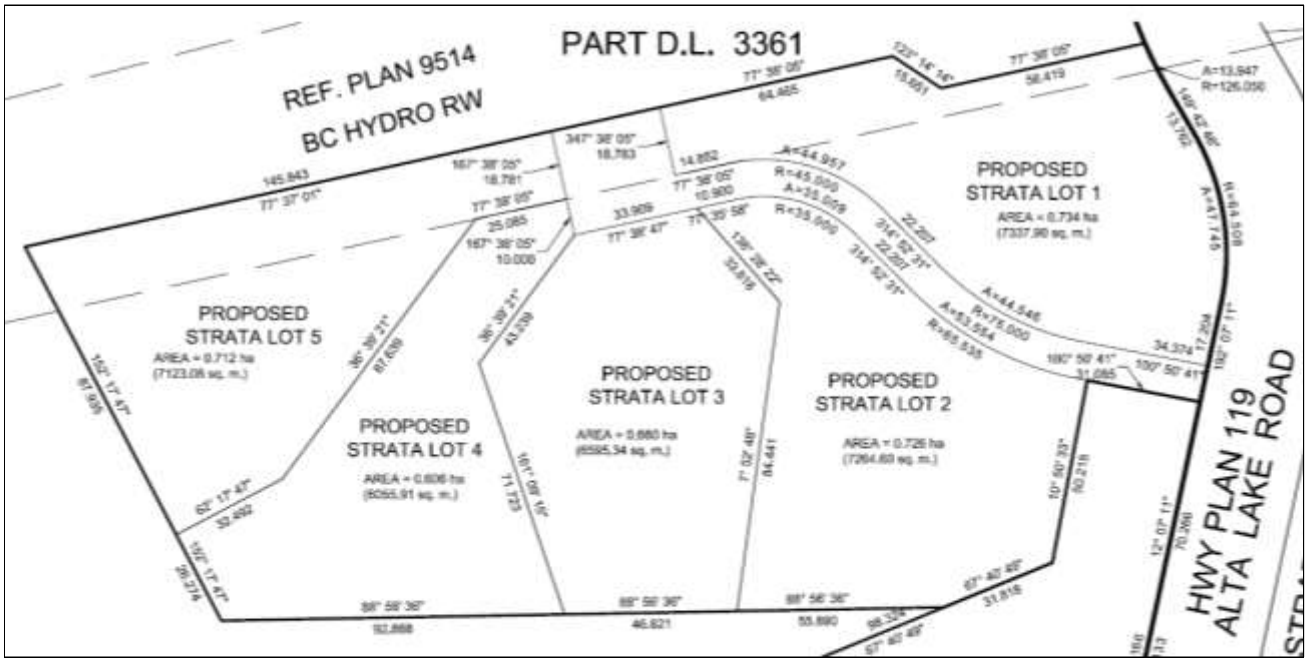


Figure 2 - Key Plan of five-lot residential subdivision

The proposed bylaw specifies that if the land in the RS-E8 Zone is subdivided prior to December 31, 2018, as is planned, then:

- The Employee Housing Parcel shall be subject to the regulations for the RS-E1 Zone until it has been consolidated with the adjacent 2-acre site owned by the RMOW and located at 1451 Alta Lake Road (Lot 1 District Lots 1754 and 3361 Group 1 New Westminster District Plan BCP7872). Once consolidated, the Employee Housing Parcel shall be subject to the regulations of the RM51 Zone. This is to assist 1451 Alta Lake Road, currently undeveloped and zoned RM51, to help realize its existing development potential of 3,050 square metres of gross floor area of apartment or townhouse use for employee housing.
- The Park Parcel shall be subject to the regulations for the LP4 Zone. The LP4 Zone is an existing zone permitting parks and playground, and auxiliary buildings and uses, with a maximum gross floor area on a parcel of 75 square metres, 4.0 metre building setbacks and 5.0 metre building height.
- The parcels created by subdivision of the Estate Lot Parcel and buildings and structures on those parcels shall be subject to the regulations for the RS-E1 Zone, other than subsections 34(5) and (9). Subsection 34(5) is not applicable to enable the two proposed lots without the minimum 24 metre frontage to each build a detached dwelling up to 465 square metres in gross floor area or a floor space ratio of 0.35, whichever is lower. Subsection 34(9) is not applicable to enable minimum parcel sizes less than 40 hectares, providing for the proposed lot sizes. The bylaw also specifies that no further subdivision beyond the 5 lots may occur.

If the land is not subdivided by December 31, 2018 then the land will continue to be subject to the regulations of the RS-E1 Zone, which is the current zoning of the lands.

WHISTLER 2020 ANALYSIS

A Whistler 2020 analysis is provided for in Administrative Report to Council No. 17-113, dated October 17, 2017.

OTHER POLICY CONSIDERATIONS

Official Community Plan

The proposed rezoning is consistent with the criteria for evaluation of zoning amendments listed under Section 4.13 of the Official Community Plan (OCP). A review of the relevant objectives and policies of the OCP is described in the table below:

POLICY NO.	OBJECTIVE/POLICY	COMMENTS
Section 4.13 Criteria - Evaluating Proposals for OCP and Zoning Amendments		
4.13.2	Proposed rezonings that increase the bed-unit capacity will only be considered if there is a clear and substantial benefit to the community, is supported by the community in the opinion of Council, does not cause unacceptable impacts, and meets all applicable criteria of the OCP.	The proposed rezoning is consistent with Policy No. 4.1.2 of the OCP which recognizes and provides for the historic development potential under previous RR1 zoning at the time of adoption of the OCP. Specifically, the historic RR1 Zone provisions that previously applied to the property permitted up to one detached dwelling per 8.09 hectares or 20 acres, permitting up to five detached dwellings for the property.
4.13.3	All developments must meet the mandatory conditions of:	
	• meets all applicable policies of the OCP,	Yes.
	• serviceable by municipal services,	Yes. A preliminary servicing plan and design brief has been prepared by a professional engineer and reviewed and accepted by staff.
	• accessible via local road system,	Yes, the proposed development is accessed from Alta Lake Road. A preliminary access plan has been prepared by a professional engineer and reviewed and accepted by staff.
	• satisfactory evaluation of impacts on: ○ traffic volumes and patterns on Highway 99,	A traffic impact study has been prepared by a professional engineer and reviewed and accepted by staff. The study indicates very minimal impacts as follows: - Total 2-way traffic volumes entering and exiting the proposed 5 lot development from Alta Lake Road is estimated as 48 vehicles per day, 4 to 5 vehicles during AM and PM peak hour. - Additional development traffic will constitute 0.2% of the annual average daily traffic volumes along Highway 99 and less that 0.3% of peak hour traffic volumes.
	○ traffic volumes and patterns on the local road system,	
	○ overall patterns of development of the community and resort,	Yes.

	○ Municipal finance,	99 acres of land will be transferred to the RMOW free and clear of all encumbrances.
	○ views and scenery,	98 acres of the total 108 acres of land will be transferred to the RMOW for parkland, preserving views and scenery.
	○ existing community and recreational facilities,	99 acres of land will be transferred to the RMOW, securing public access for existing trails.
	○ employee housing,	The 1 acre of land for employee housing will be combined to an existing adjacent 2-acre site owned by the RMOW and located at 1451 Alta Lake Road, to assist 1451 Alta Lake Road to help realize its existing development potential of 3,050 square metres of gross floor area for employee housing.
	○ community greenhouse gas emissions and heritage resource	Zoning adoption is contingent on registration of a green building covenant requiring a minimum of BC Energy Step Code 3 on the 5 estate lots, consistent with the proposed integration of the BC Energy Step Code in Whistler.
	• must exhibit high standards of design, landscaping, and environmental sensitivity	The 5 proposed estate lots fall outside of the 30 metre riparian assessment area for Millar Creek and Millar Creek wetlands. The proposal clusters the 5 estate lots to minimize disturbance, protects the 3 small wetlands on the estate lots, requires a minimum of 20% undisturbed land on each estate lots.
4.13.8	Proposal cannot negatively impact RMOWs trails, rec. areas, or open spaces.	The proposal does not negatively impact RMOW trails, recreation areas or open spaces.

The Prism Lands are located within Development Permit Area No. 19 of the OCP, designated for protection of the environment and protection of development from hazardous conditions. The proposed subdivision and development will require a Development Permit.

A geotechnical assessment has been prepared by a qualified professional addressing geotechnical and flood constraints on the proposed estate lots and employee housing lot. The proposed development lots are considered to be safe for the intended purposes.

A hazard tree assessment of the park lands bordering on the proposed development lands is underway. This is to ensure that the RMOW does not take on any potential liabilities for hazardous trees on the park lands that are to be transferred to the RMOW. Staff is currently determining the best approach to insure removal of any hazardous trees prior to the transfer of lands to the municipality.

Legal Considerations

Details related to green building, wildfire hazard and environmental monitoring are beyond the scope of zoning regulations and need to be secured by means of agreements with the property owner and registered on title.

Prior to adoption of "Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018", the owner must register a Section 219 development covenant in favour of the RMOW requiring that development on the five estate lots:

a) achieve a minimum of BC Energy Step Code 3, consistent with the proposed integration of the BC Energy Step Code in Whistler, and the requirements of Green Building Policy to register a green building covenant;

d) meet the FireSmart BC Guidelines, or sprinkler buildings and meet the exterior building recommendations of the FireSmart BC Guidelines; and

b) maintain a minimum of 20% undisturbed land, ensure no development in the three small wetlands, retain a minimum 5 metre vegetated buffer around the three small wetlands, and require that site servicing, road and driveway works be monitored by a qualified environmental monitor, consistent with the recommendations contained in the Initial Environmental Review, prepared by Cascade Environmental, dated September 25, 2017.

