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From trench safety to lifecycle reliability: A project-control framework for water and sewer reticulation delivery in U.S. communities

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Abstract

Among all civil infrastructure projects, water and sewer reticulation projects have some of the highest capital requirements, technical challenges, and public importance. Project delivery teams are under tremendous pressure to deliver reliable, code-compliant, and cost-effective systems as the American Society of Civil Engineers (ASCE) continues to grade the state's infrastructure for drinking water and wastewater systems as a D+ over the last two years. The Environmental Protection Agency (EPA) estimates that there is a combined \$744 billion funding gap between 2021 and 2040 for drinking water and wastewater infrastructure (ASCE, 2021; EPA, 2023). However, ongoing issues continue at water systems—According to EPA, approximately 240,000 water main breaks happen each year, causing water system emergency repairs and water losses of at least \$2.8 billion each year for water systems in the United States (EPA, 2023; Folkman, 2018). This article provides a comprehensive, evidence-based project-control framework that combines utility sequencing, trench control, pipe installation control, quantity measurement methods, inspection readiness checklists, detailed policies around pressure and leak testing, quality assurance/quality control (QA/QC) documentation systems, and project closeout procedures. This framework incorporates federal regulatory guidelines, industry best practices from the American Water Works Association (AWWA), OSHA trench safety regulations, and peer-reviewed research in the field of infrastructure lifecycle management to provide project managers, site engineers, and quality personnel with tangible, usable tools to minimize rework, eliminate safety incidents, and increase the operational service life of reticulation assets.

Keywords: Water Reticulation; Sewer Systems; Trench Safety; QA/QC; Project Controls; AWWA; Pipe Installation; Pressure Testing; Lifecycle Management; Infrastructure Delivery

1. Introduction: The Infrastructure Imperative

A complex water resource challenge is unfolding in the United States, with a need for not only increased investments in water infrastructure, but a review and reimagining of the way water projects are planned, managed, and delivered. The costs to protect drinking water systems across the nation are estimated at \$625 billion in the coming 20 years for drinking water systems alone, according to the ASCE 2021 Infrastructure Report Card (ASCE, 2021). Meanwhile, the Water Research Foundation in the USA has reported that many cities, including in the USA, are now obtaining mains of over 40 years of age, and that a significant proportion of mains installed in these cities before 1960 are either cast iron or ductile iron pipe with no protection. (Water Research Foundation, 2021).

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There are many other repercussions of poor project control other than cost overruns. The Congressional Budget Office estimated that poor design or poor maintenance of water systems causes 7 million illnesses each year from waterborne disease, and non-revenue water (NRW) losses -- caused by water leaks, unaccounted-for water, or system damage and failure -- amount to 16% of total water system output nationally on average, increasing to more than 30% in some older urban water systems (CBO, 2022; AWWA, 2020). A point lost in NRW exacts not only the financial cost, but it's a visible sign of structural deterioration which, if not corrected, will increase the likelihood of failure in the system.

However, all too often, construction project teams are faced with the challenges of siloed workflows, where trench safety, pipe installation quality, testing protocols, and documentation systems exist separately, not seamlessly connected as part of a unified control regime. This results in an 'execution model' that leads to unchecked bugs and delays being overlooked, and ultimately coming back to haunt the project at a high delivery price, a phenomenon the Project Management Institute (PMI) calls 'quality debt' (PMI, 2021).

The article suggests that water and sewer reticulation projects can be carried out more reliably, safely, and cost-effectively by reframing the construction process as an ongoing quality generation process, as opposed to a series of discrete tasks. The proposal is based upon OSHA trench safety standards (29 CFR 1926 Subpart P), AWWA pipe installation standards (C600, C900, and C200 series), EPA construction general permit requirements, and a growing expanse of research and experience in the infrastructure lifecycle cost modelling, which are presented to represent a seven-component project control architecture that is applicable to projects of any scale and method of delivery.

