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Pipe Rehabilitation Recommendation

Technical Memorandum

Prepared for:

City of Bozeman
Stormwater Division

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1.0 EXECUTIVE SUMMARY

The purpose of this technical memo was to review existing trenchless stormwater pipe rehabilitation technologies and recommend treatment alternatives for two sections of critical stormwater conveyance infrastructure to the City of Bozeman Stormwater Division.

The following pipe rehabilitation technologies were reviewed:

- Pipe Bursting
- Grouting
- Shotcrete
- Slip Lining
- Cured-In-Place Pipe
- Fold and Form Lining
- Spiral-Wound Lining
- Centrifugally-Cast Concrete Pipe Lining

Two rehabilitation design alternatives were considered for each project resulting in a total of four proposed designs. Two types of cured-in-place-pipe (CIPP) linings are proposed and developed in section 5 for the Downtown Trunk line rehabilitation project. The South Willson Avenue rehabilitation proposals included fold and form lining and pipe bursting. The alternatives were developed with specific design considerations, environmental impacts, potential construction problems, construction best management practices (BMPs), sustainability considerations, and cost estimates.

1.1 SUMMARY OF RECOMMENDED ALTERNATIVES

Ultimately, a single alternative was recommended for each project based on logistic feasibility, availability, and cost.

As a reliable and environmentally-friendly trenchless rehabilitation strategy for the Downtown Trunk line, the proposed alternative utilizes CIPP lining consisting of non-reinforced felt liner and epoxy resin. The non-reinforced liner is cheaper than reinforced options, and the structural integrity of the current Downtown Trunk line is already acceptable. The epoxy resin provides a more expensive but environmentally-conscious alternative to commonly used, styrene-based resins for CIPP applications.

The proposed alternative for the South Willson Avenue line is combined pipe bursting and fold and form lining. Pipe bursting is recommended for the southern portion of the proposed rehabilitation line because the site is a less densely populated residential area and the existing stormwater conveyance is limited by the 6” pipe diameter. Fold and form lining is recommended for the northern portion of the proposed rehabilitation line because it is less invasive, will recondition the structural lifespan of the deteriorating pipe, and increase conveyance capacity. The entire proposed design can be found in section 6.2.

2.0 INTRODUCTION

2.1 STUDY OBJECTIVES

The Downtown Trunk line Rehabilitation study is as follows: rehabilitate 564 ft. of +100-year-old, 36-in. Vitrified clay tile pipe and two concrete manhole structures to extend the system's life cycle 50 to 75 years with minimal disturbance to adjacent properties, utilities, and roads.

The Willson Avenue Pipe Rehabilitation study is as follows: rehabilitate 3500 ft. of +100-year-old, 6-inch to 12-inch vitrified clay pipe to extend the system's life cycle 50 to 75 years with minimal disturbance to adjacent properties and roads.

With careful consideration of local BMPs, sustainable alternatives and environmental impacts will be assessed with each study. The Willson Avenue study area presents potential for various green infrastructure and sustainable development implementations which will be explored in this report.

2.2 BACKGROUND

2.2.1 GEOTECH

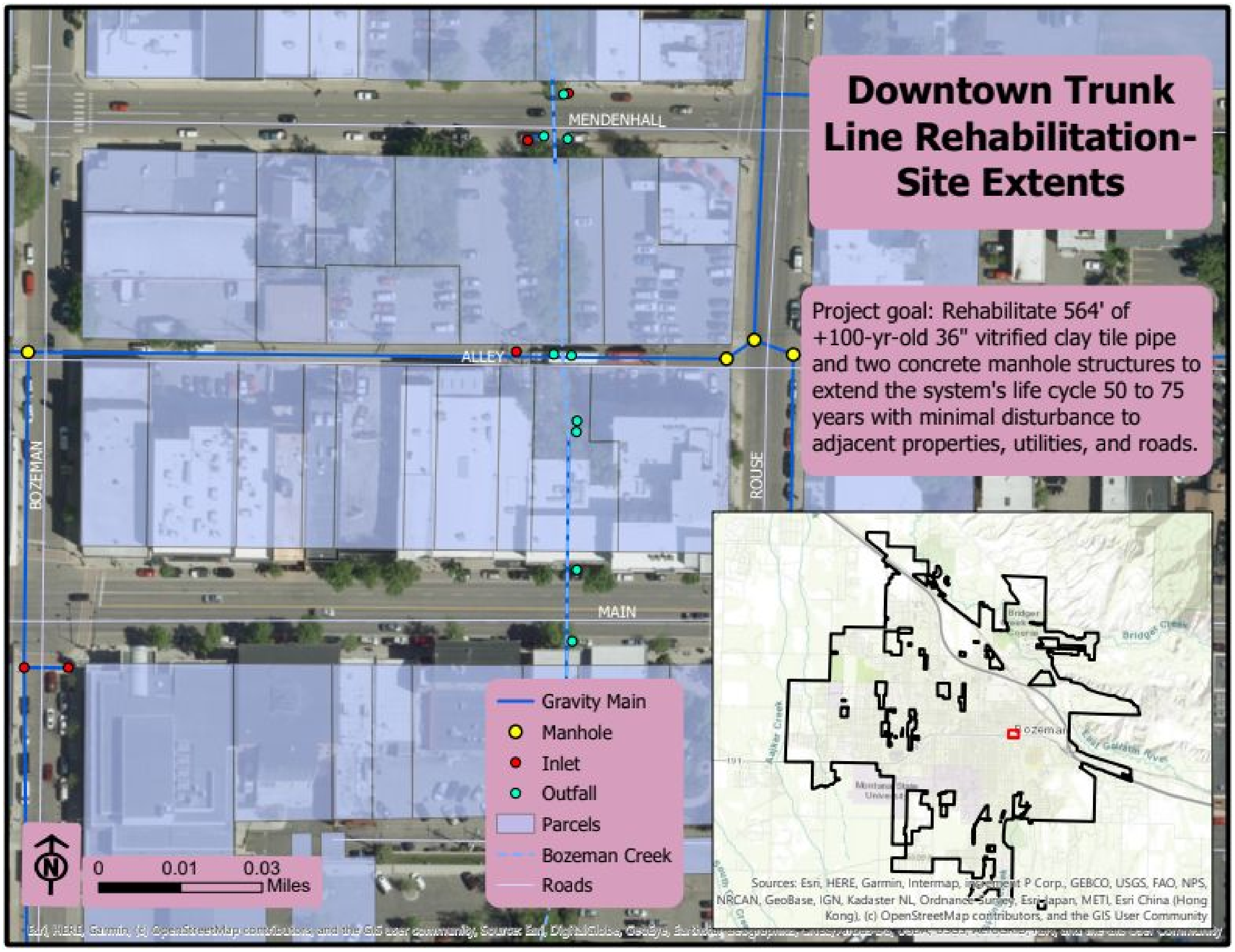
As with any underground utility work, the soil structure and properties should be considered and all alternatives should be evaluated with soils in mind.

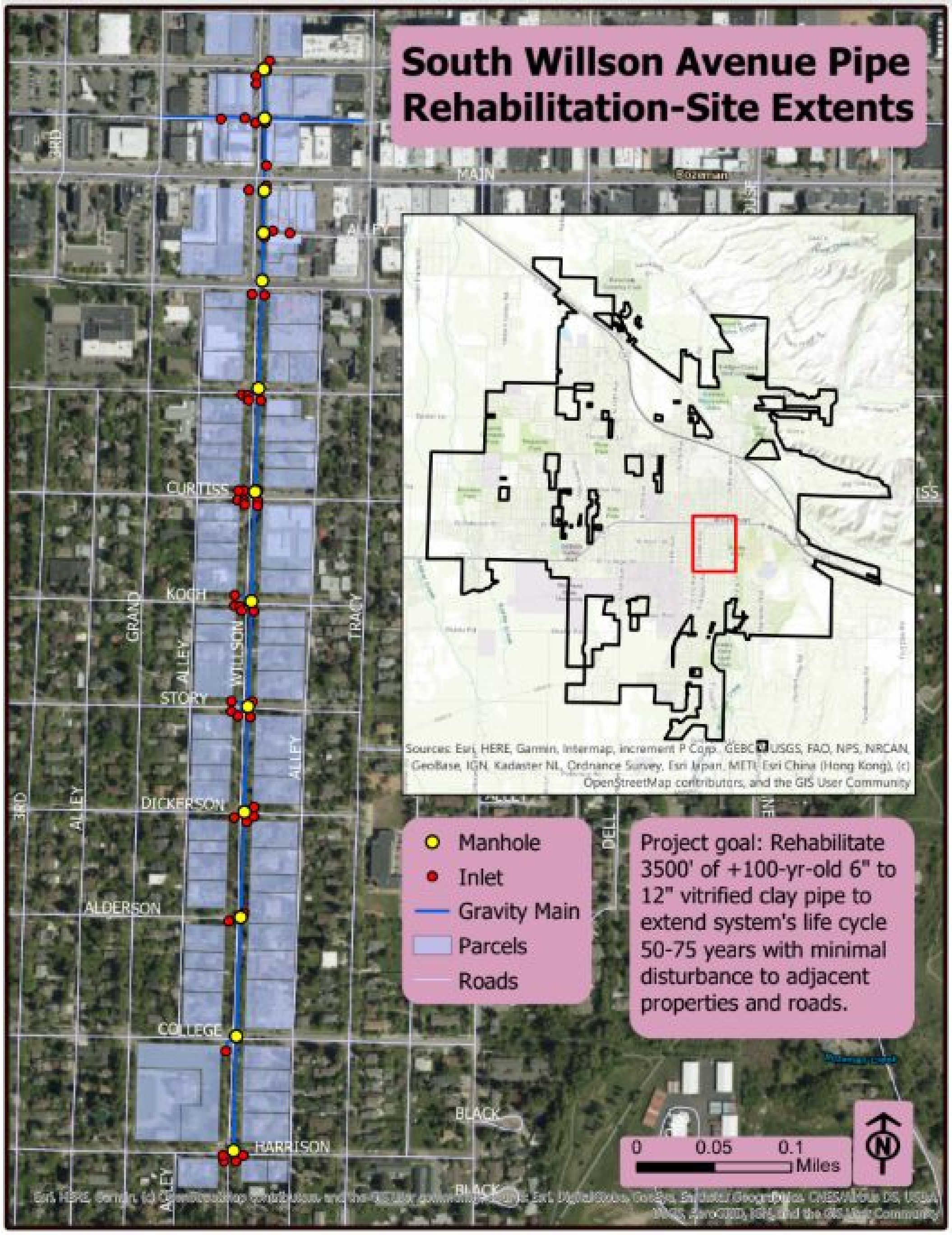
It is difficult and expensive to drill for all projects in city limits so well logs from the Montana Bureau of Mines and Geology Ground Water Information Center (GWIC) have been utilized. The GWIC has well logs from all permitted wells in Montana. There were many wells around the two project sites and a few logs were extracted to give an idea of the soils around each of the storm lines.

The Downtown Trunk line is under a couple (2-4 feet) of topsoil followed by a mix of clays and gravels common to the Bozeman area. Groundwater is likely around the pipe with static levels in the well logs ranging from 6-feet to 15-feet. There is significant variability possible in groundwater levels but it will be assumed to be somewhere near this range. Therefore groundwater is likely around the Downtown Trunk line since it is approximately 15-feet below the surface.

The Willson section is similarly under a few feet of topsoil followed by a mix of clays and gravel. Groundwater levels are a bit deeper than on the Downtown Trunk line. The water table is on a range of 10-feet to 25-feet. While the groundwater is lower on the Willson line, groundwater is still likely around the storm line with the line being around 15-feet below the surface.

2.2.2 SITE MAPS




South Willson Avenue Pipe Rehabilitation-Site Extents
Manhole
Inlet
Gravity Main
Parcels
Roads
Project goal: Rehabilitate 3500' of +100-yr-old 6" to 12" vitrified clay pipe to extend system's life cycle 50-75 years with minimal disturbance to adjacent properties and roads.
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0.05
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Miles
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MAIN
ALLEY
STORY
CURTISS
KOCH
GRAND
WILLSON
TRACY
DICKERSON
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COLLEGE
HARRISON
BLACK
3RD
DELL
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

3.0 DESIGN CONSIDERATIONS

The proposed water management strategies were designed to consider the floodplain boundaries in the City of Bozeman and appropriate sustainability and low impact development (LID) considerations. Alternatives were developed to comply with the City of Bozeman Stormwater Management Plan and the State of Montana Post-Construction Storm Water Best Management Practice (BMP) Guidance Manual.

3.1 FLOODPLAINS

The City of Bozeman's stormwater conveyance system incorporates Bozeman Creek, which intersects and flows beneath Main Street. The Downtown Trunk line lies partially in the 100 and 500 year floodplain of Bozeman Creek. Construction within the floodplain boundaries must comply with the City's Floodplain Regulations and may require a floodplain development permit.

The South Willson Avenue pipe rehabilitation site is not within a floodplain and no additional permitting is expected.

3.2 SUSTAINABILITY

Green infrastructure and implementation of sustainable stormwater development can help control peak runoff volumes and improve water quality in a stormwater system. With sustainable stormwater practices urban runoff is routed into pervious areas where ecological and hydrological functions reduce the impacts of large impervious areas on municipal infrastructure and downstream riparian areas. Sediment and contaminants can be intercepted before reaching major conveyance systems.

3.3 LOW IMPACT DEVELOPMENT LID

Stormwater is a resource that can be integrated into an urban landscape. Low impact design parameters mimic natural water cycles and use basic principles modeled after nature to manage rainfall and the resulting runoff. Progressive stormwater design through LID practices focuses on peak flow rate and total volume control within the system. Flood prevention, stream channel protection, water quality improvements, and groundwater recharge are all potential outcomes of a well developed LID program.

3.4 BEST MANAGEMENT PRACTICES (BMPs)

The stormwater rehabilitation alternatives in this memo were informed through the guidance of the State of Montana's Post-Construction Storm Water BMP Design Guidance Manual. Non-structural and structural BMPs have been considered for each rehabilitation project to minimize stormwater runoff potential throughout the construction and post-construction phases of the rehabilitation.

4.0 STORMWATER PIPE REHABILITATION TECHNOLOGY REVIEW

The following culvert rehabilitation technologies reviewed below can be used to provide initial guidance in choosing the appropriate rehabilitation method. Both the Downtown Trunk line and Willson Avenue line rehabilitations will require one or multiple of the following technologies.

Unless specifically identified, adverse water quality issues may arise in leaky stormwater pipes/damaged stormwater pipes due to sedimentation problems. As part of the pipe rehabilitation process, particular attention will be paid to eliminate gaps in piping where sediments and other suspended solids may enter the stormwater system.

4.1 PIPE BURSTING

Pipe bursting is a trenchless remediation technique that replaces the existing pipe with a new line by pulling a new pipe through the original channel. This method utilizes a hydraulic bursting unit to pull the new pipe through by way of cable or winch. The new pipe will push the existing pipe outward radially, causing it to break and leaving room for the new pipe. The tip of the new pipe, in the direction of pulling, will have an “expansion head” attachment that has conical geometry for radial pipe bursting. This method works best for similar- or larger-diameter pipe replacements. Pipe bursting requires two holes to be excavated in order to complete: one hole to pull the new pipe and one hole to give access to the new pipe.

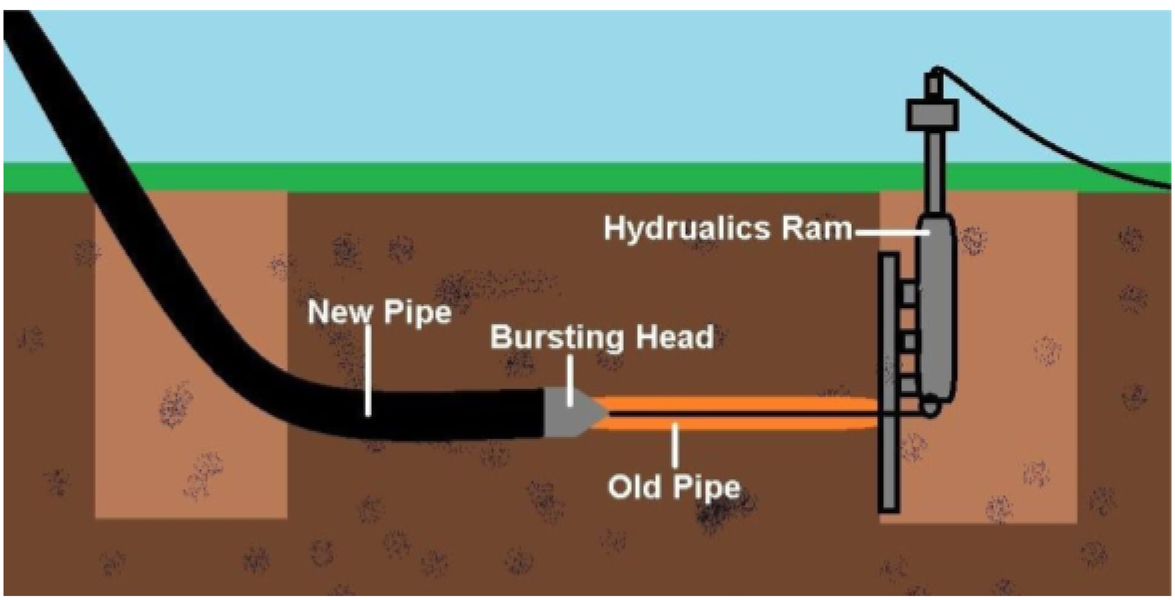


Image from Plumber of Tucson Plumbing Services. Tucson, AZ

There are two types of expansion heads: static and dynamic. Static heads are simply pulled through the existing pipe; the pipe bursting effect comes from just the pulling motion. Dynamic heads are additionally driven by either air (pneumatic) or water (hydraulic) forces pushing on the head in the direction of pulling. The static option is preferred in most cases for the purpose of minimal soil/surrounding composite disturbances, but the static option is not always possible.

While pipe bursting does not pose any immediate threats to water quality after installation, it may be necessary (depending on site conditions and equipment location) to install a protective sleeve on the outside of the new pipe (Simicevic, 2001). This sleeve would help keep localized contaminants such as dirt, oil, and exhaust gas from the operating machinery out of the rehabilitation area. Sleeves are beneficial when the pipe bursting process is intrusive to surrounding soils and the area around the pipe.

