

# TECHNICAL MEMORANDUM



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## HARVEST WATER PROJECT TRENCHLESS CONSTRUCTION ALTERNATIVES ANALYSIS

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### **Introduction**

This evaluation of trenchless feasibility for the Harvest Water program describes the construction process, applicable ground conditions, work area requirements, and installation considerations for various trenchless construction methods at the 18 potential trenchless crossing locations. The methods covered include auger boring, open-shield pipejacking, microtunneling, pipe ramming, and horizontal directional drilling (HDD). The descriptions identify which trenchless methods are appropriate for the 66-inch large diameter transmission pipeline and the 16- to 48-inch distribution pipeline of the program. The preliminary evaluation also describes recommended best practices for final design of the trenchless portions including geotechnical investigations, design criteria to be considered, and preliminary feasibility analyses of each identified trenchless crossing. The preliminary evaluations are based on reconnaissance-level site walks, and review of limited available geotechnical, existing utility, and site information.

### **Potential Trenchless Methods**

#### Auger Boring

Auger boring is a pipejacking technique for forming a cased bore from a jacking shaft to reception shaft. The casing is installed by an auger boring rig located in the jacking shaft which pushes steel casing into the ground as the soil is simultaneously excavated by means of a rotating auger string and cutting head. Spoil is removed back to the drive shaft by the helically wound auger flights rotating in the steel casing. After each casing section has been installed, the auger boring rig retracts and a new section of casing and augers are attached. The method has limited steering capability. Figure 1 shows the auger flights as they are being removed from an installed steel casing.



Figure 1. Auger Bore Rig in Shaft Installing Steel Casing

### *Applications and Limitations*

Auger boring can be used for the installation of 8- to 72-inch diameter steel casings or culverts under roads or railroads. Jacking pipe is limited to steel casing due to the potential for the rotating augers to damage the interior of the jacking pipe. Carrier pipe of any type can be installed inside the casing in a second pass. Guidance and steering limitations mean that auger boring is not typically used for on-grade applications, unless oversized casing is used to allow for adjustments of the carrier pipe to meet grade. Maximum lengths decrease with increasing diameter due to higher soil friction and torque requirements. Drive length is further impacted by line and grade considerations, as deviations can increase with bore length. Drive lengths are typically less than 400 feet; however, in favorable conditions, auger boring drives of up to 500 feet can be successfully completed.

### *Ground Conditions*

Auger boring is best suited for medium dense to very dense sands, firm to hard clays and silts, and medium dense to very dense silty and clayey gravels above groundwater. Auger boring can accommodate some cobbles and boulders less than 1/3 of the casing diameter. For pipe diameters greater than 24-inches, the augers can be retracted from the pipe to allow workers to remove cobbles and boulders or other objects at the face if necessary. Very loose to loose sands, very soft to soft clays, clean gravels, hard rock, and mixed-face conditions are unfavorable for auger boring. Risks of settlements increase in loose or soft soils and for drives beneath groundwater. Auger boring is not appropriate for projects with groundwater above the casing pipe in permeable soils due to the possibility of groundwater inflows to carry soil through the casing, resulting in overexcavation and potential voids.

### *Shafts and Work Area*

Auger boring jacking shafts are typically approximately 35 to 40 feet long. This allows for the jacking of 20-foot lengths of pipe and leaves room for the auger boring machine to sit behind the

casing. Shaft widths are typically 2.5 to 3 times the diameter of the jacking pipe to allow space on each side of the pipe for worker access. Finished shaft depths should allow 1.5 to 2 feet beneath the invert of the casing pipe for setting the auger boring rig guide rails.

The work area at the launch side of an auger boring operation needs to accommodate the jacking shaft, a crane, spoil storage, pipe storage and truck access. A minimum of 8,000 to 10,000 ft<sup>2</sup> is recommended for the jacking shaft work area. The equipment layout is flexible; therefore, work areas can have irregular footprints. The reception shaft work area can typically be smaller due to smaller shaft size requirements and no need for storage of spoils or pipe. A minimum of 8,000 ft<sup>2</sup> is recommended for the reception shaft work area to allow for construction of the shaft.

#### *Installation Considerations*

Several limitations exist when employing the auger boring technique. For example, there is no continuous tracking or steering of the head. Steering adjustments that may be made are crude; a water level is sometimes used to track grade. The augers must be recessed inside the casing in marginally stable soils to reduce over-excavation. The introduction of lubrication can reduce friction and required jacking forces. Due to the limited steering capability and risk of over-excavation, it is recommended that auger boring projects maintain at least 3 to 4 casing diameters of clearance beneath utilities or ground improvements.

#### *Advantages*

Auger boring has a long successful history and is a cost-effective method for installation of casing pipes in bores of less than 500 feet in stable soils. Construction durations are comparatively short and therefore costs remain low. There are many auger boring contractors across the country which typically results in multiple responsive bidders which often produces more competitive bids. Additionally, it is possible to withdraw the augers to reach the face and remove possible obstructions in stable soils.