2. Utility Sequencing: The Foundational Control Discipline

2.1. Principles of Underground Utility Coordination

Seek out conflict, rework, and safety hazards by scheduling underground installation work as deference to utility sequencing is widely recognized in the literature as the greatest leverage project control a construction manager has on water and sewer construction projects (Tighe and Associates, 2019; National Academy of Sciences, 2020). However, the frequency of Underground Utility Damage (UID) events — typically 19 events for every day of the year — and the resulting losses continue to reflect as a significant cause of project delays (Common Ground Alliance (CGA), 2020), with the average loss per event being \$4,592 and loss per year at more than \$1.5 billion.

Thorough subsurface utility engineering (SUE) begins with an extensive investigation of subsurface utilities, in compliance with ASCE Standard 38-22, which outlines the four levels of subsurface utility data, ranging from D (record information) to B (surface evidence correlation) to C (designating) to A (test hole excavation). For every \$1 of expenditure on a Quality Level A SUE investigation before construction, ASCE estimates that \$3-\$12 of construction savings are obtained with each SUE (ASCE, 2022).

2.2. Sequencing Logic for Combined Water and Sewer Projects

Combined water and sewer reticulation projects require additional consideration of gravity for sewer pipe design, pressure for water pipe distribution, and space associated with separation distances required by state agencies enforced by primacy. Across the United States, the Great Lakes-Upper Mississippi River Board (GLUMRB) Ten States Standards (TTS), which provide the minimum standards in the United States, require that the minimum horizontal separation between parallel water and sewer mains is at least 10 feet, and that the minimum vertical separation between crossing water and sewer mains is at least 18 inches; water mains should be located above sewer mains wherever possible (GLUMRB, 2022).

A water environment federation (WEF) recommended practical sequencing matrix for a combined project is shown below, where the numbers refer to the listed task order: (1) storm drainage and large-diameter culvert installations, (2) gravity sewer mains (sanitary) installations, (3) water transmission mains installations, (4) water service laterals installations, (5) water service installations and (6) meter pit installations and valve vault constructions (WEF, 2021). The sequence reduces the chance of trench intersection, reduces simultaneous excavations, and provides for testing and acceptance of each phase prior to installing the overlying utility.

Table 1 Recommended utility sequencing matrix for combined water and sewer reticulation projects (adapted from WEF, 2021; GLUMRB, 2022)

Phase	Activity	Separation Requirement	Testing Gate
1	Storm drainage / large culverts	N/A	Pre-CCTV inspection
2	Sanitary gravity sewer mains	18" vertical from water (GLUMRB)	Low-pressure air or hydrostatic test
3	Water transmission mains	10' horizontal from sewer (GLUMRB)	Hydrostatic + disinfection
4	Sanitary laterals	Match the main separation	Mandrel test / CCTV
5	Water service connections	Separation per local code	Meter set and pressure check
6	Valve vaults/meter pits	Above finished grade drainage	Lid security + leakage inspection

3. Trench Safety: Regulatory Compliance as a Performance Control

3.1. Regulatory Framework and Statistical Context

Many deaths that occur on job sites are trench/excavation-related and preventable in the U.S. construction industry. On average, OSHA has twelve deaths related to trenches annually from 2011 to 2021, and even in 2022, there were thirty-nine deaths OSHA reported, which prompted OSHA to release a National Emphasis Program (NEP) for trenching and excavation safety in 2023 (OSHA, 2023). Thankfully, the enforcement of this OSHA standard for excavations (29 CFR Subpart P) is historically underwhelming. Violations of this standard make up nearly all these fatalities: During FY 2022, according to OSHA, this issuance of the OSHA standard was the 6th most cited in construction with 1,611 violations and \$4.2 million in associated penalty dollars (OSHA, 2022).

Similarly, there is a proactive side to managing the safety of trenches that makes good economic sense. A 2019 study from Liberty Mutual Insurance revealed that the average cost of a construction death – direct – was \$1.26 million, and the indirect cost of those deaths was estimated to be between 4 and 10 times the direct cost, which equals \$4.4 to \$12.6 million (Liberty Mutual, 2019). A single excavation fatality for a project team working on a \$5 million installation of a water main can manifest itself as the cost of the project exceeding the straight construction costs (Musariri et al., 2026).