BUDGET CONSIDERATIONS

All costs associated with staff time for the rezoning application, Public Hearing, notices, and legal fees will be paid by the applicant and all fees will be required to be paid in full as a condition of adoption of the proposed Zoning Amendment Bylaw.

COMMUNITY ENGAGEMENT AND CONSULTATION

The required rezoning application site information sign has been posted on the property. A Public Hearing, which is subject to public notice requirements, is required as part of the statutory process for bylaw consideration and adoption.

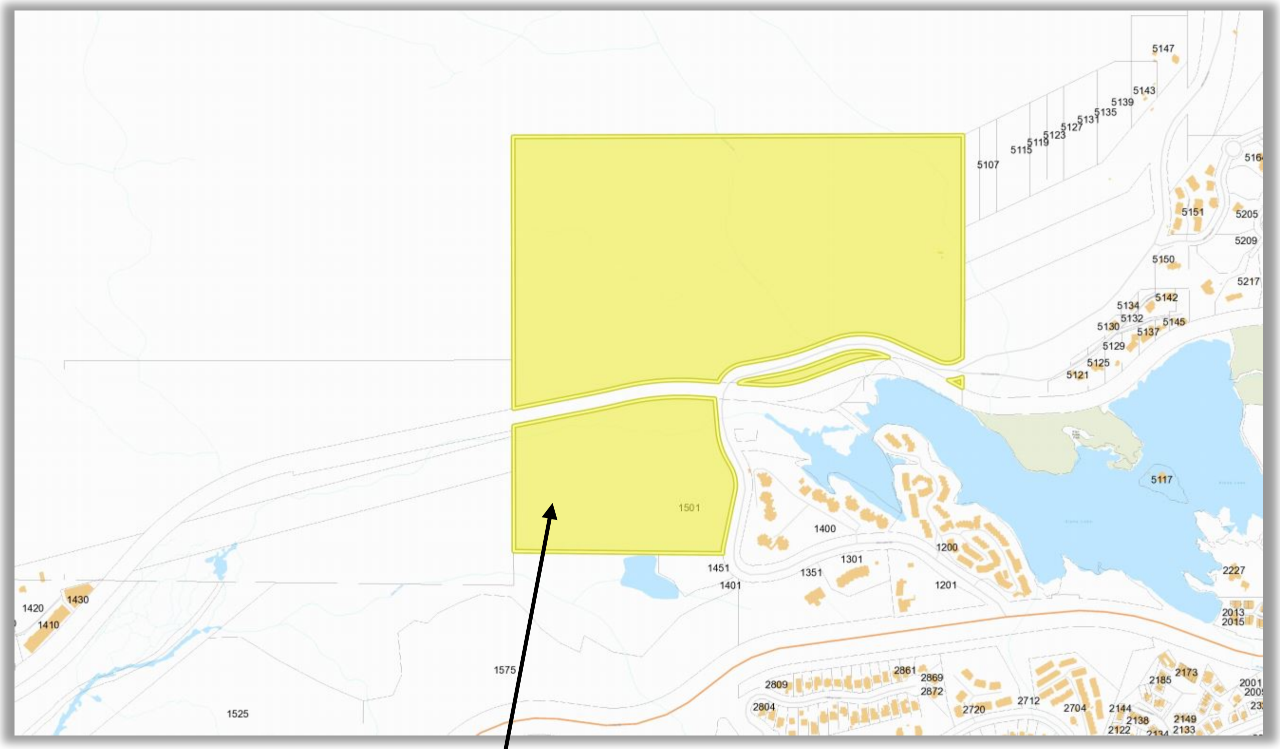
SUMMARY

This report recommends that Council consider giving first and second readings to "Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018", and that Council direct staff to schedule a Public Hearing regarding "Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018".

Respectfully submitted,

Melissa Laidlaw
SENIOR PLANNER
for
Jan Jansen
GENERAL MANAGER OF RESORT EXPERIENCE

Appendix A – Location Map



Subject Property

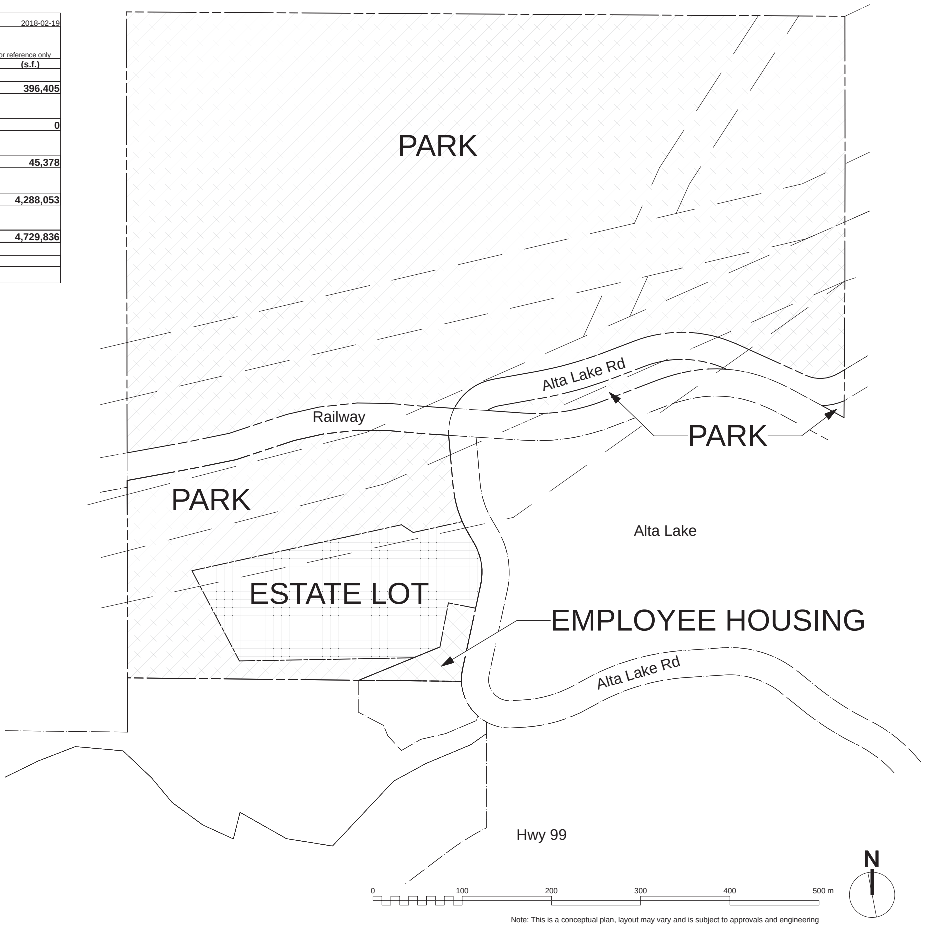
Appendix B

	PROPOSED ZONING SUMMARY:					2018-02-19
	DESCRIPTION		ZONE AREA		imperial provided for reference only	
	ZONE	DESCRIPTION	(Ha)	(M2)	(Ac)	(s.f.)
▦	RSE-(x)	Estate Lot*	3.68 ha	36,827	9.10	396,405
▨	ROAD	Public Road	0.000	0	0.00	0
☒	RM-51	Res. Housing	0.42 ha	4,216	1.04	45,378
▨	PARK	Park Land	39.84 ha	398,373	98.40	4,288,053
	Total Areas		43.94 ha	439,416	108.54	4,729,836

* Area includes strata road

Use metric units, imperial provided for reference only. Any variation in totals may be due to rounding.

Note: Areas are approximate and subject to verification by a BCLS.



Note: This is a conceptual plan, layout may vary and is subject to approvals and engineering

CROSLAND DOAK DESIGN
Landscape
Architecture +
Building Design

3121 Alta Vista Road
Whistler, BC VON 1B3
604. 966-8309
info@CroslandDoakDesign.com
CroslandDoakDesign.com

Date	Issued For
2018.04.30	Graphic Rev
2018.03.26	R/S Application Rev
2017.09.25	Rezone/Sub Application

client

Prism Lands
1501 Alta Lake Rd
Whistler, BC

project title

Proposed Zoning

drawing title

scale: 1:2000

project no. 1511

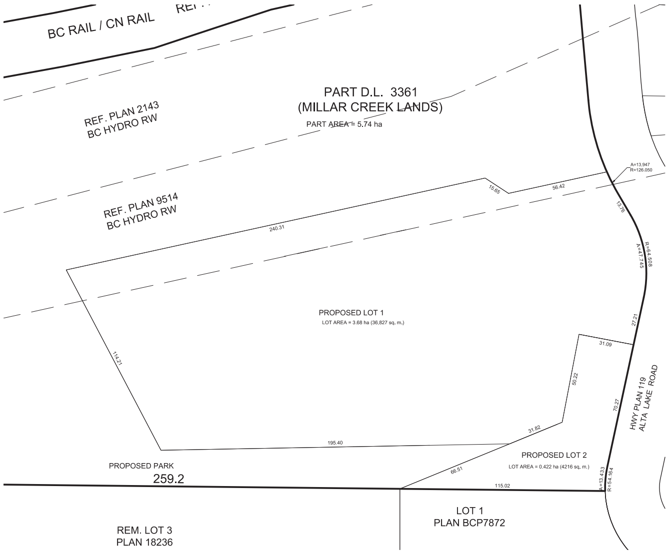
LP-2

drawing no.