#### Open-Shield Pipejacking

Often referred to as simply “pipejacking”, open-shield pipejacking (OSPJ) is a trenchless installation method where the excavation face is non-pressurized and open to the surrounding ground. Soil is excavated at the face and is typically removed by a short conveyor belt section to muck carts, as shown schematically in Figure 2. The muck carts are typically hauled by electric locomotive back to the jacking shaft to be emptied. Excavation can be accomplished manually by miners at the face, as commonly used for larger tunnels in stable ground, or by mechanized excavation. With mechanized excavation, the machine operator sits at the face of the machine (See Figure 3) in the shield and controls the speed of excavation, and provides steering corrections based on real-time observations of ground conditions, soil behavior, and position relative to design alignment and grade. The operator communicates with crew in the jacking shaft who control the advance rate of the machine. Many configurations of shields are available for various ground conditions, including completely open shields, shields with sand shelves, shields with large openings to accommodate cobbles and boulders, digger arms and boom headers for hard ground, and wheeled TBM-type excavator shields. The wheeled cutter heads can be fitted with closeable-face attachments to provide some limited face stability when groundwater and/or

unstable soils may be encountered. The closeable-face attachment cannot provide the same level of face support as microtunneling.

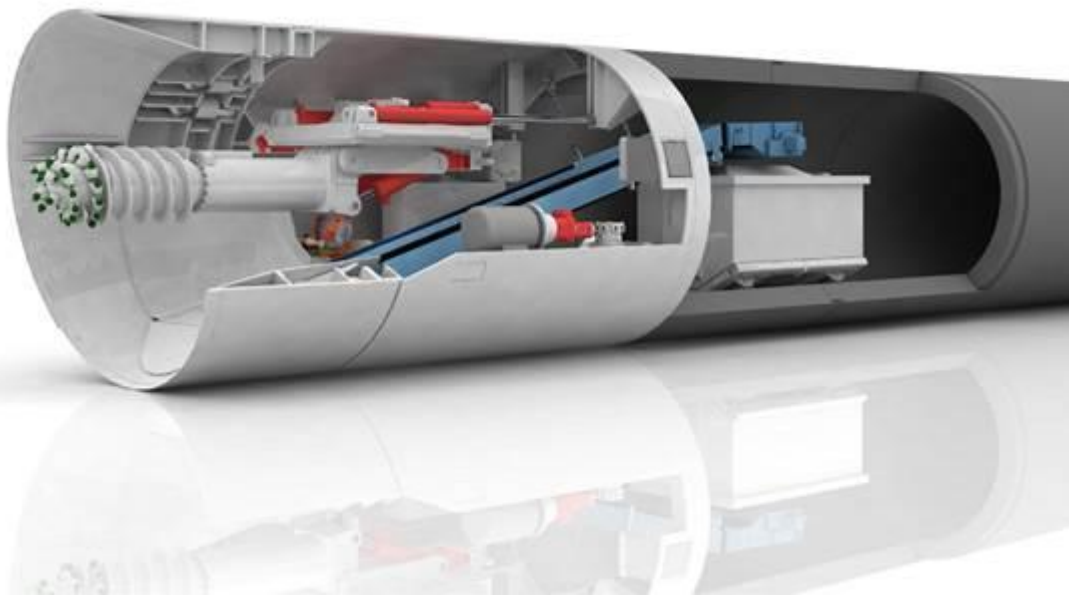


Figure 2. Schematic of Open-Shield Pipejacking with a Road Header (Conveyor for Spoils Loading of Muck Cart)



Figure 3. Operator at Front of OSPJ Machine

#### *Applications and Limitations*

OSPJ is ideal for installing jacking pipe greater than 48 inches in diameter in stable cohesive soils with little to no groundwater. This installation method can provide the accuracy necessary for gravity sewers but can also be used for pressure pipe applications. OSPJ can install any pipe material with a jacking joint, including steel casing, reinforced concrete (RCP), fiberglass reinforced pipe (FRP), and polymer concrete pipe (PCP). Alternatively, carrier pipes which cannot be direct-jacked can be installed within a casing in a second pass. The open face of the OSPJ shield provides very limited control of groundwater inflows and provides limited face stability. Therefore, OSPJ can result in over-excavation in loose sands and very

soft to soft clays, or in granular soils below the water table, which can lead to voids and settlement.

Open-shield pipejacking uses a laser system for guidance. The laser is installed in the jacking shaft behind the jacking frame and is set to design line and grade. Steering corrections are achieved using an articulated section and mechanical or hydraulic jacks in the shield. The achievable accuracy of OSPJ typical lower than for microtunneling, but still significantly better

than for auger boring which has no continuous guidance mechanism and only crude steering capabilities.

#### *Ground Conditions*

Open-shield pipejacking is appropriate in stable soils above groundwater, but due to limited face stabilization capability is inappropriate in flowing, running, or fast-raveling soils. OSPJ is not an appropriate method for use in pervious soils where high groundwater inflows are anticipated, which pose a risk of flooding the tunnel, endangering the operator, and resulting in subsidence. In some instances, it may be possible to dewater short trenchless alignments to allow for the use of OSPJ, however designers should carefully consider the costs of the dewatering efforts, treatment and/or disposal costs of the water, and the potential for dewatering-induced settlements. Adequate geotechnical investigations should be conducted and results provided to the contractor to determine ground conditions and groundwater elevations and ensure that a suitable groundwater control method and excavation head are selected for the anticipated ground conditions. Unlike microtunneling, an OSPJ machine provides access to the face, although access can be limited depending on the cutterhead configuration. Therefore, it is sometimes possible to identify obstructions and remove them manually if necessary. OSPJ can accommodate some cobbles and boulders up to  $1/3$  to  $1/2$  of the shield diameter.

