ATTACHMENT B

Seismic Design Guidelines for Water, Sewer Utilities and Roads 2022

Preamble:

The City of Nanaimo is situated on the East Coast of Vancouver Island approximately 200km from an active and major subduction zone. According to the BC Building Code, the City of Nanaimo is located in a “High Seismic Region”. There is no doubt that Nanaimo will eventually experience significant seismic events.

When earthquakes occur they can cause damage to many aspects of a community including critical infrastructure such as, water supply networks, sewers, and roads.

Many of the systems that provide essential services are buried and out of sight. These buried systems can experience considerable stress during a seismic event. If the systems are not designed to withstand or accommodate the stresses, they may fail and this failure could be widespread.

The widespread nature of a seismic event can make it difficult for crews to repair or deal with the number of problems. As such, services or transportation networks could be interrupted or unavailable for long periods of time. Lack of critical services such as water and sewer for long periods of time can have catastrophic consequences to the well-being of individuals, businesses, property, and the community.

Having a reliable supply of clean water is critical to the City. In fact, from a physiological standpoint, there is very little that is more important. Water is also critical for firefighting which is vital during the aftermath of an earthquake.

Sanitary sewers are important because they go hand in hand with the provision of water. If we provide water, and the sewers are not able to convey the waste away, a health and environmental disaster could arise as well as damage or destruction to property and other infrastructure.

Transportation routes will be critical for the response during an emergency, and for crews to repair damaged areas.

The focus of these guidelines is on the municipal water supply, sanitary sewer systems, and roads or right-of-ways that house them.

It is the goal of the City of Nanaimo to adopt policies and practices that minimize the disruption that would be caused by a seismic event. These policies and practices will not provide immediate protection;

however, over the long term (50-100 years), as changes are made to infrastructure, they will be made more robust in areas and situations where it is warranted.

This design guideline is expected to be a living document that will, in the future, be updated as better information becomes available, and as our understanding of seismic design for utilities improves.

Intent of Guideline:

The intent of these guidelines is to define the City's performance expectations for municipal infrastructure and to clarify the City's expectations related to the design approaches to be taken to satisfy these expectations.

Much of the infrastructure that exists within the City has been built up over many decades and was designed to the standards and practices of the time. The understanding of seismicity in the area has increased greatly in recent years, and as such, much of the existing infrastructure was not designed with seismic considerations. This guideline does not define what would trigger an upgrade to an existing system; the intent is to provide a benchmark or performance objective for a capacity upgrade, asset renewal, or new installation. To determine the risk to existing systems, a site specific evaluation should be considered with a review of the consequences from a failure during a seismic event. If the decision is made to upgrade, then these guidelines would come into play. In other words, this guideline takes the point of view that the decision to upgrade something or expand the system, has already been made and the question remains as to how to design and install it. This is an important point since many of the older pipes (AC watermains for instance) are not expected to perform well under elastic ground conditions during a seismic event. This means that even in areas without adverse ground conditions, there could be problems with existing older infrastructure.

Key outcomes expected from this guideline include:

a) For the engineer of record/s, utility designers, and City Staff to determine the importance level of the asset in question and to assess the soil conditions of the site with a view to seismic performance.
b) To develop an approach to utility and road design to mitigate potential adverse outcomes resulting from a seismic event.
c) For typical (normal pipelines that are the majority of the system) utilities or roads on firm ground, no special requirements are expected.
d) For typical (normal pipelines that are the majority of the system) utilities or roads on seismically adverse ground, to take steps to improve seismic resilience during a seismic event. For routine projects, the steps taken are intended to be prescriptive in nature or best practices and not to overwhelm the designer.
e) For infrastructure of exceptional importance, take measures to specifically assess seismic ground response and take specific steps to improve seismic resilience.
f) Over the long term, as the infrastructure in the City is replaced through normal asset renewal processes, more and more will be capable of remaining functional during and after a seismic event.
g) The incremental cost of improving seismic resilience should be commensurate with the value of the asset and its importance in the network. In other words, we should always ask ourselves the question, does it make sense to increase the cost of the asset to add a level of protection?