Proposed Zoning

LP-2

PROPOSED SUBDIVISION ON DISTRICT LOT 3361, GP. 1, N.W.D., EXCEPT PART IN REFERENCE PLAN 1066, PART ON PLAN 14962, PART ON PLAN 17731, PART ON PLAN 22573, PART ON HWY PLAN 119



DETAIL:
SCALE 1:1000

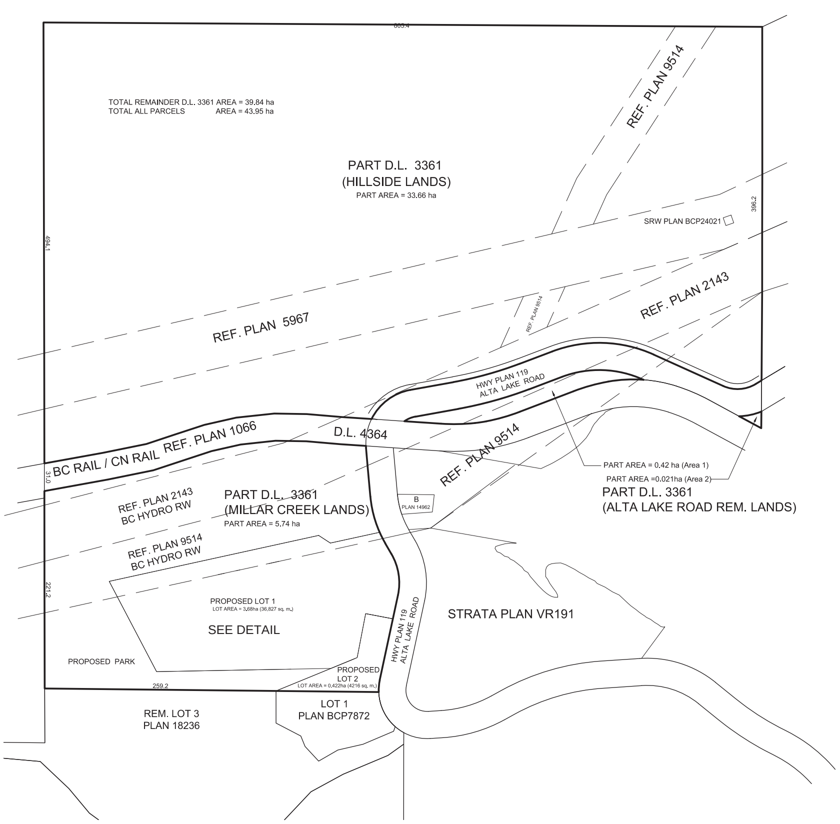
N
W E
S

NOTE:
- FIELD SURVEY COMPLETED JULY 14, 2017
- ×123.45 DENOTES SPOT ELEVATION IN METRES
- BEARINGS ARE DERIVED FROM L.T.O. RECORDS

RESORT MUNICIPALITY OF WHISTLER

80 40 0 80 160
GRAPHIC SCALE METRES 1 : 2000
All distances are in metres

AREA LOT SUMMARY		Hectares
MILLAR CREEK LANDS	PROPOSED PARK	5.74
HILLSIDE LANDS		33.67
ALTA LAKE ROAD REM. LANDS	AREA 1	0.42
	AREA 2	0.02
TOTAL REMAINDER D.L.3361		39.84
MILLAR CREEK LANDS	PROPOSED LOT 1	3.68
	PROPOSED LOT 2	0.42
TOTAL ALL PARCELS		43.95



Plotted on April 30, 2018 at 12:24:31 PM

DOUG BUSH SURVEY SERVICES Ltd.
Douglas J. Bush, AScT, RSIS
Applied Science Technologist (Geomatics)
Unit 18, 1370 Alpha Lake Road, Whistler, B.C. VON 1B1
Phone 932-3314 / Fax: 932-3039 E-mail:
dougb@dbss.ca / http://dbss.ca

REVISION :
1. CHANGED HEAVY WASH AND ADDED PART OF DL 3361 ON THE SOUTH SIDE OF ALTA LAKE ROAD.
2. PROPOSED LOTS CHANGED
3. EDITED TITLES & ADDED AREAS
4. UPDATE TO SURFACE AND TABLES

Notes:
- PROPOSED LOT DIMENSIONS AND AREAS ARE PRELIMINARY .
- DIMENSIONS AND AREAS OF THE REM. D.L. 3361 ARE APPROXIMATE ONLY AND NEED TO BE CONFIRMED BY FIELD SURVEY.

Date: April 30, 2018

Files: 17021.CRD
P.I.D. 010-682-023

Client: PRISM PROPERTIES

Project: D.L. 3361, 1501 ALTA LAKE ROAD

SCALE: 1:2000

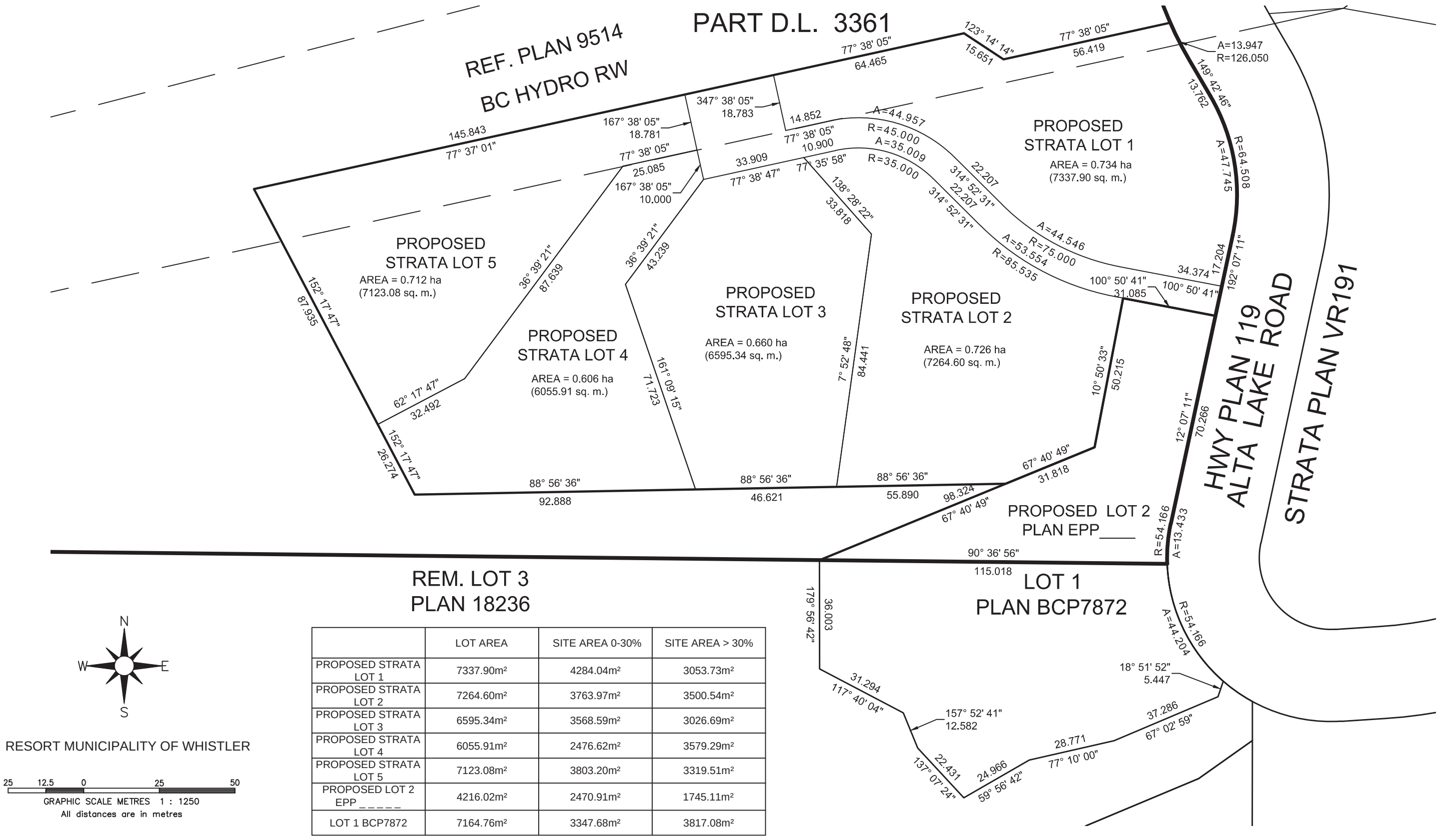
JOB NO.: J18021

DWG.: 18042-REV 2

SHEET: 1

S:\DATA18\J18021\WORK\18042-REV 2.DWG

PLAN SHOWING PROPOSED BARELAND STRATA SUBDIVISION OF LOT 1, D.L.3361, GP. 1, N.W.D., PLAN EPP_ _ _ _ _



	LOT AREA	SITE AREA 0-30%	SITE AREA > 30%
PROPOSED STRATA LOT 1	7337.90m²	4284.04m²	3053.73m²
PROPOSED STRATA LOT 2	7264.60m²	3763.97m²	3500.54m²
PROPOSED STRATA LOT 3	6595.34m²	3568.59m²	3026.69m²
PROPOSED STRATA LOT 4	6055.91m²	2476.62m²	3579.29m²
PROPOSED STRATA LOT 5	7123.08m²	3803.20m²	3319.51m²
PROPOSED LOT 2 EPP _ _ _ _ _	4216.02m²	2470.91m²	1745.11m²
LOT 1 BCP7872	7164.76m²	3347.68m²	3817.08m²

DOUG BUSH SURVEY SERVICES Ltd.
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Applied Science Technologist (Geomatics)
Unit 18, 1370 Alpha Lake Road, Whistler, B.C. VON 1B1
Phone 932-3314 / Fax: 932-3039
E-mail: dougb@dbss.ca / http://dbss.ca

REVISION:

Notes:

Client: PRISM PROPERTIES

Project: D.L. 3361, 1501 ALTA LAKE ROAD

Date: April 30, 2018

Files: 17021.CRD

SCALE: 1:1250

JOB NO.: J18021

DWG.: 18042-REV 2

SHEET: 2/b

Plotted on April 30, 2018 at 12:35:48 PM

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WHISTLER

MINUTES

REGULAR WORKSHOP OF THE TRANSIT MANAGEMENT ADVISORY COMMITTEE
TUESDAY, APRIL 3, 2018, STARTING AT 12:07 P.M.