#### *Shafts and Work Area*

OSPJ jacking shafts are typically approximately 30 to 35 feet long, or 30 to 35 feet in diameter for round shaft types. This allows for the jacking of 20-foot lengths of pipe and leaves room for the hydraulic jacks, thrust block, and shaft seals. Shaft widths are typically 2.5 to 3 times the diameter of the jacking pipe to allow space on each side of the pipe for worker access. Finished shaft depths should allow 1.5 to 2 feet beneath the invert of the casing pipe for setting the jacking frame guide rails.

The work area at the launch side of an open-shield pipejacking operation needs to accommodate the jacking shaft, a crane, generators, spoil storage, pipe storage and truck access. A minimum of 15,000 ft<sup>2</sup> is recommended for the jacking shaft work area. The equipment layout is flexible; therefore, work areas can have irregular footprints. Figure 4 shows a launch site that was located within an off-ramp cloverleaf. The reception shaft work area can be significantly smaller due to smaller shaft size requirements and no need for storage of spoils or pipe. A minimum of 8,000 ft<sup>2</sup> is recommended for the reception shaft work area to allow for construction of the shaft.



Figure 4. Work Area at Jacking Shaft of Open-Shield Pipejacking Project

### *Installation Considerations*

The maximum drive length for OSPJ projects is often controlled by increasing time to remove spoil from the tunnel face. Muck carts on rails are typically used for spoil removal, such as shown in Figure 5; as drive lengths increase, so does the time required to cycle out full muck carts, resulting in decreasing production rates. While drives of 1,200 to 1,500 feet can be achieved, drives of less than 800 to 1,000 feet are more common.

Depending on ground conditions and sensitivity of overlying features, the typical recommended depth of cover for OSPJ installations is 2 to 3 pipe diameters.



Figure 51. Full Muck Cart in Jacking Shaft

Because the operator sits at the face of the machine, adequate ventilation and lighting are required in the tunnel. OSPJ may not be an appropriate construction option if there is a possibility for noxious gases in the surrounding soil.

### *Advantages*

Open-shield pipejacking is a more economical option than microtunneling and there are more open-shield pipejacking machines and contractors available. In addition, unlike microtunneling, no separation plant is required, and spoils are not mixed with slurry, which reduces the required work area, equipment cost, and volume, cost, and difficulty of spoil disposal.

Because the operator observes the soil as it is excavated, tunneling practices can be adjusted to some extent when changes in soil conditions are detected. If an object is encountered while tunneling, open-shield machines provide access to the face, unlike most MTBMs, resulting in easier removal of objects, such as cobbles or boulders. A variety of shields and cutting tools are available for various soils, therefore the contractor can select the appropriate equipment based on evaluation of the geotechnical data, yielding more efficient construction and potentially lower bid costs.

### Microtunneling

Microtunneling is a remote-controlled, guided, pipejacking method that provides continuous face support. The microtunneling boring machine (MTBM) is operated from a control cabin at the ground surface where the operator steers the MTBM and controls slurry pressures and flows to the face. The ability to provide precise face control distinguishes microtunneling from open-shield pipejacking. Routine personnel entry is not necessary for operation of an MTBM. The guidance system is typically a laser mounted in the jacking shaft which projects onto a target in the shield.

The cutterwheel at the face of the machine can be customized with different tooling to optimize excavation for various ground conditions. Figure 6 shows two types of cutterhead options for various ground conditions. Various configurations and types of cutting tools can be matched to anticipated ground conditions.



**Figure 6. Two MTBM Cutter Head Options. Disk Type Cutters on Left for Rock, Drag Bits for Clay/Silt on Right**

Slurry is used to counterbalance earth and groundwater pressures and stabilize the face. Clean slurry is pumped through charge lines to the face, where it is mixed with the excavated spoils. The mixture of excavated spoil and slurry is pumped back to the surface through small diameter steel slurry discharge pipes within the jacking pipe. The slurry is pumped through a separation plant at the surface where the spoils are removed and the cleaned slurry is then recirculated back to the face. Separation plants can be specifically designed to handle the anticipated ground conditions, volume, and production rates.

### *Applications and Limitations*

Microtunneling can be used for a variety of utility installations from 24 to approximately 108 inches in diameter. It can be used to direct-install gravity and pressure pipelines (for pipe materials available as jacking pipe) as well as casings for carrier pipes when challenging ground and groundwater conditions are anticipated. Drive lengths are typically less than 1,500 feet due to jacking capacity and guidance system limits. Microtunneling can be used under high groundwater and in squeezing, rapid raveling, running, and flowing ground conditions, unlike

open-shield pipejacking and auger boring. In addition, because the face is fully supported, the risk of settlement due to over-excavation at the face is decreased.

#### *Ground Conditions*

Microtunneling can accommodate a range of geotechnical conditions, including soft to hard clays and silts, loose to very dense sand, and rock. An appropriate cutterhead and operating procedures must be selected for the anticipated soil conditions. Microtunneling is one of the few trenchless methods that can handle high groundwater.

