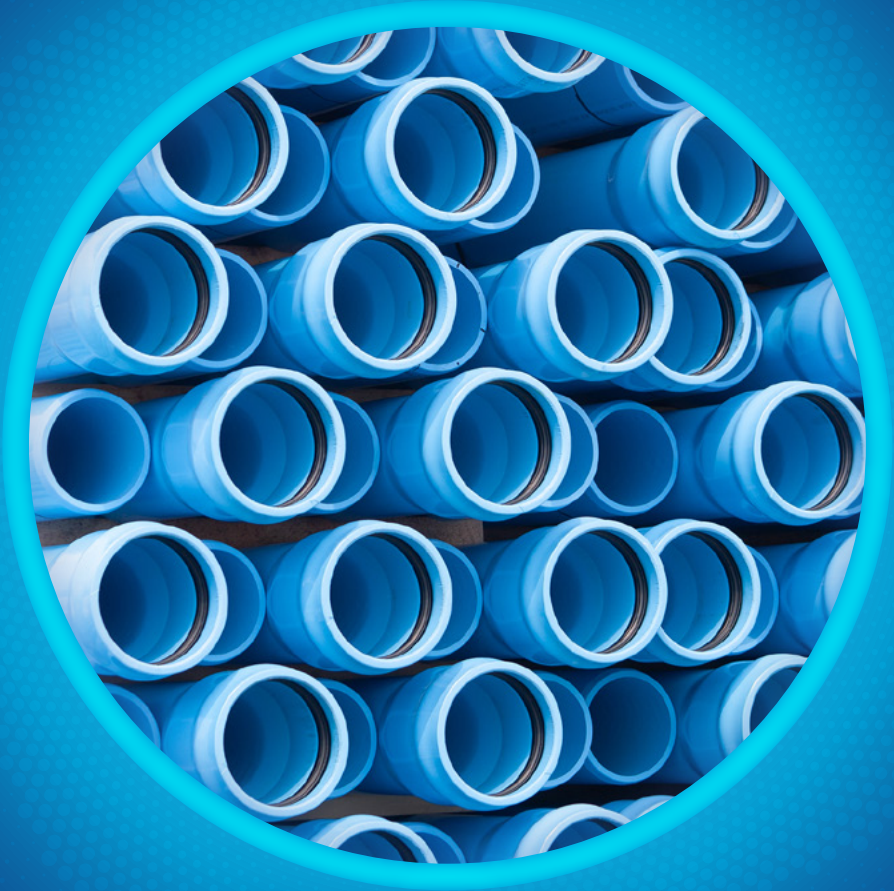


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Front Cover: Polyvinyl chloride (PVC) pipe has become a reliable choice for transporting potable water. PVC's ease of installation and low maintenance requirements have contributed to widespread adoption in water supply systems across North America. Photo from Westlake Pipe & Fittings.

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This guide, part of AWWA's Essential Knowledge Series, was prepared in partnership by AWWA and Westlake Pipe & Fittings. AWWA contributors include John R. Hughes, editor; Dawn Flancher, senior manager, technical and research programs; Paul Olson, senior manager, standards; Jason Hrdlicka, standards engineer; Daniel Feldman, designer; and Karen Pacyga, production manager. Westlake Pipe & Fittings contributors include Keith Moggach, P.Eng., MAsc, Manager, Specification Engineering, and Craig Fisher, P.E., Specification Engineer.

INTRODUCTION

Polyvinyl chloride (PVC) pipe has become a popular option for new municipal water projects and main replacement programs.¹ This is a result of its short- and long-term advantages. In the near term, it's a lightweight, rugged product that is quick and easy to install. In the long term, its corrosion resistance results in a durable, long-lived asset with minimal maintenance needs. PVC's low upfront costs combined with its longevity translate into substantial savings for water utilities over the life of this asset. This guide reviews the properties that utilities often cite when asked about PVC, provides an overview of the basic design steps for a PVC water project, and highlights two trenchless methods that allow water mains to be installed economically and with minimal societal impact.

