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City of Kingston - Third Crossing of the Cataraqui River -
Parks Canada Environmental Impact Analysis
Detailed Impact Analysis

Appendix I In Air Noise Impact Assessment for Birds and Reptiles (Jasco - April 2017)



In-Air Noise Impact Assessment for Birds and Reptiles

**Based on a Preliminary Design of the Third Crossing of the
Cataraqui River, Kingston, ON**

Submitted to:

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Contract: JASCO MSA Task Order 002

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21 April 2017

P001313-002

Document 01194

Version 1.0

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Suggested citation:

O'Neill, C. and H. Yurk. 2017. In-Air Noise Impact Assessment for Birds and Reptiles: Based on a Preliminary Design of the Third Crossing of the Cataraqui River, Kingston, ON. Document 01194, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates Ltd.

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To comply with Accessibility for Ontarians with Disabilities Act, all italicized conventions, including Latin species' names, were removed.

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Executive Summary

JASCO Applied Sciences Ltd, under contract to Golder Associates Ltd., performed an in-air acoustic modelling study of impact pile driving for constructing the Third Crossing over the Cataraqui River. The study also included analyzing airborne noise from vehicle traffic on the proposed bridge. Both scenarios were based on preliminary project designs provided by Golder Associates Ltd. The aim was to assess the effects from pile driving and traffic noise to which birds and reptiles could be exposed.

To predict the acoustic footprint associated with driving steel cylindrical pipe piles, the modelling considered the effects of pile driving equipment characteristics, land elevation, atmospheric data, and ground type. The traffic noise footprint was estimated by extrapolating expected sound levels from a prior numerical study (RWDI AIR Inc. 2012).

Potential impact of traffic noise and pile driving noise on birds and snakes is discussed. Effects of traffic noise were only considered for birds because the available information on received sound levels was restricted to A-weighted metrics, which, although applicable to birds, is not appropriate to assess the hearing sensitivity of snakes.

Based on a threshold of 125 dBA, pile driving does not have the potential to cause auditory injury (defined as PTS) in birds at distances beyond 20 m. No threshold for auditory injury in snakes was publicly available when this report was written.

Auditory impairment (defined as TTS) in birds could occur at levels greater than 93 dBA, which corresponds to a maximum distance of 113 m from the pile driving location. Auditory masking and behavioural disturbance might occur when pile driving noise exceeds the 55 dBA nominal ambient. The region of impact extends to a maximum distance of 2290 m from the source.

Auditory impairment (defined as TTS) in snakes could occur at distances of less than 37 m from the pile driving location based on a threshold of 104.5 dB. There are no publicly available criteria for auditory masking or behavioural disturbance for snakes.

1. Introduction

The City of Kinston, ON, is proposing to construct the Third Crossing of the Cataraqui River to implement additional transportation capacity between the west and east sides of the City. JASCO Applied Sciences Ltd (JASCO), under contract to Golder Associates Ltd. (Golder), performed an in-air acoustic modelling study to predict the airborne sound levels generated by impact pile driving during bridge construction. Furthermore, received sound levels from vehicle traffic during bridge operation were estimated by extrapolating expected sound levels (Data from RWDI AIR Inc. 2012). Model results and extrapolated sound levels were used to describe zones of potential impact of airborne construction and traffic noise for birds and reptiles. The zone estimates were based on guidelines by the California Department of Transportation, which is considered to be the most current impact assessment guidelines available (Dooling and Popper 2016).

This study considered un-mitigated impact pile driving of a cylindrical pile at a single location. Sound propagation was computed with JASCO's Impulse Noise Propagation Model (INPM), which uses the following inputs: topography, terrain type, and atmospheric parameters. Modelled results were presented in a sound field isopleth map, which shows the planar distribution of sound levels with ranges and azimuth directions at a fixed receiver height of 0.5 m above terrain. The criteria for noise impact on birds and reptiles were based on distance thresholds (Dooling and Popper 2016). Tables with distances to these noise thresholds are presented in the results.

Section 1.1 of this report describes the modelled scenarios. Sections 1.2 and 2 present the species of interest and the impact criteria applied for assessing noise levels. Section 3 outlines how sound source levels were estimated, the sound propagation model, and the procedure used to compute distances for given thresholds. Section 4 presents the modelled results in maps and tables. Section 5 interprets and discusses the results and is followed by a glossary of acoustic terminology. Information about acoustic metrics used in this report is presented in Appendix A. The sound propagation model used in this study is presented in Appendix B. Appendix C presents the acoustic environment parameters used in the model. A reference report on the comparison of historical weather data is included as Appendix D.

1.1. Acoustic Modelling Scenarios

This report assessed two scenarios:

1. Operational sound due to bridge traffic.

The operational sound assessment was based on the estimated sound levels presented in the environmental assessment report (RWDI AIR Inc. 2012).

For the first scenario, traffic consisted of 95% automobiles (e.g. cars, vans, and light trucks), 1.9% medium trucks, and 3.1% heavy trucks, with a posted speed limit of 60 km/hr, on a two-way bridge with a 0% gradient over flat topography with hard terrain. This model does not consider atmospheric parameters and only includes a homogeneous ground type (hard or soft).

Construction sound due to unmitigated impact pile driving of a steel cylindrical pipe pile with a planned diameter of 1.067 m.

The pile driving sound propagation modelling was performed at the center frequencies of 1/3-octave-bands from 6 Hz to 8 kHz. Broadband sound levels presented in the isopleth maps were computed by summing the received 1/3-octave-band levels.

Pier #4, located at 44°15.478' N, 76°28.552' W, was selected for modelling impact pile driving at the Third Crossing (Figure 1) because compared to other piers it has the thickest layer of sediment, which could require more strikes by a pile driver to set the pile into the bedrock, and is closest to the protected bird nesting wetlands to the north. Therefore, pile driving at this location could negatively effect birds and reptiles more so than at other locations.

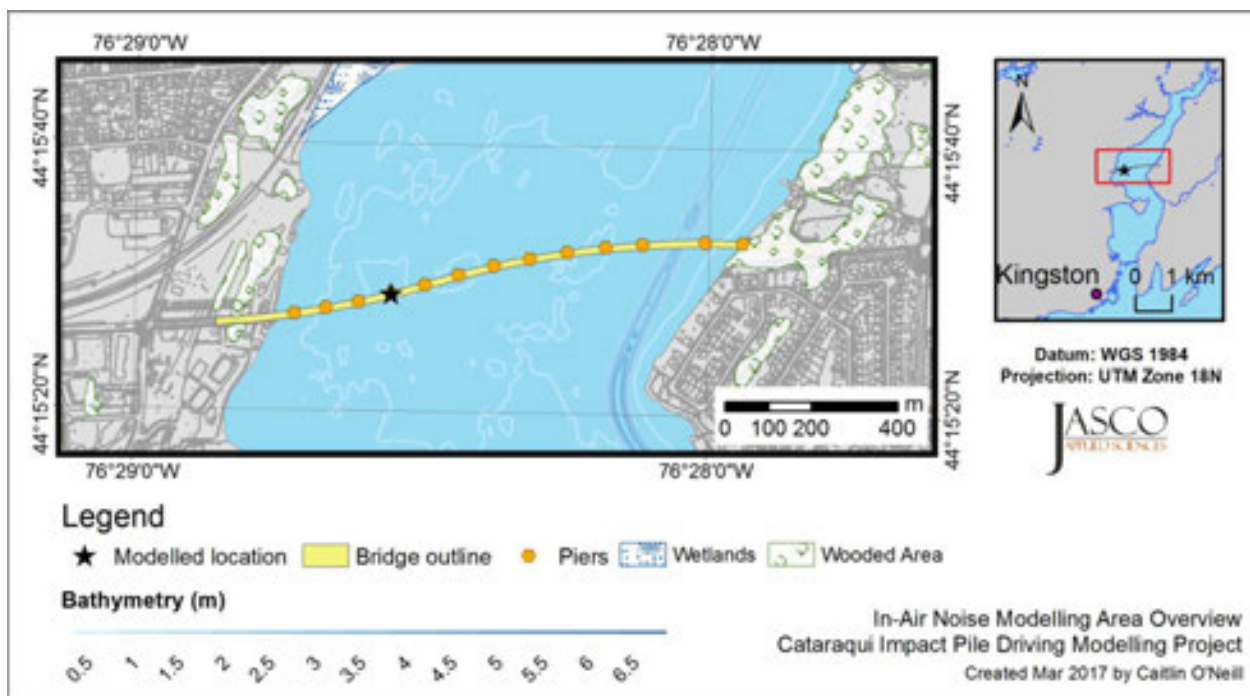


Figure 1. Map of the proposed Third Crossing, associated proposed piers, and modelled location at Pier #4 (Bowfin Environmental Consulting 2011). The inset shows an overview of the area in respect to the city of Kingston, ON.

1.2. Species of Interest

Golder provided a list of bird and reptile species that could potentially be affected by construction and traffic noise, as identified via a 2011 environmental assessment (Snetsinger 2011).

Five turtle, one snake, and 59 bird species were identified as species of interest (Table 1). Li and Zeddies (2017) describe the potential impact of underwater noise on turtles.

Table 1. Bird and non-aquatic reptile species that are likely occurring in and/or inhabiting the study area. Modified from the [Natural Heritage Information Center \(NHIC\) website](#). SRank (subnational rank) indicates how rare the animal is in Ontario. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) advises the Canadian government on the status of wildlife species; it was established as a legal entity under the Species at Risk Act (SARA). See table footnote for ranking and status descriptions.

Species Name	Common Name	SRank*	SARA/COSEWIC Status	Status in Ontario
Reptiles				
<i>Lampropeltis triangulum</i>	Eastern milk snake		Special Concern	
Birds				
<i>Agelaius phoeniceus</i>	Red-winged Blackbird	S5B		
<i>Aix sponsa</i>	Wood Duck	S5B		
<i>Anas americana</i>	American Wigeon	S4B		
<i>Anas platyrhynchos</i>	Mallard	S5B		
<i>Anas rubripes</i>	American Black Duck	S4B		
<i>Anas strepera</i>	Gadwall	S4B		
<i>Ardea herodias</i>	Great Blue Heron	S5B		
<i>Aythya affinis</i>	Lesser Scaup	S4B		
<i>Aythya collaris</i>	Ring-necked Duck	S5B		
<i>Aythya marila</i>	Greater Scaup	S4B		
<i>Bombycilla cedrorum</i>	Cedar Waxwing	S5B		
<i>Branta canadensis</i>	Canada Goose	S5B		
<i>Bucephala albeola</i>	Bufflehead	S4B		
<i>Bucephala clangula</i>	Common Goldeneye	S5B		
<i>Butorides virescens</i>	Green Heron	S4B		
<i>Cardinalis cardinalis</i>	Northern Cardinal	S5		
<i>Carduelis tristis</i>	American Goldfinch	S5B		
<i>Charadrius vociferus</i>	Killdeer	S5B		
<i>Chlidonias niger</i>	Black Tern	S3B	NAR	SC
<i>Cistothorus palustris</i>	Marsh Wren	S5B		

Species Name	Common Name	SRank*	SARA/COSEWIC Status	Status in Ontario
<i>Colaptes auratus</i>	Northern Flicker	S4B		
<i>Corvus brachyrhynchos</i>	American Crow	S5B		
<i>Cygnus columbianus</i>	Tundra Swan	S4B		
<i>Dendroica petechia</i>	Yellow Warbler	S5B		
<i>Dryocopus pileatus</i>	Pileated Woodpecker	S5		
<i>Dumetella carolinensis</i>	Gray Catbird	S5B		
<i>Fulica americana</i>	American Coot	S4B	NAR	NAR
<i>Gallinula chloropus</i>	Common Moorhen	S4B		
<i>Geothlypis trichas</i>	Common Yellowthroat	S5B		
<i>Hirundo rustica</i>	Barn Swallow	S5B		
<i>Hydroprogne caspia</i>	Caspian Tern	S3B	NAR	NAR
<i>Icterus galbula</i>	Baltimore Oriole	S4B		
<i>Larus argentatus</i>	Herring Gull	S5B		
<i>Larus delawarensis</i>	Ring-billed Gull	S5B		
<i>Lophodytes cucullatus</i>	Hooded Merganser	S5B		
<i>Melospiza georgiana</i>	Swamp Sparrow	S5B		
<i>Melospiza melodia</i>	Song Sparrow	S5B		
<i>Mergus merganser</i>	Common Merganser	S5B		
<i>Molothrus ater</i>	Brown-headed Cowbird	S5B		
<i>Myiarchus crinitus</i>	Great Crested Flycatcher	S4B		
<i>Pandion haliaetus</i>	Osprey	S4B		
<i>Passer domesticus</i>	House Sparrow	SNA		
<i>Phalacrocorax auritus</i>	Doublecrested Cormorant	S4B	NAR	NAR
<i>Picoides pubescens</i>	Downy Woodpecker	S5		
<i>Picoides villosus</i>	Hairy Woodpecker	S5		
<i>Podilymbus podiceps</i>	Pied-billed Grebe	S4B		

Species Name	Common Name	SRank*	SARA/COSEWIC Status	Status in Ontario
Poecile atricapillus	Black-capped Chickadee	S5		
Progne subis	Purple Martin	S4B		
Quiscalus quiscula	Common Grackle	S5B		
Spizella passerina	Chipping Sparrow	S5B		
Stelgidopteryx serripennis	Northern Rough-winged Swallow	S5B		
Sterna hirundo	Common Tern	S4B	NAR	NAR
Sturnus vulgaris	European Starling	SNA		
Tachycineta bicolor	Tree Swallow	S5B		
Thryothorus ludovicianus	Carolina Wren	S4		
Troglodytes aedon	House Wren	S5B		
Turdus migratorius	American Robin	S5B		
Vireo gilvus	Warbling Vireo	S5B		
Zenaida macroura	Mourning Dove	S5B		

SRank: S3 is Vulnerable–Vulnerable in the nation or state/province due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation; S4 is Apparently Secure–Uncommon but not rare; some cause for long-term concern due to declines or other factors; S5 is Secure–Common, widespread and abundant in the nation or state/province; SNA is Not Applicable–A conservation status rank is not applicable because the species is not a suitable target for conservation activities. B refers to breeding status, i.e. if a species breeds in Ontario. SC is a species of Special Concern. NAR is an evaluated species determined to not be at risk.