3.2. Protective Systems and Soil Classification

For excavations that are 5 feet or more deep, OSHA 29 CFR 1926.652 mandates that some protective system be installed, except for excavations in stable rock. The standard identifies three main types of protective systems: sloping/benching, shoring, or trench shields (trench boxes). The type of system to be used will vary in line with soil type (Type A, B, and C), depth of excavation, and presence of any surcharge loading, including stockpiled material, construction equipment, and surrounding structures.

Research published in the Journal of Construction Engineering and Management has documented that the use of pre-engineered aluminum hydraulic shoring reduces the setup time per trench section by an average of 23% compared to timber shoring while providing equivalent or superior protection, making it the preferred system for water and sewer installation in Type B soils at depths between 5 and 15 feet (Guo et al., 2020). For projects in urban environments where Type C soils (granular, wet, or previously disturbed material) are common, trench boxes combined with dewatering systems represent the dominant industry practice.

Table 2 OSHA soil classification and protective system requirements for excavations (OSHA, 2023; Guo et al., 2020)

Soil Type	Description	Max Slope (H:V)	Recommended System
Type A	Cohesive, unconfined compressive strength ≥ 1.5 tsf	3/4:1	Sloping or benching is acceptable
Type B	Cohesive with fissures; granular; previously disturbed	1:1	Hydraulic shoring preferred
Type C	Granular, saturated, sloped, or disturbed	1½:1	Trench box + dewatering required
Layered	The most restrictive layer governs the entire excavation	Per Type C	Engineer-designed system

A key operational control that high-performing project teams deploy is the Competent Person pre-excavation inspection protocol, which OSHA requires before each shift, after rainfall or other hazard-increasing events, and as conditions change. Progressive contractors supplement OSHA's minimum requirements with daily trench safety checklists that document soil condition, equipment proximity, access/egress ladder placement, spoil pile setback distances (minimum 2 feet from trench edge per 29 CFR 1926.651(j)(2)), and protective system adequacy. These checklists create an auditable record that serves both as a liability shield and as a continuous improvement mechanism (Musariri et al., 2026).

4. Pipe Installation Controls: Achieving Specification Compliance from the First Run

4.1. Bedding and Backfill: The Foundation of Lifecycle Performance

Pipe bedding and backfill practices have been identified in multiple forensic engineering studies as the primary determinant of long-term pipe structural performance more influential than pipe material selection or wall thickness for flexible pipes (Moser and Folkman, 2022). AWWA M23 (PVC Pipe Design and Installation) and AWWA M45 (Fiberglass Pipe Design) both specify that the combined pipe zone backfill including the pipe bed (haunch to springline), the initial backfill (springline to 12 inches above crown), and the final backfill must achieve a minimum Proctor density of 90% for HDPE and PVC flexible pipes in most soil environments, rising to 95% in trafficked areas.

The haunch area (outside the pipe springline) was the most missed compaction zone in the 41%, according to field studies by the Plastics Pipe Institute that were conducted at 200 installations in 14 states, the area that is most difficult to compact because it is limited space next to the pipe (Plastics Pipe Institute, 2021). The same study also recorded a statistically significant relationship between the compaction of the haunch zone of less than 85% Proctor density and 5-year pipe deflection of installations, which had an average deflection of 4.1% and were nearing or exceeding the 5% deflection limit specified in ASTM D2321 for most applications (Musariri et al., 2026).

4.2. Joint Assembly and Connection Controls

For PVC and ductile iron pipe, the common pipe material for water distribution and gravity sewer pipe connections in the United States, the assembly process for push-on joints demands a series of controls for the process that are often jammed into a schedule and are missing. Consistent per the AWWA C600 (Installation of Ductile-Iron Mains and their Appurtenances) and AWWA C605 (Underground Installation of PVC Pressure Pipe) the following checks are required: checking gasket for cuts, foreign material and correct seat; cleaning pipe bell; lubricating joint surface with a NSF-approved lubricant; verifying deflection angle against maximum angular deflection tables provided by the pipe manufacturer, and measuring after pull-out to ensure that the joint is engaged.