GENERAL PROPERTIES OF PVC

PVC is a versatile material with unique properties. It was first synthesized in the late 19th century and gained attention mainly due to its chemical inertness. Over time, advancements in technology led to the ability to use PVC as the primary ingredient in a wide range of applications. Of these, PVC pipe and fittings are the largest end use and account for roughly half of the world's PVC resin manufactured annually.²

PVC pipe was first developed in the 1930s, but it wasn't until the 1950s and 1960s that the product gained widespread acceptance and usage in various applications, including water distribution.³ Subsequent advancements in production methods brought about the development of a molecularly oriented PVC (PVCO) pipe, which was introduced to North America in the 1980s and became commercially available in the 1990s.⁴

Today, PVC pipe is a common choice for a variety of piping systems across North America; however, this guide focuses on its use in buried municipal and rural water systems. The PVC and PVCO piping products used in these applications are usually made to one of the following standards:

- ANSI/AWWA C900, Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1500 mm)⁵
- ANSI/AWWA C909, Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe, 4 In. (100 mm) and Larger⁶
- ASTM D2241, Standard Specification for Poly(Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series).⁷

The general properties described in the following sections are shared by all of these PVC piping options and help explain why utilities consider PVC for their buried water systems.

Chemical Inertness. Some aspect of this attribute is usually considered when end users ask about PVC pipe.⁸ This is a broad property that has been separated into the following subsections for closer examination.

Water Quality. Maintaining the safety of the drinking water transported through piping systems is of paramount importance. Government regulators ensure the safety of drinking water systems through entities like the US Environmental Protection Agency and NSF International. Each pipe material is evaluated for potential contaminants that may leach from the pipe material into the drinking water being transported, and a maximum contaminant level (MCL)

Using a nonmetallic pipe product is one way for a utility to solve internal and external corrosion issues.



is established for each potentially harmful element of each pipe material. Exposure testing protocols have been established for everything that comes in contact with drinking water. Any contaminants that are found must be below the MCL, which is lower than the level found to be the threshold for causing harm by a conservative factor of safety. As an inert and stable material, PVC has a long history of proven safety documented by decades of testing by outside regulators.⁹

Corrosion Resistance. Using a nonmetallic pipe product is one way for a utility to solve internal and external corrosion issues. Of the nonmetallic pipe options available, PVC is a common choice.

Hydraulic Efficiency. Without proper protection, corrosion by-products can build up on the inside of metallic pipe over time and reduce hydraulic efficiency. Nonmetallic products like asbestos cement (AC) pipe can lose carrying capacity over time from tuberculation, which can occur in water systems that have soluble encrustants like calcium carbonate in their raw water source. The mineral can precipitate onto the inside of the AC pipe and gradually build-up over time. (Note: Although AC pipe hasn't been installed for decades, it still makes up part of our buried water piping infrastructure.) Conversely, PVC's smooth, nonporous pipe wall prevents tuberculation from occurring.¹⁰

Chemical Resistance. Industry literature lists the chemical resistance of PVC to hundreds of chemicals. This is rarely an issue when designing a PVC water system because experience has shown it to be resistant to the chemicals typically encountered.¹¹

Biological Attack. This is defined as the degradation of the pipe caused by the action of living microorganisms or macroorganisms.

Microorganisms. Fungi and bacteria are examples of a type of microorganism responsible for biological attacks. In essence, when they feed off organic materials, they cause natural decay. These organisms also help break down many man-made products and contribute to their natural decay. Plastics have been an exception to this natural process because they usually don't break down over time, and they deny microorganisms nutrients necessary for their survival.¹²

Macroorganisms. These types of organisms include tree roots, insects, and rodents. Tree roots have been a problem in older gravity sanitary sewer systems but aren't an issue for pressure water systems. The main insect of concern is the termite, but they aren't an issue for PVC. Lastly, there are rodents that have been known to gnaw through flexible materials like hoses. Again, research has shown that rodents aren't an issue for PVC.¹³

Flexibility. Unlike rigid pipe like cast iron, PVC water pipe has sufficient flexibility to accommodate ground movement caused by frost heave or from dry clay soils expanding from absorbing groundwater or wet clay soils shrinking by losing groundwater during a drought. There are other properties that may need to be quantified for specific projects. The Fifth Edition of the *Handbook of PVC Pipe Design and Construction*, published by Uni-Bell PVC Pipe Association, has information on weathering, thermal effects, abrasion, fatigue life, and other PVC properties. Also, consult AWWA Manual of Water Supply Practices M23, *PVC Pipe—Design and Installation* (www.awwa.org/M23) for additional PVC pipe design and installation considerations.