2. Impact Criteria for Birds and Reptiles

Noise can negatively affect birds and reptiles by causing them to lose hearing sensitivity temporarily or permanently or by increasing their stress levels by altering the production of stress hormones or through other physiological effects such as negatively affecting the cardio-vascular system. Noise can also mask important signals, thus preventing individuals from receiving important biological information such as signals of predators or prey or through interfering with acoustic communications between conspecifics. The latter can interfere with finding mates and/or change how animals select foraging locations (Dooling and Popper 2016). How animals respond to noise is usually related to the type of the noise, the sound level, the frequency structure of noise relative to the animal's hearing ability, and the distance of the noise source from the animal.

2.1. Hearing Overview and Acoustic Impact Criteria for Birds and Reptiles

2.1.1. Birds

In contrast to the hearing in snakes and other terrestrial reptiles, both bird hearing and their responses to resulting noise is well studied (Schwartzkopff 1955, Okanoya and Dooling 1987, Brittan-Powell et al. 2002, Dooling 2002, Lohr et al. 2003, Beason 2004). The impact of traffic noise on birds was studied extensively (Kociolek et al. 2011, Grade and Sieving 2016). Birds are a keystone species used to describe the effects of road noise on wildlife (Kaseloo 2005, Shannon et al. 2014, Shannon et al. 2015). Our study referenced the latest report published by CALTRANS (Dooling and Popper 2016) to describe and define impact thresholds of noise on birds.

The functionality of avian hearing is related to the sensitivity of their auditory system; hearing ranges affect their survival and reproduction (Fay and Popper 2000). Since the inner structures of all vertebrate ears are somewhat similar, and because birds and humans share many of the same environments, hearing and acoustic effects in birds has often been compared to that of humans (Fay and Popper 2000, Dooling and Popper 2016).

Table 1 shows detected species of 28 passerines (perching birds) and 31 non-passerines (birds of prey), but no strigiformes (owls) in the study area. Dooling and Popper (2016) created a composite audiogram by using the median hearing sensitivity of tested frequencies of all passerines and non-passerines (Figure 2). Because owls have much higher hearing sensitivities for all tested frequencies, and could also hear well above the typical hearing sensitivity of most other birds, the composite audiogram may not reflect the typical hearing thresholds of birds in the study area.

Most birds hear sounds between 100 Hz and 12 kHz reasonably well, with their best hearing range between 1 and 5 kHz (Figure 2), which is similar to human hearing. A-weighting (measured in dBA), commonly used to evaluate human hearing, is applied to traffic and construction noise to assess impact on birds.

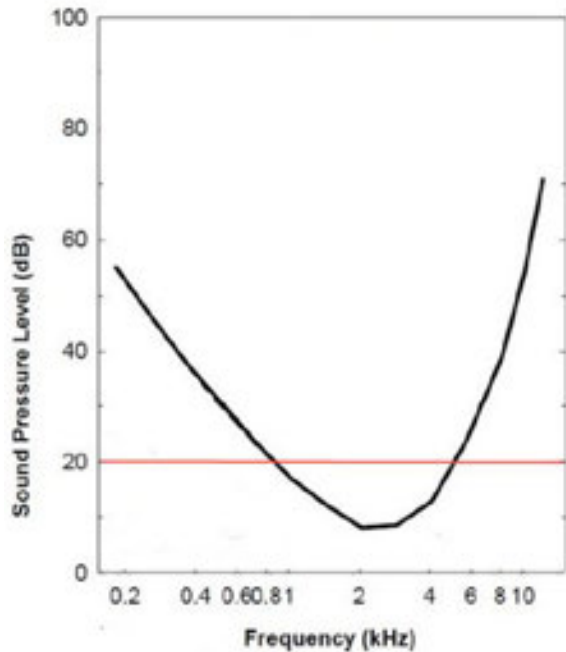


Figure 2. Composite audiogram (black line) based on median hearing thresholds of 49 species of birds in the 3 major bird groups (Dooling and Popper 2016). The red line at 20 dB represents the birds' masking threshold such that levels above the line will not affect their hearing thresholds (i.e., no masking).

The CALTRANS guidance report recommends the risk potential be assessed for:

- Permanent threshold shift–PTS (permanent hearing loss in specific frequency bands)
- Temporary threshold shift–TTS (temporary hearing loss in specific frequency bands)
- Masking of important biological signals
- Other behavioural and/or physiological effects

The possibility of these risks occurring is represented as zones radially around the sound source, i.e., Zones 1 to 4 (Figure 3).

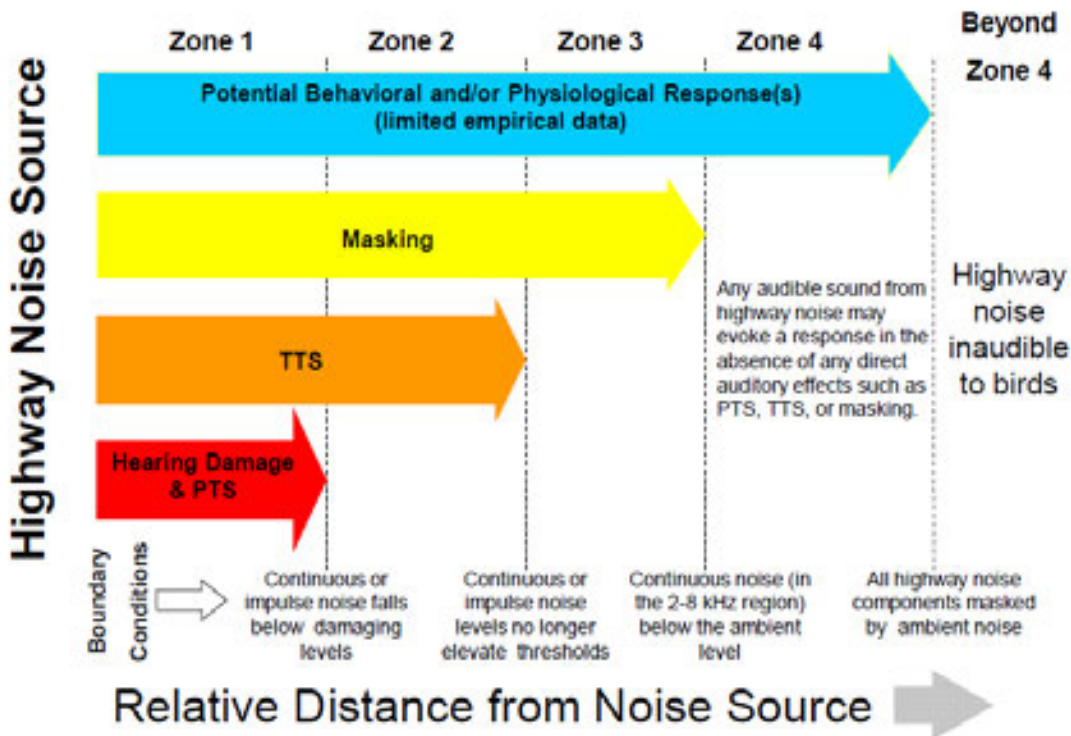


Figure 3. The effect of traffic and construction noise on birds over distance (Figure ES 2 from Dooling and Popper 2016).

The authors of the CALTRANS report recommend using interim criteria to assess potential effects of noise on birds. The criteria are considered interim due to a scarcity of data on some of the potential effects, such as sound levels that can cause TTS, at what sound level masking could occur, and if there are differences in the effects of masking due to differences in critical ratios (ability to detect signals in noise) that sound levels need to exceed in each auditory filter band to mask an important biological signal.

Grade and Sieving (2016) investigated road traffic masking the responses of northern cardinals (*Cardinalis cardinalis*) to alarm calls produced by the tufted titmouse (*Baeolophus bicolor*). The authors found that the cardinals stopped responding to the titmouse alarm calls when the ambient noise exceeded 47 dBA. The alarm call, however, is a pure tone signal at 9.5 kHz. The inner ears of birds, like the inner ears of mammals, detect signals using a set of auditory filters (frequency bands) that are roughly 1/3-octave wide. Several auditory filters in the cardinal's inner ear likely did not detect the alarm call, thus simulating a masking hearing test for the cardinals rather than a realistic hearing test. Because the results from several studies that investigated masking were highly variable (Dooling and Popper 2016), the authors of the CALTRANS report proposed criteria on noise assessments should be used cautiously, which is why although we have applied the interim criteria proposed by Dooling and Popper, these criteria are conservative (Table 2).

The criteria were used to determine distances from the noise source at which potential effects could occur. We used the results of the sound propagation modelling to calculate a typical distance at which hearing damage could occur. Bird hair cells can regrow so hearing damage in birds is reversible. Some residual hearing loss (around 10-15 dB lower sensitivity across the hearing range) can occur. The time it takes for hair cells to become functional again could be a period of high mortality risk due to the birds' limited ability to detect important environmental information such as predators. TTS onset is expected at a distance from the source where 93 dBA is exceeded, whereas masking could occur where the noise exceeds typical natural ambient sound levels (45 dBA, RWDI AIR Inc. 2012). As long as birds can hear any component of the noise signal, which is particularly important for sounds unfamiliar to birds, their behaviour could be affected.

Table 2. Criteria for noise effects, based on recommended interim guidelines for potential effects from different noise sources (Dooling and Popper 2016). TTS = temporary threshold shift. PTS = permanent threshold shift.

Noise Source Type	PTS	TTS	Masking	Potential Behavioural/ Physiological Effects
Multiple Impulse (e.g., jack hammer, pile driver)	125 dBA ¹	NA ³	Ambient dBA ⁵	Any audible component of traffic and construction noise has the potential to affect an animal's behaviour or physiology, which is independent of any direct effects due to PTS, TTS, or masking on the animal's auditory system.
Non-Strike Continuous (e.g., construction noise)	None ²	93 dBA ⁴	Ambient dBA ⁵	
Traffic and Construction	None ²	93 dBA ⁴	Ambient dBA ⁵	

¹ Estimates based on bird data from Hashino et al. (1988) and other impulse noise exposure studies in small mammals.

² Noise levels from these sources do not reach levels capable of causing auditory damage and/or permanent threshold shift based on empirical data on hearing loss in birds from the laboratory.

³ No data available on TTS in birds caused by impulsive sounds.

⁴ Estimates based on study of TTS by continuous noise in the budgerigar and similar studies in small mammals.

⁵ Conservative estimate based on addition of two uncorrelated noises. Above ambient noise levels, critical ratio data from 14 bird species, well-documented short-term behavioral adaptation strategies, and a background of ambient noise typical of a quiet suburban area would suggest noise guidelines in the range of 50–60 dBA.

2.1.2. Snakes

Little is known about the hearing abilities of snakes. Because they lack outer ears, snakes have long been considered deaf or not very sensitive to sounds, but can possibly detect vibrations through their skin (Young 2003). Research conducted during the second half of the 20th century, however, has shown that most snakes are sensitive to ground vibration and airborne sounds (Hartline 1971b, 1971a, Wever 1978, Young 2003). Notably, Hartline showed that airborne sounds and vibrations can elicit mid-brain responses in snakes (Hartline 1971a) while Wever (1978) postulated that responses to stimuli in the hind brain can be elicited by airborne sounds alone and that ground vibrations might play a minor role for the sensory systems of snakes.

Hartline (1971a, 1971b) used intracellular recordings from neurons in the midbrain to test snakes' sensitivity to airborne sounds and groundborne vibrations and confirmed Wever's postulation that snakes are more sensitive to airborne stimuli. Hartline also demonstrated that snakes perceive sounds as well as vibrations via skin cells (somatic hearing) and the inner ear. Somatic hearing is characterized by lower sensitivity, but a greater frequency range. Young (2003) used Wever's and Hartline's data to create an audiogram for both somatic and inner ear hearing (Figure 4).