Ground conditions that can cause problems for microtunneling projects include very soft to soft clay and silt, clean gravel (i.e. with little to no fines), extensive cobbles, boulders, hard rock, and mixed face conditions. Mixed face conditions occur when an alignment is sited along a contact between two soil layers with significant contrast in stiffness/hardness, e.g. sand over rock. In some circumstances, the MTBM can be deflected off grade into the less dense soil layer. Alternatively, the MTBM may have difficulty advancing through the hard layer and can over-excavate the overlying soft layer, resulting in settlement above the alignment. Mixed face soil conditions should be avoided if possible, by conducting a thorough geotechnical investigation to identify the contact elevation, and then choosing an alignment elevation that will be completely contained within one soil layer. We should make a bigger deal about not having access to the machine face to change tooling or deal with objects such as large cobbles or boulders. At what size could a traditional TBM (non micro) be used?

#### *Shafts and Work Area*

Microtunnel jacking shafts are typically approximately 30 to 35 feet long, or 30 to 35 feet in diameter for round shaft types. This allows for the jacking of 20-foot lengths of pipe and leaves room for the hydraulic jacks, thrust block, and shaft seals. Shaft widths are typically 2.5 to 3 times the diameter of the jacking pipe to allow space on each side of the pipe for worker access. Finished shaft depths should allow 1.5 to 2 feet beneath the invert of the casing pipe for setting the jacking frame guide rails.

The recommended minimum work area for the launch side of a microtunneling drive is approximately 16,000 ft<sup>2</sup>. The work area must be able to accommodate the jacking shaft, crane, separation plant, control cabin, generators, lubrication plant, and pipe storage, as shown in Figure 7. Similar to open-shield pipejacking, the equipment layout is flexible and therefore the work area can be a variety of shapes, although it must have adequate space around the shaft to construct the shaft itself and to house the crane and control container. In addition, trucks must have access to the separation plant to remove spoils from the site.



**Figure 72. Work Area for Microtunneling Jacking Shaft for 84-inch Concrete Pipe**

The work area required for the reception side of a microtunneling crossing is the same as for open-shield pipejacking, approximately 8,000 ft<sup>2</sup>. The work area needs to accommodate the construction of the reception shaft and a crane for removing the MTBM at the completion of the drive.

#### *Installation Considerations*

When microtunneling is selected as a trenchless construction method because of high groundwater, watertight shafts and shaft seals are also required. This is especially true for crossings near rivers or creeks which can provide a nearby source of unlimited groundwater recharge which may not be effectively controlled with dewatering measures alone. Depending on ground conditions, the presence of surface water, and the sensitivity of overlying features, the typical recommended depth of cover for microtunneling crossings is 2 to 4 pipe diameters.

Unlike open-shield pipejacking, which provides access to the face of the machine, most MTBMs provide no face access to identify and remove obstructions. Some larger diameter MTBMs provide limited access to the face for changing cutters, but not for removing obstructions. When an obstruction blocks the MTBM's advance, it must be removed. Sometimes, the only recourse is to dig a costly rescue shaft which may be in an inconvenient or inaccessible location, such as beneath the traffic lanes.

#### *Advantages*

Microtunneling is ideal for installing on-grade pipelines under high groundwater or in unstable soils. It is suitable in most ground conditions from soft soil to rock, as long as the geotechnical conditions have been well characterized, allowing the contractor to accurately select an appropriate head.

### Pipe Ramming

Pipe ramming is a non-steerable installation method for driving an open-ended steel casing using a percussive hammer as shown schematically in Figure 8. Hammers are available in a range of sizes to install a variety of pipe diameters and lengths. The hammer transmits the ramming force to the pipe via a tapered adaptor cone which is welded to the rear of the pipe. After a section of casing has been installed, the hammer and adaptor cones are removed, and a new casing section is welded into place. The hammer assembly is reattached, and ramming operations continue. The soil may be removed from the casing using augers, jetting, or compressed air after completion of ramming, or at intervals during the drive.