The use of trenchless installation methods has become more routine over the past two decades.



DESIGN AND INSTALLATION

Designing a water system involves determining routine operating pressure and the surge pressures that result from a nonrecurring event like a power outage or a valve being shut too quickly. Table 1 lists the Pressure Classes of PVC available in AWWA C900, and Table 2 lists those in ASTM D2241. Both tables list the pipe's pressure class (PC) by its dimension ratio (DR). DR is the ratio of the pipe's outside diameter to its wall thickness. The PC remains constant for a given DR.

Horizontal Directional Drilling, PVC Upgrade Town's Entire Water System

Residents of Wheeler, Indiana, enjoy a plentiful, dependable supply of clean, good-tasting drinking water, but that wasn't always the case. Not long ago, the roughly 160 homes and dozen businesses in this small northwest Indiana town were serviced by individual water wells.

Besides the need to install a modern water distribution system, there was concern that contamination from septic tank systems, used before the community's sewer system was installed, may have leached from a closed landfill and affected the safety of the town's wells. An entirely new water distribution system was necessary to ensure a plentiful supply of safe drinking water and an ample supply of water for fire protection. However as plans for a new system were developed, concerns grew over the project possibly causing significant surface damage in the town's developed areas.

Construction of the system, including mains and services, was conducted entirely with trenchless methods with 95% of the mains installed by horizontal directional drilling (HDD).

"Directional drilling was a good choice because it permits trenchless installation of new pipe beneath streets and other surface

improvements with minimal surface disturbance," said Jeff DeWitt, senior project engineer for the Bonar Group, consulting engineers on the project.

Mains included 29,400 linear feet of C900/RJ PVC Certa-Lok[®] pipe by Westlake Pipe & Fittings, including 10,300 feet of 6-inch pipe, 4,300 feet of 8-inch pipe, and 4,800 feet of 12-inch pipe. Project leaders say the Certa-Lok[®] pipe was ideal for installation by directional boring because its sections are connected with tight-locking couplings that don't pull apart when pipe is pulled into place by the drilling machine.

Precision-machined grooves of pipe and couplers were aligned, and a nylon spline was inserted to lock the pipe and coupling together. Services were ¾- and 1-inch type K copper, the size depending on the length of the service. They, too, were installed by HDD.

Mains were installed primarily in residential areas. One line went along a state highway with mains branching off in easements adjacent to streets. Surface conditions of easements included asphalt and concrete streets and landscaped areas.

"We made approximately 300 bores for the mains and individual bores for each service connection," explained Tina Dillon, president of Atlas Excavating. "Subsurface

The designer selects a DR that results in a PC greater than or equal to the operating pressure. Another PVC property is that it has high strength for loads imposed over a short duration. In pressure applications, this results in more pressure capability when the pressure is applied for a small amount of time—as is the case with surge events. The AWWA C900 and AWWA C909 standards recognize this property when performing the design check for occasional surge pressures. The surge pressure must be less than or equal to the pipe’s PC times 1.6. The resulting short-term ratings are listed in Tables 1 and 2. AWWA

conditions included sandy clay and clay. Bore lengths for mains ranged from 45 to 900 feet.”

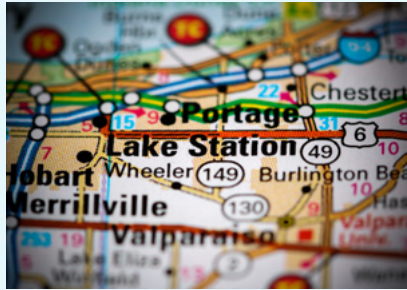
Two of the company’s four HDD units were used: a 24,000-pound pullback Vermeer D24x40 and a 30,000-pound pullback Case 6030. Pipe for 6- and 8-inch mains was pulled in directly behind a backreamer. For 12-inch pipe, one backreaming pass was made before the pull-in with PVC pipe pulled in a joint at a time.

“The connections were made so quickly it wasn’t necessary to assemble a string to install this type of pipe,” added Tony Kinsler, project manager for Atlas Project.

Kinsler said another interesting aspect of the job was that pilot holes for services went under the foundation of homes and exited into the houses. Plus, the town of Wheeler is separated by two sets of parallel railroad tracks owned by different railroads.