Use of the Guideline:

It is expected that City Staff, consultants, and any organization or individual undertaking design of infrastructure that will become the responsibility of the City of Nanaimo will meet the intent of these guidelines.

This guideline is not a standard or a policy; it is intended to provide a description of the level of seismic resilience and functionality the City of Nanaimo expects from new and upgraded systems. Where designers propose to deviate from these guidelines they should submit a written request to the City representative with an explanation as to how the objectives will be maintained.

This document does not supersede statutory requirements (such as requirements for dams or structures under statuary building codes). It is intended to clarify expectations for the minimum level of seismic performance where there is an absence of regulation or oversight by a higher level of government.

Geotechnical Seismic Hazards:

Subsurface conditions across Nanaimo are highly variable as a result of a complex history of glaciation, isotactic uplift, and subsequent down-cutting. Conditions range from areas of exposed strong bedrock to thick deposits of poorly consolidated alluvial and deltaic soils. Large areas of Nanaimo are dominated by shallow dense glacial soils that are generally resistant to permanent earthquake induced ground movements and liquefaction. However, there are areas of geologically recent deposits in which seismic ground response may be adverse in terms of liquefaction and permanent earthquake-induced ground movements. The response of steep slopes to strong earthquake shaking is a consideration in the more rugged areas of Nanaimo as well as portions of the coastline and the banks of stream systems.

The geotechnical hazards associated with seismic activity that are of concern, can be attributed to transient ground deformation (TGD), or permanent ground deformation (PGD), or both. TGD occurs as a result of seismic waves; often referred to as seismic shaking. PGD occurs as a result of liquefaction, surface faulting, landsliding, and differential settlement from the densification of loose soils. The relative magnitude of TGD and PGD determine which reaction will be of influence to the pipeline response. TGD generally induces much smaller levels of pipeline strain and deformation than PGD, but can cause soil cracks and fissures triggered by pulses of strong motion[1]. While TGD can be of concern in older brittle pipes and those susceptible to corrosion, it is widely accepted that the most serious pipeline damage during earthquakes is caused by PGD[2].

A seismic hazard map has been created for the purpose of guiding decisions on seismic soil risk for infrastructure, principally from the viewpoint of identifying deposits with a higher potential of PGD (See Appendix A and B). Although the map indicates areas of low, medium, and high risk, the coarseness of the information only serves as a planning level tool. Localized changes in soil conditions and topography can dominate seismic ground response. Therefore, it is expected that the designer will consider if the site specific soils present a seismic hazard risk (regardless of the designation on the map) and undertake a geotechnical assessment to characterize subsurface conditions and seismic ground response pertinent to the infrastructure design. For areas that are designated as medium or high seismic hazard risk on the map where there is judged to be an elevated potential for PGD, it is expected that projects within these

[1] Toprak, S. and Taskin, F (2006) Estimation of Earthquake Damage to buried Pipelines Caused by Ground Shaking. Natural Hazards, 2007.

[2] O'Rourke, T and Bonneau, A. (2007) Lifeline Performance under Extreme Loading during Earthquakes. Springer.

areas would undertake an assessment to quantify seismic ground response to enable the design engineer to develop a system appropriate to the City's performance expectations.

In terms of general screening, areas that are known or expected to be underlain by fills, post glacial alluvial, marine, and other normally consolidated soils shall be treated as potentially high risk unless otherwise confirmed by site specific investigation.

Example soils in which the seismic hazard of PGD is considered to be "low" include: glacial till and bedrock.

From a screening viewpoint, the definition of low seismic risk of PGD is as follows:

a) For liquefaction, less than 2% probability of exceedance in 50 years.
b) For slope hazard, the slope must be less than 20% as determined by the City Steep Slope Guidelines.