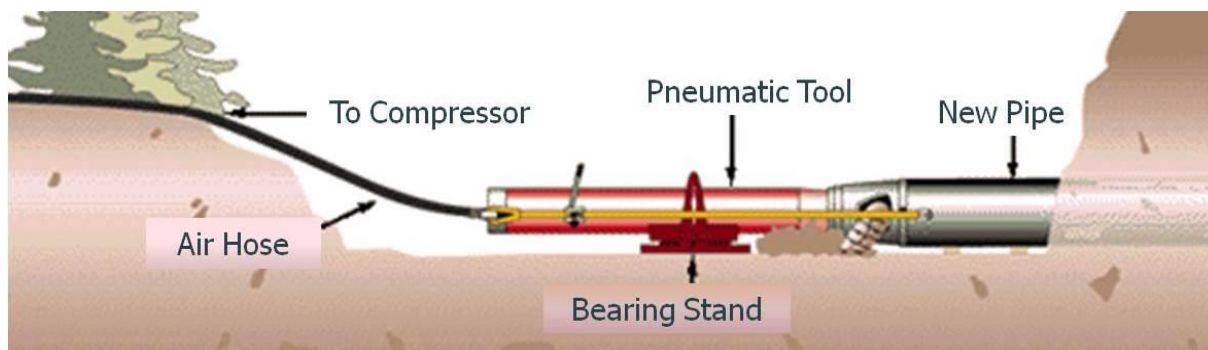


Figure 8. Schematic of the Pipe Ramming Process

### *Applications and Limitations*

Pipe ramming is used for the installation of steel casings from 8" to over 144" diameter, typically under roads or railroads. Drive lengths are typically below 300 feet, however in favorable conditions, pipe rams of up to 400 feet can be successfully completed. The soil is typically not removed from the casing until after the entire pipe string has been installed, therefore there is a relatively low risk of over-excavation and settlement. Because settlement is a large concern for railroads and DOTs, this method is often favored over methods which require excavation of soils at the leading edge of the casing, such as auger boring, or which require a large annular overcut, such as HDD. In addition, DOTs and railroads prefer the use of pipe ramming since drilling fluids are not used.

As pipe diameter increases, skin friction increases and reduces the maximum achievable drive length. Although casings with diameters as large as 144 inches have been installed with pipe ramming, those projects represent the upper limit of the technology's capabilities, and require experienced contractors, favorable ground conditions, and short drive lengths. The only pipe material that can be rammed is steel pipe, either as direct carrier or casing. Because of the dynamic installation forces, a much thicker wall than is needed for service loads is typically required to prevent pipe failure during installation. To further withstand the installation forces,

the leading edge of the casing is reinforced with a cutting shoe, which is thickened to resist damage to the pipe from impact and beveled to better displace the soil as the pipe advances. The cutting shoe also creates an overcut around the pipe, inside and outside, to allow for lubrication and to help reduce friction. Frictional resistance must be managed to control the force required to advance the pipe through the ground.

#### *Ground Conditions*

Ground conditions that are favorable for pipe ramming installations include medium dense sands and gravelly sands, soft to stiff clays and low groundwater. Some cobbles and boulders can be accommodated if they are less than half the pipe diameter. Hard or very dense soils are difficult to penetrate and may require a very large hammer or a reduced bore length. In addition, heave risk increases in hard or very dense soils with low earth cover because the soil that is displaced outward increases in volume and can heave the surrounding formation. Conversely, very loose or soft soils and soils under high groundwater may collapse or run into the leading edge of the pipe, causing over-excavation and settlement. Furthermore, soft or loose soils can settle due to vibration from the pneumatic hammer. Pipe ramming is not appropriate in rock or pervious soils under high groundwater heads.

Typically, soil is removed from the casing after ramming operations using augers, water jets, compressed air, or by mini-excavator or skid steer for large diameter pipes. However, in some cases, soil may be removed periodically during installation to reduce soil to pipe friction, to check line and grade, or to remove an obstacle. If soil is removed prior to completion of the drive, it is common to leave a 10 to 20-foot “soil plug” at the leading edge of the pipe to prevent soil from sloughing into the casing. The minimum functional plug length will be dependent on the soil type and strength.

#### *Work Area*

Pipe ramming launch shafts are typically approximately 30 to 40 feet long, and may be as long as 55 feet. The long shaft allows for the ramming of 20- to 40-foot lengths of pipe and leaves room for the ramming hammer and air hose. Because casings for pipe ramming are especially thick, and good transfer of impact energy is important across pipe joints, it is advantageous to ram long pipe segments to reduce overall welding effort. Shaft widths are typically 2.5 to 3 times the diameter of the casing pipe to allow space on each side of the pipe for worker access. Finished shaft depths should allow 1.5 to 2 feet beneath the invert of the casing pipe for setting the ramming guide rails.

The work area for the launch side of a pipe ram project must be large enough to accommodate the launch shaft, crane, pipe storage, air compressor, end loader or other spoil removal equipment, and truck access for spoil removal. Minimum recommended work area at a launch shaft is 8,000 to 10,000 ft<sup>2</sup>, depending on pipe size. When the pipe ram is launched from a pit, as shown in Figure 9, the required pit dimensions are determined by the combined length of the pipe segments and hammer and diameter of the pipe to be installed.



Figure 93. Launch Pit Shored with Trench Boxes for 30-inch Pipe Ram

Pipe ram installations do not always require a receiving shaft, as there is no equipment that must be recovered from the lead end of the casing, allow for a blind tunnel. However, if a shaft is used to cut off the cutting shoe or to make tie-ins, the receiving area should be large enough to construct the shaft/shoring, approximately 8,000 ft<sup>2</sup>.

#### *Installation Considerations*

The maximum achievable length of a pipe ramming project decreases with increasing diameter and soil density or consistency. As pipe diameter increases, soil frictional resistance increases, which increases the force required to advance the pipe. Lubrication, both inside and outside the casing, may be used to reduce friction, but the small diameter lubrication pipe must be plumbed to the cutting shoe before the ramming starts. The lubrication pipeline is attached to the crown of the pipe and distributes the lubricant into the annular space created behind the cutting shoe, as shown in Figure 10.