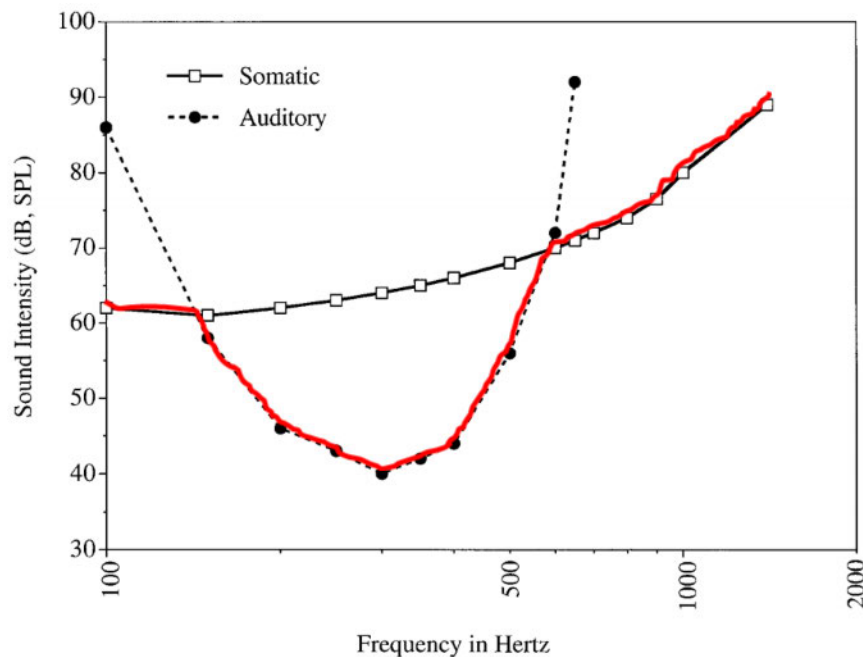


Figure 4. The audiogram curve shows how a snake hears somatically and via its inner ear (reprinted from Fig. 5 in Young 2003). The sensitivity is provided as sound pressure levels on the y-axis over frequency on the x-axis. The lower the reported sound level, the greater is the acoustic sensitivity for that frequency. The composite hearing sensitivity is shown in red.

Unweighted sound pressure levels (SPL) can be used to assess potential auditory injury in snakes due to noise, by describing the range at which an injury threshold could be

exceeded. Little published information mentions noise thresholds that could lead to specific effects such as temporary or permanent hearing loss (TTS or PTS) or behavioural disturbance. Mancini et al. (1988) discussed two earlier studies that assessed effects from off-road vehicle traffic on the desert iguana (*Dipsosaurus dorsalis*) and a sand lizard (*Uma scoparia*). In one of the studies Mancini et al. (1988) assessed, motorcycle noise played back at 114dB re 20 μ Pa caused TTS in an iguana. When noise was played for 10 hours, TTS could last up to 7 days. The sand lizard received TTS when noise from a four-by-four off road vehicle (dune buggy) was played back at 95 dB re 20 μ Pa for 510 s; recovery times were not reported. In the absence of data on permanent hearing loss (PTS) and to estimate risk conservatively the TTS onset of those two studies is used to assess the potential occurrence of auditory injury in the milk snake.

The following scheme, based on the approach taken by Dooling and Popper (2016) to assess noise impact on birds, was adopted to guide the assessment of noise on snakes. The rationale for this is that birds and reptile hearing is often considered having a number of similarities (Fay and Popper 2000).

- All audible noise that exceeds hearing thresholds established via an audiogram and that can be perceived by a reptile above ambient sound level, can affect behaviour of reptiles although it is not known how severe these effects are on individual or population health. Audible sounds are those that exceed the SPL threshold, which is the composite hearing curve in Figure 1.
- Masking of important biological sounds is likely to occur when noise levels exceed hearing thresholds in frequencies to which the reptiles are most sensitive. The area of best hearing is defined as the frequency range (150 Hz to 550 Hz) that is within 20 dB of the frequency with the highest sensitivity, which is at 300Hz. Sound levels above hearing threshold (dBht) will be reported and potential for auditory masking discussed. There are, however, no examples for masking thresholds publicly available
- Auditory (acoustic) injury occurs when reptiles are exposed to very loud sounds, although the actual onset of temporary and permanent hearing loss or hearing threshold shifts (TTS and PTS) are currently unknown. To be conservative in assessing risk of auditory injury, broadband levels that caused TTS in some species (e.g. *Dipsosaurus dorsalis* and *Uma scoparia*) can be used as a proxy for the estimations of onset of TTS. The mean between TTS producing sound levels of the two species is 104.5 dB re 20 μ Pa.

To assess potential risk of behavioural effects and masking effects the audiogram weighted noise levels (levels above hearing threshold, dBht) were used.

3. Methods

This section presents the methods used to generate the in-air acoustic contour maps and radii tables for impact pile driving and traffic noise scenarios. The project design provided by Golder Associates Ltd., including the equipment and operation plans associated with impact pile driving, is preliminary.

3.1. Traffic Noise

An acoustic source model and acoustic propagation model were not used for this scenario. Threshold distances to received sound levels from vehicle traffic that would likely occur once the bridge is operational were calculated by extrapolating expected sound levels from the area of influence (AOI) estimate provided in RWDI AIR Inc. (2012). The AOI estimate was generated with the Ontario Road Noise Analysis Method for Environment and Transportation (ORNAMENT), a computer road traffic noise prediction model developed by the Ministry of the Environment and Climate Change. This model used the following prediction variables: hourly traffic volumes (for each vehicle class), posted speed of traffic flow, separation distances, angles subtended at the receiver by road segments, ground absorption coefficients, road gradients, pavement surface type, and shielding due to barriers.

3.2. Impact Pile Driving Noise

To model sound levels from impact pile driving, we followed these steps:

1. Estimated 1/3-octave-band acoustic in-air source levels from information gathered by reviewing existing literature.
2. Modelled sound propagation through the air and across terrain and topography as a function of range, height, and azimuth.
3. Computed received levels over a grid of simulated receivers, from which distances to thresholds and maps of ensonified areas were generated, by combining the source levels with the propagated sound field.

JASCO's Impulse Noise Propagation Model (INPM) was used to model the in-air propagation of the acoustic fields resulting from impact pile driving. INPM computes acoustic fields by modelling transmission loss along evenly spaced radial traverses covering a 360° swath from the source (so-called N×2-D modelling). Acoustic transmission losses were computed for each of the center frequencies for all 1/3-octave-bands between 6 Hz and 8 kHz. Received sound pressure levels in each band were computed by applying frequency-dependent transmission losses to the corresponding 1/3-octave-band source levels obtained from the literature. INPM takes environmental inputs including atmospheric data, ground elevation, and terrain type as inputs (Appendix C). Appendix B describes INPM in detail.

INPM was run for 72 radials with 5° azimuth angle spacing and a 20 m range step for each radial over the modelling area. A modelling area of 4 km x 4 km was chosen to

include sound level contours down to 55 dBA and 65 dB. A source height of 10 m was used for the pile, as the maximum height at which the hammer strike could occur, with the assumption that most in-air noise originates at the strike point. A receiver height of 0.5 m was used as an approximate height of birds and reptiles in the study area.

3.2.1. Impact pile driving acoustic source

Plans for the Third Crossing include 13 piers composed of multiple steel cylindrical pipe piles. These piles have a planned diameter of 1.067 m, length of 50 m, and wall thickness of 0.025 m. Construction plans assume that impact pile driving will only be required for the final 10 m of pile insertion. The impact hammer that will install the piles is an APE D100-42 single acting diesel impact hammer with 334.88 kNm maximum rated energy and a 10,000 kg ram.

Airborne source levels (Figure 5) were calculated from two measurements of 0.9144 m piles with an APE D70-52 diesel impact hammer (234.42 kNm maximum rated energy and a 7,000 kg ram), recorded at 15 m (Illingworth & Rodkin 2015). The measurements were reported as 1-second “fast” unweighted SPL (1-minute LA_{max}), which uses a 125-millisecond time constant for averaging. The measured 1/3-octave-bands were back-propagated using spherical spreading to obtain source levels (at 1 m) for both sets of measurements, to which A-weighting was applied. A correction factor was applied to account for the difference in maximum rated energy between the two hammer sizes. It was assumed that the difference in measured and modelled pile diameters would minimally affect the impact hammer source levels because the hammer generates most of the in-air sound.

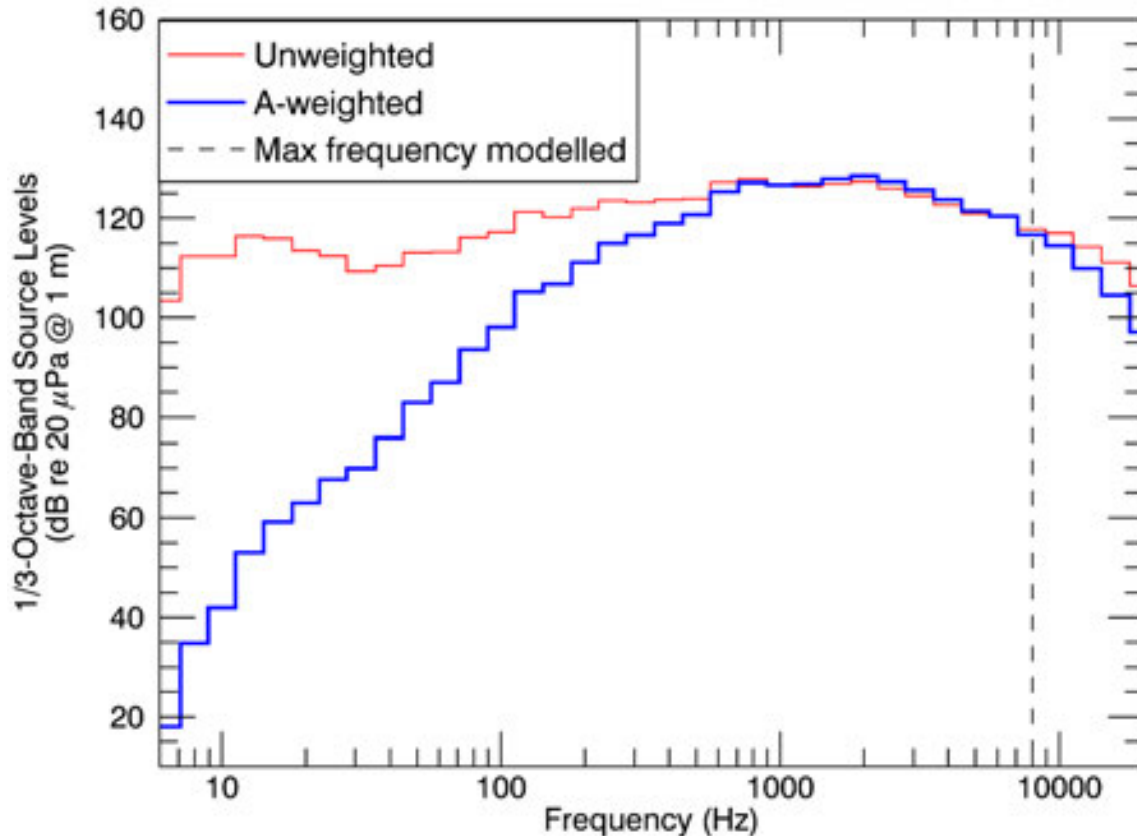


Figure 5. Airborne source levels, 1/3-octave-bands source levels of unweighted and A-weighted airborne pile driving. The center frequencies of 1/3-octave-bands from 6 Hz to 8 kHz were modelled, with maximum frequency shown with dashed line.

3.3. Estimating Distances to Threshold Levels

Sound level contours and distances to specific sound levels were calculated based on the in-air sound fields predicted by the propagation model at the receiver height. Two distances relative to the source are reported for each sound level: 1) R_{max} , the maximum range to the given sound level over all azimuths, and 2) $R_{95\%}$, the range to the given sound level after the 5% farthest points were excluded (see examples in Figure 6).

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in the image in Figure 6(a). In cases such as this, where relatively few points are excluded in any given direction, R_{max} can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative. In strongly asymmetric cases such as shown in Figure 6(b), on the other hand, $R_{95\%}$ neglects to account for significant protrusions in the footprint. In such cases R_{max} might better represent the region of effect in specific directions. Cases such as this are usually associated with topographic features affecting propagation. The difference between

R_{max} and $R_{95\%}$ depends on the source directivity and the non-uniformity of the acoustic environment.