Seismic Performance Objectives:

Assets have varying degrees of importance. For the purposes of this guideline, the following levels have been designated:

Importance Level	Potential examples
Exceptional	The main water supply lines that bring water from the watershed. Treatment plants, pump stations, or primary reservoirs. Arterial roads and emergency response.
High	Water supply trunk mains or Sanitary trunk sewers larger than 600mm diameter, pump stations, etc. Collector roads.
Moderate	Normal or ordinary water distribution pipelines. Water pipes with limited or no redundancy. Sanitary sewer pipes greater than 500mm diameter.
Low	Pipelines that represent a very low hazard to human life in the event of a failure. Not needed for post earthquake system performance, response, or recovery.

The examples listed do not constitute a definition of each level; they merely serve as a guide to consider when designating the level of a particular asset.

Note: The designation for importance level for a particular project will be developed by the Engineer of Record, Geotechnical Engineer, Utility Designer and City Staff; however, the final determination of the importance class will be at the discretion of the Director of Engineering or delegate.

Asset importance level	Design Earthquake (return period years)[1]	Performance Objectives	Example design approach
Exceptional	1:975	Remains serviceable, minor damage easily repaired. No interruption to service.	Comprehensive geotechnical assessment to characterize site conditions and determine anticipated seismic ground response. Comprehensive structural evaluation with specific design measures to meet performance objectives.
	1:2475	Structurally intact, may have moderate damage but is serviceable. Can still perform its intended function.	
High	1:975	Structurally intact, minor localized damage acceptable. Serviceability may be interrupted for short periods of time (several hours) to complete repairs.	Comprehensive geotechnical assessment to characterize site conditions and determine anticipated seismic response. Comprehensive structural evaluation with specific design measures to meet the performance objectives.
Moderate	1:475	Minimal damage. Some interruptions to service might occur; however, they are to be minimized as far as reasonably possible. No joint separation or flotation of the pipe.	To use BMPs for design (restrained joints, flexible connections, materials, etc). Seismic structural analysis may not be required. When in areas identified through investigation to contain seismically poor soils. Water: restrain all joints, provide flexible connections to rigid structures, extra isolation valves, pipe material choice, etc. Sewers: design pipe and manholes so they are neutrally buoyant or anchored, pipe material choice to accommodate permanent ground deformations.
Low	none	No seismic design requirements.	Nothing specific.

[1] As determined from the most recent Building Code.

For assets that are designated as High or Exceptional, a comprehensive geotechnical investigation shall be conducted in support of the design including considerations of alignment and the potential and magnitude of TGD and PGD under the specified design earthquake. For assets that are designated as moderate importance level, the site specific geotechnical investigation shall include a scope of work to assess earthquake ground response under a 1:475 year design earthquake when near or in an area known or suspected to have soils that present a risk greater than “low” in accordance with the seismic hazard map or known site conditions.

The potential and magnitude for collateral damage may be considered in the designation of a project’s importance level classification.

<u>Where These Guidelines Apply:</u>

These guidelines shall apply to municipal buried pipes, structures, and roads that are not covered under the BC Building Code. For example:

a) Water supply and distribution pipelines.
b) Sanitary sewer pipelines, manholes, pump stations, etc.
c) Aspects of water or sewer pump stations, pressure reducing valves, valve chambers, etc, where the BC Building Code does not apply.
d) Roads.

Water Supply and Distribution System:

The City's goal is to maintain the integrity of the water supply system following an earthquake and ensure the safe provision of water. This is to be achieved through reduced failure probability, reduced consequences from failures, and a reduced time to attain recovery.

For "Exceptional" or "High" ranked infrastructure, the design process shall include a comprehensive geotechnical assessment in which seismic ground response will be assessed and the findings incorporated in the design.

For ordinary or typical pipelines (moderate or low importance level), a greater emphasis will be placed on pragmatic steps to enhance seismic resilience, including pipe material selection and the use of special provisions for items such as fixtures, restraints, and connection details. This section will describe typical measures that can be considered for pipelines ranked "moderate", or low and are situated in an area having a soil risk greater than "low":

Evaluation of water utility damage from earthquakes around the world indicates that many of the failures occur as a result of straining at pipeline joints. Either the joints are pulled apart or are forced together beyond the structural capacity of the material, typically as a result of PGD.

