PVC & PVCO Pipes & Contaminated Soil

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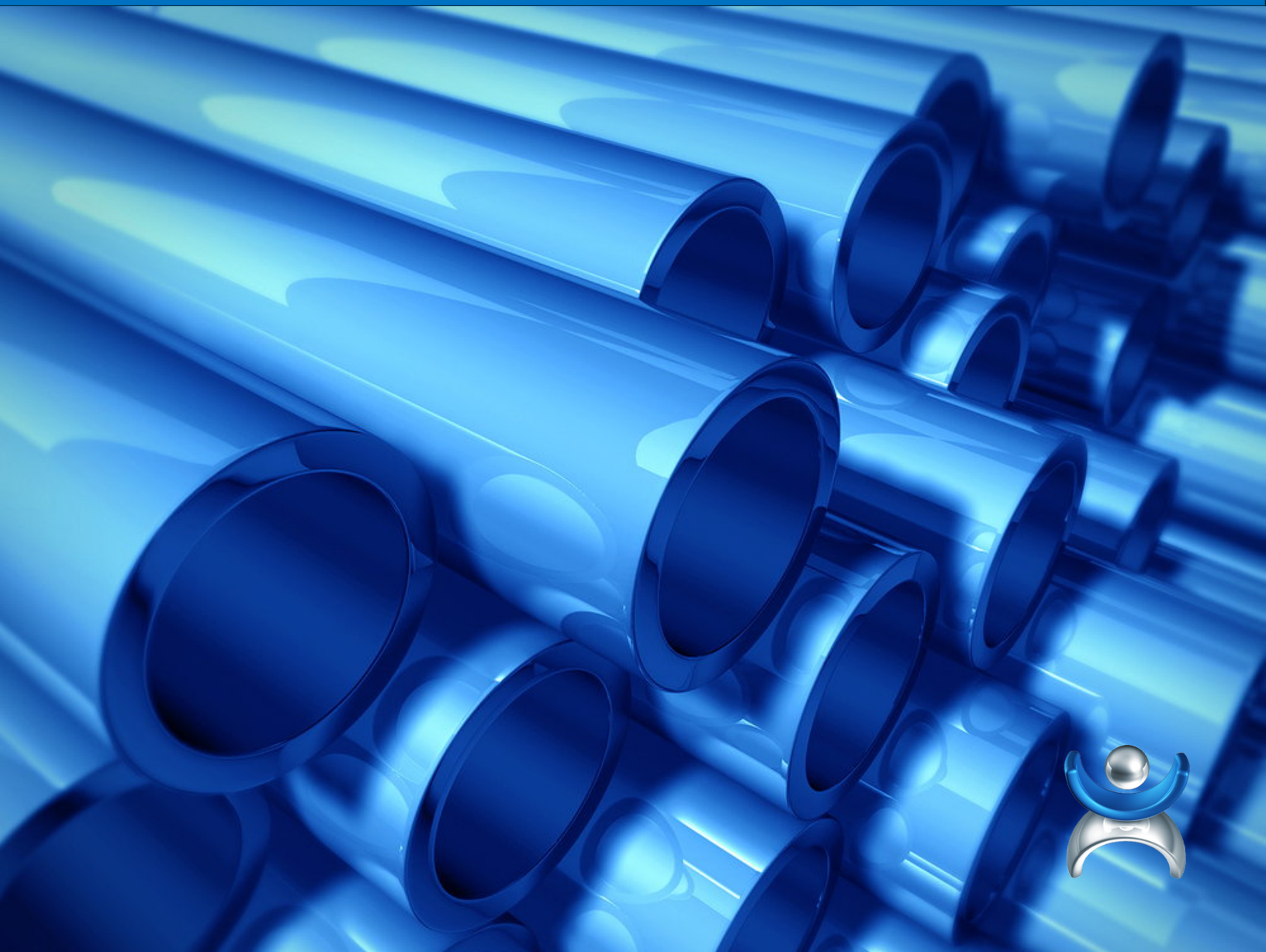


PVC & PVCO Pipes & Contaminated Soil

Dr. Chris DeArmitt, PhD, FRSC, FIMMM

Introduction

PVC pipes have been proven to be safe, reliable, cost-effective, durable and to have low environmental impact. Despite all these positives and decades of experience, utilities perform their due diligence to ensure that in any given situation, the correct type of pipe material is selected.