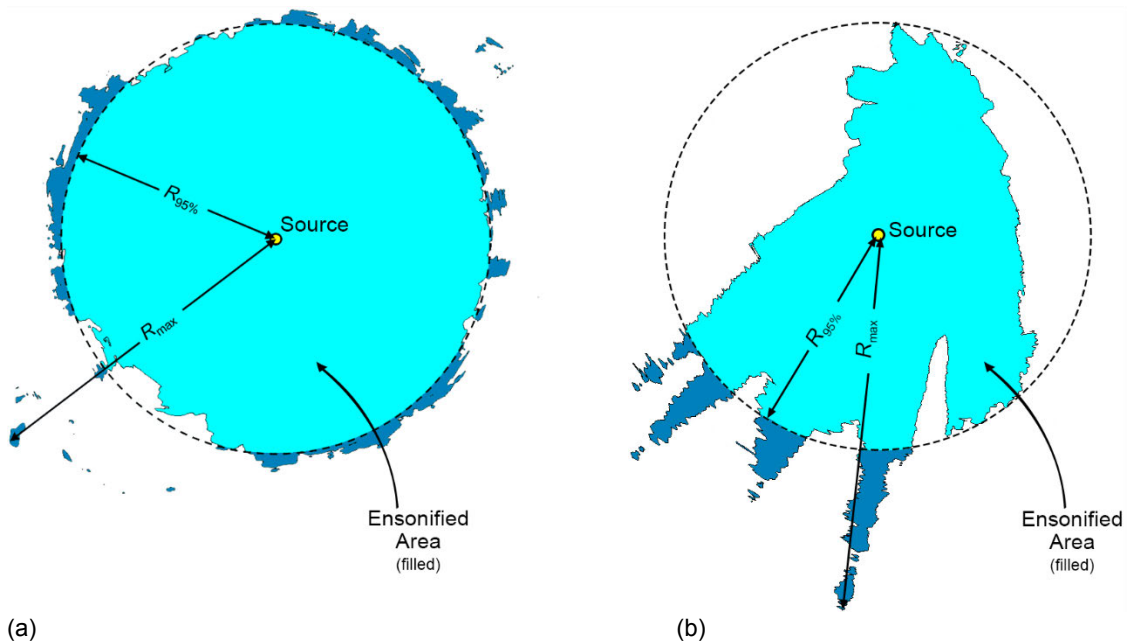


Figure 6. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two different scenarios. (a) Largely symmetric sound level contour with small protrusions. (b) Strongly asymmetric sound level contour with long protrusions. Light blue indicates the ensonified areas bounded by $R_{95\%}$; darker blue indicates the areas outside this boundary which determine R_{max} .

4. Results

This section presents estimated unweighted and A-weighted received levels from bridge traffic and pile driving. Directivity and range to various sound level isopleths are presented as contour maps; tables contain the distances to the corresponding thresholds.

4.1. Operational Sound – Bridge Traffic

RWDI AIR Inc. (2012) modelled traffic noise from the proposed bridge and reported A-weighted received sound pressure levels at various ranges. These levels were interpolated to determine a transmission loss curve and calculate ranges to thresholds in 5 dBA steps. The resulting contours are presented in Table 3 and Figure 7.

Table 3. A-weighted sound level threshold distances for bridge traffic.

SPL (dBA re 20 μ Pa)	Range (m)
70	16
65	32
60	64
55	129
50	257
45	515

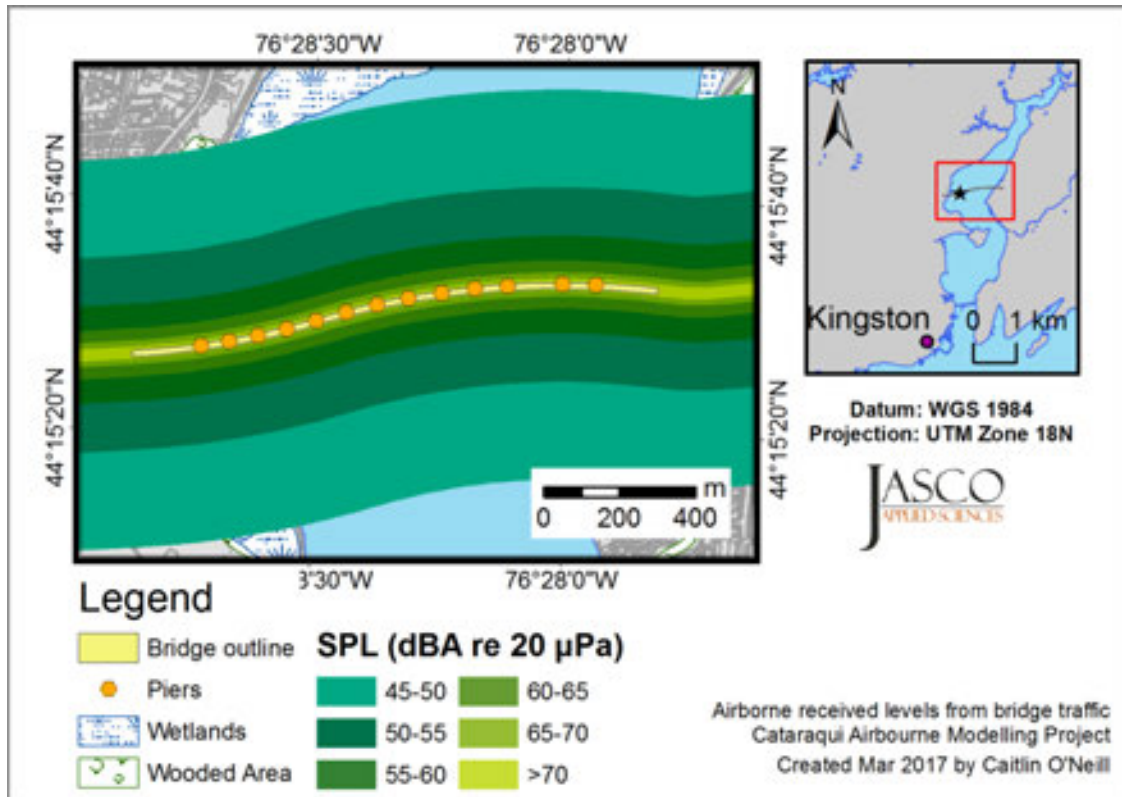


Figure 7. Airborne received A-weighted sound pressure level contours from bridge traffic.

4.2. Construction Sound – Impact Pile Driving

This section presents unweighted (Table 4 and Figure 8), and A-weighted (Table 5 and Figure 9) SPLs in sound level contour maps and tables of distances to given threshold levels for unmitigated impact pile driving. Due to the strong acoustic reflectiveness of water, and the elevated sides of the Cataraqi River, sound from impact pile driving was estimated to travel farther in the northeast and south directions.

Table 4. Unweighted sound level threshold distances for impact pile driving without mitigation.

SPL (dB re 20 µPa)	Distance (m)	
	R _{max}	R _{95%}
105	37	34
100	88	86
95	162	158
90	264	255
85	418	404

SPL (dB re 20 μ Pa)	Distance (m)	
	R _{max}	R _{95%}
80	661	624
75	1060	944
70	1700	1370
65	2430	1690

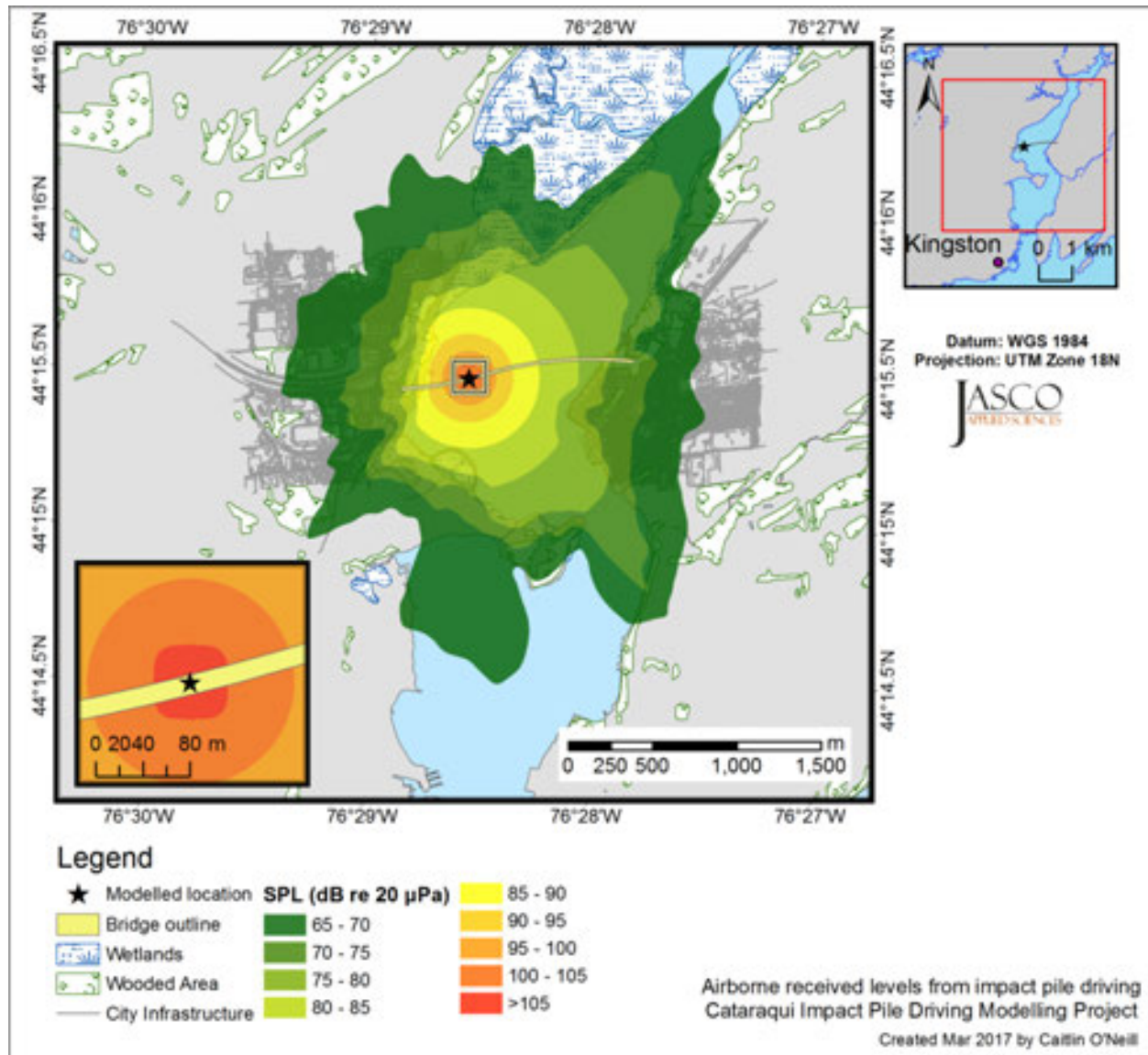


Figure 8. Impact pile driving without mitigation: Sound level contour maps of unweighted SPL contours.

Table 5. A-weighted sound level threshold distances for impact pile driving without mitigation.

SPL (dBA re 20 µPa)	Distance (m)	
	R _{max}	R _{95%}
100-125	< 20	< 20
95	116	113
90	192	186
85	288	279
80	421	402
75	627	556
70	851	771
65	1190	1040
60	1730	1380
55	2290	1670

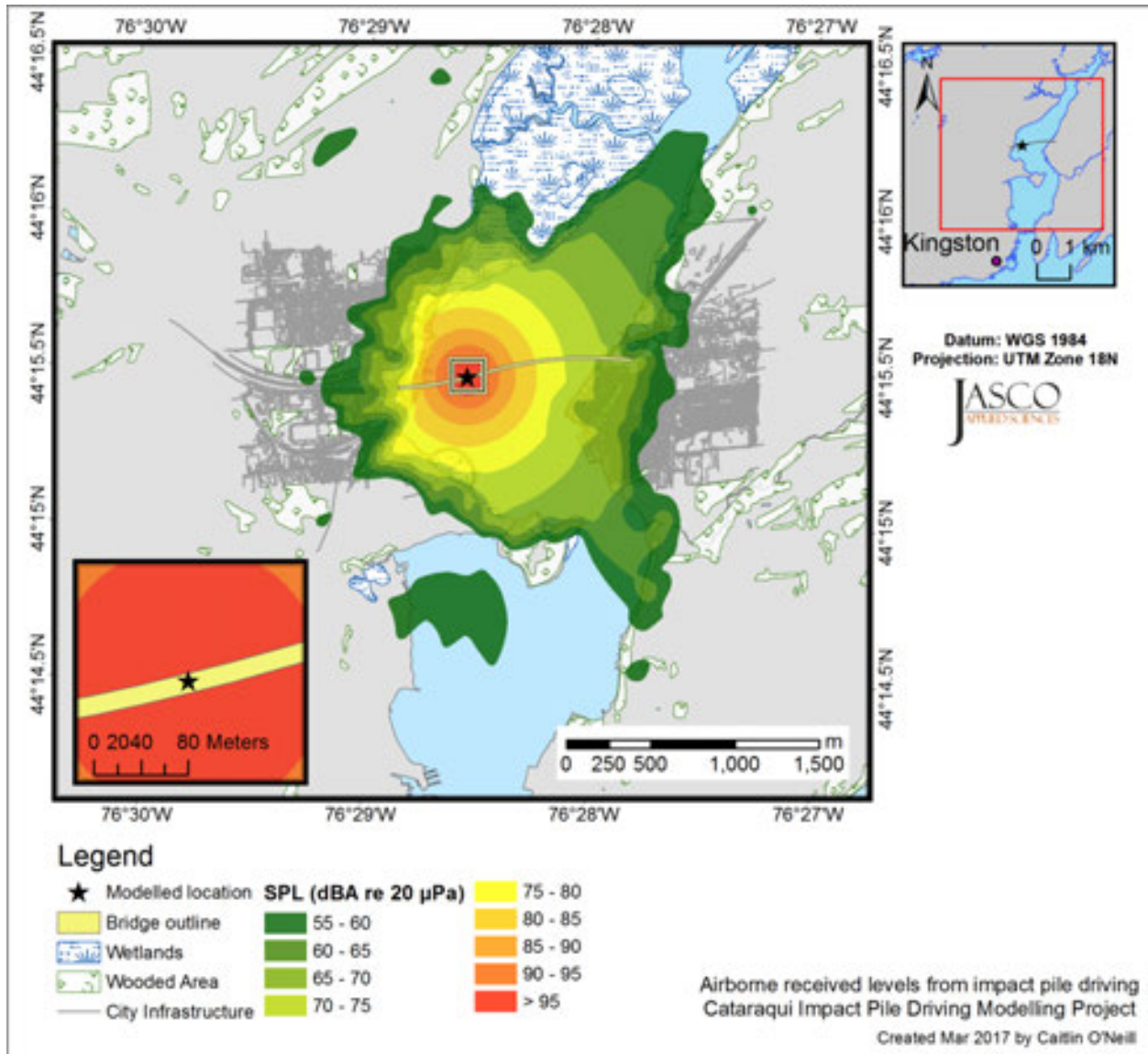


Figure 9. Impact pile driving without mitigation: Sound level contour maps of A-weighted SPL contours.