In the Piccolo Room
4325 Blackcomb Way, Whistler, BC V0N 1B4

PRESENT:
TMAC Chair – RMOW Councillor, J. Ford
BC Transit, Senior Regional Transit Manager, L. Trotter
Whistler Transit Ltd. – Operations Manager, S. Antil
RMOW – General Manager Infrastructure Services, J. Hallisey
RMOW – TDM Planner & Recording Secretary, E. DalSanto

PRESENT:
BC Transit – Senior Transit Planner, L. Megenbir (by phone)

REGRETS:
Whistler Transit Ltd.– Manager, C. Gomez

ADOPTION OF AGENDA

Moved by J. Hallisey
Seconded by L. Trotter

That Transit Management Advisory Committee (TMAC) adopt the TMAC Committee Agenda of April 3, 2018 with the addition of upcoming special presentation/education forums and the 2018/2019 Annual Operating Agreement discussion.

CARRIED

ADOPTION OF MINUTES

Moved by S. Antil
Seconded by L. Megenbir

That Transit Management Advisory Committee (TMAC) adopt the Regular TMAC Minutes of October 11, 2017.

CARRIED

PRESENTATIONS/DELEGATIONS

Project Updates

CNG / Diesel buses

- All 25 CNG buses have arrived in Whistler.
- The Whistler mechanics have reset the interior lighting on the CNG buses to be more comfortable for both passengers and drivers.
- Most of the diesel buses have left Whistler. There are still a few diesel buses in Whistler but they will be reassigned to other locations in BC over the next month.
- CNG related upgrades to the Whistler Transit facility are complete.

Whistler Transit Facility Leasing of excess unused parking/office space

ACTION 1:

L. Trotter will get information from D. Strobl about the Whistler Transit Facility rental/lease space for spring/summer/fall 2018 so that RMOW staff can update information for charter buses coming to Whistler this summer/fall.

SmartBus/Real Time Project in Whistler

- BC Transit's SmartBus team visited Whistler in March to prepare for installation this summer of software to active automatic vehicle locators and display of real-time bus location.
- The development and installation of the custom software for BC Transit buses is taking place in Nanaimo and Comox this spring/summer. Whistler and Squamish are next BC Transit locations scheduled.
- BC Transit has sent a bus stop location list to the RMOW this is being checked for attributes.

ACTION 2:

BC Transit has sent a bus stop location list to the RMOW this is being checked for attributes. RMOW staff will work with WTL staff to make sure the appropriate local names for bus stop call out are included and then send it back to BC Transit.

Regional Transit Study:

RMOW senior management staff are working with Sea-to-Sky senior management on a potential governance and funding model for regional transit to present to the Province.

Winter Customer Service Hours

ACTION 3:

Whistler Transit Ltd staff will report out on this winter customer service staff and hours at the next TMAC meeting after the 2017/2018 project ends on April 22.

Spring/Summer/Fall – Late Winter Service Ends April 22, 2018

BC Transit Marketing has focused their marketing effort on the April 3rd date for service change and do not believe that more paid advertising is needed for the April 23 ramp down of service.

ACTION 4:

That BC Transit, the RMOW and Whistler Transit Ltd staff be proactive to communication and mitigate known complaints that will happen on April 23rd. RMOW staff will to continue with personal emails and visits to Visitor Centre, TW, hotel concierges and work with Whistler Transit Ltd staff to put up signs at bus stops to inform riders about Route 4. Whistler Transit Ltd staff will reach out to customers via social media.

Transit Related Infrastructure Updates

Gondola Transit Exchange (GTEX)

Gondola Transit Exchange has capacity issues at peak times in winter especially at Post 2 and 3. This will is a limiting factor for transit expansion.

ACTION 5:
BC Transit to draft document outlining Key Objective of the review, current conditions, constraints, community uses, stakeholders and to share that with the RMOW as the basis for a consultant review of GTEX capacity review/analysis. The goal is to have recommendations for 2018 construction/implementation for this winter and medium/long term recommendations for 2019 to allow for appropriate transit service expansion in winter 2018/2019 and beyond.

ACTION 6:
Whistler Transit Lt staff will circulate the Whistler Transit Ltd's operation plan to help with this process

MOTI Highway Betterment Program
BC Transit and the RMOW have not heard back from MOTI about the Whistler applications for additional bus stops on Highway 99 at Rainbow, Nesters and Alta Lake Road.

ACTION 7:
RMOW staff to follow up with the new local MOTI Area Manager.

Other Bus Stop Issues in Whistler
Whistler Transit Ltd and TMAC request that the RMOW review the following areas to improve transit access especially during winter when there are large amounts of snow in the Valley.

- the in-bound stop at Village Gate Boulevard to allow for offloading of more than one bus at a time
- the turnarounds at Function, Spring Creek, Blackcomb Way on Route 5 by Lost Lake Park, Crabapple/Barnfield

ACTION 8:
Set up meeting in September/October between RMOW snow clearing staff and Whistler Transit Ltd. staff to review areas where snow clearing becomes an issues (i.e. Crabapple/Barnfield/Function turnaround).

Whistler OCP Refresh

RMOW staff outlined the Whistler OCP Refresh project and process. There was a discussion regarding the Transportation Advisory Group process and the community feedback received to date related to the Transportation Chapter goals, objectives and policies.

ACTION 9:
TMAC to review the draft OCP Transportation chapter and send comments back to the RMOW by Wednesday April 11th 12 noon.

3-year Expansion Plan

BC Transit requires sign off by June 15th on the 2019/2020 Expansion plans. The general plan is to have 6,500 annual hours of expansion for 2018/2019 of which ~1,700 hours have been added to the 2018 Spring/Summer/Fall schedule. The remaining hours will be added to winter 2018/2019.
BC Transit is also suggesting 2,500 annual hour and one bus expansion in both 2019/2020 and 2020/2021.

ACTION 10:
BC Transit will aim to share the draft expansion memo at the next TMAC meeting.

ACTION 11:
As part of the winter 2018/2019 schedule planning, review the start-end dates for winter as well as the ramp-up (Early Winter) and ramp-down (Late Winter) service – goal – more clarity for the customer. This should be reviewed with the new Day Lot 4/5 peak seasons of June 15 – Sept 15 and Dec 15 to April 15.

Communications and Marketing

BC Transit Circulated the draft Communications and Marketing plan. TMAC members will review the plan and provide comments at the next TMAC meeting.

Other Business

2018/2019 Annual Operating Agreement

- *As the AOA was received by RMOW staff after the TMAC Agenda package was distributed, a special meeting of TMAC will be held in late April to review the AOA with the goal of presenting the AOA to Council in May 2018.*

Upcoming transit and transportation presentation and education events

- *April 6, 2018 – School District #48 (SD48) Housing and Transportation Forum, Whistler*
- *June 4 – 7, 2018 – BC Transit Annual Workshop, Parksville*
- *June 13, 2018 – Canadian Urban Transit Association (CUTA), New Mobility Symposium, Vancouver*

TERMINATION

Moved by L. Trotter
Seconded by S. Antil

That the Transit Management Advisory Committee Meeting of April 3, 2018 be terminated at 2:12 p.m.

CARRIED

J CFord

Chair, J. Ford

Recording Secretary, E. DalSanto

RESORT MUNICIPALITY OF WHISTLER
ZONING AND PARKING AMENDMENT BYLAW NO. 2172, 2018

A BYLAW TO AMEND THE WHISTLER ZONING AND PARKING BYLAW NO. 303, 2015

WHEREAS Council may, in a zoning bylaw pursuant to Section 479 of the *Local Government Act,* divide all or part of the area of the Municipality into zones, name each zone and establish the boundaries of the zones, regulate the use of land, buildings and structures within the zones, and require the provision of parking spaces for uses, buildings and structures;

NOW THEREFORE the Council of the Resort Municipality of Whistler, in open meeting assembled, ENACTS AS FOLLOWS:

1. This Bylaw may be cited for all purposes as "Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018".

2. Resort Municipality of Whistler Zoning and Parking Bylaw No. 303, 2015 is amended by changing the zoning designation of the land with the following legal description from RS-E1 to RS-E8: District Lot 3361, Group 1 New Westminster District Except Firstly: Part in Reference Plan 1066, Secondly: Part on Plan 14962, Thirdly: Part on Plan 17731, Fourthly: Part on Plan 22573, Fifthly: Part on Highway Plan 119.

3. Resort Municipality of Whistler Zoning and Parking Bylaw No. 303, 2015 is amended in Part 24 by adding Single Estate Eight RS-E8 under the heading "Residential Zones" in Schedule "A" Legend of Zones.

4. Resort Municipality of Whistler Zoning and Parking Bylaw No. 303, 2015 is further amended in Part 12 by adding as Section 53 the regulations attached to and forming part of this Bylaw as Schedule 1.