C. DeArmitt, Shattering the Plastics Illusion: Exposing Environmental Myths, 2025

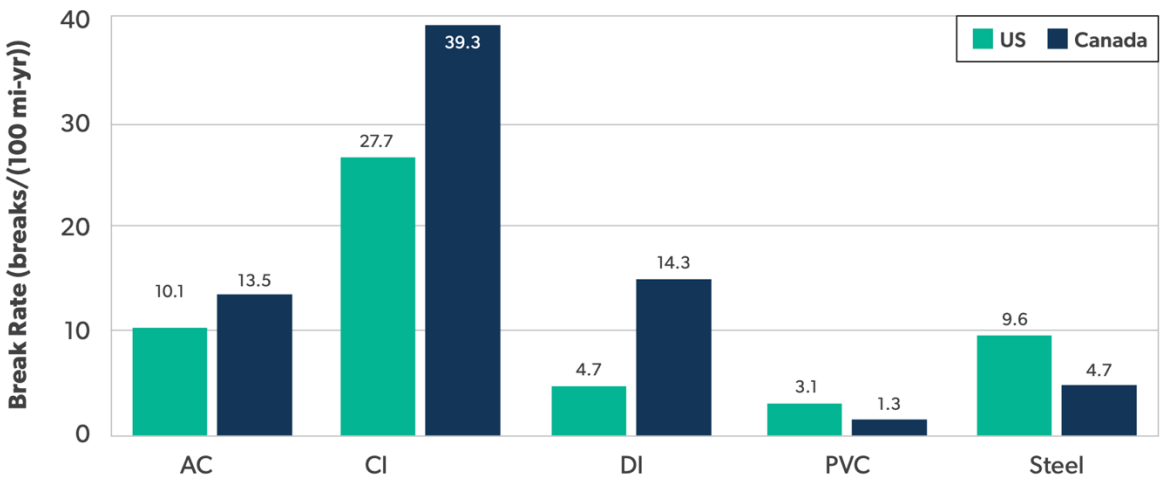
This report considers the published data on PVC and PVCO (oriented PVC) pipes with particular emphasis on the influence, if any, when such pipes are installed in soil contaminated with solvents or other organic liquids such as gasoline.

Perspective

When considering any given subject, it is often prudent to look at the bigger picture, as this lends important perspective that can be otherwise missed. A comprehensive report on water main break rates in USA and Canada covering 400,000 miles of pipe compared the reliability of the common pipe materials. More than 800 water utilities were surveyed including a wide range of pipe diameters from 3 inches all the way up to over 48 inches.

S. L. Barfuss, Water Main Break Rates in the USA and Canada: A Comprehensive Study, Utah Water Laboratory, Utah State University, 2023.

FIGURE 36: BREAK RATES FROM THE US AND CANADA FOR COMMON PIPE MATERIALS (BASIC SURVEY)



Data from the field shows that PVC water main pipe has lower failure rates than asbestos cement (AC), cast iron (CI), ductile iron (DI) or steel.

75% of utilities surveyed reported one or more areas with corrosive soil conditions and ductile iron pipe had six times higher failure rate in highly corrosive soil compared to low corrosivity soil.

Plastic pipes show extremely high resistance to high and low pH conditions that attack metal pipes. Metal pipes are extremely resistant to solvents, gasoline and many other organic liquids, where plastic pipes, are at least in theory, susceptible to such liquids.

Metal pipes corrode whereas plastic pipes do not. Liquids do not change the chemistry of the PVC, rather, at high concentrations specific liquids can penetrate into plastic and eventually diffuse through.

This report looks at the scientific studies related to PVC and PVCO pipes and their suitability for use in soils contaminated with organic liquids.

Permeation of Plastic Pipes

The word "permeation" refers to the transfer of liquids or gasses through a solid material. Whereas metal pipes can fail due to corrosion (at high and low pH), plastic pipes can potentially experience permeation, but how often does that actually occur?

The EPA has issued a report covering the topic.

"More than 100 incidents of drinking water contamination resulting from permeation of subsurface mains and fittings have been reported in the United States (Glaza and Park, 1992). The majority of these incidents were associated with gross soil contamination in the area surrounding the pipe."

Permeation and Leaching, Office of Water, Office of Ground Water and Drinking Water, Prepared by AWWA, US EPA, 2002

"Gross soil contamination" is associated with pollutant levels are far beyond normal, making them readily apparent and toxic such as found from industrial spills or chemical dumps, not residential areas.