ADVANTAGES

- The existing pipe length is under the specified capability length (750')
- Video footage assures no major debris or pipe obstructions on the existing pipe
    - Major debris or pipe obstructions may induce a larger force requirement or make pipe bursting impossible
- Manholes could likely be used as access points unless desired pipe has a larger diameter than the manholes themselves

DISADVANTAGES

- The existing pipe is 36" which may require a large amount of force to pull through
    - Typical range of diameters for pipe bursting is between 2" and 24"
- There are 26 connection pipes into the downtown line that would likely be damaged during bursting
    - If not damaged, their connection to the trunk line would need to be realigned/accommodated
- There are multiple utilities and structures nearby
    - Any ground disturbance or upheaval could be dangerous for the surroundings
- Base flow must be bypassed
- Pipe bursting debris could build up in manhole area or cause damage to the manhole alignment
- Dynamic bursting may cause underground, unknown structural damage to nearby buildings

4.2 GROUTING

Grouting is either a cement based or chemical mixture used as a pipe rehabilitation technique for minor repairs like cracks and joint defects. The grout technique can be applied robotically or by human entry where the storm drain is large enough. Voids are filled pneumatically or with gravity-assisted injection. Void spaces can be addressed adjacent and outside of the storm drain as needed. Injecting grout requires onsite mixing on grouting materials, because of this, colder regions and below freezing ambient temperatures pose significant challenges to effectively injecting a continuous stream of grout. Grouting is ideal for simple, short term repairs and should not be used for major structural defects. Chemical grout when properly applied will create a water-tight seal in leaky joints and will withstand normal ground movement.

ADVANTAGES

- Helps prevent long-term deterioration
- Cost effective
- Repairs cracks seals voids
- Seals joints
- Provides stabilization for the surrounding groud

DISADVANTAGES

- Potential toxicity of grouting materials and environmental effect
- Soil type/chemistry can affect the process
    - Also temperature, moisture, and ground water can have effects
- External grout pressure can collapse new lining

4.3 SHOTCRETE

Shotcrete is similar to grouting but uses primarily a cement-based mixture and compressed air to apply. The shotcrete mixture can include additives like steel fibers to improve the strength of the cured product. However, shotcrete is not preferred in areas where the minimum daily temperature is less than 40 degrees fahrenheit. Shotcrete is applied to the interior of the pipe both by human entry and robotic application. Human entry is appropriate for large diameter pipes and requires trained personnel.

Image from Proshot Concrete, Inc.

Robotic application is reserved for smaller diameter (< 30 inches) pipes where human entry is not possible and can be used in coordination with CCTV. Wet or dry mixes can be used, both require the pipe to be clean and moisturized before the repair process begins.

ADVANTAGES
- Not environmentally invasive assuming a CCTV device is capable of holding a spray device
  - Pneumatic application does not require expansive access point(s)
- Increased structural integrity
- Potential for increased corrosion resistance (certain mix)

DISADVANTAGES
- Reduces hydraulic capacity via diameter reduction
  - Can be significant depending on desired/design shotcrete thickness
- Must bypass the base flow long enough to clean the inside diameter of the existing pipe as well as dry the shotcrete mixture
- Any significant void spaces must be filled or blocked before shotcrete application, otherwise the wet shotcrete mixture will run or block holes
- 36” existing pipe is too small for human application

4.4 SLIP LINING

Slip Lining is a technique that involves threading a small pipe through the existing pipe. The ends of the pipes are sealed so that there is only one line between the existing pipe and the new pipe. High density polyethylene, PVC, and fiberglass-reinforced pipe are used for the new pipe material. This method is common for pipe rehabilitation in the form of pipe repair and to reinforce stability. This method can be used on pipes sized from 8 inches to 60 inches.

ADVANTAGES
- Stops infiltration
- Provides structural stability
- Cost effective
- Doesn’t necessarily require bypass of baseflow
- Easy to install
- Can install with manhole access

DISADVANTAGES
- Reduces the diameter of the pipe
- Continuous slip lining does require a bypass of the base flow
- Sewer laterals must be reconnection with excavation
- Any ties must be reconnected after the fact

4.5 CURED-IN-PLACE PIPE

Cured-in-place pipe (CIPP) involves a step-by-step process of inserting a flexible fabric liner, coated with a resin, into the existing pipeline. The flexible liner is then cured to form a new liner along the inside of the existing pipe. The liner can be inserted via manhole access, and typical resins include unsaturated polyester, vinyl ester, and epoxy.

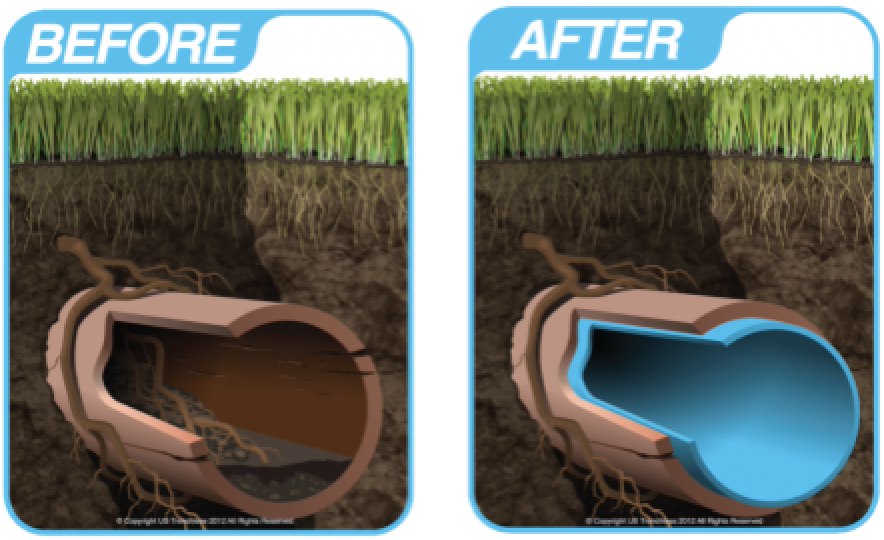


Image from US Trenchless, General Engineering & Plumbing

The chosen resin is thermosetting, and will form a stronger bond with existing pipe materials than most other trenchless rehabilitation techniques. There are two typical practices of feeding the liner tube through the existing pipe: winch-in-place and invert-in-place. Winch-in-place involves using a winch system to pull the liner through the existing pipe, at which point the tube is inflated to push the liner with resin up against the sides of the pipe. Invert-in-place, which is more commonly applied, utilizes gravity and either hydraulic or pneumatic forces to force the tube through the pipe and invert it (turn it inside-out). The inversion pushes the resin side of the liner up against the existing pipe.

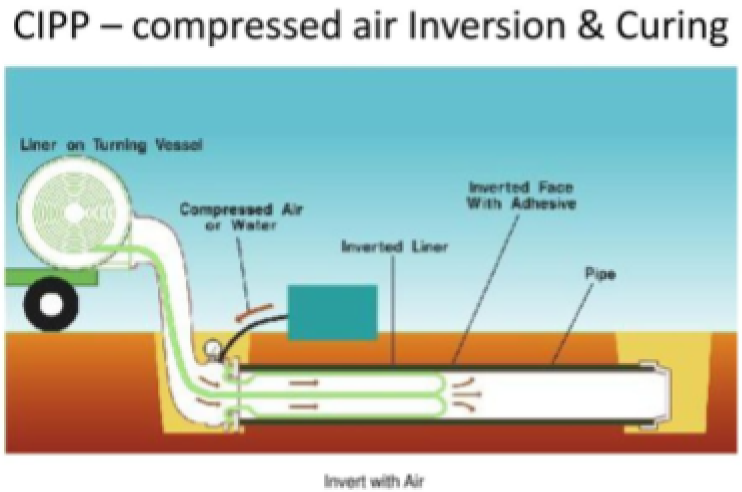


Image from the Hong Kong Institute of Utility Specialists (HKIUS)

In both cases, and after the resin side of the liner has been applied to the existing pipe material, heat is then circulated through the system to form that strong resin bond with the existing pipe's inner diameter. Typical steps in the inversion CIPP process are as follows (many of these steps also apply for the winch CIPP process):

1. View CCTV footage to identify connections and any noticeable damage areas
2. Wash out pipe with high-powered water jet
3. Assemble the liner (inversion may require a calibration tube setup provided by contractor specializing in this practice)
4. Mix the resin/epoxy
5. Pour the mixture into the liner
6. "Wet-out" the liner (squeeze like a tube of toothpaste) so all material fibers become coated in the resin
    a. Store in ice until ready for inversion so the system does not start to cure (heated cure)
7. Load the inversion tank/mechanism (contractor-owned) to instigate the inversion process
    a. The inversion process enables the liner to slide invertedly out of the calibration tube, ultimately filling the pipe
8. Fore compressed air or pump water through the tube to push the liner out through the inversion head (tip)
9. After a few hours to cure, cut the appropriate branches (inlets) with a robotic arm or other machinery

In conjunction with the U.S. Department of Transportation, a research project was conducted regarding the potential for adverse water quality impacts from CIPP liners. The two liners were Vinyl Ester CIPP lining and UV CIPP lining (Donaldson, 2012). Donaldson was attempting to analyze the contamination from these two specific CIPP liners, but noted that "traditional CIPP" already had regulations regarding curing time before allowing water in the system:

i) Contractor must place an impermeable sheet immediately upstream and downstream of the host culvert prior to liner insertion and dispose of any waste materials (VDOT, 2008)

ii) Liner must be rinsed following installations (and the rinse water must be properly disposed of)

These specifications are not in place for Vinyl Ester CIPP, but “adherence to these procedures may have prevented the high contaminant concentrations found in water samples” (Donaldson, pg. 10).

The Vinyl Ester CIPP lining exhibited high concentrations of Vinylic Monomer, a similar result compared to traditional CIPP applications. While the UV CIPP did not exhibit concernable levels of contaminants during the tests, the UV-setting resin contains styrene, which is “reasonably anticipated to be a human carcinogen” (National Toxicology Program, 2011). Due to the carcinogenic nature of styrene, there are already CIPP requirements for installations that are “styrene-based.”

Donaldson used both flowing water tests and immersion tests to identify water quality issues with these CIPP practices:

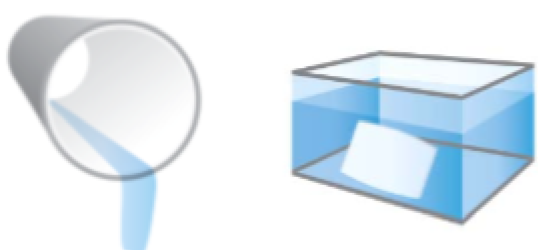


Figure courtesy of Donaldson's review of "Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners"

Donaldson notes that significantly lower traces of contaminants were recorded during the flowing water test, lending the idea that certain contaminants (i.e. styrene) are potentially mitigated by water flow. She also notes that the CIPP liners were not given substantial setting time before testing, leading to higher contaminant measurements—and consequently more adverse water quality impacts. Donaldson recommends the following: removing the term “styrene-based” from CIPP requirements so that all liners must follow the same safety requirements and adding a water sampling aspect to current requirements to ensure neutral water quality impacts (Donaldson, pg. 22).

ADVANTAGES

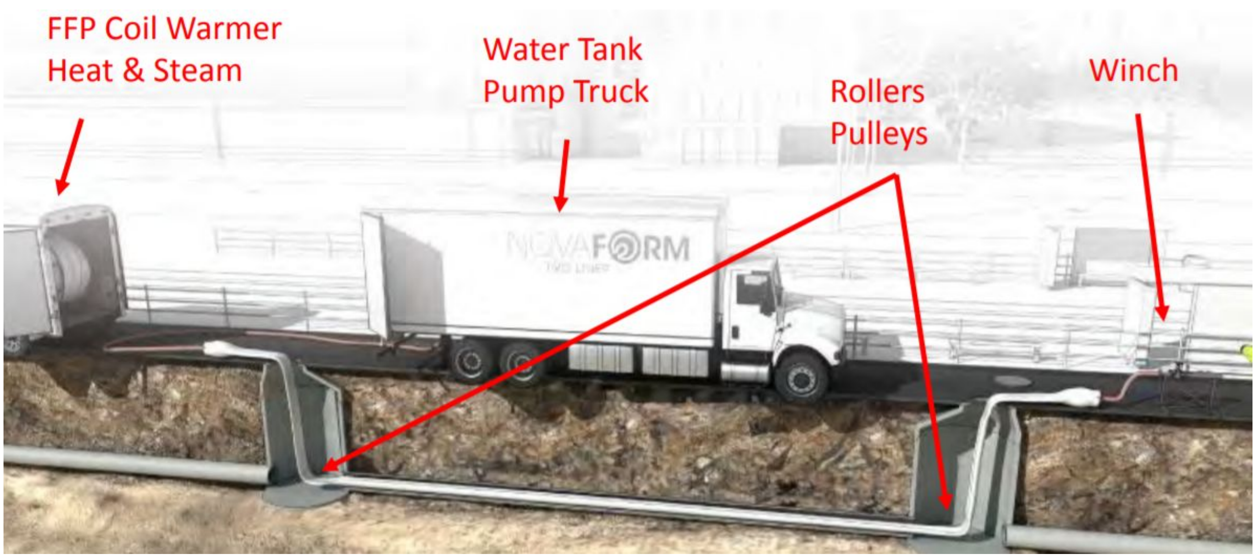
- Can be cured using multiple methods
  - Ultraviolet light, air, steam, heating water and recirculation

- Can be used on pipes sized up to 108 inches
- Lining can decrease the surface Manning's n value
    - Thereby increasing hydraulic capacity
- Cost-effective
- Entry possible through manhole or pipe ends
- Non-toxic epoxy can be used for sensitive environments
- Can be structural or non-structural depending on needs

DISADVANTAGES
- Slightly smaller diameter
- May require baseflow bypass depending on site

4.6 FOLD AND FORM LINING

Fold and Form Pipe (FFP) is used to rehabilitate many different underground utilities including water mains, gas lines, and sewer mains. This rehabilitation technique gets its name from the way the liner is 'folded' to fit through the old pipe. The old (to be rehabilitated) pipe is carefully measured to ensure the liner will fit snugly but still able to fully expand after being folded. Extruded PVC or PE thermoplastics are 'folded' into a U or H shape and coiled up in a factory. On-site the coil is heated until pliable and pulled through the old pipe. The liner is then pressurized with steam to expand to fit the existing round pipe. The liner is then cooled to harden and any laterals cut out.



ADVANTAGES
- Can be performed on smaller pipes ranging from 3" to 30"
- Local crews can be trained to perform this work in approximately one week
- Has an approximately 50 year life like other PVC products
- No need for pits, it can be installed manhole to manhole
- Can be installed in pipes of any material
- Can be used on potable water lines

- Minimal environmental impact (no residues)

DISADVANTAGES
- Requires special installation equipment
- Need to bypass or hold flow during installation
- Not applicable to larger than 30” pipes

4.7 SPIRAL-WOUND LINING

Spiral Wound-Lining, also called SWL, is used to rehabilitate sewer and culvert pipelines. The method consists of sliding a plastic strip, either PVC or HDPE, through a widening machine that moves along the pipe. This provides interlocking edges that form a smooth, leak-tight, continuous liner. A sealant is used to keep the seams watertight. Rigid pipes and flexible pipes can be used. The rigid (fixed-diameter) pipe is appropriate for non-circular culverts with access restrictions. The flexible pipes can be expanded to fill the pipe by pulling a wire that runs through the spiral joint. Steel reinforcement can be added to increase the structural integrity of the system.

ADVANTAGES
- Pipes can range in sizes from 8” to 60”
- Has an approximately 50 year life like other PVC products
- Can be installed with live flow - no need to bypassing
- No need for pits, it can be installed manhole to manhole
- Can be installed on any pipe material

DISADVANTAGES
- Relatively thick (7mm +) lining
- Requires special installation equipment
- Need to cut out and seal laterals after lining

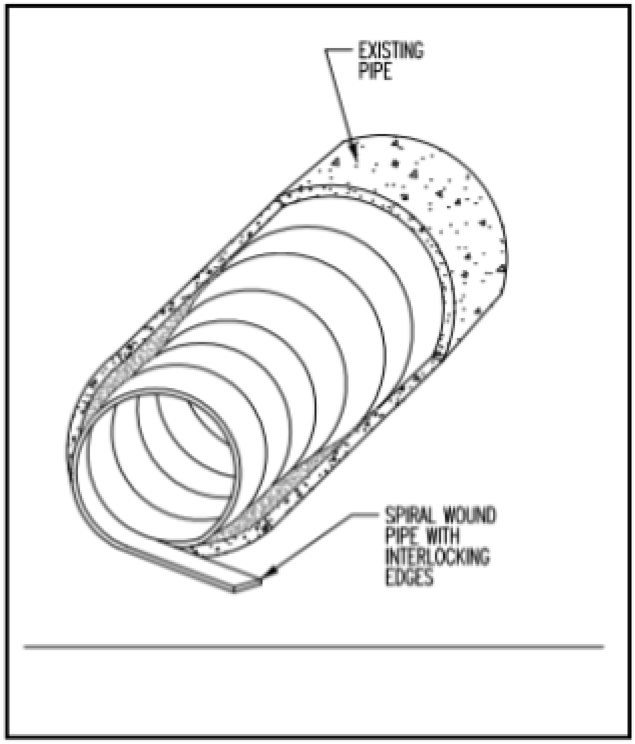


Image from the EPA Trenchless Rehab Fact Sheet

4.8 CENTRIFUGALLY-CAST CONCRETE PIPE LINING

Centrifugally-Cast Concrete Pipe Lining (CCCP) is a strategy for rehabilitating corrosion defects in CMP pipes, sewer and culvert pipelines. This method utilizes a spincaster (can be manually or robotically mounted) which applies a thin coat of fiber-reinforced cement material at high velocities on the inside of the pipe. This effectively waterproofs the pipe, prevents corrosion and inhibits abrasion. Structural integrity is reliant on how this the layer of material is.