5. Discussion and Conclusion

5.1. Acoustic Modelling

In-air acoustic sound propagation was calculated with INPM to estimate sound radiated into the environment by impact pile driving activities. Sound propagation was modelled in three dimensions (range, height, and azimuth), although only a single receiver height was presented in the results. The topography and terrain type are the most important environmental factors governing propagation of sound from pile driving activities in this study.

We made the following assumptions to compensate for incomplete project plans, and so as not to underestimate potential effects on terrestrial animals:

- The modelling location was selected to coincide with a thick layer of overburden, which could require more forceful strikes to set into bedrock, and is near the bird nesting wetland area to the north.
- All distances (R_{max} , $R_{95\%}$) and noise level contours represent the sound levels at a height of 0.5 m.
- The piles will be installed by impact pile driving because this method generates more in-air noise than either vibratory pile driving or rock socket drilling.
- Acoustic blocking or reflective effects due to high buildings were not included as part of the topography input.

5.2. Potential Effects on Animals

The transmission loss curve extrapolated for the traffic scenario did not consider ambient sound levels, which are influenced by sources other than vehicles travelling on the bridge. The noise contours, therefore, do not reflect the influence of ambient sound.

Li and Zeddies (2017) presented the impact potential of underwater noise on turtles, which is likely the dominant component affecting their acoustic environment because the turtles in the area are primarily aquatic.

5.2.1. Birds

5.2.1.1. Traffic noise

Birds hear well between 200 Hz and 12 kHz, matching the hearing sensitivities of humans in that frequency range. Auditory injury is not expected to result from traffic noise exposure because received sound levels do not exceed levels that are not considered high enough to cause injury even at very close distances from the sound sources. Auditory impairment (TTS) could occur when received sound levels exceed 93 dBA (Table 2), a level unlikely to be reached anywhere near the roadway.

Auditory masking in birds due to traffic noise might occur at received levels above ambient. At a background level of 55 dBA, this threshold will be exceeded within 197 m from the bridge.

Behavioural disturbances could also occur when received levels exceed the future estimated ambient noise level of 55 dBA. Therefore, the potential onset of behavioural disturbance, like the onset of masking, could happen at distances of 197 m from the bridge.

Traffic noise is in frequencies that both birds and humans hear and likely not in frequencies that birds do not hear well. Traffic noise mitigation applied to lower the risk of impact on humans will therefore also lower the risk of impact on birds. It can be expected that with appropriate mitigation, traffic noise might not substantially effect birds nesting in marshlands below and away from the bridge. Impact may therefore be limited to birds flying at distances very close to the bridge (197 m or less). The risk to birds from either auditory masking or behavioural disturbance from traffic is low if they do not need to communicate over large distances when they are flying near the bridge.

5.2.1.2. Impact pile driving noise

Auditory injury in birds could occur at levels above 125 dBA. For impact pile driving this level will only be exceeded within 20 m from the pile (Table 5). Overall the risk of auditory injury to birds due to pile driving is low but not negligible because sound levels attenuate to below injury thresholds before the sound reaches the shoreline, but waterfowl on the water surface very close to the pile driving location can still be effected. Typical nesting and perching sites are farther than 20 m from the modelled sound source location.

Temporary hearing loss (TTS) could occur at distances where the received sound levels from pile driving exceeds 93 dBA. This threshold could be reached at distances within 113 m from the pile driving source.

Auditory masking and behavioural disturbance could occur when pile driving noise exceeds the 55 dBA nominal ambient. The region of impact extends to a maximum distance of 2290 m from the source.

5.2.2. Snakes

At 37 m from the pile driving, the sound levels exceed the 104.5 dB TTS threshold (Table 4), which means that within that distance from the pile snakes could temporarily lose their hearing sensitivity. A TTS risk to milk snakes thus exists for pile driving close to shore.

There are no publicly available criteria for auditory masking or behavioural disturbance to snakes.

5.3. Mitigation

For mitigation of in-air noise effects on wildlife, refer to the Third Crossing of the Cataraqui River Preliminary Design Natural Heritage Protection and Enhancement Plan (Golder 2017).

Glossary

1/3-octave-band

Non-overlapping passbands that are one-third of an octave wide (where an octave is a doubling of frequency). Three adjacent 1/3-octave-bands comprise one octave. One-third-octave-bands become wider with increasing frequency.

A-weighting

Frequency-selective weighting for human hearing in air that is derived from the inverse of the idealized 40-phon equal loudness hearing function across frequencies.

acoustic impedance

The ratio of the sound pressure in a medium to the rate of alternating flow of the medium through a specified surface due to the sound wave.

ambient noise

All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

audiogram

A graph of hearing threshold level (sound pressure levels) as a function of frequency, which describes the hearing sensitivity of an animal over its hearing range.

audiogram weighting

The process of applying an animal's audiogram to sound pressure levels to determine the sound level relative to the animal's hearing threshold (HT). Unit: dB re HT.

azimuth

A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

background noise

Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise.

bandwidth

The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI/ASA S1.13-2005 R2010).

broadband sound level

The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period (ANSI/ASA S1.13-2005 R2010). A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

critical ratio

The difference between the sound pressure level of a masked tone, which is barely audible, and the spectrum level of the background noise at similar frequencies. Unit: decibel (dB).

decibel (dB)

One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004).

ensonified

Exposed to sound.

fast-average sound pressure level

The time-averaged sound pressure levels calculated over the duration of a pulse (e.g., 90%-energy time window), using the leaky time integrator from Plomp and Bouman (1959) and a time constant of 125 ms. Typically used only for pulsed sounds.

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f . 1 Hz is equal to 1 cycle per second.

hearing threshold

The sound pressure level that is barely audible for a given individual in the absence of significant background noise during a specific percentage of experimental trials.

hertz (Hz)

A unit of frequency defined as one cycle per second.

impulsive sound

Sound that is typically brief and intermittent with rapid (within a few seconds) rise time and decay back to ambient levels (NOAA 2013, ANSI S12.7-1986 R2006). For example, seismic airguns and impact pile driving.

masking

Obscuring of sounds of interest by sounds at similar frequencies.

non-impulsive sound

Sound that is broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically does not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level) that impulsive signals have (ANSI/ASA S3.20-1995 R2008). For example, marine vessels, aircraft, machinery, construction, and vibratory pile driving (NIOSH 1998, NOAA 2015).

parabolic equation method

A computationally-efficient solution to the acoustic wave equation that is used to model transmission loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of transmission loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

permanent threshold shift (PTS)

A permanent loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

point source

A source that radiates sound as if from a single point (ANSI S1.1-1994 R2004).

pressure, acoustic

The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: p .

received level

The sound level measured at a receiver.

rms

root-mean-square.

sound

A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound field

Region containing sound waves (ANSI S1.1-1994 R2004).

sound intensity

Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

sound pressure level (SPL)

The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004).

For sound in air, the reference sound pressure is one micropascal ($p_0 = 20 \mu\text{Pa}$) and the unit for SPL is dB re 20 μPa :

$$\text{SPL} = 10\log_{10}(p^2 / p_0^2) = 20\log_{10}(p / p_0)$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level. See also fast-average sound pressure level. Non-rectangular time window functions may be applied during calculation of the rms value, in which case the SPL unit should identify the window type.

source level (SL)

The sound level measured in the far-field and scaled back to a standard reference distance of 1 metre from the acoustic center of the source. Unit: dB re 1 μPa @ 1 m (sound pressure level) or dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ (sound exposure level).

spectrogram

A visual representation of acoustic amplitude compared with time and frequency.

temporary threshold shift (TTS)

Temporary loss of hearing sensitivity caused by excessive noise exposure.

transmission loss (TL)

The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment. Also called propagation loss.

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Appendix A. Acoustic Metrics

A.1. Airborne Acoustics Metrics

Airborne sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of $p_0 = 20 \mu\text{Pa}$. Because the perceived loudness of sound, especially impulsive noise, such as the noise generated by pile driving, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate noise and its effects on terrestrial life. Where possible, we follow the American National Standards Institute (ANSI) and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The sound pressure level (SPL; dB re 1 μPa) is the rms pressure level in a stated frequency band over a specified time window (T , s) containing the acoustic event of interest. It is important to note that SPL always refers to an rms pressure level, not instantaneous pressure:

$$L_p = 10 \log_{10} \left(\frac{1}{T} \int_T p^2(t) dt / p_0^2 \right) \quad (\text{A-1})$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalization, the passage of a vessel, or over a fixed time window.

A.2. A-Weighting

Birds and reptiles can detect sounds in the frequency range roughly between 20 Hz and 12 kHz. Exact hearing limits are unique to each species and may be affected by individual factors such as age and sound exposure history. For example, the human ear can detect sounds between 100 Hz and 20 kHz but is not equally sensitive to sound at all frequencies and the human ear is most sensitive at around 1 kHz. For noise assessments considering human impacts, noise levels are typically frequency-weighted to reflect the relative sensitivity of the ear as a function of frequency. The frequency dependence of the ear's sensitivity varies with sound intensity; a few different weighting filters are in general use, known as A-, B-, and C-weighting.

The filter most commonly applied for ranges of sound pressure levels in this assessment is known as A-weighting and is represented by the following function as defined in the International Standard IEC 61672-1 (IEC 2003):

$$W_A(f_n) = 20 \log \left(\frac{R_A(f_n)}{R_{A,1000}} \right) \quad (\text{A-2})$$

where

$$R_A(f) = \frac{12200^2 f^4}{(f^2 + 20.6^2)(f^2 + 12200^2)(f^2 + 107.7^2)^{1/2}(f^2 + 737.9^2)^{1/2}} \tag{A-3}$$

and $R_{A,1000}$ is $R_A(f)$ for $f = 1000$ Hz. Here, f_n is the frequency of interest expressed in Hz.

The A-weighted sound pressure level is commonly referred to simply as “sound level” (symbol L_A) and is computed from the unweighted sound pressure level, $L_p(f_n)$, and $W_A(f_n)$ as follows:

$$L_A(f_n) = L_p(f_n) + W_A(f_n) \tag{A-4}$$

Sound levels are presented in A-weighted decibels (dBA). A-weighted L_{eq} values use the symbol L_{Aeq} . Some typical sound levels measured at 1 m range are provided in the table below. For sounds that have most of their energy/sound pressure between 200 Hz and 12 kHz A-weighting is an appropriate proxy for noise impact assessments on birds (Dooling and Popper 2016).

Table A-1. Examples of typical sound levels.

Sound Source	Level (dBA)
Quiet Room	30
Typical Living Room	40
Normal Conversation @ 1m range	55–65
Lawn Mower @ 1m range	88–94
Hairdryer @ 1m range	80–95
1/4” Drill @ 1m range	92–95

Appendix B. Sound Propagation Model

INPM uses a split-step Padé solution (Collins 1993) for the parabolic form of the wave equation to determine frequency-dependent transmission losses as a function of range away from a point source. The split-step Padé solution is computationally faster than the finite-difference solution of the Parabolic Equation (PE) by approximately two orders of magnitude and is more accurate than the split-step Fourier solution for wide angle propagation. This approach is also superior to standard ray tracing models that can yield unrealistically large received sound level values due to caustics, which are computationally intensive to remove (Salomons 2001). The model uses a two-dimensional implementation of the PE method that takes into account diffraction, air turbulence, and sound interaction with the terrain.

INPM can output the complete sound level field in range and height along a radial from the source. This can be rendered as an image plot as in the figure below, which presents an example of noise propagation in a slightly upwind condition (noise tends to bend upward in this case) in non-turbulent air.

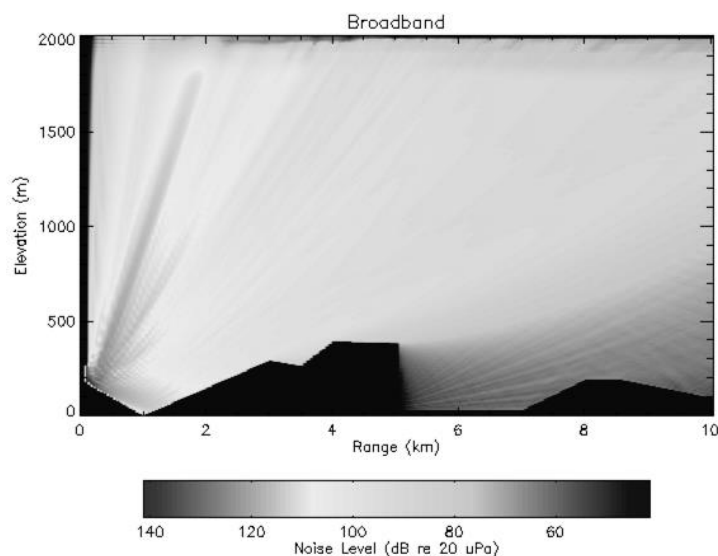


Figure B-1. Example of in-air received sound level vertical radial plot from INPM.