"The overall impact of permeation on the water industry is relatively small. Reports of permeation incidents involving potable water distribution are rare, with reports of one incident per 14,000 miles of mains and 0.9 incidents per million service connections in this survey."

S. Ong et al., The impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets, Awwa Research Foundation, Subject Area Infrastructure Reliability Report DRPT-91204, 2007

Of the USA related cases where plastic pipe was permeated by liquids, the vast majority related to polybutylene pipes (16.5 cases per million miles of pipe per year), not PE (3.6 cases per million miles of pipe per year) or PVC (just 2.2 per million miles of pipe per year).

From this we can see that permeation of plastic pipes is a very rare occurrence and it occurred mainly with polybutylene, a kind of plastic pipe that is no longer used for modern installations. PE and PVC pipes are extremely reliable with PVC performing best of all.

The EPA goes on to say.

"The contaminants most likely to permeate plastic are lipophilic and non-polar in nature. Diesel and petroleum products (gasoline-range organics) were involved in 89% of the incidents, while volatile chlorinated solvents accounted for 5% of the incidents."

This is very valuable information. Approximately 90% of permeation cases are due to gasoline and diesel, which tells us that this type of exposure should be prioritized for investigation.

To summarize, we now know that incidence of permeation events is very low and that when it does occur, it requires a significant spill, which is usually of gasoline or diesel fuel.

HDPE Plastic Pipe Permeation

The potential for permeation through plastic pipes has been recognized for many years and has therefore been studied in detail. Here is some information on polyethylene pipes and permeation.

"According to a survey completed in the 1980s, polyethylene pipes were involved in 39% of total incidents of drinking water contamination resulting from permeation by organic contaminants."

"HDPE pipe was rapidly permeated when exposed to gasoline-contaminated water or gasoline-contaminated unsaturated soils."

F. Mao et al., Permeation of BTEX compounds through HDPE pipes under simulated field conditions, Journal AWWA, 102 (3), pp. 107-118, 2010

It is apparent that polyethylene pipes can allow gasoline to permeate through them and contaminate the water. From a chemistry point of view this is expected because polyethylene is a low polarity material and gasoline is also low polarity.

Because they are similar in nature, the PE can absorb gasoline and allow it to pass through. In fact, gasoline tanks for cars are made from polyethylene and permeation of gasoline through the tank wall was found to be unacceptably high, so special coatings are used to prevent loss of fuel.

The Flory–Huggins solution theory allows prediction of how a solvent will interact with a polymer, i.e. plastic. Low polarity solvents can penetrate through low polarity plastics. The way to quantify polarity is the so-called "Solubility Parameter".

Polyethylene and gasoline have very similar Solubility Parameters (polarity) which is why gasoline can pass through polyethylene.

Plastic Type	Solubility Parameter ($MPa^{0.5}$)	Solvent Type	Solubility Parameter ($MPa^{0.5}$)
PTFE	12.6	n-Hexane	14.9
Polyethylene	16.2	n-Octane	15.5
Polypropylene	16.8	Gasoline	16.2
Polystyrene	18.7	Toluene	18.3
PVC	19.4	Benzene	18.6
PET	20.7	Dichloromethane	20.2
Nylon 6,6	28.0	Water	~48

PVC Plastic Pipe Permeation

What about PVC? We see in the table that PVC is significantly more polar than polyethylene. This means that gasoline and diesel cannot enter and pass through PVC pipes. As we saw earlier, gasoline and diesel account for ~90% of permeation cases, so PVC is resistant in the vast majority of cases involving solvent contamination of soil.

"The calculated permeation rates are virtually zero for many centuries, indicating that rigid PVC pipe is an effective barrier against permeation of environmental pollutants."

A. R. Berens, Prediction of Organic Chemical Permeation Through PVC Pipe, Research & Technology, AWWA, 77 (11), pp. 57-64, 1985

"However, the diffusion coefficients of organic compounds in rigid PVC are so small that the time that elapses between the first contact of the PVC pipe with a contaminant and the achievement of the stationary state (i.e. the situation in which the flow of material through the pipe wall is constant and maximal) will amount to thousands of years. In practice, therefore, permeation through PVC pipes as a result of Fickian diffusion will be negligible."

M. Vonk, Permeation of Organic Soil Contaminants through Polyethylene, Polyvinylchloride, Asbestos-Cement and Concrete Water Pipes, Nieuwegein, Netherlands, KIWA 1985

Experimental tests confirm those predictions from calculations.