ADVANTAGES

- Great for larger pipes 30” to 120”
- Only need one manhole end to apply as opposed to two manholes like many other rehabilitation techniques
- Can be applied to any cleaned pipe material
- Can also be used to rehabilitate manholes
- Lasts as long as standard concrete pipe
- Could be applied on pipes with varying diameters

DISADVANTAGES

- Flow needs to be diverted during application
- Need to cover laterals during application
- Requires special installation equipment
- Cannot be used on smaller < 30” pipes
- Relatively thick finished product varying around ¾”

5.0 SELECTION OF ALTERNATIVES AND PROPOSED DESIGN FOR THE DOWNTOWN TRUNK LINE REHABILITATION

5.1 ALTERNATIVE 1—REINFORCED CIPP LINER WITH EPOXY RESIN

There are two prominent types of reinforced CIPP liners—glass fiber and carbon fiber (Hyun et al., 2018). The glass fiber liners are typically accompanied with a UV-setting resin, which creates complications related to UV light penetration limitations in the liner thickness. For UV-setting resins, UV light penetration is limited to approximately 1.2 m for the pipe diameter (Hyun et al., 2018), otherwise the light will not be able to cure the circumferential span of the pipe. Hyun et al. also notes that it is an industry standard to assume the UV light can penetrate approximately 10 mm of glass fiber liner thickness. Both carbon and glass fiber greatly increase the mechanical properties of the pipe, including flexural strength and modulus (Hyun et al., 2018). However, due to the complications associated with glass fiber liners and UV-setting resins, only carbon fiber liners will be further considered. The following discussion takes a closer look at the implementability of fibrous carbon liners:

On a basic level, increasing the structural integrity of the existing pipe as much as possible is the end goal. However, there are some caveats associated with choosing the appropriate reinforced liner. Fiber layers with high Elastic Moduli substantially increase project costs and may cause issues related to resin-setting on fibrous material layers (Smith et al. 2005). Notice the following table illustrating the tensile strength (psi) and Elastic Modulus (psi):

Property	Carbon Fiber	Glass Fiber	Uni-directional Carbon + resin	Uni-directional Glass + resin	Bi-axial Glass + resin
Tensile Strength psi	450,000	350,000	182,000	161,000	80,000
Tensile Modulus	33,000,000	11,600,000	21,000,000	7,500,000	3,000,000
S.G.	1.7	2.54	1.5–1.6	2–2.1	
Elongation At break	1.2	4.6	1.2	3.5	?
Flexural Strength			290,000	170,000	80,000
Flexural Modulus			18,000,000	7,500,000	2,800,000

Table of material properties from Smith et al., 2005

Thus, carbon fiber exhibits a higher Elastic Modulus than its competitor, the glass fiber composition. Despite the previously-noted potential for higher costs related to higher Elastic Moduli, it is later explained that “this [price] difference disappears in view of the three times greater modulus of the carbon fiber compared to glass. This is due to the fact that the volume of reinforcing fiber needed is inversely proportional to the modulus. In view of this, only one-third the volume of carbon compared to that of glass is required (Smith et al., 2005).” So, the carbon fiber option is not more expensive after all. Here is another table from the same patent paper, illustrating a summarized view of more material parameters to be considered:

Material	E Modulus p.s.i.	Relative Density	Coefficient of Thermal Expansion*
Resin/felt	250 to 400 × 10^3	1.2 to 1.3	30 × 10^{-6} in/in ° F.
Carbon Fiber	33 × 10^6	1.77	–.05 × 10^{-6} in/in ° F.
E-Glass	10 × 10^6	2.54	

*Measured between 75° and 195° F.

Table of material properties from Smith et al., 2005

Again, this table shows the comparison of Elastic Modulus between the two reinforced liners—carbon fiber and glass. This time, the reinforced liners are compared to the non-reinforced liners and the difference in stiffness, which can bolster the structural integrity of the rehabilitated pipe, is quite apparent. Even though the carbon fiber exhibits a greater stiffness (Elastic Modulus), it has been applied in a substantial amount of trenchless rehabilitation projects and proves to function. There cannot be any significant bends in the rehabilitated pipe or major ground upheavals, but those will not be as prevalent within this Downtown Trunk line setting. On a final note, the carbon fibers are not as susceptible as glass fibers to wicking and corrosion attack from acidic composites in stormwater (Smith et al., 2005). This concept is especially important at openings where the liner fibers may be exposed laterally to the stormwater—such as at cut-out lateral connections. The acidic composites can corrode glass fibers easier, comprising the stiffness and structural improvements at connections and other lateral placements (Smith et al., 2005). After these considerations, carbon fiber will continue to be the optimal choice for reinforced CIPP lining.

With regards to the epoxy resin, the initial cure and lifespan of the epoxy resin is dependent on the hardener used during installation. There are various types of hardeners that can be used depending on site conditions (Moore, 2011), but the key is to follow the manufacturing guidelines for ambient temperatures during curing. The epoxy resin manufacturer will ensure proper mix of the epoxy resin and hardener as well as provide those temperature guidelines. It is then up to the installer to follow those guidelines. Many epoxy resins are fully cured in under 7 hours, with a maximum cure time of 24 hours in colder or less ideal conditions (Moore, 2011). The epoxy resin mixture has an exotherm that heats up while curing and then noticeably cools down once the resin is fully stable.

DESIGN CRITERIA

The reinforced CIPP liner with epoxy must be capable of rehabilitating the 564-ft., 36-in. vitrified clay tile pipe, ultimately extending the system's life cycle by approximately 50 to 75 years. Additionally, during and post-construction, there must be minimal intrusion/disturbance to nearby properties, utilities, and roads.

Consideration of maintaining the hydraulic capacity of the Downtown Trunk line must be made as well. Hydraulic capacity calculations are shown in Appendix 9.2 regarding both CIPP alternatives at a range of bed slopes. In all cases, hydraulic capacity post-CIPP lining is greater than the existing pipe capacity. Since carbon fiber has a similar texture composition to fiberglass (Notchtex, 2017)—which has a Manning's roughness of 0.008 (ACO Polymer Products, Inc., 2020)—a manning's roughness coefficient of 0.009 was used for the carbon fiber hydraulic capacity calculations. This roughness coefficient is slightly higher than that of fiberglass for a more conservative calculation. A carbon fiber liner thickness of 15 mm. was used for the hydraulic capacity calculations, as well as 1 mm. additional thickness of resin (Das, 2016). The optimal slope information for the bed slope of the Downtown Trunk line is an approximation, so a range of slopes between 0.75% and 1.25% were used for the hydraulic capacity calculations. Additionally, using a range of bed slopes for these calculations allows a generalizable capacity calculation approach for other pipe systems around Bozeman.

The concrete manhole structure on the upstream end of the trunk line (Manhole ID: M.F04.00062) was installed in 1915 and is shown by the Bozeman GIS Infrastructure Viewer to be scheduled for maintenance. Its access diameter is 26-in., and the non-intrusive nature of the CIPP liner installation will allow both rehabilitation of the trunk line and upstream manhole structure to be completed in a timely manner. The downstream concrete manhole structure (Manhole ID: M.F04.00061) has already received maintenance.

ASTM guidelines specify that base flow must be rerouted via pumping to a downstream point location (Donaldson, 2009). ASTM further specifies that heated water or steam (depending on which type of used for the CIPP inversion process) must be drained on the downstream end of the liner and flush the system with cool water. This prevents any environmental degradation from occurring during the initial, heated segment of the curing process.

ENVIRONMENTAL IMPACTS

Epoxy resins are the more "environmentally friendly" resin as they do not emit VOC emissions or HAP, do not produce odors, take less time to set, and instigate less surface disruption (Jones, 2011). As a movement towards green infrastructure, the epoxy resins provide a means of achieving minimal environmental degradation while not compromising the system's life cycle. Epoxy, most commonly Ethylene Oxide or Diglycidyl Ether of Bisphenol-A in CIPP liner resins (Bruzzone et al., 2007), is resistant to hydrolysis due to its chemical structure.

With that said, the installer still must make careful consideration to follow ASTM guidelines as "it is the responsibility of the user to establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use (Donaldson, 2009).

POTENTIAL CONSTRUCTION PROBLEMS

For the epoxy resin to set properly, the temperature inside of the liner must be appropriate following manufacturer guidelines. Many industry applications estimate the cure time based on an ambient temperature inside the liner of 77 degrees Fahrenheit, potentially requiring hot air to be pumped through the system during cure time (Wodalski, 2013).

Using a robotic device and CCTV, there are 26 connections in the Downtown Trunk line that must be identified and reconnected to the system.

CONSTRUCTION BMPS

The following BMPs that must take place during construction are from the MT DEQ 2018 SWPPP Form (Department of Environmental Quality, 2018):

Erosion Control BMPs:

- Minimizing ground disturbance

Sediment Control BMPs:

- Tarps/plastic coverings to minimize sediment movement (especially near access zones like manholes)
- Stabilized parking/staging area (especially for the vehicles carrying CIPP materials for installation)

Administrative Control BMPs:

- Worker toilets
- Dumpsters/waste receptacles
- Material storage and stockpile area
- Traffic control

SUSTAINABILITY CONSIDERATIONS

Under the same ambient conditions, epoxy resins cure faster than other, styrene-based resins (Jones, 2011). Because of this reduced project timeframe, the overall carbon footprint of the trenchless rehabilitation is reduced. Furthermore, the reinforced carbon fiber liner will add structural integrity to the system that will last at least the target lifespan of 50 years. Additionally, it is estimated the epoxy resins continue to function for up to 75 years (Selvakumar, et al., 2002).

COST ESTIMATES

Epoxy resin is more expensive than other resin options (Selvakumar, et al., 2002). The following table provides an approximate cost breakdown for epoxy resins:

Table 1. Summary of Rehabilitation/Replacement Methods

Method	Pipe size range[b] (diameter in inches)	Common Materials	Generic cost ($/in. diameter/ft)	References for cost
Cement mortar lining	4–60	Cement-sand	1–3	Gumerman et al. 1992
Epoxy lining[a]	4–12	Epoxy resin	9–15	Conroy et al. 1995
Sliplining	4–108	HDPE, PVC, fiberglass reinforced polyester	4–6	Gumerman et al. 1992
Cured-in-place pipe	6–54	Polyester resins	6–14	Gumerman et al. 1992
Fold and form pipe	8–18	HDPE, PVC	6	Jeyapalan 1999 (personal communication)
Close-fit-pipe	2–42	PE, PVC	4–6	Arthurs 1999 (personal communication)
Pipe bursting	4–36	HDPE, PVC, ductile iron	7–9	Boyce and Bried 1998
Microtunneling	12–144	HDPE, PVC, concrete steel, fiberglass	17–24	Boyce and Bried 1998
Horizontal directional drilling	2–60	HDPE, PVE, steel, copper, ductile and cast iron	10–25	Boyce and Bried 1998

Note: HDPE = high density polyethylene; PVC = polyvinyl chloride; PE = polyethylene.
[a]Cost is in $/ft.
[b]To convert from inches to centimeters, multiply by 2.54.

Table of rehabilitation/replacement method costs from Selvakumar, et al., 2002

This table provides rough estimates for solely the material costs. Costs related to construction procedures and installations are not included as part of the “generic cost” column of the table. Extrapolating the data for epoxy resin lining for 4-in. to 12-in. pipes shown above yields an approximate price per foot of $35 for epoxy resin (for a 36-in. pipe). Thus, approximate costs for the Downtown Trunk line lining with epoxy resin would be around $20,000. These cost estimates are suitable for a rough preliminary design estimate, but consulting a local contractor for more accurate pricing is likely the best way to gauge project costs (Selvakumar, et al., 2002).

Multiple sources cite carbon fiber as a more expensive liner alternative compared to traditional, non-reinforced liners (Smith et al., 2005, Hyun et al., 2018, Keaffaber, et al., 2015). The table on the next page is an approximate cost breakdown of just the raw materials for the carbon fiber liner. This approximation does not include either unique installation costs for a carbon fiber liner or the production and manufacture costs of carbon fiber. Thus, the actual carbon fiber liner cost would be much higher than what is displayed and less cost-effective than non-reinforced liners.

1	2	3	4	5	6	7	8	9
Carbon fiber price per kg	Density of carbon fiber	Density of carbon fiber	Liner thickness	Annulus Area	Pipe length	Volume of liner	Mass of liner	Cost of liner
($/kg)	(g/cm^3)	(kg/m^3)	(m)	(m^2)	(m)	(m^3)	(kg)	($)
32	2	2000	0.015	0.0797	171.91	13.7063	27.4127	877.21

1. Shama Roa N. et al., (2018). "Carbon Composites are Becoming Competitive and Cost Effective." *Infosys. Navigate your next*. Web. 27 April 2020. <https://www.infosys.com/engineering-services/white-papers/documents/carbon-composites-cost-effective.pdf> ***note that this price does not include production and manufacture of carbon fiber as well as installation procedural costs***

2. Minus, M. et al., (2005). "The processing, properties, and structure of carbon fibers." *JOM* 57, 52-58. Web. 27 April 2020. <https://doi.org/10.1007/s11837-005-0217-8>

3. 1 g/cm^3 = 1000 kg/m^3

4. Specified liner thickenss of 15 mm (see Hydraulic Capacity calculations in the appendix); converted to meters

5. $A_{annulus} = \pi(R^2 - r^2)$;

$$\text{where } R = 36" - 1\,mm = 0.9134\,m\,(converted)$$
$$\text{and } r = 36" - 15\,mm = 0.8994\,m\,(converted)\,(15\,mm \text{ is liner thickness})$$

6. 564 ft. is approximately 171.91 m

7. Annulus area of CIPP liner multiplied by total length of pipe to be rehabilitated

8. Volume multiplied by density of carbon fiber liner

5.2 ALTERNATIVE 2—NON-REINFORCED CIPP LINER WITH STYRENE-BASED RESIN

The second alternative for the Downtown Trunk line is similar to the first alternative because both use CIPP methods to rehabilitate the pipe. However, the second alternative utilizes a nonstructural liner for the CIPP. This includes a felt liner with resin, which is most common for sewer applications. The material used for the resin is styrene-based (polyester and vinylester). Polyester is more common, but both are used more than epoxy in sewer systems.

DESIGN CRITERIA

The design standard for this method is ASTM F1216 Appendix X1. The rehabilitation strategy is appropriate from pipes from sizes of 6 inches to 78 inches in diameter or larger. It works best for circular/round/oval shaped pipes and should be expected to have a lifespan of 50 plus years. This method does require a flow bypass/diversion, as the conditions must be right for the resin to dry.

ENVIRONMENTAL IMPACTS

While the traditional use of resins does not pose a significant health risk, it has an extremely low odor threshold and can be detected 0.5 parts per million. There are several instances of small (not hazardous) amounts of styrene escaping from CIPP projects and entering into homes and businesses, and for this reason some specifications dictate that CIPP installers must use epoxy resins instead.

POTENTIAL CONSTRUCTION PROBLEMS

All resins shrink after being applied and cured. Also, it is impossible to use a resin on surfaces that have oil, grease, and fats in between the CIPP and the existing pipe because the resin won't bond. The cure time for resins falls in the 4 to 6 hour timeline, rather than an epoxy which can cure in half that time. Another problem that this method must address is bypassing the baseflow in the pipe. The temperature for curing is also important and usually needs to be raised above ambient air temperature.

CONSTRUCTION BMPS

The following BMPs that must take place during construction are from the MT DEQ 2018 SWPPP Form (Department of Environmental Quality, 2018):

Erosion Control BMPs:

- Minimizing ground disturbance

Sediment Control BMPs:

- Tarps/plastic coverings to minimize sediment movement (especially near access zones like manholes)
- Stabilized parking/staging area (especially for the vehicles carrying CIPP materials for installation)

Administrative Control BMPs:

- Worker toilets
- Dumpsters/waste receptacles
- Material storage and stockpile area
- Traffic control

SUSTAINABILITY CONSIDERATIONS

The use of polystyrene resin and a felt type liner will add another 50 years to the lifespan of the existing pipe. Although it provides less structural integrity than the reinforced liner, it still acts as a seal for the pipe and helps to maintain the current level of sturdiness.

COST ESTIMATES

Alternate 1 has a table of cost estimates for common pipe rehabilitation and replacement methods. According to this table, polyester resins for the cured-in-place pipe technique cost between \$6 and \$14 per foot. This depends on the size of the pipe, ideally between 6 and 54 inches. This brings the estimate of the rehabilitation for polyester resins to just under \$10,000.

Table 1. Summary of Rehabilitation/Replacement Methods

Method	Pipe size range[b] (diameter in inches)	Common Materials	Generic cost ($/in. diameter/ft)	References for cost
Cement mortar lining	4–60	Cement-sand	1–3	Gumerman et al. 1992
Epoxy lining[a]	4–12	Epoxy resin	9–15	Conroy et al. 1995
Sliplining	4–108	HDPE, PVC, fiberglass reinforced polyester	4–6	Gumerman et al. 1992
Cured-in-place pipe	6–54	Polyester resins	6–14	Gumerman et al. 1992
Fold and form pipe	8–18	HDPE, PVC	6	Jeyapalan 1999 (personal communication)
Close-fit-pipe	2–42	PE, PVC	4–6	Arthurs 1999 (personal communication)
Pipe bursting	4–36	HDPE, PVC, ductile iron	7–9	Boyce and Bried 1998
Microtunneling	12–144	HDPE, PVC, concrete steel, fiberglass	17–24	Boyce and Bried 1998
Horizontal directional drilling	2–60	HDPE, PVE, steel, copper, ductile and cast iron	10–25	Boyce and Bried 1998

Note: HDPE = high density polyethylene; PVC = polyvinyl chloride; PE = polyethylene.

[a]Cost is in $/ft.

[b]To convert from inches to centimeters, multiply by 2.54.

Table of rehabilitation/replacement method costs from Selvakumar, et al., 2002

6.0 SELECTION OF ALTERNATIVES AND PROPOSED DESIGN FOR THE WILLSON AVENUE LINE REHABILITATION

6.1 ALTERNATIVE 1 - PIPE BURSTING

Rehabilitating the Willson line presents its own challenges including the trunk being made of four different pipe sizes. The line ranges from 6-inches to 12-inches increasing as more flow is collected flowing north from West Harrison Street. The pipe is made of approximately 3500-feet of 100-year old vitrified clay tile in need of rehabilitation. The City of Bozeman requires that storm trunk lines are a minimum diameter of 15-inches and none of the pipes under Willson meet this requirement.

The first alternative for the trenchless rehabilitation of the Willson line is pipe bursting. Pipe bursting could be a great choice as this technique allows for replacing the existing line with a larger, smoother pipe. There are a few outfits that perform pipe bursting in Montana which helps lower the cost of this rehabilitation option.

Replacing the entire Willson line with one 2-inch larger polyethylene pipe would approximately double the hydraulic capacity and take a step closer towards the city's minimum diameters. See calculations for this anticipated increase in the appendix. The increase in diameter and decrease in the roughness from clay tiles to plastic provides larger possible flow rates. It may not be feasible to increase the size of all diameters of the line due to environmental constraints as the line gets larger towards downtown. An expert should be consulted to ensure the success of a rehabilitation project with specialized techniques.

Manholes are spaced along Willson at an average distance of 350-feet. This is right in the standard 300 to 400-feet range of pipe bursting. Since the manholes are certainly larger than the line itself, pipe bursting can be done from manhole to manhole and the new pipe inserted through the manhole opening. Going from manhole to manhole minimizes the disturbances to the road surface and traffic.

DESIGN CRITERIA

The rehabilitation of the storm line under Willson needs to replace or extend the life of the existing line so that the collection system can last approximately 50 to 75 years. It also must not decrease the hydraulic capacity. Pipe bursting will need to be done in a manner that will not damage the existing manholes and road surface or disturb the adjacent properties and public utilities.

The pipe bursting engineering design shall be in accordance with ASTM C1208 / C1208M-18, Standards for vitrified clay pipe and joints for use in microtunneling, slip lining, pipe bursting and tunnels. The newly installed pipe shall assume all conveyance and utility connections of existing conditions.

This method requires that base flow be bypassed or blocked during construction. Groundwater may need to be lowered in the immediate area to ensure that the surrounding soils can compact readily.

ENVIRONMENTAL IMPACTS

Pipe bursting will have minimal environmental impacts. There are no chemicals or resins used during the installation process. The new pipe will be made of polyethylene or like material that is generally accepted to be safe and pose little risks. Noise pollution will affect the surrounding environment during construction.