The watermain materials that typically perform well in earthquakes (for pipes in this general size range) are:

a) HDPE with butt fused joints.
b) Ductile Iron with joint restraints (any joint restraints shall be protected from corrosion so as to last as long as the main pipeline).
c) PVC with locking joints (any joint restraints shall be made to last a long as the main pipeline).

Redundant looping and isolation valves are critical to minimize disruption of service in the event of failure.

Sanitary Sewer:

It is common for important or large diameter sewers to be located in low lying areas that frequently contain loose and normally-consolidated soils with the potential for poor seismic ground response. In a conventional gravity sewer, the flow is downhill, which tends to follow the natural topography and river valley bottoms. This combination of important sewers and poor soils can make it particularly challenging for some of the larger important pipelines.

One of the biggest risks of seismically induced damage for gravity sewers are PGD caused by soil liquefaction, lateral spread, and differential settlement through densification. Gravity sewers and manholes are essentially open structures which can become buoyant if the surrounding soils liquefy. When they become buoyant, they can float or lift up creating a high point or even a break in the pipe. This uplift problem can be an issue for both the pipe and any manholes or other structures.

Given that gravity sewers rely on grade (slope) to convey their contents, any disruption to the grade can have adverse consequences ranging from breaks, to complete blockages, to requiring increased maintenance. When blockages occur, the sewage takes the path of least resistance which can include overland flooding and often enters nearby watercourses. The consequences, ultimately, can lead to property damage, environmental contamination, and public health issues.

For new sewers, it may be possible to avoid areas prone to large PGD, or liquefaction, or to implement ground improvement measures to mitigate the likelihood of liquefaction (to the level consistent with the importance classification of the facility).

For upgrades to existing infrastructure, the design philosophy should investigate the feasibility of re-routing through areas of favourable ground, providing appropriate ground improvement, or introducing redundancy (this can be challenging or impractical in a gravity sewer) into the overall system.

Joint integrity is an important factor for segmented pipelines since it is a common mode of failure during earthquakes. Pipeline joints can either separate or be crushed as a result of axial forces exerted on the pipeline.

Materials that have historically performed well in earthquakes include:

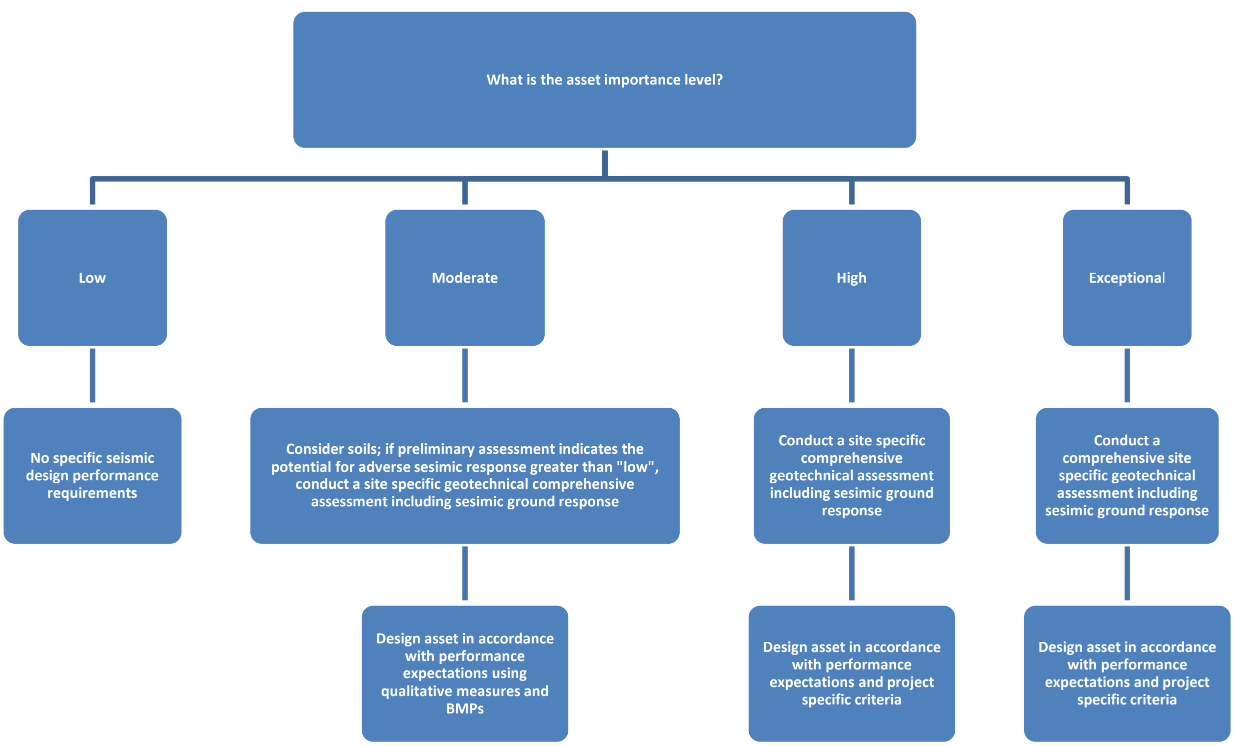
a) HDPE with butt fused joints.
b) PVC with restrained joints (made to last as long as the rest of the pipeline).