Figure 10. Lubrication Pipe Attached Near Top of Pipe. Adaptor Cone to Transmit Hammer Forces to Casing

There is no mechanism to steer a pipe ram, and therefore it is critical to align the pipe accurately prior to launch and to check alignment during the initial ramming phase. Proper survey and a correct initial setup of bearing stand can help ensure that proper line and grade are maintained during launch and subsequent ramming. Because pipe ramming cannot be steered, the achievable accuracy is relatively low, which limits the practical length for direct installations. The low accuracy can be mitigated by oversizing the casing to allow for grade corrections with the carrier pipe via adjustable casing spacers.

Lack of steering capability also increases the risk of striking an existing utility. Pipe rams should be designed with a minimum of 5 feet, or one to two casing diameters of clearance from existing utilities. In addition to damage from direct strikes, overlying utilities can be damaged from vibration and ground movements. Critical overlying utilities should be evaluated for vibrational risks.

Pipe ramming produces significant noise. The impact hammers cycle several hundred times per minute at very high decibels. When designing pipe ramming projects in residential neighborhoods, limiting work hours may be advisable, and the public should be made aware of the project and its anticipated duration. In sensitive environmental areas, restrictions on noise levels may complicate the permitting process. Sound baffles may be used to reduce noise transmitted to residents.

#### *Advantages*

Pipe ramming is a simple trenchless technique that requires relatively little support equipment and therefore requires a smaller footprint than other trenchless installation methods. Ramming works in a wide range of soil types for short culvert pipe lengths. Since the force to install the pipe is provided by the pneumatic hammer, a thrust block is not required. The construction duration for pipe ramming projects is typically short, but is dependent on whether a shaft is required, the required pipe joint welding time, and the ease of soil removal from the pipe. Use of mechanical, press-fit jointed pipes, such as Permalok, can result in faster joint times, especially for larger diameter pipes where welding time is significant.

#### Horizontal Directional Drilling (HDD)

HDD installation is a surface-launch three-stage process: pilot bore, reaming, and pipe pullback. The pilot bore (Figure 11) is drilled along the designed alignment from entry to exit, using vertical curves. The minimum radii of the curves are dependent on the product pipe to be installed, as well as the drill pipe for the HDD rig. Once the alignment has been established, the pilot bore is then reamed to a large enough diameter to allow product pipe pullback. Reaming involves enlarging the pilot bore to facilitate installation of the product pipe. The final stage is pipe pullback where the fabricated pipe string is attached to the drill pipe with a swivel and pulled into place. During drilling, a bentonite-based drilling fluid is pumped through the hollow drill pipes to the pilot bit or reamer. This fluid helps to excavate the ground, and is mixed with the cuttings to carry them back to the drill rig through the annular space between the drill pipe and the bore. The drilling fluid also supports the un-cased borehole to prevent collapse and hold back

groundwater pressures. Small pits are excavated at the entrance and exit points to facilitate containment of returning drilling fluids.

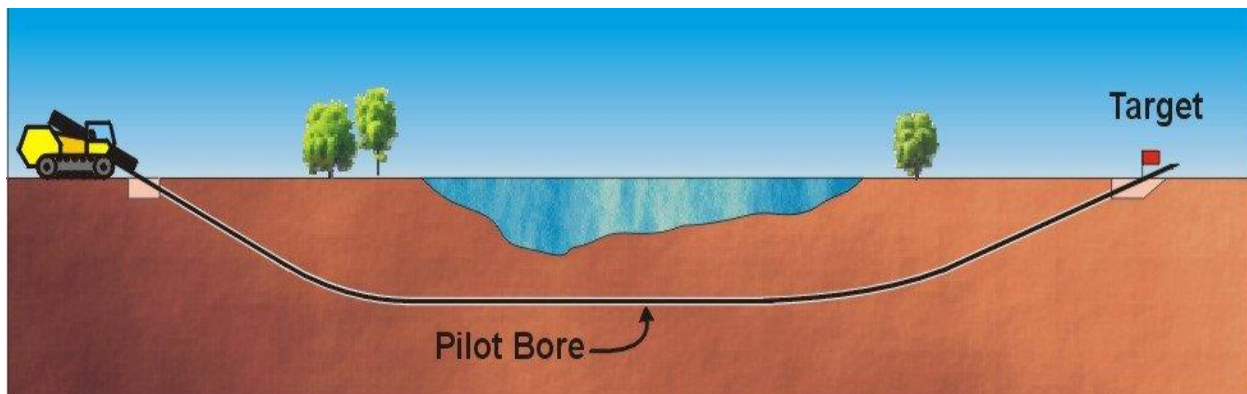


Figure 11. Typical Pilot Bore Alignment under a Waterbody

### *Applications and Limitations*

HDD is used to install product pipe diameters ranging from 2-inches to 54-inches over distances up to 14,000 ft; however, most HDDs are less than 3,000 feet and diameters are more typically 36-inches or less. HDD is typically used for pressure pipelines; however, HDD has been successfully used for installing gravity sewer pipelines. HDD is limited to the installation of continuous fused or welded pipe, or pipes with tension-capable mechanical joints since the product is pulled into place. Common pipe materials used include ductile iron; high density polyethylene (HDPE); polyvinylchloride (PVC); and steel.