"Pipe-bottle experiments indicated that PVC pipes were impervious to gasoline and gasoline-saturated water over two years of exposure and, therefore, can be used in soils contaminated with gasoline, regardless of the level of contamination."

Permeation of hydrocarbons through polyvinyl chloride (PVC) and polyethylene (PE) pipes and pipe gaskets, Feng Mao, PhD thesis, Iowa State University, 2008

Another study concluded that effects of gasoline and various solvents was "negligible" with regard to affecting PVC pipe.

"Using the gravimetric sorption test, sorption of premium gasoline by PVC pipes was found to be negligible with less than 1% weight gain - implying that no permeation occurred. Sorption was insignificant for concentrations of toluene ≤ 40% (v/v) in NIST reference fuel - implying that no permeation of toluene occurred at these concentrations. With aqueous solutions of benzene, toluene, and TCE, the weight gains for 60% saturated aqueous solutions and below were less than 2% after 8 months of exposure. Sorption of the 20% saturated aqueous solutions was found to be statistically similar to that of the control experiment - implying that sorption was negligible for contaminant levels below 20% saturated aqueous solutions of benzene, toluene, and TCE."

S. Ong et al., The impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets, Awwa Research Foundation, Subject Area Infrastructure Reliability Report DRPT-91204, 2007

Theory predicts, and experiments confirm that, PVC pipes resist gasoline which accounts for ~90% of all permeation cases as well as other common liquids.

The application of Solubility Parameters is powerful because values can be found or calculated for any organic liquid. While there cannot possibly be test data for every liquid and PVC (or any other plastic material), we can still assess the potential for liquid-pipe interaction via the Solubility Parameter.

For example, 1-Methylnaphthalene was found in trace levels in contaminated soil but the specific data for PVC has not been published. The Solubility Parameter for 1-Methylnaphthalene is 20.3 $MPa^{0.5}$, which means it is far too polar to permeate through PVC pipe. The same applies to the traces of pyrene detected in the soil.

Furthermore, it has been noted that contamination of soil before pipe installation is not the problem. Instead, it is large spills during the service of the pipe that present the potential for permeation.

"Soil contamination occurred after pipe installation in almost 95 percent of the permeation incidents."

"This work demonstrated that the majority of permeation incidents were associated with gross soil contamination in the area surrounding the pipe. Soil contamination occurred mainly after pipe installation, suggesting that soil analysis prior to pipe installation will not significantly decrease the number of incidents. The occurrence of about half the incidents in low risk areas indicates that limiting plastic pipe use to these areas will not be effective in preventing permeation."

T. Holsen et al., Contamination of Potable Water by Permeation of Plastic Pipe," Journal AWWA, 83 (8), pp. 53-56, 1991

Looking at the other trace organic contaminants reported, we see that most are solids and therefore, the molecules are immobilized and unable to permeate into the pipe. The rest are present in very low concentrations not expected to have any effect on PVC pipe.

T. Holsen, et al., The Effect of Soils on the Permeation of Plastic Pipes by Organic Chemicals, Journal AWWA, 83 (11), pp. 85-91, 1991

A quarter of all failures was attributed to corrosion, which does not occur for plastic pipes, and reports on causes of failure do not even mention permeation because it is not significant in the wider picture.

S. L. Barfuss, Water Main Break Rates in the USA and Canada: A Comprehensive Study, Utah Water Laboratory, Utah State University, 2023.

While these studies were on PVC pipes, the newer PVCO pipes should be even more resistant as orientation improves strength and barrier properties.

Pipe Gaskets and Permeation

We have seen that PVC pipes are resistant to permeation of common solvents, but the gaskets are made of a different material. We need to consider whether the gaskets can allow permeation.

"This study investigated the permeation of petroleum-based hydrocarbons (BTEX) through PVC pipes equipped with Rieber gasket systems by conducting pipe-drum tests as well as model simulation. Under premium gasoline-exposure conditions, benzene was the first compound detected with a breakthrough time of approximately 21 days for 2-inch PVC pipe joints. The steady-state permeation rates of benzene were found to be 0.73±0.29 mg/joint/day and 0.19±0.18 mg/joint/day for 2-inch SBR and NBR gaskets, respectively. The corresponding diffusion coefficients of benzene in SBR and NBR gaskets were determined to be 1.1×10-7 cm^2/s and 6.0×10-8 cm^2/s, respectively. No significant amounts of BTEX compounds were detected in the pipe-water for pipes using either SBR or NBR Rieber gaskets after 9 months of exposure to any level of gasoline contamination in water, even at 100% saturated."