POTENTIAL CONSTRUCTION PROBLEMS

The largest potential issue to be expected during a pipe bursting operation would be ground displacement. The effects are minimized when the line is deep and not significantly upsized. The consequence of displacement can be large, harming deteriorating utilities and heaving the road surface. Proper geotechnical investigations will be necessary to determine the expected displacement and identify nearby utilities. These anticipated problems can be designed for, minimizing their possible negative impacts.

CONSTRUCTION BMPS

The following BMPs that must take place during construction are from the MT DEQ 2018 SWPPP Form (Department of Environmental Quality, 2018):

Erosion Control BMPs:

- Minimizing ground disturbance

Sediment Control BMPs:

- Tarps/plastic coverings to minimize sediment movement (especially near access zones like manholes)
- Stabilized parking/staging area (especially for the vehicles carrying CIPP materials for installation)

Administrative Control BMPs:

- Worker toilets
- Dumpsters/waste receptacles
- Material storage and stockpile area
- Traffic control

SUSTAINABILITY CONSIDERATIONS

The new polyethylene pipe will have an approximate lifespan of 100 years (PE100+, 2018). If standard maintenance and cleaning are performed the system will last for years to come. Sediment traps and other structural stormwater controls can be implemented to help with the maintenance and sediment loads prior to reaching the Downtown Trunk line. Timing scheduled construction activities with other projects can reduce disruptions to the community and limit the amount of construction related environmental impacts.

COST ESTIMATES

Based on the 'Pipe Bursting Fact Sheet' (Herrin 2006) a rough estimate would be around $200/ft. This is a cursory number from case studies that include activities not directly related to pipe bursting. Total cost for the Willson line could be around $700,000.

6.2 ALTERNATIVE 2- COMBINED PIPE BURSTING AND FOLD AND FORM LINING

The South Willson Avenue site presents difficult rehabilitation challenges due to the variable pipe diameters that exist in the conveyance network. The COB requires newly constructed conveyance infrastructure to meet a minimum of 15" diameter. The stormwater conveyance pipe network that makes up the South Willson Avenue line is 12" diameter or less with 43% of the pipe diameter 8" or less. The ground surface slope from Harrison Street to the Trunk Line between Mendenhall Street and Main Street is 1.8%, and the total length is approximately 3500 ft.

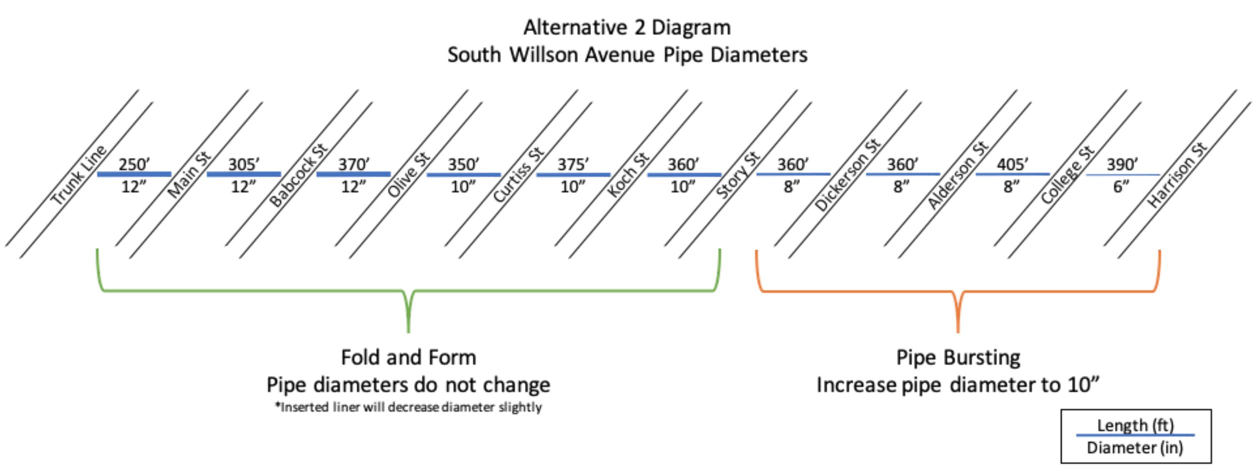
Alternative 2 for the South Willson Avenue rehabilitation site suggests two trenchless rehabilitation techniques combined to improve stormwater conveyance capacity and restore infrastructure nearing the end of it's estimated life cycle: pipe bursting and fold and form lining. Both pipe bursting and fold and form technologies are common trenchless rehabilitation practices available in Montana. Utilizing two rehabilitation techniques allows for more invasive rehabilitation to accomplish significant pipe diameter expansion and life cycle restoration in the residential area and less invasive rehabilitation to increase conveyance capacity and restore the life cycle of the existing infrastructure.

Traveling south along Willson from the downtown trunk line between Mendenhall and Main Street, pipe diameters range from 12” to 6”. Sections of pipe with 8” or less diameter can be expanded to 10” through pipe bursting and installation of polyethylene pipe to increase conveyance capacity and renew structural integrity. Pipe bursting is considered to be reasonably non-invasive and low impact to surrounding utilities, soils, and stresses during installation are not expected to disrupt or damage the replacement pipe and surrounding connections (Atalah, 1998). Excavated access pits are required at both ends of the burst pipe. Typical pipe bursting lengths are 300’ - 400’, the average length between manholes on the Willson Avenue site is approximately 350’. Access pits will need to be dug at each intersection, unless otherwise specified by contractors.

Sections of larger diameter pipes can be rehabilitated with fold and form lining to renew the integrity of existing stormwater infrastructure and increase conveyance. Fold and form is minimally invasive and can be installed without access pits. The process, as detailed in section 4.6, is implemented from the road surface using manholes as access points. Existing pipes are relined with PVC which effectively increases stormwater conveyance by lowering the roughness of the inner surface of the pipe and reducing infiltration resulting from failing vitrified clay pipe. Pipe diameters will decrease slightly in the 10” and 12” sections of pipe, however the decreased roughness of the new lining increases the overall estimated conveyance.

Post-rehabilitation increased conveyance is estimated to be increased by 160% for the entire Willson line. Estimated conveyance calculations are attached in the appendix using conservative PVC roughness values and maximum wall thickness required for fully deteriorated existing pipe up to 6 feet below ground surface (bgs).

The figure below is a diagram of the proposed rehabilitation alternative.



DESIGN CRITERIA

Both technologies have been chosen to extend the system's life cycle by approximately 50 to 75 years. Additionally, during and post-construction, there must be minimal intrusion/disturbance to nearby properties, utilities, and roads.

The pipe bursting engineering design shall be in accordance with ASTM C1208 / C1208M-18, Standards for vitrified clay pipe and joints for use in microtunneling, slip lining, pipe bursting and tunnels. The newly installed pipe shall assume all conveyance and utility connections of existing conditions.

The fold and form engineering design shall be in accordance with ASTM F 1867 or ASTM F1947 for fold and form technologies. The installed fold and form pipe shall assume all conveyance and utility connections of existing conditions.

Other design considerations include:

- Obtaining as much history as possible about the pipe's construction
- Bypassing existing utility connections
- Pressure testing new pipe
- Tie new pipe into existing system
- Reconnecting services

ENVIRONMENTAL IMPACTS

During pipe rehabilitation activities noise pollution is expected to impact nearby public and urban areas. Post rehabilitation conveyance structures are not expected to have long term impacts on pH, alkalinity, chemical oxygen demand, biological oxygen demand, total organic carbon, and total nitrogen (Donaldson, 2012).

Furthermore, installers must make careful consideration to follow ASTM guidelines as "it is the responsibility of the user to establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use (Donaldson, 2009).

POTENTIAL CONSTRUCTION PROBLEMS

Ground displacement during pipe bursting is expected, degree of displacement depends on the soils in the vicinity of the pipe bursting section. A combination of factors can result in either ground upheaval or collapse. The most critical factors influencing displacements are: if the existing pipe is not deep and the ground displacements are directed upwards; already large diameter pipes are significantly upsized; there are deteriorated existing utilities within 2-3 diameters of the existing pipe (Simicevic, 2001). A more thorough site specific geotechnical report is required to determine expected displacement and existing utilities in close proximity to the bursted pipe.

Existing utilities and pipes within two pipe diameters of the pipe to be upsized through pipe bursting would need to be locally excavated to provide stress relief to the existing pipe. An undiscovered pipe in close proximity to the replacement operation can result in significant unaccounted for problems.

CONSTRUCTION BMPS

The following BMPs that must take place during construction are from the MT DEQ 2018 SWPPP Form (Department of Environmental Quality, 2018):

Erosion Control BMPs:

- Minimizing ground disturbance

Sediment Control BMPs:

- Tarps/plastic coverings to minimize sediment movement (especially near access zones like manholes)
- Stabilized parking/staging area (especially for the vehicles carrying CIPP materials for installation)

Administrative Control BMPs:

- Worker toilets
- Dumpsters/waste receptacles
- Material storage and stockpile area
- Traffic control

SUSTAINABILITY CONSIDERATIONS

Both polyethylene pipe and fold and form PVC liners have an estimated lifespan of at least 50 - 70 years (Folkman, 2014). Sediment traps and other structural stormwater controls can be implemented prior to reaching the Downtown Trunk line. Combining construction projects by installing treatment technologies during the pipe rehabilitation can reduce disruptions to community and traffic.

COST ESTIMATES

Costs based on the ‘Pipe Bursting Fact Sheet’ (Herrin 2006) a rough estimate would be around $200/ft. The estimated cost of pipe bursting 43% of the Willson Avenue line is approximately $300,000.

Fold and form lining is estimated at $135/ft for 24” pipe. However, liner technologies are generally more expensive as pipe diameter increases (Hollingshead, 2009). The estimated cost of fold and form lining 57% of the Willson Avenue line is approximately $270,000. The combined South Willson Avenue rehabilitation cost estimate is $570,000.

7.0 CONCLUSIONS & RECOMMENDATIONS

7.1 RECOMMENDATION FOR THE DOWNTOWN TRUNK LINE

Upon further review of the specific site needs and potential alternatives for the Downtown Trunk line, DALT Engineering recommends a cured-in-place pipe rehabilitation strategy that combines the non-reinforced liner element from Alternative 2 and the epoxy resin from Alternative 1.

The Downtown Trunk line has plenty of structural stability, thus the added reinforcement from a reinforced liner is not necessary and would be more effort than it is worth—it could be difficult to implement a carbon fiber liner for this project. This notion, along with the fact that a carbon fiber liner would be more expensive, is why the non-reinforced felt liner from Alternative 2 is recommended. Coupling the felt liner with an epoxy resin—rather than a styrene-based resin—allows for faster curing time, less environmental detriments, and no odors that may damage health of the workers and surrounding community.

DALT Engineering, with the implementation of this recommendation as a trenchless rehabilitation strategy for the Downtown Trunk line, plans to focus future efforts on rerouting the baseflow during installation and utilizing CCTV to identify exact locations of line connections post-installation.

7.2 RECOMMENDATION FOR THE WILLSON LINE

After careful review of the trenchless rehabilitation options and further analysis of the alternatives applicable to the Willson line, the DALT Engineering team has arrived at a conclusion.

Pipe bursting is a great option to replace expired pipe systems and allows for increasing the diameter of the line. It will be very suitable for the downstream or southern end of the line where there is more space for the soil to be displaced. As the line gets larger and into downtown Bozeman, more issues with underground space and surrounding utilities present themselves. Pipe bursting is not as ideal in this sort of situation, but a fold and form lining is. Fold and form linings allow for no change outside of the deteriorating pipe while still increasing the capacity of the line and being a fully structural solution. It is also less expensive than its counterpart helping reduce the cost of the project while still improving the system.

In the future when more details are known about the condition of the pipe and surrounding area, modifications to the proposed solution are expected. The sections implementing pipe bursting or fold and form could shift depending on many factors including hydraulic capacity desired, condition of the existing line, relative locations of utilities, and budget. DALT Engineering recommends Alternative 2 – Combined Pipe Bursting and Fold and Form Lining as the rehabilitation option for the Willson line.

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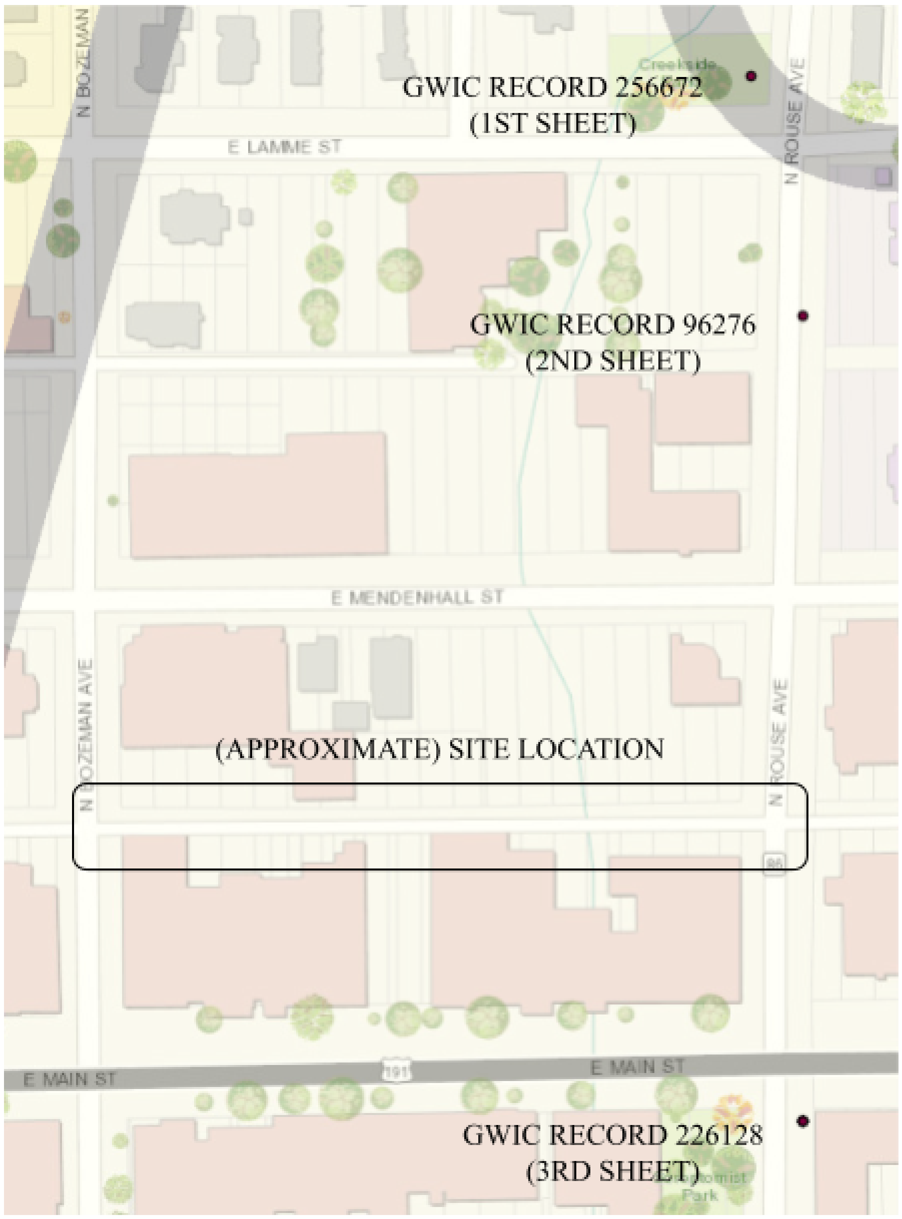
9.0 APPENDICES

9.1 GWIC DATA SHEETS

9.1.1 DOWNTOWN TRUNK LINE DATA SHEETS

The following data sheets were gathered from the MBMG Data Center GWIC Web Mapping Application. Data sheets are organized in the North-South direction:



MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps

Site Name: CITY OF BOZEMAN
GWIC Id: 256672
DNRC Water Right: C30049222

Section 1: Well Owner(s)

1) CITY OF BOZEMAN (MAIL)
P.O. BOX 1230
BOZEMAN MT 59771-1230 [06/28/2010]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	SE¼ NW¼

County	Geocode
GALLATIN	06079907227170000

Latitude	Longitude	Geomethod	Datum
45.6816	-111.03214	SUR-GPS	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date

Addition	Block	Lot

Section 3: Proposed Use of Water

OTHER (1)

Section 4: Type of Work

Drilling Method: ROTARY
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Monday, June 28, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	38	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	38	6	0.25		WELDED	A53B STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
38	38	6			OPEN BOTTOM

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	25	BENTONITE GRANULES	Y

Section 7: Well Test Data

Total Depth: 38
Static Water Level: 7.5
Water Temperature:

Air Test *

40 gpm with drill stem set at 35 feet for 1 hours.
Time of recovery 0.25 hours.
Recovery water level 7.5 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

INTENDED USE OF WELL IS TO CONTROL ICE BUILD UP IN BOZEMAN CREEK

Section 9: Well Log

Geologic Source

Unassigned

From	To	Description
0	2	TOPSOIL
2	13	DIRTY SAND TO MEDIUM COBBLES
13	27	SAND TO LARGE GRAVELS, DIRTY
27	38	SAND & GRAVEL, MODERATLY DIRTY

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: DAVE POTTS
Company: POTTS DRILLING INC.
License No: WWC-512
Date Completed: 6/28/2010

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps
View scanned well log (11/16/2007 3:55:49 PM)

Site Name: SPIETH KEN
GWIC Id: 96276
DNRC Water Right: 71506

Section 1: Well Owner(s)

1) SPIETH, KEN (MAIL)
204 N BOZEMAN BOZEMAN MT 59715
N/A N/A N/A [05/01/1989]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	NE¼ SE¼ NW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.681043	-111.031968	TRS-SEC	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date

Addition	Block	Lot

Section 3: Proposed Use of Water

IRRIGATION (1)

Section 4: Type of Work

Drilling Method: CABLE
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Monday, May 1, 1989

Section 6: Well Construction Details

There are no borehole dimensions assigned to this well.

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
0	55	6				

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
55	55	6			OPEN BOTTOM *

Annular Space (Seal/Grout/Packer)

There are no annular space records assigned to this well.