GIVEN FIRST READING this __ day of _____, 2018.

GIVEN SECOND READING this __ day of _____, 2018.

Pursuant to Section 464 of the *Local Government Act*, a Public Hearing was held this __ day of _____, 2018.

GIVEN THIRD READING this __ day of _____, 2018.

Approved by the Minister of Transportation and Infrastructure this __ day of _____, 2018.

ADOPTED by the Council this __ day of _____, 2018.

Nancy Wilhelm-Morden, Mayor	Brooke Browning, Municipal Clerk

I HEREBY CERTIFY that this is a true copy of "Zoning Amendment Bylaw (Prism Lands) No. 2172, 2018."

Brooke Browning,
Municipal Clerk

SCHEDULE 1

53. RS-E8 Zone (Residential Single Estate Eight)

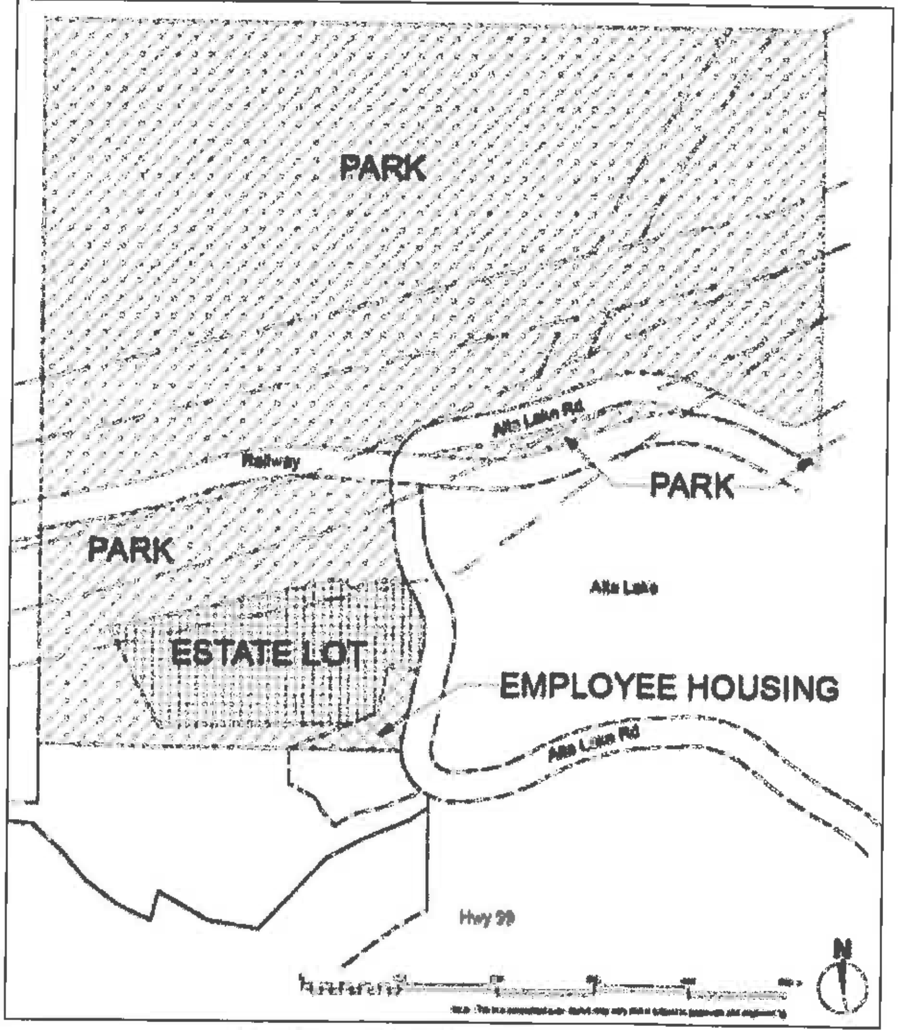
Intent

(1) The intent of this zone is to provide for low density detached dwelling residential use with greater density of development permitted as a condition of the provision of amenities and land for affordable housing.

Subdivision and Use of Park, Housing and Estate Lot Parcels

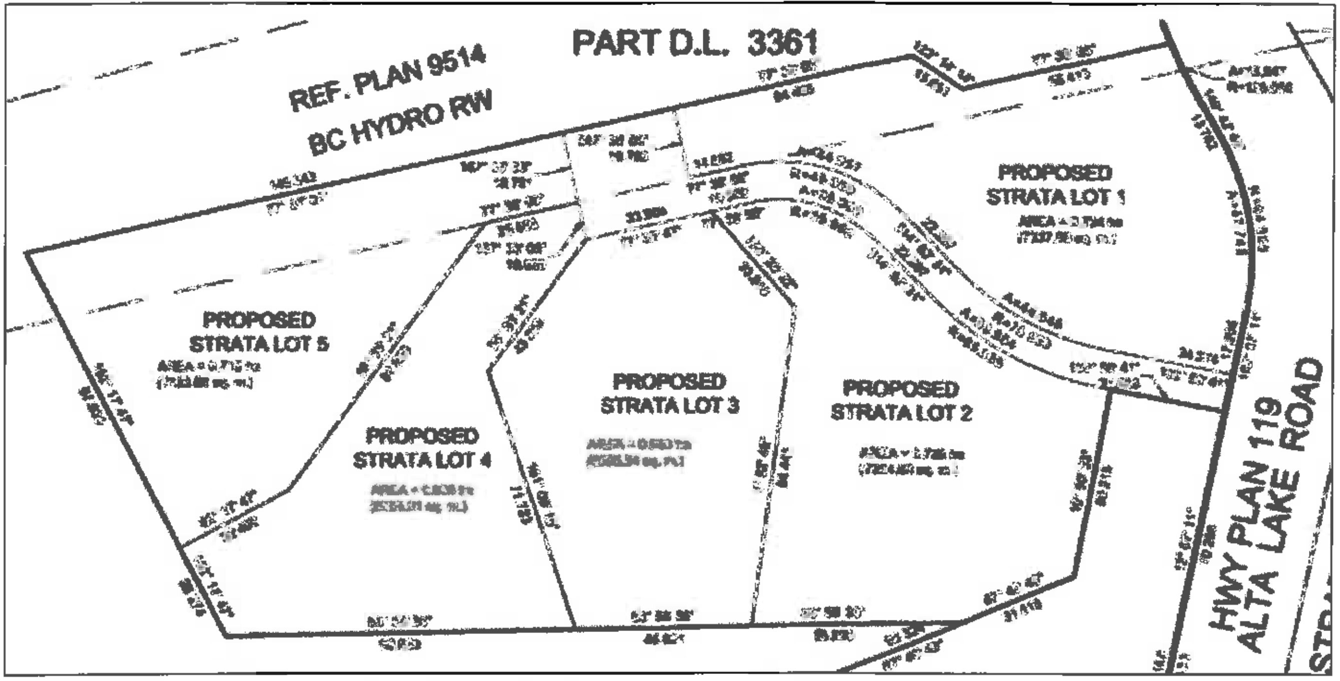
(2) The land in the RS-E8 Zone may be subdivided only as follows, and only in the following sequence:

(a) to create the three parcels illustrated in the following Key Plan, comprising a 98-acre parcel in the northerly portion of the lands (the "Park Parcel"), a 1-acre parcel in the southerly portion of the lands (the "Employee Housing Parcel"), and an 9-acre portion between those two portions (the "Estate Lot Parcel"), each of which parcels must have an area no more than 5% greater than and no more than 5% less than the stated areas: and



Key Plan of initial subdivision

(b) to create from the Estate Lot Parcel the five parcels illustrated in the following Key Plan, and the subdivision may vary from the Key Plan but not so as to create any number of parcels greater than five or any lot with an area that varies by more than 5% from the area stated on the Key Plan:



Key Plan of five-lot residential subdivision

(3) The subdivision described in paragraph (2)(b) may be approved by the Approving Officer and deposited in the Land Title Office only if the owner of the land has transferred the Park Parcel and the Employee Housing Parcel to the Resort Municipality of Whistler for nominal consideration, free and clear of all encumbrances except those approved in writing by the Resort Municipality.

(4) Unless the land in the RS-E8 Zone is subdivided in accordance with paragraphs (2)(a) and (b) by December 31, 2018, it shall be subject to the regulations for the RS-E1 Zone.

(5) The Employee Housing Parcel and buildings and structures on the Employee Housing Parcel shall be subject to the regulations for the RS-E1 Zone unless it has been consolidated with Lot 1 District Lots 1754 and 3361 Group 1 New Westminster District Plan BCP7872, and having been so consolidated shall, despite anything in this Section 53, be subject to the regulations for the RM51 Zone.

(6) The Park Parcel once it has been created in accordance with subsection (2) shall be subject to the regulations for the LP4 Zone.

(7) The parcels created by subdivision of the Estate Lot Parcel and buildings and structures on those parcels shall be subject to the regulations for the RS-E1 Zone, other than subsections 34(5) and (9), and may not be further subdivided.

RESORT MUNICIPALITY OF WHISTLER

ZONING AMENDMENT BYLAW (CTI1 ZONE) NO. 2187, 2018

A BYLAW TO AMEND THE RESORT MUNICIPALITY OF WHISTLER "ZONING AND PARKING BYLAW NO. 303, 2015"

WHEREAS the Council may in a zoning bylaw pursuant to the *Local Government Act*, divide all or part of the area of the Municipality into zones, name each zone and establish the boundaries of the zone, regulate the use of land, buildings and structures within the zones and require the provision of parking spaces and loading spaces for uses, buildings and structures;

NOW THEREFORE the Council of the Resort Municipality of Whistler, in open meeting assembled, **ENACTS AS FOLLOWS:**

1. This Bylaw may be cited for all purposes as "Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018".

2. Part 10, Industrial Zones, of "Zoning and Parking Bylaw No. 303, 2015" is hereby amended by replacing, in section 16, the regulations for the CTI1 (Community and Transportation Infrastructure One) with the regulations attached to and forming part of this Bylaw as Schedule "A".