A failure analysis conducted in 2021 and published in the Journal of Pipeline Systems Engineering analyzed 48 joint failures within water distribution systems in the U.S. over the last 10 years, and determined that 67% of the failures were related to the improper installation of gaskets either they were upside down or twisted or they were not lubricated 21% were caused by excessive deflection at the joint in curved alignment and 12% were related to inadequate thrust restraint at bends or tees (Rajani and Kleiner, 2021). The results highlight the very significant role of joint-by-joint inspection procedures, including those carried out by trained inspection staff. They can be used to help reduce the incidence of failures because of joints by an estimated 78% if compared with uninspected joints.

5. Quantity Measurement and Pay Item Verification

Accurate quantity measurement on water and sewer projects has a two-fold purpose: 1) to serve as the basis for paying by the unit price (the most common method of billing contracts for delivery to a municipal utility); and 2) to provide the foundation necessary for proper as-built documentation and record to populate the asset management system. One of the most documented reasons for contract claims on underground projects in the utility industry is the measurement of quantities. An American Public Works Association (APWA) survey conducted in 2020 reported that 38% of the claims in the utility project industry filed that year cited quantity measurement as a primary or contributing cause of claim (APWA, 2020).

Best-practice quantity measurement systems for reticulation projects require a three-tiered system of verification from daily in-the-field review by the construction inspector, to weekly review with the engineer's quantity review sheets, to an audit with the owner monthly against the project quantity schedule. For a work item that in most cases is the highest value item, in the case of trench excavation, dimensions of the trench (width, depth, length) are documented daily using calibrated boring, cutting, or lifting tools, and a photograph of the ground surface prior to excavation would document the pre-excavation profile of the ground surface. According to a 2019 study conducted by Construction Management and Economics, projects using this three-tier structure experienced 64% lower occurrence of quantity disputes and \$47,000 lower cost per quantity dispute than those that lacked such a structure (Arditi and Yasamis, 2019).

Table 3 Recommended quantity measurement methods and documentation requirements for unit-price water and sewer contracts (adapted from APWA, 2020)

Pay Item	Measurement Method	Documentation Required	Verification Frequency
Trench excavation (CY)	Cross-section survey, daily	Survey notes, photos, cut sheets	Daily
Pipe installation (LF)	Tape measure per joint, as laid	As-built stationing, photo per 500 LF	Daily
Granular bedding (TON)	Scale tickets + field verification	Delivery tickets, compaction test	Per delivery
Concrete encasement (CY)	Formed volume calculation	Pour records, batch tickets	Per pour
Maintenance holes (EA)	Inspection before backfill	Elevation, rim, and invert records	Per structure
Service connections (EA)	GPS-located completion record	Photo + GPS coordinate	Per connection

6. Inspection Readiness and Hold Points

One of the most important ways to avoid the burial of bad work and the associated costs of an excavation and reinstallation is using formal inspection hold points – points of the work which are specified in the contract and must be stopped until they are inspected by the regulators and/or owner and documented. The projects that have defined and enforced inspection hold points have 2.3% rework compared to 6.8% for projects with no formal hold points (acknowledgement to the Construction Industry Institute [CII] for this result, through its benchmarking program, and as referenced in their benchmarking report EE-2020 (CII, 2020), which equates to some ~\$450,000 in avoided rework costs on a \$10 million (re-)reticulation project.

Water and sewer reticulation should incorporate the following minimum hold point structure: Pre-installation trench inspection (soil conditions, bedding preparation, and utility clearance); Pre-burial pipe inspection (Joint assembly, gasket condition, pipe condition, grade, and alignment); Pre-pressure test valve and hydrant installation verification; and Post-test review of documentation before authorizing connections to the service. A standardized Inspection Release Form should be produced by each hold and should be signed by both the inspector and the contractor superintendent to ensure a clear record of the condition of the location at each point.