Section 7: Well Test Data

Total Depth: 55
Static Water Level: 15
Water Temperature:

Bailer Test *

_20_ gpm with _ feet of drawdown after _1_ hours.
Time of recovery _ hours.
Recovery water level _ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source

Unassigned

From	To	Description
0	5	TOPSOIL
5	26	CLAYBOUND GRAVEL
26	53	CLAY
53	55	SAND & GRAVEL

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:
Company: VAN DYKEN DRILLING INC
License No: WWC-380
Date Completed: 5/1/1989

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps
View scanned well log (6/5/2006 12:55:14 PM)
View scanned well log (11/16/2007 4:00:32 PM)

Site Name: MDOT * *REPLACEMENT-P86-ROUSE AVENUE*ST-10
GWIC Id: 226135

Section 1: Well Owner(s)
1) MONTANA DEPARTMENT OF TRASPORTATION (MAIL)
2701 PROSPECT AVE
HELENA MT 59620-1001 [10/13/2005]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	SE¼ SE¼ NW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.67918280655	-111.031967696	TRS-SEC	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date
4750			10/13/2005

Addition	Block	Lot

Section 3: Proposed Use of Water
GEOTECH (1)

Section 4: Type of Work
Drilling Method: AP-1000
Status: NEW WELL

Section 5: Well Completion Date
Date well completed: Thursday, October 13, 2005

Section 6: Well Construction Details
Borehole dimensions

From	To	Diameter
0	91.5	9

There are no casing strings assigned to this well.
There are no completion records assigned to this well.
Annular Space (Seal/Grout/Packer)

There are no annular space records assigned to this well.

Section 7: Well Test Data

Total Depth: 91.5
Static Water Level: 10
Water Temperature:

Unknown Test Method *

Yield _ gpm.
Pumping water level _ feet.
Time of recovery _ hours.
Recovery water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

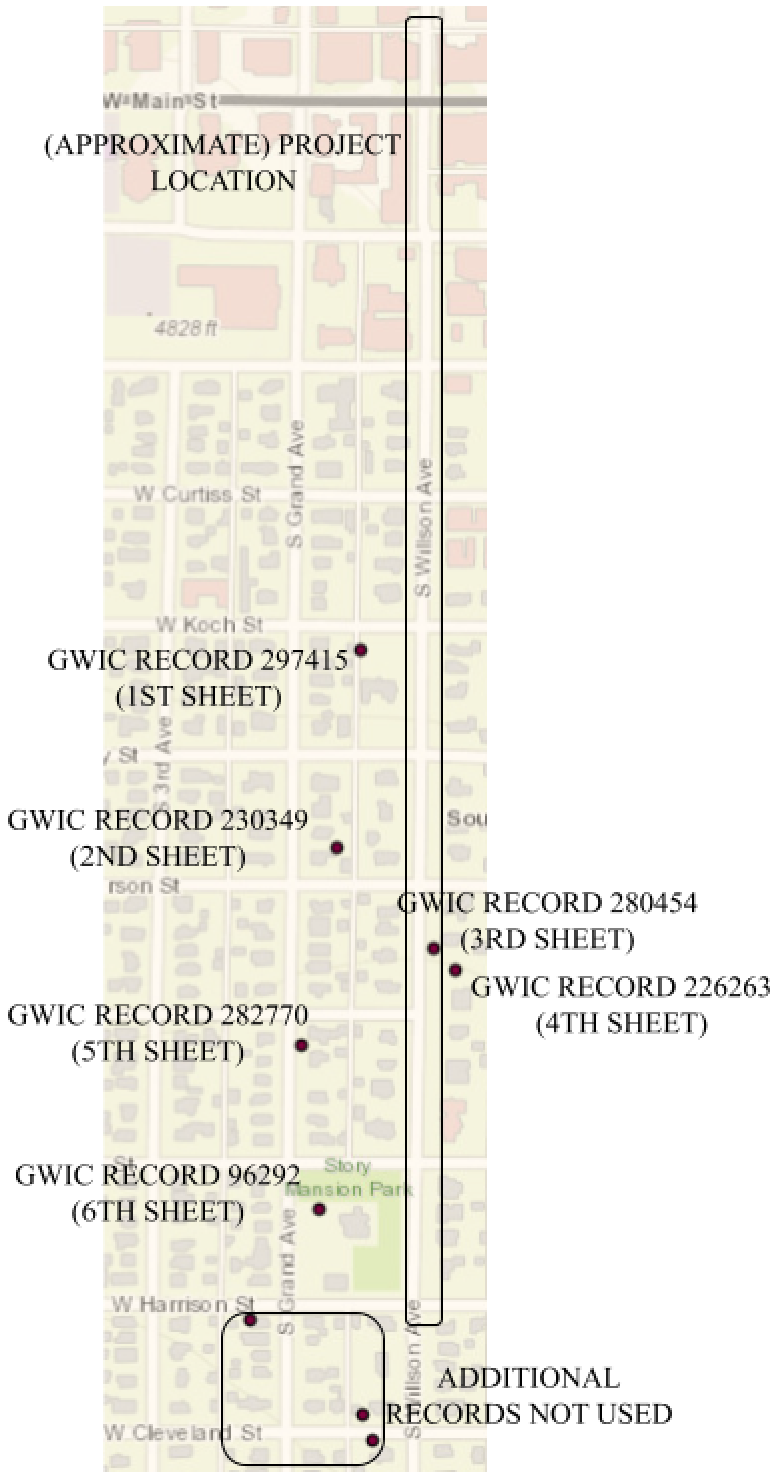
Section 9: Well Log
Geologic Source
Unassigned

From	To	Description
0	3.9	FILL: SILTY GRAVEL WITH SAND AND COBBLES (GM), FINE-TO COARSE-GRAINED, SOME COAL AND CINDERS, GRAY AND BLACK, MOIST, MEDIUM DENSE
3.9	5.9	SANDY ORGANIC CLAY (OL), LOW PLASTICITY, TRACE GRAVEL, BLACK, MOIST,STIFF (BURIED TOPSOIL)
5.9	9.5	SANDY LEAN CLAY (CL), LOW PLASTICITY, TRACE SALTS, DARK BROWN, MOIST, STIFF (ALLUVIUM)
9.1	10.5	SANDY LEAN CLAY (CL), MEDIUM PLASTICITY, YELLOWISH BROWN, MOIST, HARD (TERTIARY SEDIMENTS)
9.5	18	POORLY GRADED GRAVEL WITH SILT, SAND AND COBBLES (GP), FINE- TO COARSE-GRAINED, NONPLASTIC, DARK BROWN, MOIST, DENSE (ALLUVIUM) WATER BEARING BELOW 3.4M
10.5	11.6	CLAYEY GRAVEL WITH SAND AND COBBLES (GC), FINE- TO COARSE-GRAINED, LOW PLASTICITY, LAYERS OF SANDY LEAN CLAY, BROWN, WATERBEARING, VERY DENSE (TERTIARY SEDIMENTS)
11.6	13.1	SILTY GRAVEL WITH SAND AND COBBLES (GM), FINE-TO COARSE-GRAINED, NONPLASTIC, BROWN, WATERBEARING, VERY DENSE (TERTIARY SEDIMENTS)
13.1	15.4	CLAYEY SAND (SC), FINE-GRAINED, HIGH PLASTICITY, YELLOWISH BROWN, MOIST, HARD (TERTIARY SEDIMENTS)
15.4	16.2	CLAYEY SAND WITH GRAVEL (SC), FINE- TO COARSE-GRAINED, LOW PLASTICITY, BROWN, WET, VERY DENSE (TERTIARY SEDIMENTS)
16.2	22.1	SANDY LEAN CLAY (CL), LOW TO MEDIUM PLASTICITY, YELLOWISH BROWN, MOIST, HARD (TERTIARY SEDIMENTS), CLAYEY GRAVEL LAYER AT 18.6M
18	21	CLAYEY GRAVEL WITH SAND AND COBBLES (GC), FINE- TO COARSE-GRAINED, LOW PLASTICITY, SUBROUNDED GRAVELS, YELLOWISH BROWN AND BROWN, WATERBEARING, DENSE (ALLUVIUM)
21	26.6	SANDY LEAN CLAY (CL), MEDIUM PLASTICITY, TRACE

From	To	Description
		GRAVEL, YELLOW, MOIST, HARD (TERTIARY SEDIMENTS)
22.1	24.7	SILTY GRAVEL WITH SAND AND COBBLES (GM), FINE-TO COARSE-GRAINED, NONPLASTIC, BROWN, WATERBEARING, VERY DENSE (TERTIARY SEDIMENTS)
24.7	26.5	SANDY LEAN CLAY (CL), LOW PLASTICITY, SOME GRAVEL, YELLOWISH BROWN, MOIST, HARD (TERTIARY SEDIMENTS)
26.5	27.9	CLAYEY SAND (SC), FINE- TO MEDIUM-GRAINED, LOW PLASTICITY, TRACE GRAVEL, REDDISH BROWN, MOIST, DENSE (TERTIARY SEDIMENTS)

9.1.2 WILLSON AVE LINE DATA SHEETS

The following data sheets were gathered from the MBMG Data Center GWIC Web Mapping Application. Data sheets are organized in the North-South direction:



MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps

Site Name: DELANEY INDRELAND LIVING TRUST
GWIC Id: 297415

Section 1: Well Owner(s)

1) DELANEY INDRELAND LIVING TRUST (MAIL)
101 EAST MAIN ST
BOZEMAN MT 59715 [06/05/2018]
2) DELANEY INDRELAND LIVING TRUST (WELL)
401 S WILSON AVE
BOZEMAN MT 59715 [06/05/2018]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	NW¼ SW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.6751	-111.03944	NAV-GPS	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date

Addition	Block	Lot
FAIRVEIW ADDITION	2	1-3

Section 3: Proposed Use of Water

IRRIGATION (1)

Section 4: Type of Work

Drilling Method: ROTARY
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Tuesday, June 5, 2018

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	72	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-1.5	70.5	6	0.25		WELDED	A53B STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
70.5	72	6			OPEN HOLE

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	25	BENTONITE	Y

Section 7: Well Test Data

Total Depth: 72
Static Water Level: 25
Water Temperature:

Air Test *

_40_ gpm with drill stem set at _60_ feet for _1_ hours.
Time of recovery _1_ hours.
Recovery water level _25_ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source

Unassigned

From	To	Description
0	4	TOPSOIL & CLAY
4	10	CLAY, GRAVEL, COBBLES
10	29	COBBLES, GRAVELS, SAND
29	35	CLAY, SAND, GRAVELS, COBBLES
35	60	CLAY & SAND
60	72	GRAVELS & SAND

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: CURT SAMPSON
Company: BRIDGER DRILLING INC
License No: WWC-560
Date Completed: 6/5/2018

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps
View scanned well log (10/19/2006 3:44:41 PM)
View scanned well log (11/16/2007 4:07:06 PM)

Site Name: CAMPBELL ROB
GWIC Id: 230349

Section 1: Well Owner(s)

1) CAMPBELL, ROB AND KAREN (MAIL)
411 W KOCH
BOZEMAN MT 59715 [09/18/2006]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	NW¼ SW¼ SW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.673604	-111.039693	TRS-SEC	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date

Addition	Block	Lot

Section 3: Proposed Use of Water

DOMESTIC (1)

Section 4: Type of Work

Drilling Method: ROTARY
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Monday, September 18, 2006

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	100	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	70	6	0.25		WELDED	STEEL
60	100	4.5		160.0		PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
80	100	4.5		1/8	DRILLED HOLES

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	0	BENTONITE	Y

Section 7: Well Test Data

Total Depth: 100
Static Water Level: 33
Water Temperature:

Air Test *

_50_ gpm with drill stem set at _100_ feet for _2_ hours.
Time of recovery _0.5_ hours.
Recovery water level _33_ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source

Unassigned

From	To	Description
0	4	TOPSOIL
4	11	TAN CLAY
11	40	SAND AND GRAVEL
40	90	TAN CLAY
90	100	SAND GRAVEL & TAN CLAY

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:
Company: HILLMAN DRILLING
License No: WWC-436
Date Completed: 9/18/2006

MONTANA WELL LOG REPORT

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Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps
View scanned update/correction (11/7/2014 1:39:43 PM)

Site Name: WARREN, CARL
GWIC Id: 280454

Section 1: Well Owner(s)

1) WARREN, CARL (WELL)
610 S WILSON AVE
BOZEMAN MONTANA 59715 [11/07/2014]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	SW¼ SW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.672833	-111.038639	NAV-GPS	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date

Addition	Block	Lot
FAIRVIEW ADDITION	7	39-41

Section 3: Proposed Use of Water

IRRIGATION (1)

Section 4: Type of Work

Drilling Method: ROTARY
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Monday, October 27, 2014

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	102	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-1.5	100	6	0.25		WELDED	A53B STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
100	102	6			OPEN BOTTOM

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	25	BENTONITE	Y

Section 7: Well Test Data

Total Depth: 102
Static Water Level: 29
Water Temperature:

Air Test *

_30_ gpm with drill stem set at _95_ feet for _1_ hours.
Time of recovery _1_ hours.
Recovery water level _29_ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source

Unassigned

From	To	Description
0	2	TOPSOIL
2	6	CLAY
6	14	SAND AND GRAVEL
14	29	SILTY CLAY
29	33	CEMENTED GRAVEL
33	102	CLAY WITH THIN LAYERS OF CEMENTED GRAVEL

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: KURT WESTRA
Company: VAN DYKEN DRILLING INC
License No: WWC-656
Date Completed: 10/27/2014

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps

Site Name: DELANEY, MIKE & ILEANA
GWIC Id: 226263
DNRC Water Right: C30024212

Section 1: Well Owner(s)

1) DELANEY, MIKE AND ILEANA (MAIL)
415 S. WILLSON
BOZEMAN MT 59715 [06/02/2006]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	SW¼ SW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.672674	-111.038405	TRS-SEC	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date

Addition	Block	Lot

Section 3: Proposed Use of Water

IRRIGATION (1)

Section 4: Type of Work

Drilling Method: ROTARY
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Friday, June 2, 2006

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	80	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	78	6	0.250		WELDED	A53B STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
30	35	6	3/FT	3/4 X 1/4 INCH	HOLTE PERFORATOR SLOTS
45	55	6	3/FT	3/4 X 1/4 INCH	HOLTE PERFORATOR SLOTS

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	20	BENTONITE	Y

Section 7: Well Test Data

Total Depth: 80
Static Water Level: 30
Water Temperature:

Air Test *

_15_ gpm with drill stem set at _75_ feet for _1_ hours.
Time of recovery _1_ hours.
Recovery water level _30_ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source

Unassigned

From	To	Description
0	1	TOPSOIL
1	8	CLAY
8	50	GRAVEL & SAND
50	77	SILTY CLAY
77	79	GRAVEL
79	90	SILTY CLAY

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:
Company: KEVIN HAGGERTY DRILLING INC
License No: WWC-353
Date Completed: 6/2/2006

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps

Site Name: BERTELLI, PAUL
GWIC Id: 282770

Section 1: Well Owner(s)

1) BERTELLI, PAUL (MAIL)
702 S. GRAND
BOZEMAN MT 59715 [05/18/2015]
2) BERTELLI, PAUL (WELL)
702 S. GRAND
BOZEMAN MT 59715 [05/18/2015]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	7	SW¼ SW¼ SW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.672111	-111.040083	NAV-GPS	WGS84

Ground Surface Altitude	Ground Surface Method	Datum	Date

Addition	Block	Lot

Section 3: Proposed Use of Water

GEOTHERMAL-INJECTION (1)

Section 4: Type of Work

Drilling Method: ROTARY
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Monday, May 18, 2015

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	300	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-1.5	95	6	0.25		WELDED	A53B STEEL
20	300	4			SPLINE	PVC-SCHED 40

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
100	120	4		.025	SCREEN-CONTINUOUS-PVC
160	240	4		.025	SCREEN-CONTINUOUS-PVC
260	280	4		.025	SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	25	BENTONITE	Y

Section 7: Well Test Data

Total Depth: 300
Static Water Level: 30
Water Temperature:

Air Test *

_9_ gpm with drill stem set at _ feet for _1_ hours.
Time of recovery _1_ hours.
Recovery water level _30_ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source

Unassigned

From	To	Description
0	2	TOPSOIL
2	8	CLAY
8	49	CLAY & PEA GRAVEL
49	51	CEMENTED GRAVEL
51	96	CLAY WITH THIN CEMENTED GRAVEL LAYERS
96	172	ORANGE, WHITE & RUST GRANITE
172	300	BLACK, WHITE, GREY & RED GRANITE

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: KURT WESTRA
Company: VAN DYKEN DRILLING INC
License No: WWC-656
Date Completed: 5/18/2015

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Go to GWIC website
Plot this site in State Library Digital Atlas
Plot this site in Google Maps
View hydrograph for this site
View field visits for this site
View scanned well log (12/11/2007 10:08:48 AM)
View scanned update/correction (10/1/2010 2:34:39 PM)

Site Name: CITY OF BOZEMAN - STORY MANSION/SAE FRATERNITY
GWIC Id: 96292
DNRC Water Right: 61576

Section 1: Well Owner(s)

1) CITY OF BOZEMAN - PARKS DEPT (MAIL)
814 N BOZEMAN
BOZEMAN MT 59715 [06/24/2010]
2) SAE FRATERNITY (MAIL)
811 S WILLSON AVE
BOZEMAN MT 59715 [06/02/1986]

Section 2: Location

Township	Range	Section	Quarter Sections
02S	06E	18	NE¼ NW¼ NW¼ NW¼

County	Geocode
GALLATIN	

Latitude	Longitude	Geomethod	Datum
45.67085	-111.03989	NAV-GPS	NAD83

Ground Surface Altitude	Ground Surface Method	Datum	Date
4865	MAP	NGVD29	6/24/2010

Measuring Point Altitude	MP Method	Datum	Date Applies
4867.95	MAP	NGVD29	6/24/2010

Addition	Block	Lot

Section 3: Proposed Use of Water

IRRIGATION (1)

Section 4: Type of Work

Drilling Method: FORWARD ROTARY
Status: NEW WELL

Section 5: Well Completion Date

Date well completed: Monday, June 2, 1986

Section 6: Well Construction Details

There are no borehole dimensions assigned to this well.

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
0	60	6				
57	77	4				PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
57	77	4			.025 SLOT SCRN

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	0	BENTONITE	

Section 7: Well Test Data

Total Depth: 77
Static Water Level: 18
Water Temperature:

Pump Test *

Depth pump set for test _ feet.
25 gpm pump rate with _ feet of drawdown after 2 hours of pumping.
Time of recovery _ hours.
Recovery water level _ feet.
Pumping water level 70 feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log
Geologic Source

120SNGR - SAND AND GRAVEL (TERTIARY)

From	To	Description
0	2	TOPSOIL
2	9	CLAY
9	14	CLAY GRAVEL MIX
14	19	CLAY
19	57	CLAY & GRAVEL MIX
57	77	FRACTURED ROCK LAYERS

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:
Company: HAGGERTY DRILLING
License No: WWC-353
Date Completed: 6/2/1986

9.2 HYDRAULIC CAPACITY CALCULATIONS—DOWNTOWN TRUNK LINE

Hydraulic capacities in section 9.2.1 and 9.2.2 are calculated with a range of slopes from 0.75% (0.0075 ft/ft) to 1.25% (0.0125 ft/ft).