GIVEN FIRST and SECOND READINGS this 24th day of April, 2018.

Pursuant to section 464 of the *Local Government Act,* a Public Hearing was held this 8th day of May, 2018.

GIVEN THIRD READING this __ day of _______, 2018

Approved by the Minister of Transportation and Infrastructure this __ day of _______, 2018.

ADOPTED by the Council this __ day of _______, 2018.

Nancy Wilhelm-Morden, Mayor	Brooke Browning, Municipal Clerk

I HEREBY CERTIFY that this is a true copy of "Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018".

Brooke Browning,
Municipal Clerk

Schedule A to Zoning Amendment Bylaw (CTI1 Zone) No. 2187, 2018

CTI1 Zone Regulations

16. CTI1 (Community and Transportation Infrastructure One) (Bylaw No. 2187)

Intent

(1) The intent of this zone is to provide industrial type uses supporting community and transportation infrastructure, and civic uses.

Permitted Uses

(2) The following uses are permitted and all other uses are prohibited;

- (a) auxiliary buildings and auxiliary uses;
- (b) auxiliary residential dwelling unit for a caretaker or watchman or other persons similarly employed on the premises;
- (c) fuel service station / fuel card lock;
- (d) indoor recreation (Bylaw No. 2076);
- (e) indoor storage;
- (f) indoor and outdoor storage and maintenance of construction equipment;
- (g) landscaping services;
- (h) messenger, courier service, shipping agent and freight forwarder;
- (i) motor vehicle maintenance and storage facility;
- (j) nature conservation parks and buffers;
- (k) non-motorized outdoor recreation, excluding rifle range and paintball facility, and excluding any other non-motorized outdoor recreation use that is likely, because of noise or dust it generates, to cause a nuisance to the owners, occupiers or users of adjacent lands or to the public (Bylaw No. 2076);
- (l) parks and playgrounds;
- (m) storage and works yard including storage of construction equipment;
- (n) recycling depot for household goods;
- (o) taxi dispatch and storage yard; and
- (p) vehicle impound yard.

Density

(3) The maximum permitted gross floor area of all buildings and structures in the CTI1 Zone is 18,581 square metres.

(4) The maximum permitted gross floor area of all buildings and structures on each site within the CTI1 Zone, as shown on the Key Plan attached to this CTI1 Zone, shall be as shown

in the following table, and, for clarity, if any of the sites is further subdivided, the gross floor area for that site may be distributed among the new parcels but shall remain restricted to the maximum for the site as shown in the table.

Site as shown on Key Plan	Gross Floor Area (square metres)
Lot 1 of Lot A	1,161.3
Lot 2 of Lot A	1,161.3
Lot B	6,410.3
Lot C	3,251.6
Lot D	6,410.3
Lot E	185.8

(5) The maximum floor space ratio is 0.5.

Height

(6) The maximum permitted height of a building is 12 metres.

Site Area

(7) The minimum permitted parcel area is 2000 square metres.

(8) The minimum parcel frontage is 23 metres.

Site Coverage

(9) The maximum allowable site coverage is 40 percent.

Setbacks

(10) The minimum permitted front setback is 7.5 metres.

(11) The minimum permitted side setback is 3.0 metres.

(12) The minimum permitted rear setback is 3.0 metres.

(13) Notwithstanding any other regulation in this zone, a minimum 20 metre setback is required from the right of way of Highway 99 and a minimum 10 metre setback is required from the railway right of way.

Off Street Parking and Loading

(14) Off street parking and loading spaces shall be provided and maintained in accordance with the regulations contained in Part 6 of this Bylaw.

Other Regulations

(15) A maximum of 1 auxiliary residential dwelling unit is permitted per parcel.

(16) An auxiliary residential dwelling unit shall contain a gross floor area no greater than 75 square metres and no less than 32.5 square metres.

(17) A maximum of 40 percent of the gross floor area of a principal building is permitted to be used for auxiliary office use.

(18) Setback areas described in subsection (13) shall be landscaped to visually screen the buildings, structures and storage areas from Highway 99 and the railway tracks.

(19) In addition to subsection (18), all uses on parcels adjacent to the railway shall be screened by a landscape berm in the 10 metre setback area described in subsection (13) and a fence at least 2.4 metres high constructed and maintained upon such parcels at a 10 m setback from the southeast property line of the railway right of way.

(20) In addition to the landscaped area required by subsection (18), a minimum of 10% of a parcel shall be landscaped, such landscaped area to be located to the maximum extent possible in the setback area adjacent to the front parcel line.

(21) Snow storage shall be predominantly located at the rear of the parcel.

(22) Storage yards shall be screened from adjacent parcels and highways.

(23) Auxiliary storage uses must be related to a principal use on the same parcel.

(24) Fencing shall not be of a barb wire construction below the height of 2.0 metres.

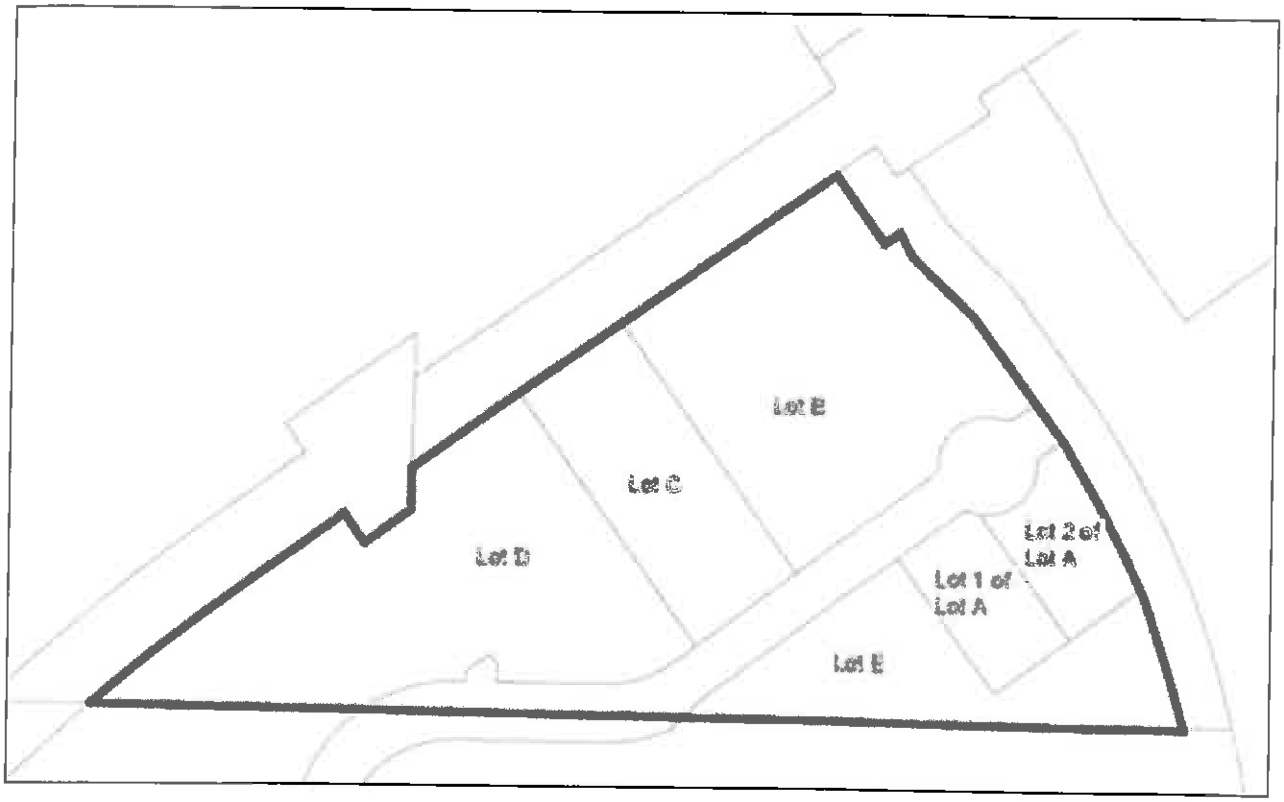
(25) All roof top apparatus shall be screened from public view at ground level and from Highway 99 and the railway.

(26) Any storage vessel with a liquid capacity exceeding 7570 liters (2000 gallons) capable of storing liquefied fuels under pressure shall:

(a) be sited at least 15 metres from any parcel line; and

(b) be sited at least 120.0 metres away from any building that may be used for public assembly such as schools, hospitals, theatres, tourist accommodations, and campgrounds and from any residential buildings.