Apart from the minimum contractual structure, state environmental and public health agencies frequently set up other required inspection points. For instance, in California, inspectors must be certified and documented as holding a license by the State Water Resources Control Board Division of Drinking Water before a new water main can be put into service

(California DDW, 2021). Public health implications of these inspections apply to 38 other states, along with New York, Texas, and Florida.

7. Pressure and Leakage Testing: Coordinating the Critical Quality Gate

7.1. Regulatory and Standards Framework

Hydrostatic pressure testing is required on completed water main installations according to AWWA C600, C605, and C900. It is usually stipulated in the state design standards as a requirement for the approval of new water system installations. The test is divided into two sections: the pressure test that determines the integrity of joints and fittings; the leakage test that sets a maximum average rate of water leakage. AWWA C600 specifies a test pressure of 1.5 times the system's maximum operating pressure or 150 psi, whichever is greater, sustained for a minimum of two hours. Allowable leakage is calculated using the formula $L = (N \times D \times P^{0.5}) / 7,400$, where L is the allowable leakage in gallons per hour, N is the number of joints, D is the nominal pipe diameter in inches, and P is the average test pressure in psi (AWWA, 2017).

For gravity sewer systems, low-pressure air testing per ASTM C828 or hydrostatic (exfiltration/infiltration) testing per ASTM C969 is the standard quality gate before acceptance. A 2022 survey by the National Association of Sewer Service Companies (NASSCO) found that low-pressure air testing is specified in approximately 74% of U.S. municipal sewer projects due to its speed and simplicity, while hydrostatic testing is preferred for large-diameter mains and systems in high-groundwater environments (NASSCO, 2022).

7.2. Testing Coordination and Documentation

The pre-planning of project sewage test segments, location of temporary plugs, placement of blow-off valves, and water supply arrangements are critical in coordinating the testing efforts, not done as an afterthought at the end of installations. Testing arrangements that were pre-planned, as part of a project, shortened the average testing time from installation since the tests were completed by 8.4 days (Grigg, 2019).

Test documentation shall include: Test date and timing, Ambient temperature and pressure conditions, Test equipment calibration records, Pressurization curve (Pressure vs. Time graph), Calculated allowable vs. Actual leakage. A quality record is created when the gauge readings are photographed at the beginning and end of the test period, and the engineer states their signature on the test record form, creating an impervious quality record that can then be used for project closeout and future asset management.

Table 4 Pressure and leakage testing standards for water and sewer reticulation systems (AWWA, 2017; ASTM International, 2022; NASSCO, 2022)

System Type	Test Standard	Test Pressure	Duration	Pass Criterion
Potable water main	AWWA C600/C605/C900	1.5× MOP or 150 psi min	2 hours	Leakage ≤ allowable per AWWA formula
Gravity sewer (air)	ASTM C828	3.5 psig initial	Variable per diameter	Pressure drop < 0.5 psig in the hold period
Gravity sewer (hydrostatic)	ASTM C969	2 ft above HGL	1 hour	Exfiltration ≤ 50 gpd/in-dia/mile
Force main	AWWA C600	1.5× MOP	2 hours	Same as a potable water main

8. QA/QC Documentation: Building the Project's Quality Memory

A good water and sewer documentation addresses all three of these at the same time: 1) giving real-time feedback to the teams involved in the water and sewer project for corrective action; 2) meeting regulatory requirements for project acceptance; and 3) feeding into asset management systems that utility owners rely on for long-term operations and maintenance planning. The GAO stated that the lack of as-built documentation is among the main causes of unplanned infrastructure failures, as utilities without up-to-date records of what is installed, the type of joints, and the type and location of valves will result in repairs taking 2.3 times longer (GAO, 2021).

Reticulation project QA/QC documentation should include: daily construction report including details of crew being deployed, quantities being installed, weather conditions, non-conformance observed; material submittals and approved product list to identify product contents of installed materials; welder/joiner qualifications for any fusion and/or mechanical joint system; compaction test data by station and/or depth; materials as-built detail (station by station including as built elevations, deflections, joint movement observed); inspection hold points, release form; pressure and leakage test data; disinfection data in accordance with AWWA C651 (chlorination) or AWWA C665 (disinfection system).