### *Ground Conditions*

HDD installations can be completed in most ground conditions since tooling and drilling fluids can be matched to the anticipated geology and can be easily be changed throughout the process. Ideal conditions are medium to stiff non-plastic clays, medium dense to dense cohesive sands, and other soils which provide adequate steering response and have good bore stability. Because the goal is to suspend and transport cuttings to the surface entry or exit pits, drilling through rock, cobbles, or gravels can pose challenges to HDD as the larger, heavier spoil particles are difficult to suspend in the drilling fluids and tend to drop to the bottom of the borehole. Groundwater is not typically a concern for HDD bores, unless the driving pressure will lead to groundwater flow through the bore and out to the ground surface at either end.

### *Work Area*

Required work area is dependent on rig size, drilling fluid processing equipment needed, product pipe size, and length of installation. Rig side work areas are generally 3,000 to 5,000 ft<sup>2</sup> for small installations and up to 15,000 ft<sup>2</sup> for large installations that require large drill rigs and ancillary equipment. A typical work area for a medium sized rig is shown in Figure 12. In general, work area layouts are flexible, but constrained or awkward spaces will often result in reduced productivity. Sufficient space should be provided near the drill rig for drill pipe storage areas and drill pipe handling equipment. Spoil separation plants are typically used for medium to large size rigs and it is important that work areas be designed to provide adequate access for dump trucks

or other spoil removal equipment at and around the plant. Shafts are not typically required for HDD bores, though small drilling fluid pits are often excavated at each end of the bore which may measure 3 to 8 feet wide by 5 to 15 feet long, depending on installation size.



**Figure 12. Typical Work Area for a Medium Sized HDD Project**

### *Installation Considerations*

Drilling fluids and additives are an integral component of any HDD installation. Proper design of fluids to match anticipated geological conditions is critical to project success. Drilling fluids may be either bentonite-based or polymer-based and include additives to assist in varying capacity. Additionally, care must be taken to control downhole fluid pressures to reduce the likelihood of inadvertent drilling fluid releases (IDFRs, sometimes referred to as frac-outs) which occur when the fluid escapes the borehole into the surrounding formation. IDFRs can result in loss of circulation and therefore reduced spoil removal from the bore. They are also of concern where environmentally sensitive features may be negatively impacted by surface releases. Good practices indicate that IDFR risk should be evaluated during design to select the appropriate alignment as a mitigation measure. The risk of inadvertent returns generally controls the depth of HDD bores beneath waterways, with typical recommended clearances varying from 15 to 30 feet, depending on the type and strength of soils present between the bore and the waterway.

HDD bores are guided and steerable, however the achievable accuracy is typically measured in a matter of feet, rather than inches. Therefore, HDD is best-suited to pressure-flow applications where variations in line and grade between 1 to 5 feet are acceptable.

### *Advantages*

HDD is a versatile surface-launched technique for installing a wide range of pipelines in various geological conditions. Setup times are relatively short compared to other trenchless techniques. HDD is particularly advantageous for installation of utilities under water bodies and critical roadways. HDD typically has the longest feasible trenchless reaches. An inherent advantage of HDD is the ability to retract the drill pipe to change the drill bit or reamer should changing geology deem it necessary.

Summary

Table 1 presents a comparison of the trenchless construction methods discussed in this TM, including applicable pipe diameters, feasible lengths, typical accuracy, suitable ground conditions, limitations, and relative cost. All these methods provide the ability to install various product pipes either directly or inside casing, with minimal disruption to surface activity.

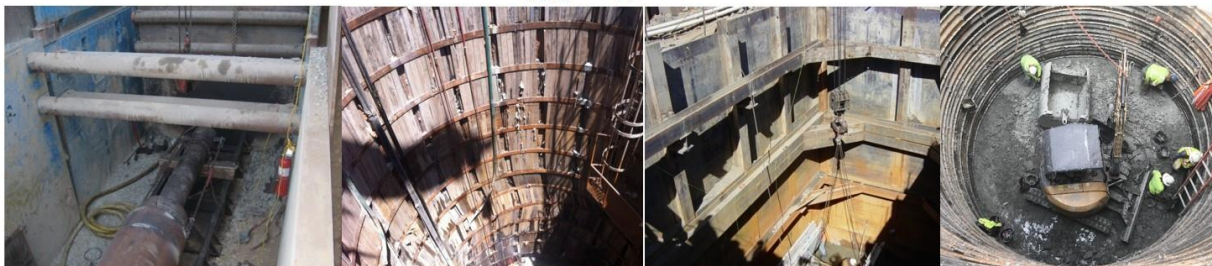
Table 1. Summary of Trenchless Construction Methods						
Method	Pipe Outer Diameter	Typical Length	Accuracy	Suitable Ground Conditions	Relative Cost	Limitations
<b>HDD</b>	2 – 54"	< 3,000 ft*	± 1 - 10 ft	Sand, silt, and clay, full-face rock, groundwater	\$ to \$\$\$	Not appropriate in loose sand, very soft clay, or extensive gravels**, highly fractured rock, mixed face conditions
<b>Pipe Ramming</b>	8 – 144"	< 300 ft	± 2 - 5'	Stable to marginally stable displaceable soil, can handle some cobbles and boulders***	\$\$\$ to \$\$\$\$	Not appropriate in soft/loose unstable soils, rock, groundwater; no steering, steel casing only
<b>Auger Boring</b>	8 – 72"	< 400 ft	± 1 to 5' (1-2% of length)	Stable soils, soft to medium strength rock above groundwater	\$ to \$\$	Not suitable in unstable soils or permeable soils with groundwater; limited steering; steel casing only
<b>Open-Shield Pipe Jacking</b>	48 – 144"	< 1,000 ft	± 3.0"	Stable soils, soft to medium strength rock above groundwater; can handle some cobbles/boulders***	\$\$\$ to \$\$\$\$	Not suitable in unstable soils or permeable soils with groundwater
<b>Microtunneling</b>	24 – 108"	< 1,500 ft	± 1.0" to 2.0"	Sands, clays, silts, soft to weak rock, unstable soils, groundwater	\$\$\$\$\$	Not suitable in extensive gravels, cobbles, or boulders
<p>* Some bores have been completed beyond 10,000 feet; however, most bores are less than 3,000 feet.  ** Conductor casings may be used to mitigate risks of running, flowing, or squeezing soils near entry and exit points.  *** Anticipated maximum cobbles and boulders should be less than 25% to 40% of tunnel OD.</p>						