Manhole floatation is an issue that needs to be addressed specifically for each location and condition.

Use of this Guideline:

The following decision flow chart is provided to assist designers to satisfy the City's performance expectations with seismic design for a given asset.

Decision Flow Chart



Examples:

The following hypothetical examples are provided to demonstrate an acceptable approach for a given set of circumstances. The Engineer of Record shall be responsible for developing the design to meet the seismic performance expectations regardless of these examples. They are intended to provide clarification. They are not intended to provide all the possible solutions for mitigating seismic risk; they merely provide a snap shot for a given situation. Furthermore, these examples outline situations where new or replacement infrastructure is contemplated; they are not intended to provide guidance in evaluating the performance of older or existing systems.

<u>Example 1: Northfield Road (near Industrial area) Watermain and Sewer Replacement</u>

a) The terrain in this area has slope of less than 3%, as such, there is no slope hazard concern.
b) The soils in this area have been confirmed by geotechnical evaluation to be seismically favorable to new infrastructure.
c) The watermain will be 250mm diameter and looped.
d) The sewer will be 300mm diameter.

Result: The importance level of this infrastructure is declared <u>moderate</u> and there are no particular design actions required with respect to further seismic ground assessment. In this case, no special seismic considerations are required for this infrastructure.

<u>Example 2: North Nanaimo Area (between Lost Lake Road and Hammond Bay Road) Residential Development Project</u>

a) The terrain in this example area meets the criteria for “steep slope” development. The land generally has an overall slope of 32% (18°).
b) The soils have been evaluated and generally consist of sand/silty sand, dense glacial till then bedrock. The soils in this area have been confirmed by geotechnical evaluation to not be at risk of liquefaction during a seismic event (2% probability of exceedance in 50 years).
c) The watermains are proposed to be 200mm diameter, non looped.
d) The sewers will be 200mm diameter and only serve the development.

Result: The importance level of this infrastructure is declared <u>moderate</u>. The seismic soil risk for liquefaction is low. The slope hazard rating based on liquefaction potential is also low since the terrain is less than 30°. Overall the seismic hazard rating is low, no special seismic design is required unless there are localized alignments through steeper sections.

<u>Example 3: Millstone Trunk Sewer Replacement</u>

a) 750mm diameter gravity sanitary sewer crossing the Millstone River with multibarrel siphon.
b) Soils on the bank of the river have been determined to be susceptible to liquefaction during 1:475 year return period earthquake (10% probability of exceedance in 50 years).