Since 2018, documents on construction have been transitioning to digital format at a rapid pace, with many construction firms today successfully leveraging platforms like Procore, Autodesk's Construction Cloud, and Trimble's Viewpoint to manage their heavy civil projects with over 60% success rates, particularly for those exceeding \$5 million (JBKnowledge, 2022). These platforms allow for real-time photo geotagging, automated routing for approvals, and cloud-based storage, helping to avoid paper record loss – a documented source of project claims and closeout delays in utility projects.

9. Project Closeout: Converting Construction into Long-Term Asset Value

Although project closeout on water and sewer projects is often viewed as an administrative function and not a value-adding effort, records of the quality of closeout documentation often play a direct role in the operating cost of delivered infrastructure over time. According to a Water Research Foundation (2020) study, water utilities with as-built records in a GIS system incur an average cost savings of \$18/mi.

The water and sewer reticulation project will start with a structuring of the punch list, moving to the submission of regulatory reports, including all as-built drawings, test results and bacteriological clearance letters for portable systems, and then proceed to the training and transition of the operators, transfer of OWM documents, valve and maintenance hole exercise records, and spare parts inventories; asset data population in the owner's CMMS or GIS system, with material data, installation date, and location data for each pipe segment, valve, maintenance hole, and service connection entered; documentation of the warranties (including those for mechanical equipment and pipe, fittings, and valves); and the final payment application reconciling to confirm quantities on as-built have matched payment history and all change orders and claims have been resolved.

10. An Integrated Framework: Connecting All Controls

Each of the seven components outlined in this article contributes data and quality signals to the project control system, and is most effective when all the components operate together. Figure 1 illustrates this as a closed-loop control system outlining the inputs to documenting a day in the field, the QA/QC review of that documentation to provide an acceptance signal or corrective action requirements, and the flow of accepted documentation into closeout and asset management systems that will determine the value of the delivered infrastructure in the long term.

Implementation research is helping to inform this whole-of-approach. CII's (2020) Study of the impact of Process Integration on Quality Outcomes demonstrated that projects with 5 or more of the seven framework components achieved both a statistically significant improvement in Owner Satisfaction Index (OSI) of 23 percentage points, along with a statistically significant reduction of first year operational defect rate (FYODR) from 8.4 to 1.9 defects per mile. The qualitative results drive immediate and tangible reductions in warranty costs, in operating costs of the utility's infrastructure, and in service life of the assets—true value in public infrastructure delivery outcomes.

11. Conclusion

Water and sewer reticulation projects placed in U.S. communities are public trust responsibilities that require a systematic project control approach from the first excavation through to project acceptance. The examples in this article show that every component of the seven framework elements (utility sequencing, trench safety, installation controls, quantity measurement, inspection hold points, testing coordination, QA/QC documentation, and closeout) can provide tangible, independently documented cost and schedule savings, and enhanced safety risk mitigation and LTO expense reductions when effectively deployed.

Water infrastructure delivery of reticulation projects is anticipated to grow significantly in size and speed due to the maximum funding of \$55 billion for water infrastructure in 2022-2026 using the Infrastructure Investment and Jobs Act (Infrastructure Investment and Jobs Act, 2021). The increased pace will make it increasingly difficult to meet the

increasingly demanding requirements of public reporting and federal funding agencies to have consistent project quality assurance and control unless project teams adopt some systematic project control that will satisfy the expectations of an increasingly demanding public.

Further research ideas, such as using real-time trench condition monitoring through IoT sensors to meet OSHA's competent person inspection requirements, real-time simulation of the results of a hydraulic test with a digital twin model, and development of machine learning support for automated review and completeness verification of QA/QC documents. These new technologies offer the potential for further advancing the adoption of project control practices by projects and for further narrowing the performance gap between the designed and delivered infrastructure.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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