INPM has been verified by comparing model outputs against a set of benchmarks available in the open literature. The model shows nearly perfect agreement to the published results (Racca et al. 2006).

Appendix C. Acoustic Environment

This section describes the inputs to INPM for this study, including atmospheric parameters, terrain topography, and terrain cover (variable ground impedance).

C.1. Atmospheric Profile Data

The atmospheric profiles used in the pile driving modelling were calculated from twice-daily weather balloon launches from Maniwaki, Québec during September 2016. Maniwaki is approximately 240 km north of Kingston, Ontario. Upper-atmospheric parameters are regionalized and therefore are representative of the upper atmospheric parameters in Kingston.

The authors of Appendix D, a Dispersion Meteorology report, compared September 2016 Maniwaki surface data to long-term climate norms, and found that Maniwaki in September 2016 is representative of long-term surface conditions. Based on this, we concluded that if surface conditions were representative, upper air conditions would also be similar.

September 2016 Maniwaki pressure data were averaged in 50 m bins and interpolated from 0 and 3 km. Linear fits were made to temperature and dew point data from 200 to 3000 m. Relative humidity was then calculated from temperature and dew point using the equation from Alduchov and Eskridge (1996). Temperature, dew point, and relative humidity at elevations less than 200 m were assumed to be constant because the lowest measurements at Maniwaki were made at 170 m. Pressure, temperature, and relative humidity profiles are shown in Figure C-1.

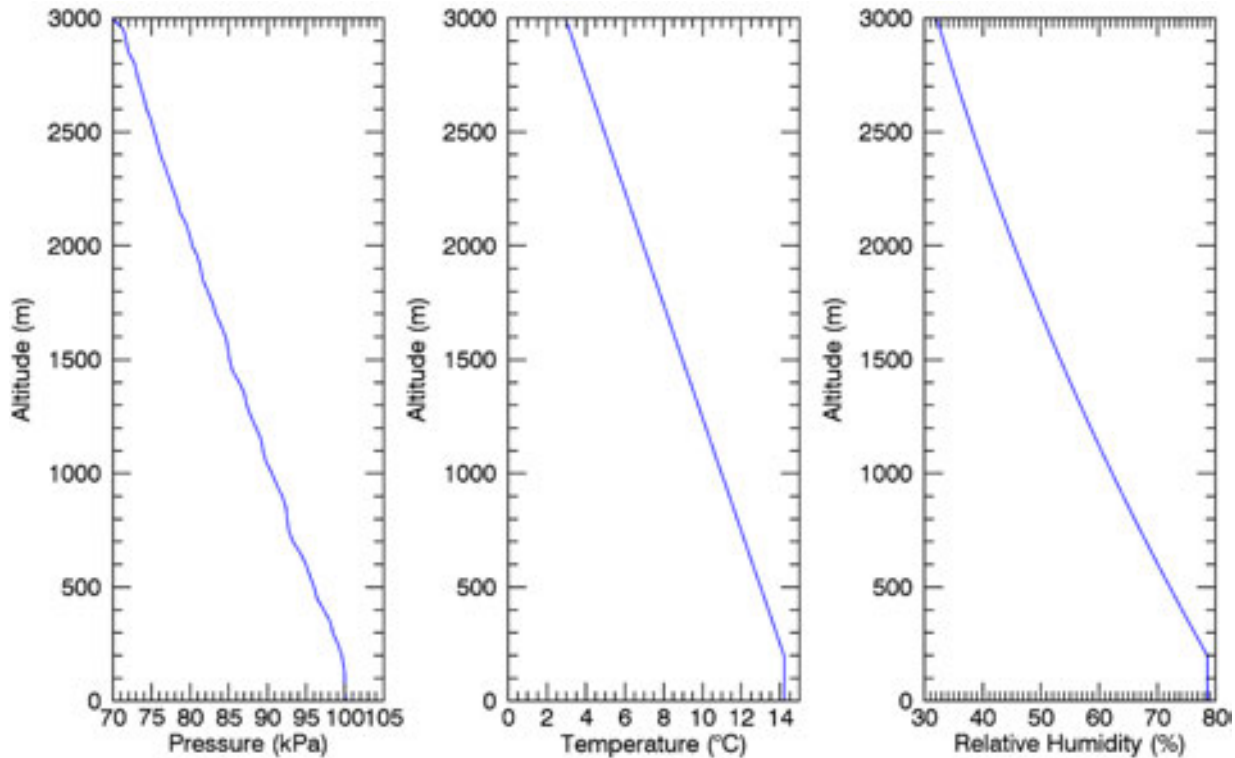


Figure C-1. Atmospheric pressure, temperature, and relative humidity profiles used to model sound propagation from pile driving.

Wind velocity, unlike the other atmospheric profile parameters used in INPM, is a vector quantity. INPM uses a scalar wind speed profile that is the wind velocity projected along the modelled sound propagation radial. We used a wind velocity of zero in our model so as not to bias the sound propagation in any direction, given that there are no prevailing winds at this location.

C.2. Ground Elevation

The ground elevation (Figure C-2) data used in the modelling came from digital terrain elevation data (U.S. Department of the Interior and U.S. Geological Survey 2017). These data have a spatial resolution of 1 arc-second (approximately 30 m). Low elevation areas fall to the north and south of the modelling location, contrasting with the higher elevations on both sides of the proposed Third Crossing.

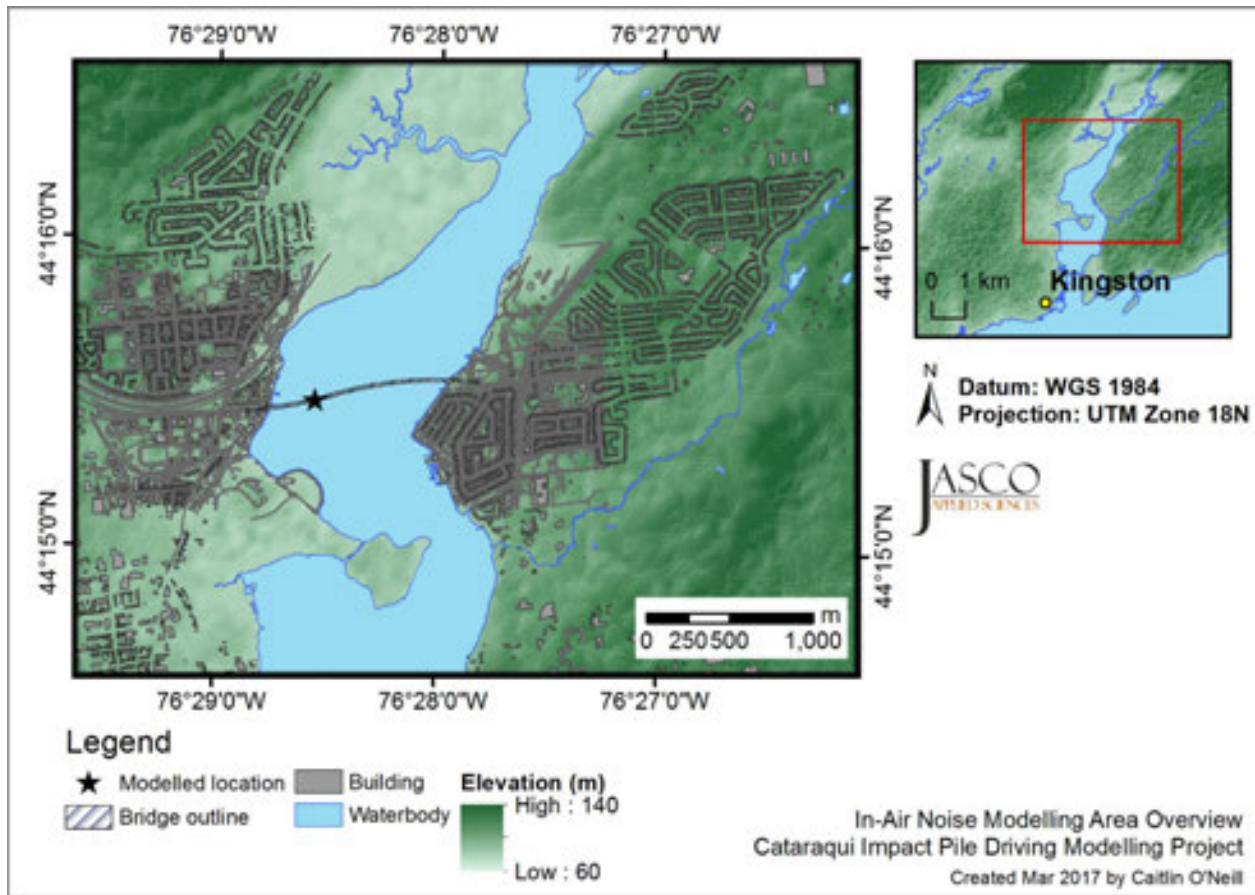


Figure C-2. Ground elevation used for acoustic modelling.

C.3. Ground Impedance

INPM includes the effects of the acoustic impedance of the ground. The relationship between the acoustic impedance of the ground and that of the atmosphere will dictate the ratio between the amount of sound energy which is reflected into the atmosphere, and the amount of sound energy which is absorbed into the ground. A single parameter describes the acoustic impedance: flow resistivity (Delany and Bazley 1970).

A 200 m grid of flow resistivity values was implemented for the modelling area, with values chosen based on land designation, land description, and satellite imagery. Table C-1 lists the five flow resistivity values used in this report's modelling, which are typical values used for atmospheric propagation modelling (Sondergaard and Plovsing)). Forest floor covered by weeds (63 kNs/m^4) was chosen for province-defined forest areas, rough grassland and peat (100 kNs/m^4) was used for rural areas and marshland, mixed paving stones and grass (630 kNs/m^4) was used for houses and residential areas, and water (2000 kNs/m^4) was used for the Cataraqui River.

Table C-1. Flow resistivity values for terrain types in modelling area.

Terrain Description	Flow Resistivity (kNs/m⁴)
Forest floor covered by weeds	63
Rough grassland and peat	100
Lawn, moderately stepped on	160
Mixed paving stones and grass	630
Water	2000

Appendix D. Dispersion Meteorology



1.0 INTRODUCTION

This Appendix discusses the meteorological conditions observed in 2016 at the Maniwaki surface and upper air meteorological station and provides an assessment as to whether the observations from 2016, in particular September of that year, can be considered “representative” for long-term (climate normal) conditions at the Maniwaki, Quebec location. The purpose of this review is to identify whether upper air “radiosonde” data from Maniwaki, for September 2016, are representative enough that they can be used for modelling noise propagation in the atmosphere. The steps for making this assessment include:

- Obtaining hourly meteorological measurements for Maniwaki PQ, from Environment Canada;
- Obtaining the 30-year climate normals for the same station, from Environment Canada; and
- Comparing the hourly meteorological data set to established climate normals to demonstrate that the dataset is comparable to long-term averages at this location, and is therefore suitable for the noise assessment.

For the purposes of this assessment, it has been assumed that if surface conditions at the Maniwaki station for September 2016 are typical of long-term climatic conditions, then it is reasonable to assume that upper air conditions for that month are also representative of long-term conditions.

The above steps are outlined in the following sections.

2.0 METEOROLOGICAL DATA SOURCES

Raw hourly surface meteorological data for the 2012 to 2016 period was obtained from Environment Canada for Maniwaki, PQ. The following table summarizes the station locations, IDs, and elements used for this assessment.

Table 1: Meteorological Station Data Summary

Station ID	Station Description	Station Location	Years	Elements
7034482	Maniwaki, PQ	46°16'29"N 75°59'31"W	2016	Hourly 10 m wind speed, wind direction, station pressure, relative humidity; 2 m temperature
7034480	Maniwaki, PQ	46°16'29"N 75°59'31"W	1971-2000*	30-year monthly averages of the same elements

* The latest climate normal period is 1981-2010, however this station did not report climate normals for this period. 1971-2000 is the most recent climate normals data for this location. Other stations in the area reporting for the 1981-2010 period did not report winds.

The assessment of the dispersion meteorology addresses whether 2016 was a representative year at this location, and, in particular, if September 2016 was representative of long-term conditions for the area.

3.0 METEOROLOGICAL DATA COMPARISON

In order to assess if 2016 meteorological data set is representative of the area, a comparison of the hourly data set was undertaken against the 30-year climate normals from Maniwaki climate station (Climate ID 7034482). To accomplish this comparison, climate normals data were obtained from Environment Canada (EC, 2017).



3.1 Winds Analysis

The predominant wind directions in the 2016 data set was south (winter, summer, and autumn), and north (2 out of 3 of the spring months). Winds were generally somewhat lower in the summer, increasing in the spring, autumn, and winter seasons.