Result: The importance level of this asset is determined to be <u>high</u> given the large population served (+15,000) and the environmentally sensitive location. The soils have been determined to be susceptible to liquefaction with a high potential for PGD. The design for this shall include provisions to protect the sewer from catastrophic failure (the inability to convey the contents of the sewer) as a result of a 1:975

year return period earthquake. Some repairs and additional maintenance may be required; however, the sewer is intended to be functional after the seismic event.

<u>Example 4: Harewood Area Sanitary Pump Station</u>

a) Based on the seismic hazard map, the liquefaction potential is low-medium.
b) Scope includes sanitary pump station and associated gravity and forcemain piping.
c) Pump station flow rate 130 l/sec.
d) There are no service connections on the proposed works.
e) The alignment of the pipes cannot be routed around the poor soils.

Result: The asset importance level assigned for this, is <u>moderate</u>. The soils are suspected to be susceptible to liquefaction with a potential for PGD. A site specific geotechnical investigation shall be required. The design will require the station and piping to withstand (remain functional after, but some repairs might be needed) a 1:475 year return period earthquake. Assuming the soils have a moderate risk level; to achieve the performance target, the designer might choose HDPE forcemain piping, and conduct ground improvement for the pump station site. Address the flexibility requirements of the forcemain connection and the gravity sewer connection to the station structure. The gravity sewer should be designed to avoid floatation, and the joints protected from separation or over compression. For example, the pipe might be HDPE butt fused gravity sewer with concrete cap or bedding for neutral buoyancy. Manholes may have a ballast slab.

<u>Example 5: 400mm diameter Watermain Replacement near Hwy 19A and Aulds Road</u>

a) Suspected liquefaction risk based on planning level seismic hazard map.
b) Terrain overall slope is less than 2%.
c) Site specific soils investigation completed and determined that there is risk of liquefaction and a potential for PGD.
d) Static water pressure is about 100 psi in this location.
e) There are no service connections on this pipe.

Result: Given this watermain is the main supply for the north end of town, the importance level is assigned “high”. The soils are known to be susceptible to liquefaction. Geotechnical assessment should characterize potential post seismic ground strains and differential settlement. Design of this watermain shall include provision for joint integrity during a seismic event. The design might be HDPE with butt fused joints or welded joint steel pipe. Counter-buoyancy provisions should be reviewed.