9.2.1 REINFORCED LINER WITH EPOXY RESIN

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CALCULATIONS FOR THE HYDRAULIC CAPACITY OF STORMWATER PIPES FLOWING PARTIALLY FULL

CURRENT CONDITIONS: 36" PIPE MADE OF VITRIFIED CLAY TILE

Known Parameters		
$n = n_{full}$ =	0.014	
D =	36	(in)
D =	3	(ft)
r =	1.5	(ft)
S =	0.0075	(ft/ft)

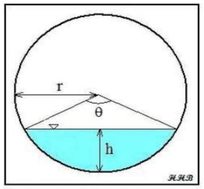
{1}

Equations for Variable Mannings Roughness Coefficient {2}

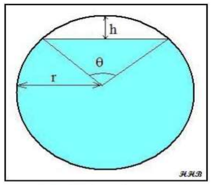
$0 \le y/D \le 0.03$:	$n/n_{full} = 1 + (y/D)/(0.3)$	(3)
$0.03 \le y/D \le 0.1$:	$n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$	(4)
$0.1 \le y/D \le 0.2$:	$n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$	(5)
$0.2 \le y/D \le 0.3$:	$n/n_{full} = 1.29$	(6)
$0.3 \le y/D \le 0.5$:	$n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$	(7)
$0.5 \le y/D \le 1$:	$n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$	(8)

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.014	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.15	1.134	0.016	0.15	0.90	0.13	1.35	0.10	1.72	0.23
0.10	0.30	1.220	0.017	0.30	1.29	0.37	1.93	0.19	2.50	0.92
0.15	0.45	1.250	0.018	0.45	1.59	0.66	2.39	0.28	3.14	2.09
0.20	0.60	1.280	0.018	0.60	1.85	1.01	2.78	0.36	3.65	3.67
0.25	0.75	1.290	0.018	0.75	2.09	1.38	3.14	0.44	4.12	5.70
0.30	0.90	1.290	0.018	0.90	2.32	1.78	3.48	0.51	4.57	8.14
0.35	1.05	1.280	0.018	1.05	2.53	2.20	3.80	0.58	5.00	11.02
0.40	1.20	1.270	0.018	1.20	2.74	2.64	4.11	0.64	5.39	14.23
0.45	1.35	1.260	0.018	1.35	2.94	3.09	4.41	0.70	5.75	17.73
0.50	1.50	1.250	0.018	1.50	3.14	3.53	4.71	0.75	6.07	21.45
0.55	1.65	1.225	0.017	1.35	2.94	3.98	5.01	0.79	6.44	25.65
0.60	1.80	1.200	0.017	1.20	2.74	4.43	5.32	0.83	6.78	30.03
0.65	1.95	1.175	0.016	1.05	2.53	4.86	5.63	0.86	7.10	34.53
0.70	2.10	1.150	0.016	0.90	2.32	5.29	5.95	0.89	7.39	39.05
0.75	2.25	1.125	0.016	0.75	2.09	5.69	6.28	0.91	7.65	43.48
0.80	2.40	1.100	0.015	0.60	1.85	6.06	6.64	0.91	7.86	47.66
0.85	2.55	1.075	0.015	0.45	1.59	6.40	7.04	0.91	8.03	51.41
0.90	2.70	1.050	0.015	0.30	1.29	6.70	7.49	0.89	8.13	54.44
0.95	2.85	1.025	0.014	0.15	0.90	6.94	8.07	0.86	8.11	56.23
1.00	3.00	1.000	0.014	0.00	0.00	7.07	9.42	0.75	7.59	53.64



Partially Full Pipe Flow Parameters (Less Than Half Full)



Partially Full Pipe Flow Parameters (More Than Half Full)

{2}

The highlighted green cell indicates the approximate flow capacity of the channel considering partially full pipe flow conditions.

PROPOSED CONDITIONS: 36" PIPE WITH 15 MM. CIPP LINING MADE OF CARBON FIBER AND 1 MM. EPOXY RESIN COMPOSITION

Known Parameters		
$n = n_{full}$ =	0.009	
D =	34.74	(in)
D =	2.90	(ft)
r =	1.45	(ft)
S =	0.0075	(ft/ft)

{3}

This adjusted diameter accounts for the 15-mm. thickness of the CIPP lining material. {4}

Equations for Variable Mannings Roughness Coefficient

$0 \le y/D \le 0.03$:	$n/n_{full} = 1 + (y/D)/(0.3)$	(3)
$0.03 \le y/D \le 0.1$:	$n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$	(4)
$0.1 \le y/D \le 0.2$:	$n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$	(5)
$0.2 \le y/D \le 0.3$:	$n/n_{full} = 1.29$	(6)
$0.3 \le y/D \le 0.5$:	$n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$	(7)
$0.5 \le y/D \le 1$:	$n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$	(8)

{5} {6}

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.009	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.14	1.134	0.010	0.14	0.90	0.12	1.31	0.09	2.61	0.32
0.10	0.29	1.220	0.011	0.29	1.29	0.34	1.86	0.18	3.79	1.30
0.15	0.43	1.250	0.011	0.43	1.59	0.62	2.30	0.27	4.77	2.95
0.20	0.58	1.280	0.012	0.58	1.85	0.94	2.68	0.35	5.54	5.19
0.25	0.72	1.290	0.012	0.72	2.09	1.29	3.03	0.42	6.26	8.06
0.30	0.87	1.290	0.012	0.87	2.32	1.66	3.36	0.49	6.94	11.52
0.35	1.01	1.280	0.012	1.01	2.53	2.05	3.67	0.56	7.59	15.59
0.40	1.16	1.270	0.011	1.16	2.74	2.46	3.96	0.62	8.19	20.13
0.45	1.30	1.260	0.011	1.30	2.94	2.87	4.26	0.67	8.73	25.08
0.50	1.45	1.250	0.011	1.45	3.14	3.29	4.55	0.72	9.22	30.35
0.55	1.59	1.225	0.011	1.30	2.94	3.71	4.84	0.77	9.78	36.28
0.60	1.74	1.200	0.011	1.16	2.74	4.12	5.13	0.80	10.30	42.48
0.65	1.88	1.175	0.011	1.01	2.53	4.53	5.43	0.83	10.78	48.84
0.70	2.03	1.150	0.010	0.87	2.32	4.92	5.74	0.86	11.22	55.24
0.75	2.17	1.125	0.010	0.72	2.09	5.30	6.06	0.87	11.61	61.50
0.80	2.32	1.100	0.010	0.58	1.85	5.65	6.41	0.88	11.94	67.42
0.85	2.46	1.075	0.010	0.43	1.59	5.96	6.79	0.88	12.20	72.73
0.90	2.61	1.050	0.009	0.29	1.29	6.24	7.23	0.86	12.34	77.02
0.95	2.75	1.025	0.009	0.14	0.90	6.46	7.79	0.83	12.31	79.54
1.00	2.90	1.000	0.009	0.00	0.00	6.58	9.09	0.72	11.53	75.87

EQUATIONS USED:

1. $h = y \ if \ \frac{y}{D} < 0.5 \ \ or \ \ h = 2r - y \ if \ \frac{y}{D} \geq 0.5$
2. see the "Equations for Variable Mannings Roughness Coefficient" subset for the n/nfull calculation
3. $n = \frac{n}{n_{full}}(n_{full})\,;where \ n_{full} = 0.009$
4. $\theta = 2cos^{-1}\left(\frac{r-h}{h}\right)$
5. $A = \frac{r^2(\theta - sin\theta)}{2} \ if \ \frac{y}{D} < 0.5 \ \ or \ \ A = \pi r^2 - \frac{r^2(\theta - sin\theta)}{2} \ if \ \frac{y}{D} \geq 0.5$
6. $P = r\theta \ if \ \frac{y}{d} < 0.5 \ \ or \ \ P = 2\pi r - r\theta \ if \ y/D \geq 0.5$
7. $R = \frac{A}{P}$
7. $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$
9. $Q = VA$

REFERENCES

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Chow, Ven Te. (1959). "Open-Channel Hydraulics." *McGraw-Hill*, New York, NY. Text. 12 April 2020

{2} Bengtson, H.H. "Spreadsheet Use for Partially Full Pipe Flow Calculations." *Continuing Education and Development, Inc.*, Course No C02-037. Web. 12 April 2020. <https://www.cedengineering.com/userfiles/Partially%20Full%20Pipe%20Flow%20Calculations.pdf>

{3} "Technical Services." *ACO Polymer Products, Inc.* Web. 12 April 2020. <https://www.buildsite.com/pdf/aco/Aco-Polyester-Fiberglass-Composition-Technical-Notes-93054.pdf>

{4} Das, S. (2016). "Evaluation of Cured-in-Place Pipe Lining Installations." *Thesis for the degree of Master of Science in Construction Engineering and Management, Department of Civil and Environmental Engineering, University of Alberta*. Web. 12 April 2020. <https://era.library.ualberta.ca/items/b02cf9f8-581b-4df1-9d69-2134bff44ebe/view/36b285e3-64bc-4e4a-9657-91cc90058e48/Das_Susen_201601_MSc.pdf.pdf>

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{6} Camp, T.R. (1946). "Design of Sewers to Facilitate Flow." *Sewage Works Journal, 18 (3)*. Web. 12 April 2020.

CALCULATIONS FOR THE HYDRAULIC CAPACITY OF STORMWATER PIPES FLOWING PARTIALLY FULL

CURRENT CONDITIONS: 36" PIPE MADE OF VITRIFIED CLAY TILE

Known Parameters		
$n = n_{full}$ =	0.014	
D =	36	(in)
D =	3	(ft)
r =	1.5	(ft)
S =	0.01	(ft/ft)

{1}

Equations for Variable Mannings Roughness Coefficient {2}

$0 \leq y/D \leq 0.03$: $n/n_{full} = 1 + (y/D)/(0.3)$ (3)

$0.03 \leq y/D \leq 0.1$: $n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$ (4)

$0.1 \leq y/D \leq 0.2$: $n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$ (5)

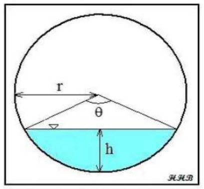
$0.2 \leq y/D \leq 0.3$: $n/n_{full} = 1.29$ (6)

$0.3 \leq y/D \leq 0.5$: $n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$ (7)

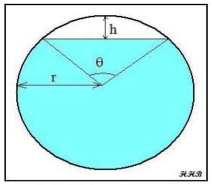
$0.5 \leq y/D \leq 1$: $n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$ (8)

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.014	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.15	1.134	0.016	0.15	0.90	0.13	1.35	0.10	1.98	0.26
0.10	0.30	1.220	0.017	0.30	1.29	0.37	1.93	0.19	2.88	1.06
0.15	0.45	1.250	0.018	0.45	1.59	0.66	2.39	0.28	3.62	2.41
0.20	0.60	1.280	0.018	0.60	1.85	1.01	2.78	0.36	4.21	4.24
0.25	0.75	1.290	0.018	0.75	2.09	1.38	3.14	0.44	4.76	6.58
0.30	0.90	1.290	0.018	0.90	2.32	1.78	3.48	0.51	5.27	9.40
0.35	1.05	1.280	0.018	1.05	2.53	2.20	3.80	0.58	5.77	12.72
0.40	1.20	1.270	0.018	1.20	2.74	2.64	4.11	0.64	6.22	16.43
0.45	1.35	1.260	0.018	1.35	2.94	3.09	4.41	0.70	6.64	20.47
0.50	1.50	1.250	0.018	1.50	3.14	3.53	4.71	0.75	7.01	24.77
0.55	1.65	1.225	0.017	1.35	2.94	3.98	5.01	0.79	7.43	29.61
0.60	1.80	1.200	0.017	1.20	2.74	4.43	5.32	0.83	7.83	34.67
0.65	1.95	1.175	0.016	1.05	2.53	4.86	5.63	0.86	8.20	39.87
0.70	2.10	1.150	0.016	0.90	2.32	5.29	5.95	0.89	8.53	45.09
0.75	2.25	1.125	0.016	0.75	2.09	5.69	6.28	0.91	8.83	50.20
0.80	2.40	1.100	0.015	0.60	1.85	6.06	6.64	0.91	9.08	55.04
0.85	2.55	1.075	0.015	0.45	1.59	6.40	7.04	0.91	9.27	59.37
0.90	2.70	1.050	0.015	0.30	1.29	6.70	7.49	0.89	9.38	62.87
0.95	2.85	1.025	0.014	0.15	0.90	6.94	8.07	0.86	9.36	64.93
1.00	3.00	1.000	0.014	0.00	0.00	7.07	9.42	0.75	8.76	61.93



Partially Full Pipe Flow Parameters (Less Than Half Full)



Partially Full Pipe Flow Parameters (More Than Half Full)

{2}

The highlighted green cell indicates the approximate flow capacity of the channel considering partially full pipe flow conditions.

PROPOSED CONDITIONS: 36" PIPE WITH 15 MM. CIPP LINING MADE OF CARBON FIBER AND 1 MM. EPOXY RESIN COMPOSITION

Known Parameters		
$n = n_{full}$ =	0.008	
D =	34.74	(in)
D =	2.90	(ft)
r =	1.45	(ft)
S =	0.01	(ft/ft)

{3}

This adjusted diameter accounts for the 16-mm. thickness of the CIPP lining material. {4}

Equations for Variable Mannings Roughness Coefficient

$0 \leq y/D \leq 0.03$: $n/n_{full} = 1 + (y/D)/(0.3)$ (3)

$0.03 \leq y/D \leq 0.1$: $n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$ (4)

$0.1 \leq y/D \leq 0.2$: $n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$ (5)

$0.2 \leq y/D \leq 0.3$: $n/n_{full} = 1.29$ (6)

$0.3 \leq y/D \leq 0.5$: $n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$ (7)

$0.5 \leq y/D \leq 1$: $n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$ (8)

{5} {6}

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.008	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.14	1.134	0.009	0.14	0.90	0.12	1.31	0.09	3.39	0.42
0.10	0.29	1.220	0.010	0.29	1.29	0.34	1.86	0.18	4.92	1.69
0.15	0.43	1.250	0.010	0.43	1.59	0.62	2.30	0.27	6.19	3.83
0.20	0.58	1.280	0.010	0.58	1.85	0.94	2.68	0.35	7.19	6.74
0.25	0.72	1.290	0.010	0.72	2.09	1.29	3.03	0.42	8.13	10.47
0.30	0.87	1.290	0.010	0.87	2.32	1.66	3.36	0.49	9.01	14.96
0.35	1.01	1.280	0.010	1.01	2.53	2.05	3.67	0.56	9.86	20.25
0.40	1.16	1.270	0.010	1.16	2.74	2.46	3.96	0.62	10.64	26.15
0.45	1.30	1.260	0.010	1.30	2.94	2.87	4.26	0.67	11.34	32.58
0.50	1.45	1.250	0.010	1.45	3.14	3.29	4.55	0.72	11.98	39.43
0.55	1.59	1.225	0.010	1.30	2.94	3.71	4.84	0.77	12.70	47.13
0.60	1.74	1.200	0.010	1.16	2.74	4.12	5.13	0.80	13.38	55.18
0.65	1.88	1.175	0.009	1.01	2.53	4.53	5.43	0.83	14.01	63.45
0.70	2.03	1.150	0.009	0.87	2.32	4.92	5.74	0.86	14.58	71.76
0.75	2.17	1.125	0.009	0.72	2.09	5.30	6.06	0.87	15.09	79.89
0.80	2.32	1.100	0.009	0.58	1.85	5.65	6.41	0.88	15.51	87.58
0.85	2.46	1.075	0.009	0.43	1.59	5.96	6.79	0.88	15.84	94.48
0.90	2.61	1.050	0.008	0.29	1.29	6.24	7.23	0.86	16.03	100.05
0.95	2.75	1.025	0.008	0.14	0.90	6.46	7.79	0.83	16.00	103.32
1.00	2.90	1.000	0.008	0.00	0.00	6.58	9.09	0.72	14.97	98.56

EQUATIONS USED:

1. $h = y \; if \frac{y}{D} < 0.5 \quad or \quad h = 2r - y \; if \frac{y}{D} \geq 0.5$

2. see the "Equations for Variable Mannings Roughness Coefficient" subset for the n/nfull calculation

3. $n = \frac{n}{n_{full}}(n_{full})\;; where\; n_{full} = 0.009$

4. $\theta = 2cos^{-1}\left(\frac{r-h}{h}\right)$

5. $A = \frac{r^2(\theta - sin\theta)}{2} \; if \frac{y}{D} < 0.5 \quad or \quad A = \pi r^2 - \frac{r^2(\theta - sin\theta)}{2} \; if \frac{y}{D} \geq 0.5$

6. $P = r\theta \; if \frac{y}{d} < 0.5 \quad or \quad P = 2\pi r - r\theta \; if \; y/D \geq 0.5$

7. $R = \frac{A}{P}$

7. $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$

9. $Q = VA$

REFERENCES

{1} NRCS. (1997). "Determining Manning's Coefficient of Roughness, 'n.'" Web. 12 April 2020 <https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_024945.pdf>

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{2} Bengtson, H.H. "Spreadsheet Use for Partially Full Pipe Flow Calculations." *Continuing Education and Development, Inc.*, Course No C02-037. Web. 12 April 2020. <https://www.cedengineering.com/userfiles/Partially%20Full%20Pipe%20Flow%20Calculations.pdf>

{3} "Technical Services." *ACO Polymer Products, Inc.* Web. 12 April 2020. <https://www.buildsite.com/pdf/aco/Aco-Polyester-Fiberglass-Composition-Technical-Notes-93054.pdf>

{4} Das, S. (2016). "Evaluation of Cured-in-Place Pipe Lining Installations." *Thesis for the degree of Master of Science in Construction Engineering and Management, Department of Civil and Environmental Engineering, University of Alberta*. Web. 12 April 2020. <https://era.library.ualberta.ca/items/b02cf9f8-581b-4df1-9d69-2134bff44ebe/view/36b285e3-64bc-4e4a-9657-91cc90058e48/Das_Susen_201601_MSc.pdf.pdf>

{5} ASCE. (1969). "Design and Construction of Sanitary and Storm Sewers." NY. Web. 12 April 2020.

{6} Camp, T.R. (1946). "Design of Sewers to Facilitate Flow." *Sewage Works Journal, 18 (3)*. Web. 12 April 2020.