“Six railroad crossings were required,” explained DeWitt. “Because mains under the tracks had to be placed in steel casings, ductile iron pipes were installed by the jack-and-bore method, so these segments also employed trenchless construction.”

Originally budgeted for \$2 million, the contract for the project came in at \$1.6 million.



“The cost was lower in part because of directional drilling,” said DeWitt. “There can be significant cost savings when restoration items such as repairs to roadways, sidewalks, and landscaping aren’t needed.”

DeWitt added that at one point during construction, the White Oak Conservancy District received complaints from citizens asking why construction hadn’t started.

“When the district council replied that 50 percent of the pipe was already in the ground, the attitude changed,” he said. “Residents simply didn’t realize water pipe could be installed without digging trenches.”

The project’s innovative use of trenchless construction earned an award from the American Council of Engineering Companies of Indiana. For more information about Westlake Pipe & Fitting and its Certa-Lok® PVC pipe, visit www.westlakepipe.com.

Table 1. AWWA C900 Pressure Classes and Short-Term Ratings

DR	Pressure Class (psi)	Short-Term Rating (psi)
14	305	488
18	235	376
21	200	320
25	165	264
26	160	256
32.5	125	200
41	100	160
51	80	128


Table 2. ASTM D2241 Pressure Classes

DR	Pressure Class (psi)	Short-Term Rating (psi)
13.5	305	504
17	235	400
21	200	320
26	165	256
32.5	125	200
41	100	160
51	80	128
64	63	100

C909 has PCs of 305 psi, 235 psi, and 165 psi. Its short-term rating matches that of C900 pipe of the same PC.

There are other design checks that less commonly concern potable water systems, such as external load capability and fatigue life. The Uni-Bell PVC Pipe Association (www.uni-bell.org) has free literature and calculators to assist engineers with these and other design checks.

Proper installation guidance is provided for AWWA products through ANSI/AWWA C605, *Underground Installation of Polyvinyl Chloride (PVC) and Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe and Fittings*.¹⁴ For the ASTM product, please refer to ASTM D2774, *Standard Practice for Underground Installation of Thermoplastic Pressure Piping*.¹⁵



The main reasons for PVC's widespread use are its ease of installation and its exceptional durability and longevity.

Figure 1. The Three Phases of an HDD Installation

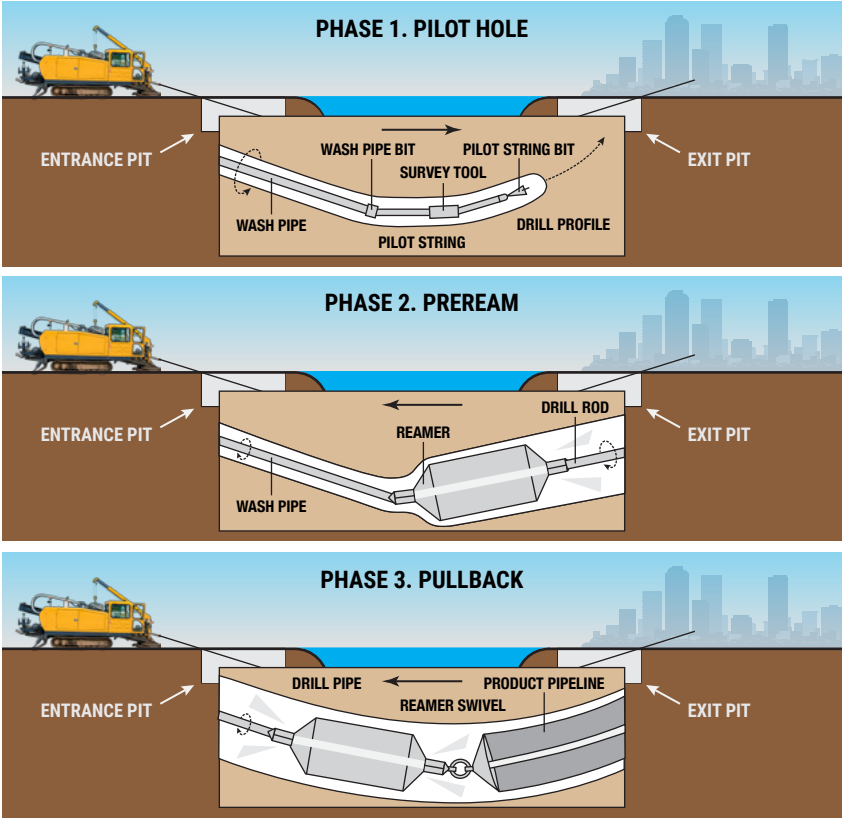
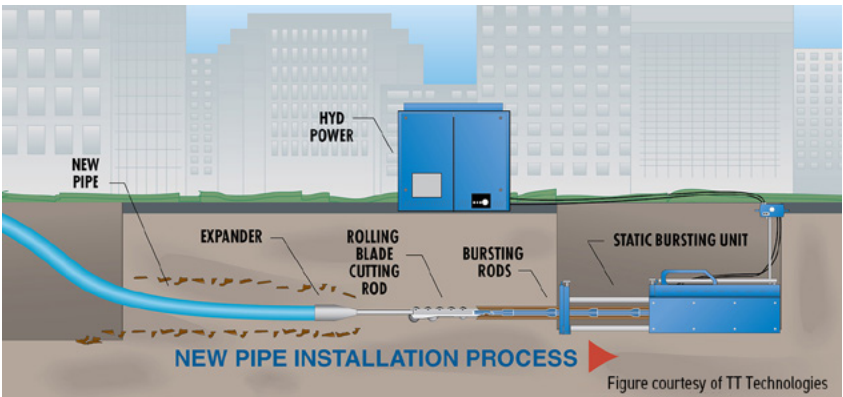