<u>Example 6: Proposed new 1200mm diameter Water Supply Transmission Main</u>

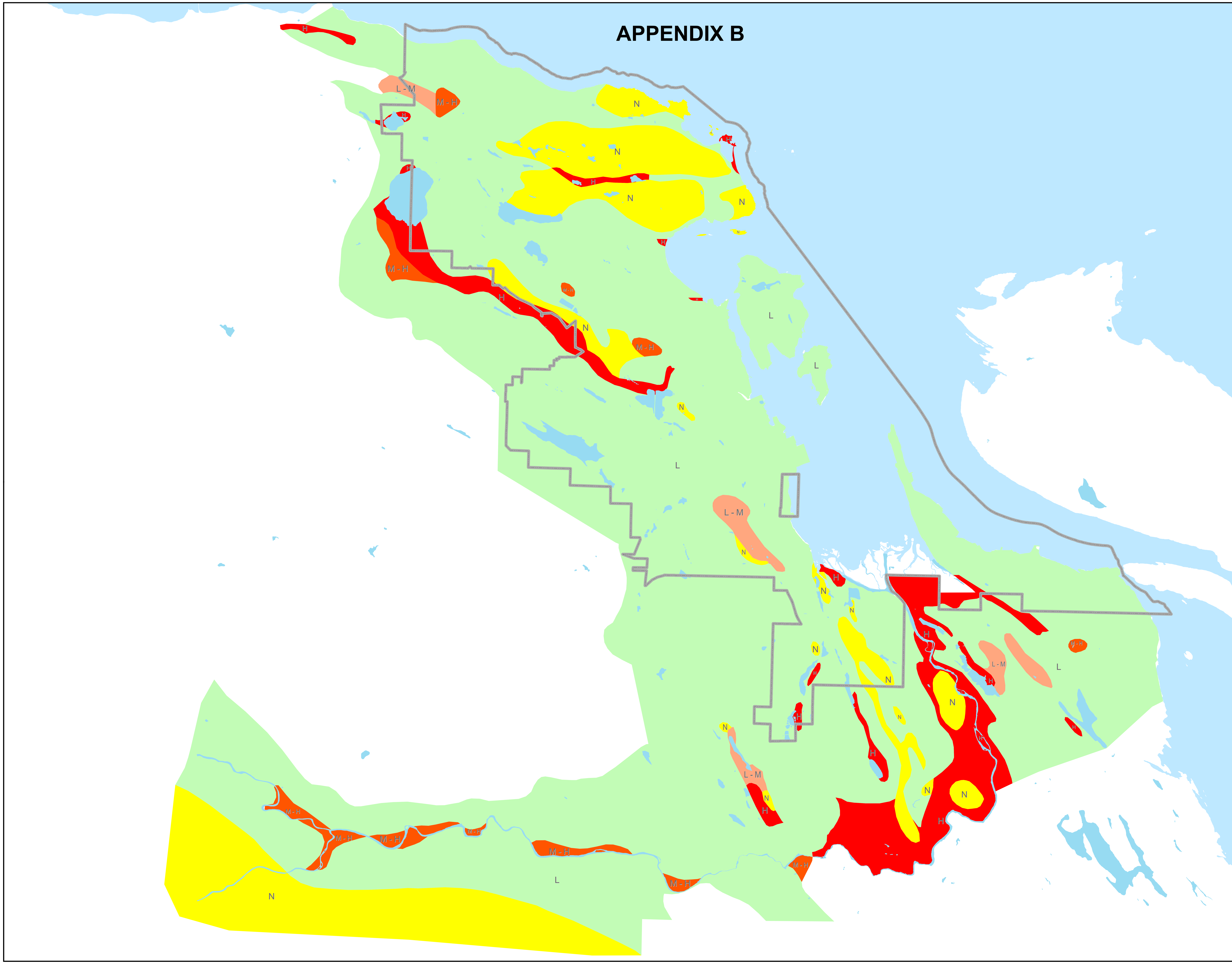
a) New pipe alignment through undeveloped area.
b) Will provide water to large portion of the City.
c) The ground along the proposed route is unknown.

Result: Given the large portion of the City this pipeline will provide water for, the asset importance level would be “exceptional”. A comprehensive geotechnical assessment of the soils and terrain along the route would be required to characterize potential seismic ground response. An emphasis would be placed on route selection to avoid any terrain other than “low” risk. Once the route has been selected, the designer would undertake design giving special consideration to the performance goals and expectations of the pipe during a seismic event. It would be expected that for the design of an exceptionally important asset such as this one, the seismic assessment would be quantitative in nature and the team would interact in the detailed structural assessment. For a pipe of this nature it is expected that there would be no service interruptions resulting from a 1:2475 year return period event. At a minimum, the designer would need to verify seismic resilience and performance requirements which would include the selection of pipeline material, the performance of the joints during an event, and flexibility of any connections to rigid structures.

APPENDIX A


City of Nanaimo
Slope Hazard
Rating
H
M
L
Bedrock
N
Published: March 15, 2022
0 0.75 1.5 3
Kilometers
1:40,000
CITY OF NANAIMO
THE HARBOUR CITY
GIS SECTION
gis.support@nanaimo.ca
DISCLAIMER
This map is intended to provide general information only and an approximate characterization of liquefaction and/or slope hazards on a broad City-level scale solely as guidance. Any assessments specific to a particular property should be based on site-specific investigation and must not rely on this map.

APPENDIX B



City of Nanaimo
Liquefaction Potential

Rating

- H
- M-H
- L-M
- L
- N

Published: March 15, 2022

0 0.75 1.5 3
Kilometers
1:40,000

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