CALCULATIONS FOR THE HYDRAULIC CAPACITY OF STORMWATER PIPES FLOWING PARTIALLY FULL

CURRENT CONDITIONS: 36" PIPE MADE OF VITRIFIED CLAY TILE

Known Parameters		
$n = n_{full}$ =	0.014	{1}
D =	36	(in)
D =	3	(ft)
r =	1.5	(ft)
S =	0.0125	(ft/ft)

Equations for Variable Mannings Roughness Coefficient {2}

$0 \le y/D \le 0.03$: $n/n_{full} = 1 + (y/D)/(0.3)$ (3)

$0.03 \le y/D \le 0.1$: $n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$ (4)

$0.1 \le y/D \le 0.2$: $n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$ (5)

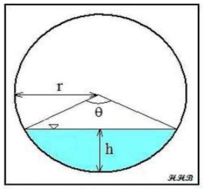
$0.2 \le y/D \le 0.3$: $n/n_{full} = 1.29$ (6)

$0.3 \le y/D \le 0.5$: $n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$ (7)

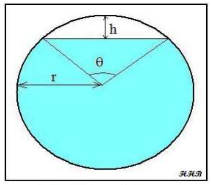
$0.5 \le y/D \le 1$: $n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$ (8)

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.014	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.15	1.134	0.016	0.15	0.90	0.13	1.35	0.10	2.22	0.29
0.10	0.30	1.220	0.017	0.30	1.29	0.37	1.93	0.19	3.22	1.18
0.15	0.45	1.250	0.018	0.45	1.59	0.66	2.39	0.28	4.05	2.69
0.20	0.60	1.280	0.018	0.60	1.85	1.01	2.78	0.36	4.71	4.74
0.25	0.75	1.290	0.018	0.75	2.09	1.38	3.14	0.44	5.32	7.35
0.30	0.90	1.290	0.018	0.90	2.32	1.78	3.48	0.51	5.89	10.51
0.35	1.05	1.280	0.018	1.05	2.53	2.20	3.80	0.58	6.45	14.22
0.40	1.20	1.270	0.018	1.20	2.74	2.64	4.11	0.64	6.96	18.37
0.45	1.35	1.260	0.018	1.35	2.94	3.09	4.41	0.70	7.42	22.89
0.50	1.50	1.250	0.018	1.50	3.14	3.53	4.71	0.75	7.84	27.70
0.55	1.65	1.225	0.017	1.35	2.94	3.98	5.01	0.79	8.31	33.11
0.60	1.80	1.200	0.017	1.20	2.74	4.43	5.32	0.83	8.75	38.77
0.65	1.95	1.175	0.016	1.05	2.53	4.86	5.63	0.86	9.16	44.58
0.70	2.10	1.150	0.016	0.90	2.32	5.29	5.95	0.89	9.54	50.41
0.75	2.25	1.125	0.016	0.75	2.09	5.69	6.28	0.91	9.87	56.13
0.80	2.40	1.100	0.015	0.60	1.85	6.06	6.64	0.91	10.15	61.53
0.85	2.55	1.075	0.015	0.45	1.59	6.40	7.04	0.91	10.36	66.37
0.90	2.70	1.050	0.015	0.30	1.29	6.70	7.49	0.89	10.49	70.29
0.95	2.85	1.025	0.014	0.15	0.90	6.94	8.07	0.86	10.46	72.59
1.00	3.00	1.000	0.014	0.00	0.00	7.07	9.42	0.75	9.80	69.24



Partially Full Pipe Flow Parameters (Less Than Half Full)



Partially Full Pipe Flow Parameters (More Than Half Full)

{2}

The highlighted green cell indicates the approximate flow capacity of the channel considering partially full pipe flow conditions.

PROPOSED CONDITIONS: 36" PIPE WITH 15 MM. CIPP LINING MADE OF CARBON FIBER AND 1 MM. EPOXY RESIN COMPOSITION

Known Parameters		
$n = n_{full}$ =	0.009	{3}
D =	34.74	(in)
D =	2.90	(ft)
r =	1.45	(ft)
S =	0.0125	(ft/ft)

This adjusted diameter accounts for the 16-mm. thickness of the CIPP lining material. {4}

Equations for Variable Mannings Roughness Coefficient

$0 \le y/D \le 0.03$: $n/n_{full} = 1 + (y/D)/(0.3)$ (3)

$0.03 \le y/D \le 0.1$: $n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$ (4)

$0.1 \le y/D \le 0.2$: $n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$ (5)

$0.2 \le y/D \le 0.3$: $n/n_{full} = 1.29$ (6)

$0.3 \le y/D \le 0.5$: $n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$ (7)

$0.5 \le y/D \le 1$: $n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$ (8)

{5} {6}

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.009	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.14	1.134	0.010	0.14	0.90	0.12	1.31	0.09	3.37	0.41
0.10	0.29	1.220	0.011	0.29	1.29	0.34	1.86	0.18	4.89	1.68
0.15	0.43	1.250	0.011	0.43	1.59	0.62	2.30	0.27	6.15	3.81
0.20	0.58	1.280	0.012	0.58	1.85	0.94	2.68	0.35	7.15	6.70
0.25	0.72	1.290	0.012	0.72	2.09	1.29	3.03	0.42	8.08	10.40
0.30	0.87	1.290	0.012	0.87	2.32	1.66	3.36	0.49	8.95	14.87
0.35	1.01	1.280	0.012	1.01	2.53	2.05	3.67	0.56	9.80	20.12
0.40	1.16	1.270	0.011	1.16	2.74	2.46	3.96	0.62	10.57	25.99
0.45	1.30	1.260	0.011	1.30	2.94	2.87	4.26	0.67	11.27	32.38
0.50	1.45	1.250	0.011	1.45	3.14	3.29	4.55	0.72	11.90	39.18
0.55	1.59	1.225	0.011	1.30	2.94	3.71	4.84	0.77	12.63	46.83
0.60	1.74	1.200	0.011	1.16	2.74	4.12	5.13	0.80	13.30	54.84
0.65	1.88	1.175	0.011	1.01	2.53	4.53	5.43	0.83	13.92	63.06
0.70	2.03	1.150	0.010	0.87	2.32	4.92	5.74	0.86	14.49	71.31
0.75	2.17	1.125	0.010	0.72	2.09	5.30	6.06	0.87	14.99	79.40
0.80	2.32	1.100	0.010	0.58	1.85	5.65	6.41	0.88	15.42	87.04
0.85	2.46	1.075	0.010	0.43	1.59	5.96	6.79	0.88	15.74	93.89
0.90	2.61	1.050	0.009	0.29	1.29	6.24	7.23	0.86	15.93	99.43
0.95	2.75	1.025	0.009	0.14	0.90	6.46	7.79	0.83	15.90	102.68
1.00	2.90	1.000	0.009	0.00	0.00	6.58	9.09	0.72	14.88	97.95

EQUATIONS USED:

1. $h = y \; if \; \frac{y}{D} < 0.5 \quad or \quad h = 2r - y \; if \; \frac{y}{D} \ge 0.5$

2. see the "Equations for Variable Mannings Roughness Coefficient" subset for the n/nfull calculation

3. $n = \frac{n}{n_{full}}(n_{full})\; ; where \; n_{full} = 0.009$

4. $\theta = 2cos^{-1}\left(\frac{r-h}{h}\right)$

5. $A = \frac{r^2(\theta - sin\theta)}{2} \; if \; \frac{y}{D} < 0.5 \quad or \quad A = \pi r^2 - \frac{r^2(\theta - sin\theta)}{2} \; if \; \frac{y}{D} \ge 0.5$

6. $P = r\theta \; if \; \frac{y}{d} < 0.5 \quad or \quad P = 2\pi r - r\theta \; if \; y/D \ge 0.5$

7. $R = \frac{A}{P}$

7. $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$

9. $Q = VA$

REFERENCES

{1} NRCS. (1997). "Determining Manning's Coefficient of Roughness, 'n.'" Web. 12 April 2020 <https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_024945.pdf>

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{2} Bengtson, H.H. "Spreadsheet Use for Partially Full Pipe Flow Calculations." *Continuing Education and Development, Inc.*, Course No C02-037. Web. 12 April 2020. <https://www.cedengineering.com/userfiles/Partially%20Full%20Pipe%20Flow%20Calculations.pdf>

{3} "Technical Services." *ACO Polymer Products, Inc.* Web. 12 April 2020. <https://www.buildsite.com/pdf/aco/Aco-Polyester-Fiberglass-Composition-Technical-Notes-93054.pdf>

{4} Das, S. (2016). "Evaluation of Cured-in-Place Pipe Lining Installations." *Thesis for the degree of Master of Science in Construction Engineering and Management, Department of Civil and Environmental Engineering, University of Alberta*. Web. 12 April 2020. <https://era.library.ualberta.ca/items/b02cf9f8-581b-4df1-9d69-2134bff44ebe/view/36b285e3-64bc-4e4a-9657-91cc90058e48/Das_Susen_201601_MSc.pdf.pdf>

{5} ASCE. (1969). "Design and Construction of Sanitary and Storm Sewers." NY. Web. 12 April 2020.

{6} Camp, T.R. (1946). "Design of Sewers to Facilitate Flow." *Sewage Works Journal, 18 (3)*. Web. 12 April 2020.

9.2.2 NON-REINFORCED LINER WITH POLYESTER-STYRENE RESIN

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CALCULATIONS FOR THE HYDRAULIC CAPACITY OF STORMWATER PIPES FLOWING PARTIALLY FULL

CURRENT CONDITIONS: 36" PIPE MADE OF VITRIFIED CLAY TILE

Known Parameters		
$n = n_{full}$ =	0.014	
D =	36	(in)
D =	3	(ft)
r =	1.5	(ft)
S =	0.0075	(ft/ft)

{1}

Equations for Variable Mannings Roughness Coefficient {2}

$0 \leq y/D \leq 0.03$: $n/n_{full} = 1 + (y/D)/(0.3)$ (3)

$0.03 \leq y/D \leq 0.1$: $n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$ (4)

$0.1 \leq y/D \leq 0.2$: $n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$ (5)

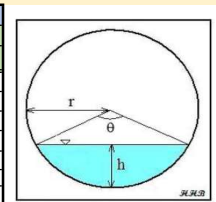
$0.2 \leq y/D \leq 0.3$: $n/n_{full} = 1.29$ (6)

$0.3 \leq y/D \leq 0.5$: $n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$ (7)

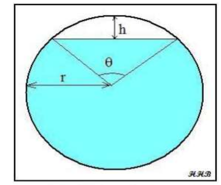
$0.5 \leq y/D \leq 1$: $n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$ (8)

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.014	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.15	1.134	0.016	0.15	0.90	0.13	1.35	0.10	1.72	0.23
0.10	0.30	1.220	0.017	0.30	1.29	0.37	1.93	0.19	2.50	0.92
0.15	0.45	1.250	0.018	0.45	1.59	0.66	2.39	0.28	3.14	2.09
0.20	0.60	1.280	0.018	0.60	1.85	1.01	2.78	0.36	3.65	3.67
0.25	0.75	1.290	0.018	0.75	2.09	1.38	3.14	0.44	4.12	5.70
0.30	0.90	1.290	0.018	0.90	2.32	1.78	3.48	0.51	4.57	8.14
0.35	1.05	1.280	0.018	1.05	2.53	2.20	3.80	0.58	5.00	11.02
0.40	1.20	1.270	0.018	1.20	2.74	2.64	4.11	0.64	5.39	14.23
0.45	1.35	1.260	0.018	1.35	2.94	3.09	4.41	0.70	5.75	17.73
0.50	1.50	1.250	0.018	1.50	3.14	3.53	4.71	0.75	6.07	21.45
0.55	1.65	1.225	0.017	1.35	2.94	3.98	5.01	0.79	6.44	25.65
0.60	1.80	1.200	0.017	1.20	2.74	4.43	5.32	0.83	6.78	30.03
0.65	1.95	1.175	0.016	1.05	2.53	4.86	5.63	0.86	7.10	34.53
0.70	2.10	1.150	0.016	0.90	2.32	5.29	5.95	0.89	7.39	39.05
0.75	2.25	1.125	0.016	0.75	2.09	5.69	6.28	0.91	7.65	43.48
0.80	2.40	1.100	0.015	0.60	1.85	6.06	6.64	0.91	7.86	47.66
0.85	2.55	1.075	0.015	0.45	1.59	6.40	7.04	0.91	8.03	51.41
0.90	2.70	1.050	0.015	0.30	1.29	6.70	7.49	0.89	8.13	54.44
0.95	2.85	1.025	0.014	0.15	0.90	6.94	8.07	0.86	8.11	56.23
1.00	3.00	1.000	0.014	0.00	0.00	7.07	9.42	0.75	7.59	53.64



Partially Full Pipe Flow Parameters (Less Than Half Full)



Partially Full Pipe Flow Parameters (More Than Half Full)

{2}

The highlighted green cell indicates the approximate flow capacity of the channel considering partially full pipe flow conditions.

PROPOSED CONDITIONS: 36" PIPE WITH 15 MM. CIPP LINING MADE OF FELT LINER AND 1 MM. POLYESTER-STYRENE RESIN COMPOSITION

Known Parameters		
$n = n_{full}$ =	0.012	
D =	34.74	(in)
D =	2.90	(ft)
r =	1.45	(ft)
S =	0.0075	(ft/ft)

This adjusted diameter accounts for the 15-mm. thickness of the CIPP lining material. {3}

Equations for Variable Mannings Roughness Coefficient

$0 \leq y/D \leq 0.03$: $n/n_{full} = 1 + (y/D)/(0.3)$ (3)

$0.03 \leq y/D \leq 0.1$: $n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$ (4)

$0.1 \leq y/D \leq 0.2$: $n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$ (5)

$0.2 \leq y/D \leq 0.3$: $n/n_{full} = 1.29$ (6)

$0.3 \leq y/D \leq 0.5$: $n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$ (7)

$0.5 \leq y/D \leq 1$: $n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$ (8)

{4} {5}

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.012	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.14	1.134	0.014	0.14	0.90	0.12	1.31	0.09	1.96	0.24
0.10	0.29	1.220	0.015	0.29	1.29	0.34	1.86	0.18	2.84	0.97
0.15	0.43	1.250	0.015	0.43	1.59	0.62	2.30	0.27	3.57	2.21
0.20	0.58	1.280	0.015	0.58	1.85	0.94	2.68	0.35	4.15	3.89
0.25	0.72	1.290	0.015	0.72	2.09	1.29	3.03	0.42	4.70	6.04
0.30	0.87	1.290	0.015	0.87	2.32	1.66	3.36	0.49	5.20	8.64
0.35	1.01	1.280	0.015	1.01	2.53	2.05	3.67	0.56	5.69	11.69
0.40	1.16	1.270	0.015	1.16	2.74	2.46	3.96	0.62	6.14	15.10
0.45	1.30	1.260	0.015	1.30	2.94	2.87	4.26	0.67	6.55	18.81
0.50	1.45	1.250	0.015	1.45	3.14	3.29	4.55	0.72	6.92	22.76
0.55	1.59	1.225	0.015	1.30	2.94	3.71	4.84	0.77	7.33	27.21
0.60	1.74	1.200	0.014	1.16	2.74	4.12	5.13	0.80	7.73	31.86
0.65	1.88	1.175	0.014	1.01	2.53	4.53	5.43	0.83	8.09	36.63
0.70	2.03	1.150	0.014	0.87	2.32	4.92	5.74	0.86	8.42	41.43
0.75	2.17	1.125	0.014	0.72	2.09	5.30	6.06	0.87	8.71	46.13
0.80	2.32	1.100	0.013	0.58	1.85	5.65	6.41	0.88	8.96	50.57
0.85	2.46	1.075	0.013	0.43	1.59	5.96	6.79	0.88	9.15	54.55
0.90	2.61	1.050	0.013	0.29	1.29	6.24	7.23	0.86	9.26	57.76
0.95	2.75	1.025	0.012	0.14	0.90	6.46	7.79	0.83	9.24	59.65
1.00	2.90	1.000	0.012	0.00	0.00	6.58	9.09	0.72	8.64	56.91

EQUATIONS USED:

1. $h = y \; if \; \frac{y}{D} < 0.5 \;\; or \;\; h = 2r - y \; if \; \frac{y}{D} \geq 0.5$
2. see the "Equations for Variable Mannings Roughness Coefficient" subset for the n/nfull calculation
3. $n = \frac{n}{n_{full}}(n_{full})\,; where \; n_{full} = 0.009$
4. $\theta = 2cos^{-1}\left(\frac{r-h}{h}\right)$
5. $A = \frac{r^2(\theta - sin\theta)}{2} \; if \; \frac{y}{D} < 0.5 \;\; or \;\; A = \pi r^2 - \frac{r^2(\theta - sin\theta)}{2} \; if \; \frac{y}{D} \geq 0.5$
6. $P = r\theta \; if \; \frac{y}{d} < 0.5 \;\; or \;\; P = 2\pi r - r\theta \; if \; y/D \geq 0.5$
7. $R = \frac{A}{P}$
7. $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$
9. $Q = VA$

REFERENCES

{1} NRCS. (1997). "Determining Manning's Coefficient of Roughness, 'n.'" Web. 12 April 2020 <https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_024945.pdf>

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{4} ASCE. (1969). "Design and Construction of Sanitary and Storm Sewers." NY. Web. 12 April 2020.

{5} Camp, T.R. (1946). "Design of Sewers to Facilitate Flow." *Sewage Works Journal, 18 (3)*. Web. 12 April 2020.

CALCULATIONS FOR THE HYDRAULIC CAPACITY OF STORMWATER PIPES FLOWING PARTIALLY FULL

CURRENT CONDITIONS: 36" PIPE MADE OF VITRIFIED CLAY TILE

Known Parameters		
$n = n_{full}$ =	0.014	
D =	36	(in)
D =	3	(ft)
r =	1.5	(ft)
S =	0.01	(ft/ft)

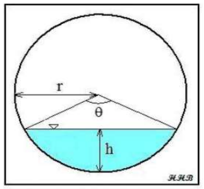
{1}

Equations for Variable Mannings Roughness Coefficient {2}

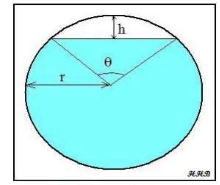
$0 \le y/D \le 0.03$:	$n/n_{full} = 1 + (y/D)/(0.3)$	(3)
$0.03 \le y/D \le 0.1$:	$n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$	(4)
$0.1 \le y/D \le 0.2$:	$n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$	(5)
$0.2 \le y/D \le 0.3$:	$n/n_{full} = 1.29$	(6)
$0.3 \le y/D \le 0.5$:	$n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$	(7)
$0.5 \le y/D \le 1$:	$n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$	(8)

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.014	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.15	1.134	0.016	0.15	0.90	0.13	1.35	0.10	1.98	0.26
0.10	0.30	1.220	0.017	0.30	1.29	0.37	1.93	0.19	2.88	1.06
0.15	0.45	1.250	0.018	0.45	1.59	0.66	2.39	0.28	3.62	2.41
0.20	0.60	1.280	0.018	0.60	1.85	1.01	2.78	0.36	4.21	4.24
0.25	0.75	1.290	0.018	0.75	2.09	1.38	3.14	0.44	4.76	6.58
0.30	0.90	1.290	0.018	0.90	2.32	1.78	3.48	0.51	5.27	9.40
0.35	1.05	1.280	0.018	1.05	2.53	2.20	3.80	0.58	5.77	12.72
0.40	1.20	1.270	0.018	1.20	2.74	2.64	4.11	0.64	6.22	16.43
0.45	1.35	1.260	0.018	1.35	2.94	3.09	4.41	0.70	6.64	20.47
0.50	1.50	1.250	0.018	1.50	3.14	3.53	4.71	0.75	7.01	24.77
0.55	1.65	1.225	0.017	1.35	2.94	3.98	5.01	0.79	7.43	29.61
0.60	1.80	1.200	0.017	1.20	2.74	4.43	5.32	0.83	7.83	34.67
0.65	1.95	1.175	0.016	1.05	2.53	4.86	5.63	0.86	8.20	39.87
0.70	2.10	1.150	0.016	0.90	2.32	5.29	5.95	0.89	8.53	45.09
0.75	2.25	1.125	0.016	0.75	2.09	5.69	6.28	0.91	8.83	50.20
0.80	2.40	1.100	0.015	0.60	1.85	6.06	6.64	0.91	9.08	55.04
0.85	2.55	1.075	0.015	0.45	1.59	6.40	7.04	0.91	9.27	59.37
0.90	2.70	1.050	0.015	0.30	1.29	6.70	7.49	0.89	9.38	62.87
0.95	2.85	1.025	0.014	0.15	0.90	6.94	8.07	0.86	9.36	64.93
1.00	3.00	1.000	0.014	0.00	0.00	7.07	9.42	0.75	8.76	61.93



Partially Full Pipe Flow Parameters (Less Than Half Full)



Partially Full Pipe Flow Parameters (More Than Half Full)

{2}

The highlighted green cell indicates the approximate flow capacity of the channel considering partially full pipe flow conditions.