Key Plan – CTI1 Zone



RESORT MUNICIPALITY OF WHISTLER
DELEGATION OF SIGNING AUTHORITY BYLAW NO. 2181, 2018

A BYLAW TO DELEGATE SIGNING AUTHORITY TO OFFICERS AND EMPLOYEES OF THE RESORT MUNICIPALITY OF WHISTLER

WHEREAS under section 154(1) of the *Community Charter*, Council may, by bylaw, delegate its powers, duties and functions, including those specifically established by an enactment, to its officers and employees;

AND WHEREAS the Resort Municipality of Whistler Bylaw "Officers Bylaw No. 1961, 2011" establishes municipal officer positions for the Resort Municipality of Whistler;

NOW THEREFORE the Council of the Resort Municipality of Whistler, in open meeting assembled, **ENACTS AS FOLLOWS**:

1. Name of Bylaw

1.1 This Bylaw may be cited for all purposes as the "Delegation of Signing Authority Bylaw No. 2181, 2018."

2. Interpretation

2.1 In this Bylaw:

"Council" means Council of the Resort Municipality of Whistler;

"Director" means any one of the Director of Finance, Director of Corporate, Economic and Environmental Services, the Director of Planning, the Director of Human Resources and the Library Director;

"employee" means an employee of the Resort Municipality of Whistler other than an officer;

"General Manager" means any one of the General Manager of Infrastructure Services, the General Manager of Resort Experience and the General Manager of Corporate and Community Services;

"municipality" and "municipal" means the Resort Municipality of Whistler; and

"officer" means a person acting in an officer position as established under the Resort Municipality of Whistler "Officers Bylaw No. 1961, 2011".

3. Delegation

3.1 A delegation of a power, duty or function under this Bylaw includes a delegation to a person who is from time to time, acting on behalf of the delegate, the deputy of the delegate or appointed to act in the capacity of the delegate in the delegate's absence.

4. Authorized Signatories for General Contracts and Agreements

4.1 Council hereby delegates the authority to execute general contracts and agreements as follows:

4.1.1 Save and except for contracts and agreements described elsewhere in this Bylaw or other bylaws of the municipality, all contracts and agreements between the municipality and a third party must be signed by any two of the following persons:

a) the Mayor;
b) the Chief Administrative Officer;
c) the Corporate Officer; or
d) General Manager.

4.1.2 Contracts approved by a bylaw must be signed by the Mayor and the Corporate Officer.

4.1.3 Contracts approved by Council resolution, between the municipality and the Government of Canada, the Government of British Columbia, the government of another province, another local government, a First Nation, or an agent of any of them, must be signed by any two of the following persons:

a) the Mayor;
b) the Chief Administrative Officer;
c) the Corporate Officer; or
d) the Director of Finance.

5. Authorized Signatories for Land and Land Use Agreements

5.1 Council hereby delegates to a General Manager the authority to execute land and land use agreements, including without limitation:

a) Easement agreements;
b) Statutory right-of-way agreements;
c) Encroachment agreements;
d) Covenant agreements;
e) Licences of occupation agreements;
f) Lease agreements; and
g) Maintenance agreements.

6. Authorized Signatories for Community Facility Leases, Licences and Use Agreements

6.1 Council hereby delegates to a General Manager the authority to execute community facility leases, licences and use agreements, including without limitation:

- a) Community facility leases;
- b) Concession licence agreements;
- c) Recreation user agreements; and
- d) Recreation revenue sharing agreements.

7. Authorized Signatories for Loan Agreements

7.1 Council hereby delegates to the Director of Finance and the Corporate Officer the authority to execute loan borrowing agreements with a term of less than five years.

8. Authorized Signatories for Grant and Contribution Agreements

8.1 Council hereby delegates to a Director the authority to execute a grant or contribution agreement awarded to the municipality in an amount less than $50,000.

8.2 Council hereby delegates to a General Manager the authority to execute a grant or contribution agreement awarded to the municipality in an amount greater than $50,000.

9. Delegation of Purchasing Authority

9.1 Council hereby delegates to the municipality's officers and employees the authority to execute any agreement respecting the activities, works or services of the municipality and/or the purchase of goods and services as set out in the Procurement Policy adopted by Council and as amended from time to time.

9.2 This section does not authorize the execution of any agreement that requires elector approval under section 175 of the *Community Charter*, whether as a result of the stated term of the agreement or any provision for extension or renewal.

10. Severability

10.1 If a portion of this Bylaw is held invalid by a Court of competent jurisdiction, then the invalid portion must be severed and the remainder of the Bylaw is deemed to have been adopted without the severed section, subsection, paragraph, subparagraph, clause or phrase.

GIVEN FIRST, SECOND, and THIRD Readings this 24th day of April, 2018.

ADOPTED this _____ day of _____, _____.

Nancy Wilhelm-Morden, Mayor	Brooke Browning, Municipal Clerk

I HEREBY CERTIFY that this is a true copy of "Delegation of Signing Authority Bylaw No. 2181, 2018".

Brooke Browning,
Municipal Clerk

RESORT MUNICIPALITY OF WHISTLER

TAX RATES BYLAW NO. 2182, 2018

A BYLAW FOR THE LEVYING OF TAX RATES FOR MUNICIPAL, HOSPITAL AND REGIONAL DISTRICT PURPOSES FOR THE YEAR 2018

The Council of the Resort Municipality of Whistler, in open meeting assembled, **ENACTS AS FOLLOWS:**

1. This Bylaw may be cited for all purposes as "Tax Rates Bylaw No. 2182, 2018".

2. The following tax rates are hereby imposed and levied for the year 2018:

   (a) For all lawful GENERAL PURPOSES OF THE MUNICIPALITY on the assessed value of land and improvements taxable for general Municipal purposes, rates appearing in column "A" of the Schedule "A" attached hereto and forming a part hereof.

   (b) For HOSPITAL PURPOSES on the assessed value of land and improvements taxable for regional hospital district purposes, rates appearing in column "B" of the Schedule "A" attached hereto and forming a part hereof.

   (c) For PURPOSES OF THE SQUAMISH LILLOOET REGIONAL DISTRICT on the assessed value of land and improvements taxable for general Municipal purposes, rates appearing in column "C" of the Schedule "A" attached hereto and forming a part hereof.

3. The minimum amount of taxation upon a parcel of real property shall be One Dollar ($1.00).

GIVEN FIRST, SECOND and THIRD READINGS this 24th day of April, 2018.

ADOPTED by Council this ____ day of _____, 2018.

Nancy Wilhelm-Morden,
Mayor

Brooke Browning,
Municipal Clerk

I HEREBY CERTIFY that this is
a true copy of "Tax Rates
Bylaw No. 2182, 2018".

Brooke Browning,
Municipal Clerk

BYLAW NO. 2182, 2018

SCHEDULE "A"

General Municipal Rate

	Class	"A" General Municipal Rate
01	Residential	1.768
02	Utility	21.378
05	Industrial	11.663
06	Business / Other	8.181
08	Recreation	8.809

Hospital District Requisition Rate

	Class	"B" Hospital District Requisition Rate
01	Residential	0.0359
02	Utility	0.1257
05	Industrial	0.1221
06	Business / Other	0.0880
08	Recreation	0.0359

Regional District Requisition Rate

	Class	"C" Regional District Requisition Rate
01	Residential	0.0437
02	Utility	0.4387
05	Industrial	0.2494
06	Business / Other	0.1971
08	Recreation	0.1992

RESORT MUNICIPALITY OF WHISTLER

SEWER USER FEE AMENDMENT BYLAW NO. 2183, 2018

A BYLAW TO AMEND THE "SEWER USER FEE BYLAW NO. 1895, 2009"

WHEREAS the Council of the Resort Municipality of Whistler has adopted "Sewer User Fee Bylaw No. 1895, 2009"

AND WHEREAS it is deemed expedient to amend the Resort Municipality of Whistler "Sewer User Fee Bylaw No. 1895, 2009";

NOW THEREFORE the Council of the Resort Municipality of Whistler in open meeting assembled, **ENACTS AS FOLLOWS**:

1. This Bylaw may be cited for all purposes as the Resort Municipality of Whistler "Sewer User Fee Amendment Bylaw No. 2183, 2018".
2. Effective January 1, 2018, Schedule "A" of "Sewer User Fee Amendment Bylaw No. 1895, 2009" is hereby replaced with the Schedule "A" attached to and forming part of this bylaw.

GIVEN FIRST, SECOND and THIRD READINGS this 24th day of April, 2018.

ADOPTED by the Council this ___ day of_____, 2018.

Nancy Wilhelm-Morden, Mayor	Brooke Browning, Municipal Clerk

I HEREBY CERTIFY that this is
a true copy of " Sewer User Fee
Amendment Bylaw No. 2183, 2018"

Brooke Browning,
Municipal Clerk

SEWER USER FEE AMENDMENT BYLAW NO. 2183, 2018

SCHEDULE "A"

SEWER USER FEES

FLAT FEE

1	Single family residential and Bed & Breakfast	173.25
2	Duplex (not strata titled)	
	i) first residential unit	173.25
	ii) each additional unit	386.16
3	Duplex (strata titled), per strata lot	173.25
4	Apartment or Multiple Family Residential parcel (not strata titled)	
	i) first residential unit	173.25
	ii) each additional unit	386.16
5	Dormitory Housing (any housing unit with a gross floor area of 45 square meters or less located within a non-stratified building containing 10 or more such housing units and normally rented for continuous periods of 30 days or more)	
	i) first residential unit	86.63
	ii) each additional unit	192.04
6	Hotel or Motel (not strata titled)	
	i) first residential unit	173.25
	ii) each additional unit	386.16
7	Pension (not strata titled)	
	i) first residential unit	86.63
	ii) each additional unit	86.63
8	Pension - residential prtion	173.25
9	Mobile home parks (not strata titled)	
	i) first rental space	173.25
	ii) each additional space	386.16
10	Trailer, Recreational Vehicles, Campgrounds	
	each space	86.63
11	Apartment of Multiple Family Residential Parcel (strata titled), per strata lot	173.25
12	Hotel or Motel (strata titled), per strata lot	173.25
13	Mobile home parks (strata titled), per strata lot	173.25
14	Schools - each classroom	389.30