Figure 2. Typical Static Pipe Bursting Setup



TRENCHLESS CONSTRUCTION

As water infrastructure ages, demand for water main replacement programs increases. This occurs whenever the cost and local inconvenience from repairs become excessive. Demand for new water infrastructure usually mirrors a city's or town's population growth.

The use of trenchless installation methods has become more routine over the past two decades. Installers often turn to trenchless technology when obstacles like rivers, roads, and wetlands make traditional digging costlier and more complex.¹⁶ Crowded urban environments can also make trenchless options more appealing. These methods allow the pipe to be installed with minimal impact on local businesses, neighborhoods, and traffic flows. As detailed in the following sections, two of the more common trenchless methods using PVC pipe are horizontal directional drilling (HDD) and static pipe bursting. Note that these installation methods require specially designed PVC pipe.

HDD. During its infancy in the 1990s, HDD was limited to road and river crossings. The use of HDD has expanded significantly since then. This process is depicted in Figure 1 and is accomplished in three phases. The initial step entails creating a pilot bore hole along the path provided by the project's design engineer. Next, a reamer is drawn back through the pilot bore to enlarge the diameter to a size suitable for the pipe's largest outside diameter. At the same time, drilling mud is pumped into the bore hole to stabilize it and prevent it from collapsing. Lastly, the new pipe is pulled in. The case study on pages 6 and 7 details how Wheeler, Ind., used HDD and PVC to replace its entire water system.

Static Pipe Bursting. Static pipe bursting is the replacement method recommended for most pipe materials. With this method, the machine applies a steady load when pulling rods through the existing pipe. Another approach is to use pneumatic pressure to create a percussive hammering action to fracture the existing pipe. Note: The North American Society for Trenchless Technology's *Pipe Bursting Good Practices Guidelines* states the following, "An air hose is inserted through the replacement pipeline for the pneumatic pipe bursting method, and this air hose could contaminate the potable water pipe."¹⁷

As shown in Figure 2, the static bursting operation pulls a bursting head that fractures or cuts the existing pipe; this is followed by an expansion head that pushes the newly burst pipe fragments and soil out into the surrounding area in order to provide sufficient room for the replacement pipe being pulled in. A pipe bursting operation can upsize the existing line by up to two pipe diameters. Lastly, a new pipe string is pulled in behind the bursting and expansion heads. The pull process is continuous, only pausing briefly to decouple a bursting rod and reconnect to the next rod.¹⁸

CONCLUSIONS

PVC pipe has become a popular material installed by utilities in their buried water systems. The main reasons for PVC's widespread use are its ease of installation and its exceptional durability and longevity. Advances in production technology have resulted in the development of a molecularly oriented PVC pressure pipe as well as PVC products suitable for installation by trenchless methods.

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