Permeation of hydrocarbons through polyvinyl chloride (PVC) and polyethylene (PE) pipes and pipe gaskets, Feng Mao, PhD thesis, Iowa State University, 2008.

A detailed report covers the effect of gasoline and gasoline/ethanol mixtures on different rubber seal materials.

That study also found that the degree to which the rubber was affected by a solvent was determined on how close the Solubility Parameters of the two were.

"The maximum absorption of a liquid by an elastomer is reported to mainly rely upon the difference in solubility parameter (δ) of fluids and elastomers, such that fluid absorption is more likely as the δ values get closer."

A Literature Survey on the Selection Criterion and Compatibility of Elastomeric Materials to the Ethanol-Gasoline Mixtures, PRCI Final Report #81173762 & 81173763, Static and Dynamic Seal Testing, CC Technologies, 2008

Rubber Type	Solubility Parameter ($MPa^{0.5}$)	Solvent Type	Solubility Parameter ($MPa^{0.5}$)
Viton / FKM	15.6	n-Hexane	14.9
Natural rubber	16.4	n-Octane	15.5
EPDM	16-18	Gasoline	16.2
SBR	17-19	Toluene	18.3
NBR – low ACN	18-20	Benzene	18.6
NBR – med ACN	20-22	Dichloromethane	20.2
NBR – high ACN	22-24	Water	~48

Nitrile rubber (NBR) is more polar than gasoline and therefore resists permeation of it. The more acrylonitrile (ACN) used to make the rubber, the more polar and more solvent resistant it becomes.

J. Lara et al., The Use of Hansen Solubility Parameters in the Selection of Protective Polymeric Materials Resistant to Chemicals, International Journal of Current Research, 9 (3), pp. 47860-47867, 2017

Gaskets are made of rubber (elastomer) material and various types are available, so we need to consider each kind. In general rubber materials have higher permeability than plastics, meaning that they let liquids pass through them more easily. This is because there is more open space between rubber molecules (the technical term is free volume).

Based on this, one might think that the gasket is the weak point and would lead to increased permeation of liquids. However, that is not found to be the case in reality, because there is far more pipe than gasket.

For 100 meters of 6 inch AWWA C900 PVC pipe, there are about 16 joints / gaskets, each rubber gasket is about 3cm in width. So, for every 100 meters of PVC pipe we have a length just 0.5m of rubber gasket, about 0.5% of the total length of pipe plus gasket. Although rubber is somewhat more permeable than plastic, the effect is negated because there is so little rubber present.

In addition, it was calculated that even if solvent were to penetrate the rubber gasket, there is over 100 liters of water in between each gasket for a 6 inch diameter pipe, so that amount of water causes the concentration of any contaminants to become much lower by dilution.

E. C. Glaza and J. K. Park, Permeation of Organic Contaminants Through Gasketed Pipe Joints, Research and Technology, AWWA, 84 (7), pp. 92-100, 1992

The same gasket materials are used for ductile iron water pipes and studies on those come to similar conclusions. Namely that EPDM performs worst on exposure to gasoline, then chloroprene rubber ≈ styrene butadiene rubber (SBR), then nitrile rubber (NBR) and fluoroelastomer (e.g. Viton) performed best.

C.-L. Cheng et al., Permeation of gasoline through DI pipe gaskets in water mains, Journal AWWA, 104 (4), E271-281, 2012

In the Toronto area, nitrile gaskets are specified for use in areas with even trace contamination as a precaution.

Design Criteria for Sewers and Watermains, 2nd Edition, p. 112, 2021

Trace Contaminants Actually Detected

The majority of contaminants detected are PAH meaning polyaromatic hydrocarbons. The studies already cited show that aromatic substances are too polar to permeate PVC. Even benzene, a smaller aromatic compound is not an issue. These much larger aromatic molecules are even less of an issue because the larger molecules are unable to penetrate inside the PVC between the molecular chains of the material.

PAH (Polyaromatic Hydrocarbons)

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(j)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Chrysene
Dibenzo(a,h)anthracene
Fluoranthene
Fluorene
Indeno(1,2,3-cd)pyrene
1-Methylnaphthalene
2-Methylnaphthalene
Na+B19:H19phthalene
Phenanthrene
Pyrene

PHC (Petroleum Hydrocarbons)

F1
F2 (C10 to C16)
F3 (C16 to C34)
F4 (C34 to C50)
F4 (Gravimetric)

These are all hydrocarbons and studies found that PVC is completely impervious to them. The only substance detected that has the potential to affect PVC is acetone. However, the amount present in the soil is just 0.00005% by weight. That concentration is far too low to be a concern.