SEWER USER FEE AMENDMENT BYLAW NO. 2183, 2018

SCHEDULE "A"

SEWER USER FEES

	PER SQUARE FOOT	
15	Public restrooms, Laundries, Laudromats, Car Washes, & Breweries each square foot	2.17
16	Restaurants, Bars, Lounges, Discotheques, Cabarets, Public Houses each square foot	1.04
17	Business, Commercial, Industrial, Hostels, Other each square foot	0.29
18	Pools, Aquatic Centres, Waterslides each square foot	0.29
	PER CUBIC METRE	
19	Metered rates (based on metered water volumes)	
	First 6,000 cubic metres	1.13
	Next 12,000 cubic metres	0.93
	Next 24,000 cubic metres	0.72
	Greater than 42,000 cubic metres	0.57
	MINIMUM CHARGE	
20	Minimum annual charge for a strata-titled unit, or the first unit in a non-strata building	128.37
21	Minimum annual charge for each additional dwelling unit in a non-strata building	342.34

RESORT MUNICIPALITY OF WHISTLER

SEWER TAX BYLAW NO. 2184, 2018

A BYLAW TO IMPOSE A SEWER TAX

WHEREAS a Municipality may construct, acquire, operate and maintain sewers and sewage disposal facilities and may establish rates and charges to be imposed upon land and improvements and may provide a formula for imposing the cost of those municipal works and services;

AND WHEREAS pursuant to Section 200 of the *Community Charter,* the Municipality may impose a parcel tax to provide all or part of the funding for a service;

AND WHEREAS the benefiting area herein defined is that area of land within the Municipality which, in the opinion of Council, benefits or will benefit from the sewers and sewage disposal facilities of the Municipality;

NOW THEREFORE the Council of the Resort Municipality of Whistler, in open meeting assembled, **ENACTS AS FOLLOWS:**

1. This Bylaw may be cited for all purposes as "Sewer Tax Bylaw No. 2184, 2018".

2. In this Bylaw,

   "benefiting area" means that area of land in which is located every parcel a boundary of which is within one hundred (100) meters of any part of a trunk sewer main and for which there is access permitting installation and maintenance of a connecting sewer line or holding tank between the parcel and the trunk sewer main; and

   "parcel" means a parcel of real property in the benefiting area and includes a strata lot.

3. A rate and charge of two hundred, seventy two dollars and forty cents ($272.40) is hereby imposed as a tax against each parcel for the year ending December 31, 2018.

4. The owner of each parcel shall pay not later than July 3, 2018 the tax imposed by Section 3 hereof against that parcel.

GIVEN FIRST, SECOND and THIRD READINGS this April 24th day of April, 2018.

ADOPTED by the Council this __ day of _______, 2018.

Nancy Wilhelm-Morden, Mayor	Brooke Browning, Municipal Clerk

I HEREBY CERTIFY that this is
a true copy of "Sewer Tax Bylaw
No. 2184, 2018".

Brooke Browning,
Municipal Clerk

RESORT MUNICIPALITY OF WHISTLER

SOLID WASTE/RECYCLING RATES AMENDMENT BYLAW NO. 2185, 2018

A BYLAW TO AMEND THE Garbage Disposal and Wildlife Attractants Bylaw No. 1861, 2008"

WHEREAS the Council of the Resort Municipality of Whistler has adopted "Garbage Disposal and Wildlife Attractants Bylaw No. 1861, 2008";

AND WHEREAS it is deemed expedient to amend the Resort Municipality of Whistler "Garbage Disposal and Wildlife Attractants Bylaw No. 1861, 2008"

NOW THEREFORE the Council of the Resort Municipality of Whistler in open meeting assembled, **ENACTS AS FOLLOWS**:

1. This Bylaw may be cited for all purposes as the Resort Municipality of Whistler "Solid Waste/Recycling Rates Amendment Bylaw No. 2185, 2018".
2. That all parts of section 23 be replaced with:
   a) Every person who delivers domestic garbage or waste to the municipal Waste Transfer Station or septage to the Waste Water Treatment Plant will be charged tipping fees as prescribed in Section "B"
   b) The owner of each residential or tourist accommodation parcel that does not possess on its property and utilize on a regular basis throughout the current year a commercial garbage container shall be charged, on the annual municipal tax notice, a Solid Waste and Recycling fee as prescribed in Schedule "C" to this bylaw.
   c) The owner of each parcel with an assessed improvement value greater than zero shall be charged, on the annual municipal tax notice, a Composter fee as prescribed in Schedule "C" to this bylaw.
3. Schedule "C" of "Garbage Disposal and Wildlife Attractants Bylaw No. 1861, 2008" is hereby replaced with Schedule "C" attached hereto and forming part of this bylaw.

GIVEN FIRST, SECOND and THIRD READINGS this 24th day of April, 2018.

ADOPTED by Council this ____ day of _____, 2018.

Nancy Wilhelm-Morden, Mayor	Brooke Browning, Municipal Clerk

I HEREBY CERTIFY that this is
a true copy of "Solid Waste/Recycling Rates
Amendment Bylaw No. 2185, 2018".

Brooke Browning,
Municipal Clerk

SCHEDULE C

SOLID WASTE/RECYCLING RATES AMENDMENT BYLAW NO. 2185, 2018

SOLID WASTE/RECYCLING RATES

Each residential or tourist accommodation parcel that does not possess on its property and utilize on a regular basis throughout the current year a commercial garbage container shall be charged, on the annual municipal tax notice, a Solid Waste and Recycling fee of two hundred and six dollars and eighteen cents ($206.18) per parcel that shall be paid by the same due date as the property taxes.

Each parcel with an assessed improvement value greater than zero shall be charged, on the annual municipal tax notice, a Composter fee of one hundred eight dollars and forty cents ($108.40) per parcel that shall be paid by the same due date as the property taxes.

RESORT MUNICIPALITY OF WHISTLER

WATER USER FEE AMENDMENT BYLAW NO. 2186, 2018

A BYLAW TO AMEND THE "WATER USER RATES BYLAW NO. 1826, 2007"

WHEREAS the Council of the Resort Municipality of Whistler has adopted "Water User Fee Bylaw No. 1826, 2007";

AND WHEREAS it is deemed expedient to amend the Resort Municipality of Whistler "Water User Fee Bylaw No. 1826, 2007";

NOW THEREFORE the Council of the Resort Municipality of Whistler in open meeting assembled, **ENACTS AS FOLLOWS**:

1. This Bylaw may be cited for all purposes as the Resort Municipality of Whistler "Water User Fee Amendment Bylaw No. 2186, 2018".
2. Effective January 1, 2018, Schedule "A" of "Water User Fee Bylaw No. 1826, 2007" is hereby replaced with the Schedule "A" attached to and forming part of this bylaw.

GIVEN FIRST, SECOND and THIRD READINGS this of 24th day of April, 2018.

ADOPTED by the Council this ___ of _______, 2018.

Nancy Wilhelm-Morden,
Mayor

Brooke Browning,
Municipal Clerk

I HEREBY CERTIFY that this is
a true copy of " Water User Fee
Amendment Bylaw No. 2186, 2018"

Brooke Browning,
Municipal Clerk

BYLAW NO. 2186, 2018

SCHEDULE A

WATER USER FEES

	FLAT FEE	2018 Rates
1	Single family residential and Bed & Breakfast	116.19
2	Duplex (not strata titled)	
	i) first residential unit	116.19
	ii) each additional unit	391.75
3	Duplex (strata titled), per strata lot	116.19
4	Apartment or Multiple Family Residential parcel (not strata titled)	
	i) first residential unit	116.19
	ii) each additional unit	391.75
5	Dormitory Housing (any housing unit with a gross floor area of 45 square meters or less located within a non-stratified building containing 10 or more such housing units and normally rented for continuous periods of 30 days or more)	
	i) first residential unit	57.58
	ii) each additional unit	197.41
6	Hotel or Motel (not strata titled)	
	i) first residential unit	116.19
	ii) each additional unit	391.75
7	Pension (not strata titled)	
	i) first residential unit	57.58
	ii) each additional unit	197.41
8	Pension - residential portion	116.19
9	Mobile home parks (not strata titled)	
	i) first rental space	116.19
	ii) each additional space	391.75
10	Trailer, Recreational Vehicles, Campgrounds	
	each space	57.58
11	Apartment of Multiple Family Residential Parcel (strata titled), per strata lot	116.19
12	Hotel or Motel (strata titled), per strata lot	116.19
13	Mobile home parks (strata titled), per strata lot	116.19
14	Schools - each classroom	466.80

BYLAW NO. 2186, 2018

SCHEDULE A

WATER USER FEES

	PER SQUARE FOOT	
15	Public restrooms, Laundries, Laudromats, Car Washes, & Breweries each square foot	1.64
16	Restaurants, Bars, Lounges, Discotheques, Cabarets, Public Houses each square foot	0.98
17	Business, Commercial, Industrial, Hostels, Other each square foot	0.41
18	Pools, Aquatic Centres, Waterslides each square foot	0.62
	PER HECTARE	
19	Golf courses, parks, playgrounds, Ski Runs each hectare	886.30
	PER CUBIC METRE	
20	Metered rates (based on metered water volumes)	
	First 6,000 cubic metres	0.85
	Next 12,000 cubic metres	0.66
	Next 24,000 cubic metres	0.54
	Greater than 42,000 cubic metres	0.48
	MINIMUM CHARGE	
21	Minimum annual charge for a strata-titled unit, or the first unit in a non-strata building	83.29
22	Minimum annual charge for each additional dwelling unit in a non-strata building	365.01