PROPOSED CONDITIONS: 36" PIPE WITH 15 MM. CIPP LINING MADE OF FELT LINER AND 1 MM. POLYESTER-STYRENE RESIN COMPOSITION

Known Parameters		
$n = n_{full}$ =	0.012	
D =	34.74	(in)
D =	2.90	(ft)
r =	1.45	(ft)
S =	0.01	(ft/ft)

This adjusted diameter accounts for the 15-mm. thickness of the CIPP lining material. {3}

Equations for Variable Mannings Roughness Coefficient

$0 \le y/D \le 0.03$:	$n/n_{full} = 1 + (y/D)/(0.3)$	(3)
$0.03 \le y/D \le 0.1$:	$n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$	(4)
$0.1 \le y/D \le 0.2$:	$n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$	(5)
$0.2 \le y/D \le 0.3$:	$n/n_{full} = 1.29$	(6)
$0.3 \le y/D \le 0.5$:	$n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$	(7)
$0.5 \le y/D \le 1$:	$n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$	(8)

{4} {5}

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.012	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.14	1.134	0.014	0.14	0.90	0.12	1.31	0.09	2.26	0.28
0.10	0.29	1.220	0.015	0.29	1.29	0.34	1.86	0.18	3.28	1.12
0.15	0.43	1.250	0.015	0.43	1.59	0.62	2.30	0.27	4.13	2.56
0.20	0.58	1.280	0.015	0.58	1.85	0.94	2.68	0.35	4.80	4.50
0.25	0.72	1.290	0.015	0.72	2.09	1.29	3.03	0.42	5.42	6.98
0.30	0.87	1.290	0.015	0.87	2.32	1.66	3.36	0.49	6.01	9.98
0.35	1.01	1.280	0.015	1.01	2.53	2.05	3.67	0.56	6.57	13.50
0.40	1.16	1.270	0.015	1.16	2.74	2.46	3.96	0.62	7.09	17.44
0.45	1.30	1.260	0.015	1.30	2.94	2.87	4.26	0.67	7.56	21.72
0.50	1.45	1.250	0.015	1.45	3.14	3.29	4.55	0.72	7.99	26.28
0.55	1.59	1.225	0.015	1.30	2.94	3.71	4.84	0.77	8.47	31.42
0.60	1.74	1.200	0.014	1.16	2.74	4.12	5.13	0.80	8.92	36.79
0.65	1.88	1.175	0.014	1.01	2.53	4.53	5.43	0.83	9.34	42.30
0.70	2.03	1.150	0.014	0.87	2.32	4.92	5.74	0.86	9.72	47.84
0.75	2.17	1.125	0.014	0.72	2.09	5.30	6.06	0.87	10.06	53.26
0.80	2.32	1.100	0.013	0.58	1.85	5.65	6.41	0.88	10.34	58.39
0.85	2.46	1.075	0.013	0.43	1.59	5.96	6.79	0.88	10.56	62.98
0.90	2.61	1.050	0.013	0.29	1.29	6.24	7.23	0.86	10.69	66.70
0.95	2.75	1.025	0.012	0.14	0.90	6.46	7.79	0.83	10.66	68.88
1.00	2.90	1.000	0.012	0.00	0.00	6.58	9.09	0.72	9.98	65.71

EQUATIONS USED:

1. $h = y \; if \; \frac{y}{D} < 0.5 \quad or \quad h = 2r - y \; if \; \frac{y}{D} \ge 0.5$
2. see the "Equations for Variable Mannings Roughness Coefficient" subset for the n/nfull calculation
3. $n = \frac{n}{n_{full}}(n_{full})\,; where \; n_{full} = 0.009$
4. $\theta = 2cos^{-1}\left(\frac{r-h}{h}\right)$
5. $A = \frac{r^2(\theta - sin\theta)}{2} \; if \; \frac{y}{D} < 0.5 \quad or \quad A = \pi r^2 - \frac{r^2(\theta - sin \;)}{2} \; if \; \frac{y}{D} \ge 0.5$
6. $P = r\theta \; if \; \frac{y}{d} < 0.5 \quad or \quad P = 2\pi r - r\theta \; if \; y/D \ge 0.5$
7. $R = \frac{A}{P}$
7. $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$
9. $Q = VA$

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{1} NRCS. (1997). "Determining Manning's Coefficient of Roughness, 'n.'" Web. 12 April 2020 <https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_024945.pdf>

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{2} Bengtson, H.H. "Spreadsheet Use for Partially Full Pipe Flow Calculations." *Continuing Education and Development, Inc.*, Course No C02-037. Web. 12 April 2020. <https://www.cedengineering.com/userfiles/Partially%20Full%20Pipe%20Flow%20Calculations.pdf>

{3} Das, S. (2016). "Evaluation of Cured-in-Place Pipe Lining Installations." *Thesis for the degree of Master of Science in Construction Engineering and Management, Department of Civil and Environmental Engineering, University of Alberta*. Web. 12 April 2020. <https://era.library.ualberta.ca/items/b02cf9f8-581b-4df1-9d69-2134bff44ebe/view/36b285e3-64bc-4e4a-9657-91cc90058e48/Das_Susen_201601_MSc.pdf.pdf>

{4} ASCE. (1969). "Design and Construction of Sanitary and Storm Sewers." NY. Web. 12 April 2020.

{5} Camp, T.R. (1946). "Design of Sewers to Facilitate Flow." *Sewage Works Journal, 18 (3)*. Web. 12 April 2020.

CALCULATIONS FOR THE HYDRAULIC CAPACITY OF STORMWATER PIPES FLOWING PARTIALLY FULL

CURRENT CONDITIONS: 36" PIPE MADE OF VITRIFIED CLAY TILE

Known Parameters		
$n = n_{full}$ =	0.014	
D =	36	(in)
D =	3	(ft)
r =	1.5	(ft)
S =	0.0125	(ft/ft)

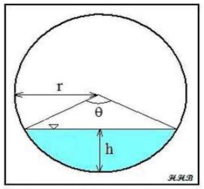
{1}

Equations for Variable Mannings Roughness Coefficient {2}

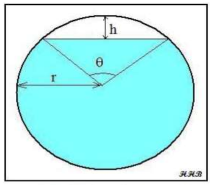
$0 \leq y/D \leq 0.03$:	$n/n_{full} = 1 + (y/D)/(0.3)$	(3)
$0.03 \leq y/D \leq 0.1$:	$n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$	(4)
$0.1 \leq y/D \leq 0.2$:	$n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$	(5)
$0.2 \leq y/D \leq 0.3$:	$n/n_{full} = 1.29$	(6)
$0.3 \leq y/D \leq 0.5$:	$n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$	(7)
$0.5 \leq y/D \leq 1$:	$n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$	(8)

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.014	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.15	1.134	0.016	0.15	0.90	0.13	1.35	0.10	2.22	0.29
0.10	0.30	1.220	0.017	0.30	1.29	0.37	1.93	0.19	3.22	1.18
0.15	0.45	1.250	0.018	0.45	1.59	0.66	2.39	0.28	4.05	2.69
0.20	0.60	1.280	0.018	0.60	1.85	1.01	2.78	0.36	4.71	4.74
0.25	0.75	1.290	0.018	0.75	2.09	1.38	3.14	0.44	5.32	7.35
0.30	0.90	1.290	0.018	0.90	2.32	1.78	3.48	0.51	5.89	10.51
0.35	1.05	1.280	0.018	1.05	2.53	2.20	3.80	0.58	6.45	14.22
0.40	1.20	1.270	0.018	1.20	2.74	2.64	4.11	0.64	6.96	18.37
0.45	1.35	1.260	0.018	1.35	2.94	3.09	4.41	0.70	7.42	22.89
0.50	1.50	1.250	0.018	1.50	3.14	3.53	4.71	0.75	7.84	27.70
0.55	1.65	1.225	0.017	1.35	2.94	3.98	5.01	0.79	8.31	33.11
0.60	1.80	1.200	0.017	1.20	2.74	4.43	5.32	0.83	8.75	38.77
0.65	1.95	1.175	0.016	1.05	2.53	4.86	5.63	0.86	9.16	44.58
0.70	2.10	1.150	0.016	0.90	2.32	5.29	5.95	0.89	9.54	50.41
0.75	2.25	1.125	0.016	0.75	2.09	5.69	6.28	0.91	9.87	56.13
0.80	2.40	1.100	0.015	0.60	1.85	6.06	6.64	0.91	10.15	61.53
0.85	2.55	1.075	0.015	0.45	1.59	6.40	7.04	0.91	10.36	66.37
0.90	2.70	1.050	0.015	0.30	1.29	6.70	7.49	0.89	10.49	70.29
0.95	2.85	1.025	0.014	0.15	0.90	6.94	8.07	0.86	10.46	72.59
1.00	3.00	1.000	0.014	0.00	0.00	7.07	9.42	0.75	9.80	69.24



Partially Full Pipe Flow Parameters (Less Than Half Full)



Partially Full Pipe Flow Parameters (More Than Half Full)

{2}

The highlighted green cell indicates the approximate flow capacity of the channel considering partially full pipe flow conditions.

PROPOSED CONDITIONS: 36" PIPE WITH 15 MM. CIPP LINING MADE OF FELT LINER AND 1 MM. POLYESTER-STYRENE RESIN COMPOSITION

Known Parameters		
$n = n_{full}$ =	0.012	
D =	34.74	(in)
D =	2.90	(ft)
r =	1.45	(ft)
S =	0.0125	(ft/ft)

This adjusted diameter accounts for the 15-mm. thickness of the CIPP lining material. {3}

Equations for Variable Mannings Roughness Coefficient

$0 \leq y/D \leq 0.03$:	$n/n_{full} = 1 + (y/D)/(0.3)$	(3)
$0.03 \leq y/D \leq 0.1$:	$n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$	(4)
$0.1 \leq y/D \leq 0.2$:	$n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$	(5)
$0.2 \leq y/D \leq 0.3$:	$n/n_{full} = 1.29$	(6)
$0.3 \leq y/D \leq 0.5$:	$n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$	(7)
$0.5 \leq y/D \leq 1$:	$n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$	(8)

{4} {5}

Calculations for Variable Mannings Roughness Coefficient

y/D	y (ft)	n/n_{full}	n	h (ft)	Θ (rad)	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Q (cfs)
0.00	0.00	1.000	0.012	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.14	1.134	0.014	0.14	0.90	0.12	1.31	0.09	2.53	0.31
0.10	0.29	1.220	0.015	0.29	1.29	0.34	1.86	0.18	3.67	1.26
0.15	0.43	1.250	0.015	0.43	1.59	0.62	2.30	0.27	4.61	2.86
0.20	0.58	1.280	0.015	0.58	1.85	0.94	2.68	0.35	5.36	5.03
0.25	0.72	1.290	0.015	0.72	2.09	1.29	3.03	0.42	6.06	7.80
0.30	0.87	1.290	0.015	0.87	2.32	1.66	3.36	0.49	6.71	11.15
0.35	1.01	1.280	0.015	1.01	2.53	2.05	3.67	0.56	7.35	15.09
0.40	1.16	1.270	0.015	1.16	2.74	2.46	3.96	0.62	7.93	19.49
0.45	1.30	1.260	0.015	1.30	2.94	2.87	4.26	0.67	8.45	24.29
0.50	1.45	1.250	0.015	1.45	3.14	3.29	4.55	0.72	8.93	29.39
0.55	1.59	1.225	0.015	1.30	2.94	3.71	4.84	0.77	9.47	35.13
0.60	1.74	1.200	0.014	1.16	2.74	4.12	5.13	0.80	9.97	41.13
0.65	1.88	1.175	0.014	1.01	2.53	4.53	5.43	0.83	10.44	47.29
0.70	2.03	1.150	0.014	0.87	2.32	4.92	5.74	0.86	10.87	53.48
0.75	2.17	1.125	0.014	0.72	2.09	5.30	6.06	0.87	11.24	59.55
0.80	2.32	1.100	0.013	0.58	1.85	5.65	6.41	0.88	11.56	65.28
0.85	2.46	1.075	0.013	0.43	1.59	5.96	6.79	0.88	11.81	70.42
0.90	2.61	1.050	0.013	0.29	1.29	6.24	7.23	0.86	11.95	74.57
0.95	2.75	1.025	0.012	0.14	0.90	6.46	7.79	0.83	11.92	77.01
1.00	2.90	1.000	0.012	0.00	0.00	6.58	9.09	0.72	11.16	73.46

EQUATIONS USED:

1. $h = y\ if\ \frac{y}{D} < 0.5\ \ or\ \ h = 2r - y\ if\ \frac{y}{D} \geq 0.5$
2. see the "Equations for Variable Mannings Roughness Coefficient" subset for the n/nfull calculation
3. $n = \frac{n}{n_{full}}(n_{full})\ ;\ where\ n_{full} = 0.009$
4. $\theta = 2cos^{-1}\left(\frac{r-h}{h}\right)$
5. $A = \frac{r^2(\theta - sin\theta)}{2}\ if\ \frac{y}{D} < 0.5\ \ or\ \ A = \pi r^2 - \frac{r^2(\theta - sin\theta)}{2}\ if\ \frac{y}{D} \geq 0.5$
6. $P = r\theta\ if\ \frac{y}{d} < 0.5\ \ or\ \ P = 2\pi r - r\theta\ if\ y/D \geq 0.5$
7. $R = \frac{A}{P}$
7. $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$
9. $Q = VA$

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9.3 HYDRAULIC CAPACITY CALCULATIONS - WILLSON AVENUE LINE

9.3.1 ALTERNATIVE 1 - PIPE BURSTING

*Assuming full pipe flow

Original Size and Roughness			→	Proposed Size and Roughness		
Diameter	6	in		Diameter	8	in
	0.5	ft/ft			0.7	ft/ft
Area	0.196	ft^2		Area	0.349	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	1.571	ft		Wetted Perimeter	2.094	ft
Hydraulic Radius	0.125	ft		Hydraulic Radius	0.167	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	0.699	cfs		Flow Rate	2.108	cfs
			Change	302 %		

Original Size and Roughness			→	Proposed Size and Roughness		
Diameter	8	in		Diameter	10	in
	0.667	ft/ft			0.8	ft/ft
Area	0.35	ft^2		Area	0.545	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	2.094	ft		Wetted Perimeter	2.618	ft
Hydraulic Radius	0.167	ft		Hydraulic Radius	0.208	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	1.505	cfs		Flow Rate	3.821	cfs
			Change	254 %		

Original Size and Roughness			→	Proposed Size and Roughness		
Diameter	10	in		Diameter	12	in
	0.833	ft/ft			1.0	ft/ft
Area	0.545	ft^2		Area	0.785	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	2.618	ft		Wetted Perimeter	3.142	ft
Hydraulic Radius	0.208	ft		Hydraulic Radius	0.250	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	2.730	cfs		Flow Rate	6.214	cfs
			Change	228 %		

Original Size and Roughness			→	Proposed Size and Roughness		
Diameter	12	in		Diameter	14	in
	1	ft/ft			1.2	ft/ft
Area	0.785	ft^2		Area	1.069	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	3.142	ft		Wetted Perimeter	3.665	ft
Hydraulic Radius	0.250	ft		Hydraulic Radius	0.292	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	4.439	cfs		Flow Rate	9.373	cfs
			Change	211 %		

9.3.2 ALTERNATIVE 2 - COMBINED PIPE BURSTING & FOLD AND FORM

Original Size and Roughness				Proposed Size and Roughness		
Diameter	6	in		Diameter	10	in
	0.5	ft/ft				
Area	0.196	ft^2		Area	0.545	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	1.571	ft		Wetted Perimeter	2.618	ft
Hydraulic Radius	0.125	ft		Hydraulic Radius	0.208	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	0.699	cfs		Flow Rate	3.821	cfs
		Change	547 %			

Original Size and Roughness				Proposed Size and Roughness		
Diameter	8	in		Diameter	10	in
	0.667	ft/ft				
Area	0.35	ft^2		Area	0.545	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	2.094	ft		Wetted Perimeter	2.618	ft
Hydraulic Radius	0.167	ft		Hydraulic Radius	0.208	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	1.505	cfs		Flow Rate	3.821	cfs
		Change	254 %			

Original Size and Roughness				Proposed Size and Roughness		
Diameter	10	in		Diameter	10	in
	0.833	ft/ft		Wall thickness	0.2	in
Area	0.55	ft^2		Area	0.498	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	2.618	ft		Wetted Perimeter	2.503	ft
Hydraulic Radius	0.208	ft		Hydraulic Radius	0.199	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	2.730	cfs		Flow Rate	3.389	cfs
		Change	124 %			

Original Size and Roughness				Proposed Size and Roughness		
Diameter	12	in		Diameter	12	in
	1.000	ft/ft		Wall thickness	0.2	in
Area	0.785	ft^2		Area	0.729	ft^2
Slope	0.018	ft/ft		Slope	0.018	ft/ft
Wetted Perimeter	3.142	ft		Wetted Perimeter	3.026	ft
Hydraulic Radius	0.250	ft		Hydraulic Radius	0.241	ft
Manning's n	0.014	-		Manning's n	0.01	-
Flow Rate	4.439	cfs		Flow Rate	5.625	cfs
		Change	127 %			

Original Conveyance				Increased Conveyance		
Weighted Q	2.58	cfs		Weighted Q	4.19	cfs
		Change	162 %			

*Assuming full pipe flow *Assuming fully deteriorated existing pipe & 6 ft bgs