A comparison of the winds in the dispersion meteorological data set to the long-term averages for the region is provided in Table 3.

Table 2: Wind Speed Comparison for the Hourly Meteorological Data Set to the Climate Normals

Month	2016 Hourly Meteorological Data		Maniwaki Climate Average Reported by Environment Canada ^(a)	
	Wind Speed (km/h)	Most Frequent Direction	Wind Speed (km/h)	Most Frequent Direction
January	7.2	S	7.0	NW
February	7.4	N	6.9	NW
March	7.8	N	7.7	NW
April	6.9	N	8.1	NW
May	7.3	N	7.5	NW
June	7.8	N	6.8	S
July	6.5	N	5.7	S
August	6.7	S	5.5	S
September	6.0	N	6.1	S
October	7.1	S	7.3	NW
November	6.1	N	7.6	NW
December	7.8	S	6.8	NW

Note:

(a) The Climate Normals reporting period used was 1971-2000. Actual data are from 1971 to 1993, with one missing year in that period.

In the 2016 period, reported winds were generally higher than the long-term averages for the area in winter and early spring (January through March, and December) and in summer (June, July, and August), but were lower than the long-term averages in late spring and in the autumn. This is likely due to normal year-to-year variability in meteorological data, as the climate normals represent 30-year averages.

A wind-rose showing the annual and seasonal winds in the dispersion meteorological data set is provided in Figure 3. For the purposes of this, and following, “seasonal” descriptions, “Spring” occurs from March 1 to May 31, “Summer” is from June 1 to August 31, “Fall” or “Autumn” is from September 1 to November 30, and “Winter” is from December 1 to February 28 (or 29 in leap years).

Figure 4 shows the diurnal (daytime vs. nighttime) wind roses for the dispersion meteorological data set. Nighttime winds during this period were found to be slightly higher than daytime winds (19.0 km/h compared to 17.4 km/h), mostly due to higher early morning (1 to 2 hours before sunrise) and early evening (1 to 2 hours after sunset) winds. Winds in the dispersion meteorological data set generally showed the same trends as the reported climate



APPENDIX D

Dispersion Meteorology

normals, and were only slightly higher on average than those in the reported climate normals, and are therefore considered representative for the region.



APPENDIX D Dispersion Meteorology

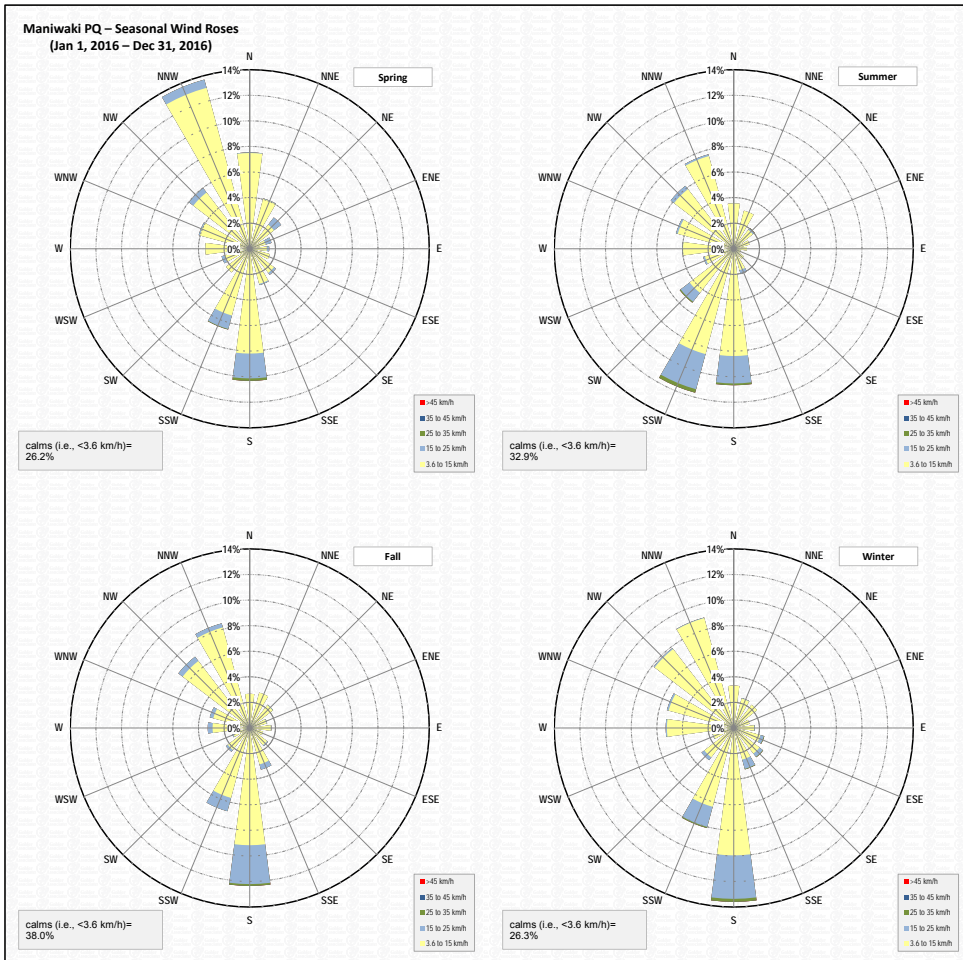
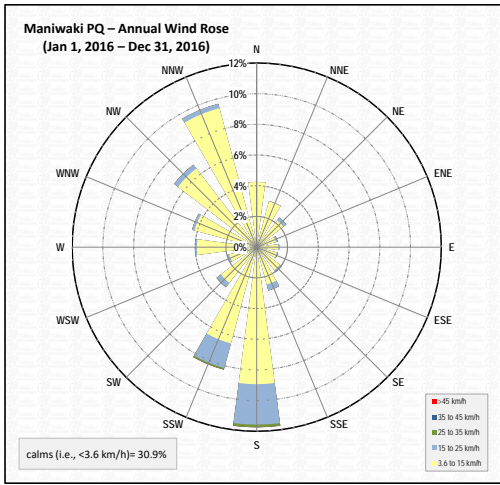


Figure 1: Annual and Seasonal Wind Roses for 2016

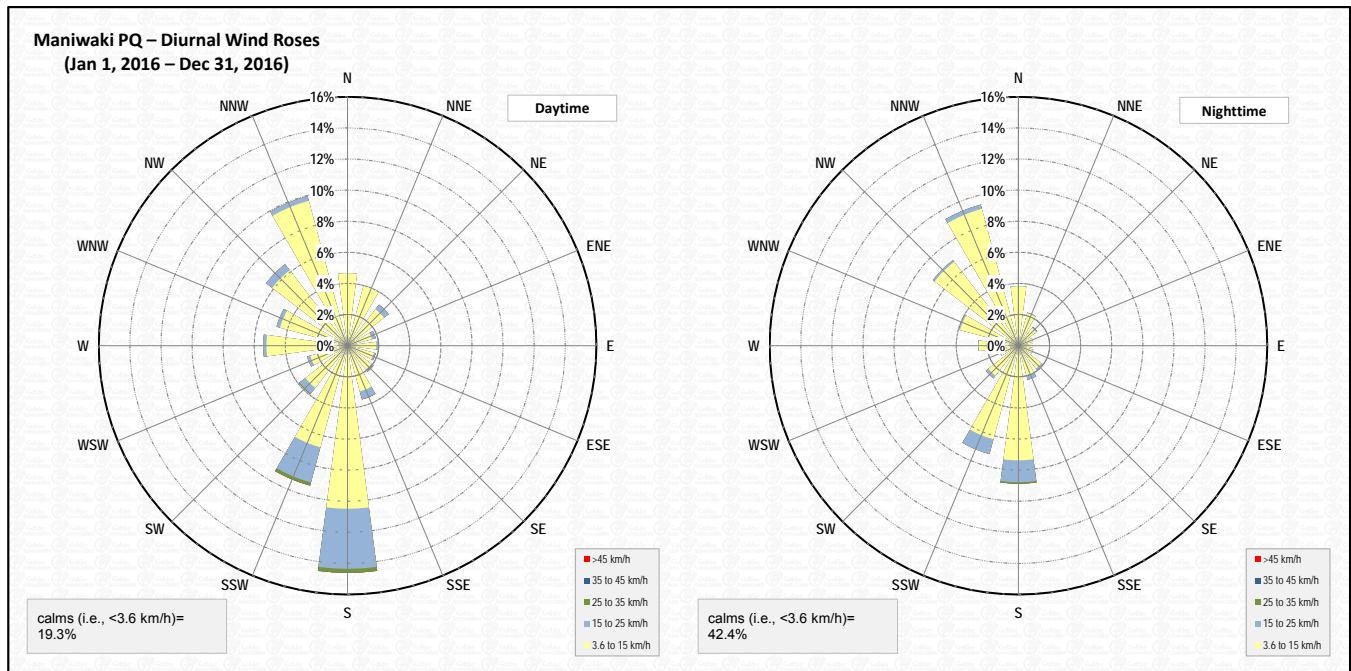


Figure 2: Daytime and Nighttime Wind Roses for 2016

3.2 Temperature Analysis

In 2016, the average temperature in the winter season was approximately -8.6°C, while the extreme minimum temperature in the area may reach as low as -35.7°C. Summer temperatures were warm, with an average of approximately 18.8°C. The extreme maximum temperature may reached 30.4°C in the summer.

The expected values of any weather parameters can be expressed in terms of normal values obtained from the long-term averages. Figure 5, below, illustrates that the temperature field for 2016 is within the expected monthly temperature variations. This figure uses a “box-and-whisker” plot to show the range of temperatures obtained from the 2016 data set compared to reported climate normals. The box in the graph represents the middle 50% of the observations (i.e., from the 25th to 75th percentiles). The whiskers extend up to the maximum observation and down to the minimum. The diamond represents the average of the observations in each month. The green lines on the graph represent the climate normals at Maniwaki for the extreme maximum (dashed line above the average normal), the daily maximum (dotted line above the average normal), the average (solid line), the daily minimum (dotted line below the average normal), and the extreme minimum temperatures (dashed line below the average normal) for each month. The hourly temperature data in the data set falls within the extreme climate normals throughout the year.



APPENDIX D Dispersion Meteorology

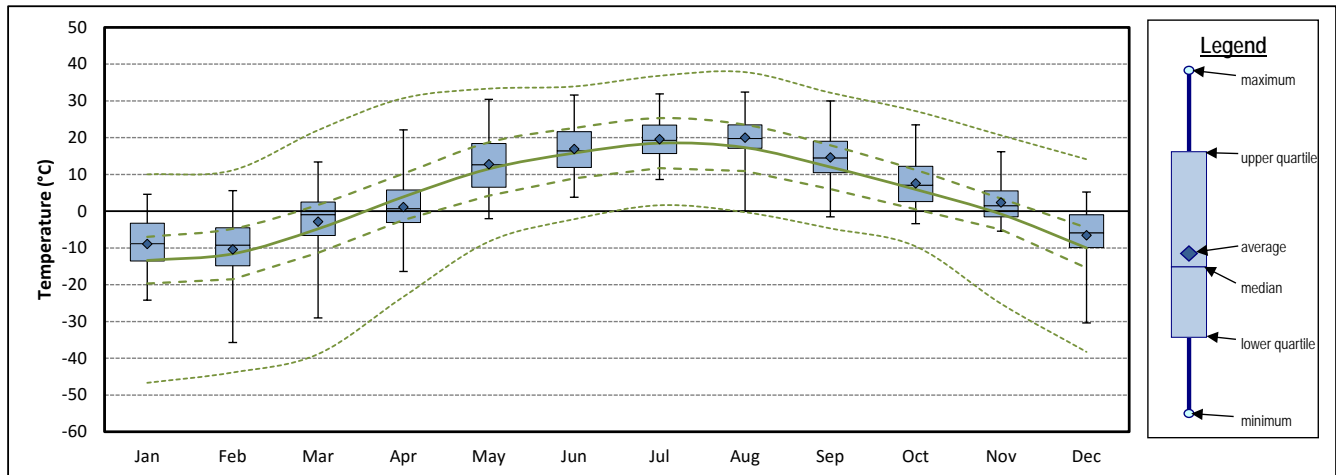


Figure 3: Monthly Temperature Distribution for 2016 Compared to the Climate Normals.

A more detailed breakdown of the monthly temperature distribution in the 2016 data set is shown in Table 4. Temperatures above 30°C occur occasionally from May to September. Temperatures below -10°C occurred in January, February and December. A similar table summarizing the reported climate normals is provided in Table 5. Overall, the 2016 data set contained daily average temperatures that were 1 to 4.5°C higher than the reported climate normals average. Temperatures in the 2016 data set fell within the range shown in the reported climate normals, however, and are therefore considered representative for the region.