Factors Specific to Toronto and Canada

Whereas the occurrence of permeation events reported in the USA is extremely low, there have been no such occurrences in Canada. This may be because of differences in pipe installation in the two regions. Pipe installation depth is determined by the frost line.

In both countries, building codes and best practices dictate that any pipe conveying water must be installed at least 12 inches below the maximum expected frost line to prevent the water inside from freezing and potentially bursting the pipe. The frost line is the maximum depth that the ground is expected to freeze during winter.

Therefore, while the specific pipe material (PVC) handles deep burial well (it can be buried 50 feet or more if engineered correctly), the required depth is an environmental and code-based necessity, not a material limitation.

General Guidelines

Minimum Cover: Most codes require a minimum cover of at least 12 inches of soil even in non-freezing climates, simply to protect the pipe from surface damage from light traffic or digging.

Local Authorities: The ultimate authority for required burial depth in any specific location is the local municipal building or plumbing code authority, as they set the official frost line depth for their jurisdiction.

Sewer/Drain Lines: Pipes not intended to hold standing water (like sewer or drain lines) generally do not need to be buried below the frost line, as long as they have a proper slope to drain completely.

Northern US: Burial depths are below the frost line (e.g., Minnesota can require 3.5 to 5 feet).

Southern US: In warmer regions, the frost line may be only a few inches or a foot deep, so pipes can be buried much shallower, sometimes as little as 12 to 18 inches (0.3 to 0.46 meters) below grade.

Toronto Canada: The City of Toronto requirements for watermain are 1.8m under a paved road, 2.1m under an unimproved surface.

Design Criteria for Sewers and Watermains, 2nd Edition, p. 152, 2021

Thus, the pipes in Canada are buried at a much greater depth compared to the US, which protects them from spillages on the surface and explains why there are no reports of permeation events in Canada.

Furthermore, it is important to note that soil contamination reports are based on the native soil, which is replaced in the bedding zone and as the cover material with imported granular materials. This removes the contaminants from the soil immediately surrounding the pipe and provides additional safety against permeation. It not until the backfill zone, above the pipe cover, that workers are allowed to use native materials. It is very common in installations under the road to use imported materials or unshrinkable fill (aka low strength concrete). In this case, there is no contact between the pipe and the site soil.

Conclusions

After careful review of decades of studies, the science indicates that there is nothing to prevent the installation of PVC and PVCO drinking water pipes in the proposed locations. PVC pipes are highly resistant to permeation and occurrences are exceedingly rare.

Only in grossly contaminated soil is there any need to evaluate the details of the situation, whereas the soil analysis provided shows only trace contaminant levels, not of concern. Furthermore, the trace contaminants found are not of the type that affect PVC. They are not of the correct polarity to permeate PVC and have molecular weights too high to pass through PVC pipe.

Using soil analysis as a tool for deciding whether plastic pipes are suitable has been shown to be invalid because soil contamination before installation is not the problem. Rather, it is only large spills after installation that have the potential to raise concern. Even in those instances, 90% are gasoline spills to which PVC pipe is immune. In Canada, pipes are buried much deeper than in the US which is why there are no reports of permeation.

To conclude, there is no scientific evidence to suggest that PVC pipe and suitably specified gasket materials should not be used. This includes trenchless, so-called "no dig" installation as well as the more traditional methods. The newer generation of pipes made from orientated PVC (PVCO) further improve performance because the orientation process increases both strength and barrier properties.

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Further Reading

Handbook of PVC Pipe Design and Construction, 6th Edition, Uni-Bell, 2024

Polymer Handbook, 4th Edition, J. Bandrup, E. H. Immergut, E. A. Grulke (Eds.), Wiley-Interscience, 1999

D. W. van Krevelin and K. te Nijenhuis, Properties of Polymers: Their Correlation with Chemical Structure; their Numerical Estimation and Prediction from Additive Group Contributions, 4th Edition, Elsevier, 2009

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This report is provided for informational and scientific purposes only and presents a review of available evidence regarding the suitability of PVC (and PVCO pipes gaskets) for use in lightly contaminated soil. It does not constitute engineering, legal, regulatory, or professional advice.

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