APPENDIX D Dispersion Meteorology

Table 3: Monthly Temperature Distribution of the Hourly Meteorological Data Set

Surface Data Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual ^(a)
Daily Average (°C)	-8.9	-10.4	-2.8	1.1	12.8	16.9	19.6	20.0	14.6	7.5	2.4	-6.6	5.6
Standard Deviation (°C)	6.6	8.4	7.6	7.1	7.6	6.5	5.0	5.0	6.0	5.9	4.6	7.1	12.6
Daily Maximum (°C)	-4.5	-4.3	2.1	7.0	19.2	23.1	25.5	25.9	21.0	12.1	6.5	-3.1	10.9
Daily Minimum (°C)	-13.8	-17.0	-8.2	-5.1	5.5	10.2	13.4	13.8	7.4	2.9	-1.4	-10.9	-0.2
Extreme Maximum (°C)	4.6	5.6	13.4	22.1	30.4	31.6	31.9	32.4	30.0	23.5	16.2	5.2	32.4
Extreme Minimum (°C)	-24.2	-35.7	-29.0	-16.4	-2.0	3.8	8.6	0.0	-1.5	-3.4	-5.4	-30.4	-35.7
Days with Maximum Temperatures Above 30°C	0	0	0	0	0	1	0	1	0	0	0	0	2
Days with Minimum Temperatures Below -10°C	4	5	2	1	0	0	0	0	0	0	0	3	15

Note:

(a) Data are annualized and may not appear to add across columns due to rounding.



APPENDIX D Dispersion Meteorology

Table 4: Monthly Temperature Distribution of the Maniwaki Climate Normals

Surface Data Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual ^(a)
Daily Average (°C)	-13.4	-11.6	-4.8	3.9	11.5	15.8	18.5	17.3	12.0	5.9	-0.8	-10.0	3.7
Standard Deviation (°C)	2.7	3.1	2.8	2.1	1.5	1.2	0.9	1.3	1.3	1.8	1.5	3.7	1.8
Daily Maximum (°C)	-7.0	-4.8	1.7	10.2	18.7	22.6	25.3	23.5	17.9	11.2	3.4	-4.5	9.9
Daily Minimum (°C)	-19.7	-18.5	-11.3	-2.4	4.2	8.9	11.7	10.9	6.0	0.5	-5.0	-15.4	-2.5
Extreme Maximum (°C)	10.0	11.1	22.0	30.7	33.3	33.9	36.8	37.8	32.2	27.2	20.6	14.1	37.8
Extreme Minimum (°C)	-46.7	-43.9	-38.9	-23.3	-8.3	-2.2	1.6	-0.3	-4.7	-9.6	-25.2	-38.3	-46.7
Days with Maximum Temperatures Above 30°C	0	0	0	0	1	2	3	1	0	0	0	0	7
Days with Minimum Temperatures Below -10°C	25	23	16	2	0	0	0	0	0	0	6	22	93

Note:

(a) Data are annualized and may not appear to add across columns due to rounding.



4.0 OTHER VARIABLES

The climate normals data for Maniwaki do not include variables such as station pressure, relative humidity, or dewpoint temperature. The data for the 2016 period are below to provide context with the other data.

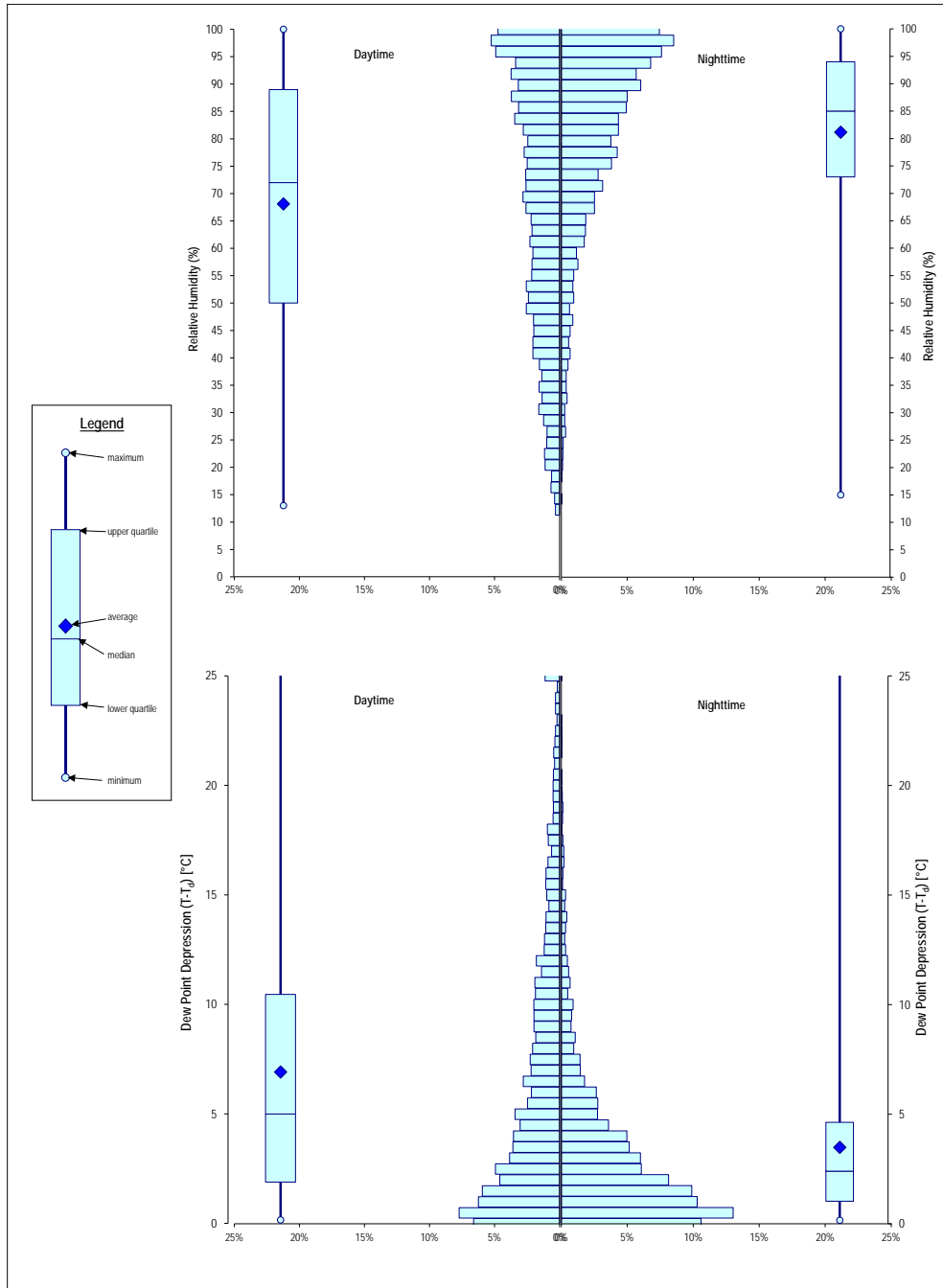


Figure 4: Diurnal Relative Humidity for the 2016 Period



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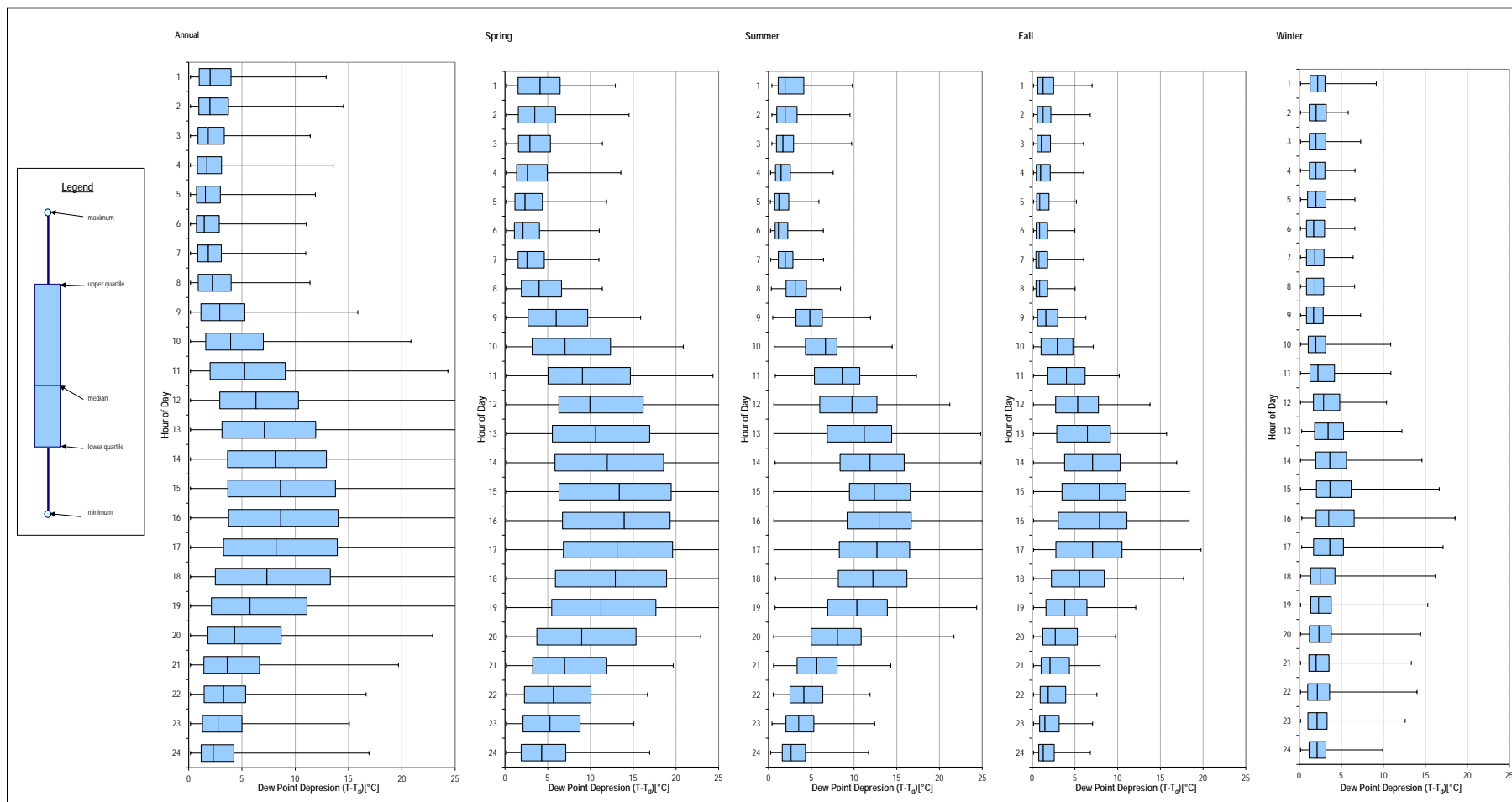


Figure 5: Seasonal Dewpoint Depression Measured in 2016

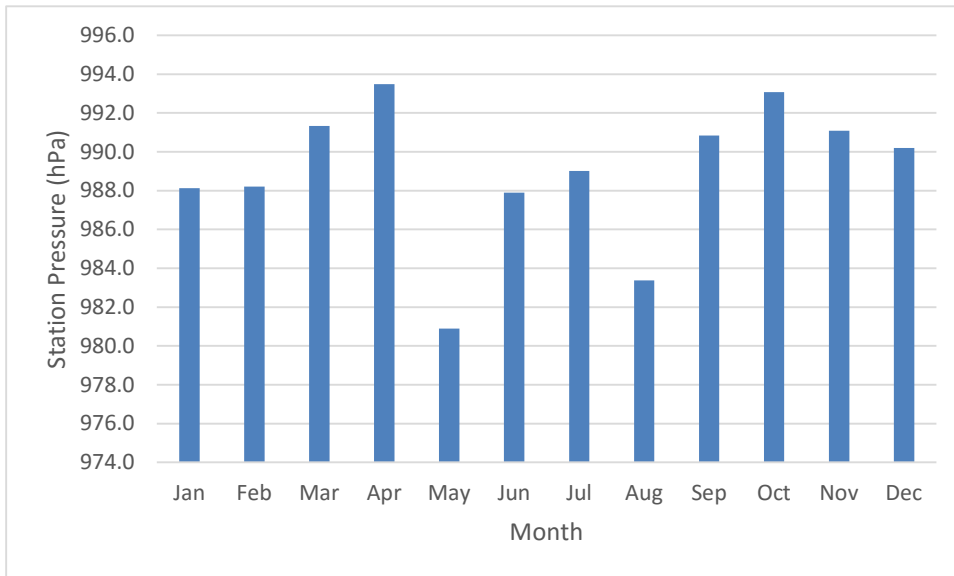


Figure 6: Monthly Station Pressure at Maniwaki (2016)

5.0 SUMMARY AND CONCLUSIONS

Comparisons between the 2016 hourly surface meteorological data set for the site and the Maniwaki climate normals (1971 – 2000) showed that the 1-year data set appears representative of the long-term climate in the area. Based on the analyses presented here, it has been demonstrated that the September 2016 surface data is representative for the area, and based on this demonstration, it has been assumed that upper air conditions as demonstrated in the September 2016 radiosonde measurements are also likely to be presentative of longer-term conditions in the area.

6.0 REFERENCES

- EC. 2017. Environment Canada Climate Normals from http://climate.weather.gc.ca/climate_normals/index_e.html accessed January 10, 2017.
- NOAA. 2017a. ISHD data from <ftp://ftp.ncdc.noaa.gov/pub/data/noaa/> accessed January 10, 2017.
- NOAA. 2017b. RAOB data from <https://www.esrl.noaa.gov/raobs/> accessed January 10, 2017.

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