### Shafts

Access shafts or pits are generally required for auger boring, open-shield pipejacking, pipe ramming, and microtunneling. The type, size, and shape of shafts and pits are influenced by the trenchless method, ground and groundwater conditions, and length and diameter of the individual pipe segments and equipment. Shaft length is typically dictated by the length of equipment and pipe. Shaft diameter or width tends to increase as pipe diameter increases, or if multiple, parallel crossings will be launched from, or received into, the same shaft.

Watertight shafts are recommended for projects in pervious soils below groundwater, typically combined with microtunneling. Watertight shaft methods include interlocking steel sheetpiles, secant piles, cutter soil mixing shafts, auger-drilled shafts, sunken caissons, slurry wall shafts, and ground freezing. Rubber gasketed entry and exit seals should be specified in combination with watertight construction methods to limit infiltration of ground and groundwater. Simpler, less expensive non-watertight shafts may be sufficient for auger boring, open-shield pipejacking, pipe ramming, and other methods in most soils above groundwater. Non-watertight shafts include soldier piles and lagging, slide rail shafts, trench boxes, and liner plate shafts. It is not recommended to allow the use of trench boxes for jacking shafts; the shoring at the front and rear of the shaft are often not in tight contact with the surrounding ground which can result in substandard thrust capacity at the rear of the shaft and soil sloughing into the entry portal, resulting in subsidence at the surface or undermining of nearby utilities. Various types of shafts are illustrated in Figure 13.

### **Trench Boxes   Rib & Lagging   Soldier Piles   Liner Plates**



### **Caisson   Secant Piles   Sheetpiles   Auger-Drilled**



Figure 13. Various Shaft Types - Top Row: Non-Watertight Shafts; Bottom Row: Watertight Shafts

Most trenchless installation methods advance the machine with hydraulic rams that push against a thrust block at the back of the jacking shaft. Thrust blocks must effectively transfer the jacking load to the soil behind the shaft to provide adequate thrust reaction. If soils behind the thrust block are too weak or too shallow to provide adequate thrust, deep foundation reinforcing, such as soldier beams or piling, can be used.

Trenchless design engineers should specify allowable shaft construction methods based on the anticipated ground conditions at each shaft location. It is recommended that multiple shaft methods be allowed, if possible, to provide options for bidders. The specifications must clearly address performance requirements: dry interior, stable shaft invert, adequate thrust reaction, and sufficient area to perform tie-ins to open-cut portions of the work. In addition, the design engineer should ensure that there is adequate work area for construction of the allowable methods, including traffic control, constructability of the shaft, clearances from other underground and overhead utilities, and trenchless construction operations. Where clearances to adjacent structures is minimal, selection of appropriate shaft construction methods is critical to limit the risk of damage due to ground loss during shoring installation or excavation. Running or flowing ground conditions further increase the risk of damage due to ground movement.

It is the responsibility of the contractor to determine the actual dimensions of the shaft to ensure compatibility with their proposed means and methods. The contractor's shoring design engineer is responsible for the design of the temporary shaft excavation and should submit calculations demonstrating the shoring design is adequate to safely withstand anticipated earth and groundwater pressures. The shoring designer should also submit stamped calculations for the thrust block capacity taking into consideration the soil strength outside the shaft as well as contractor means and methods, such as the capacity of the contractor's jacking frame, the use of lubrication, or the planned use of intermediate jacking stations.

### Shaft Portals

The locations where the tunnel exits and enters the shafts are called the portals. The primary shoring at the portal locations must be removed prior to launch, resulting in a temporarily unsupported excavation. Portal instability can result in excessive groundwater and soil entering the shaft during launch or retrieval and is often problematic in fast raveling, running, or flowing soils, and for locations with high groundwater. If the soil outside of the portal has not been suitably stabilized prior to opening a portal in the shoring, serious issues can arise, such as creation of voids outside the shoring that can result in settlement of overlying utilities, ground surface, or roadways. Several methods are commonly used to provide a stable shaft portal, including ground improvement, guillotine-type double-walled sheets, or methods that are integral to the shaft construction method. In addition to stabilization measures during launch and retrieval, most trenchless projects require rubber gaskets or seals at the portals, as shown in Figure 14. These seals prevent soil, water, and lubrication from entering the shaft around the machine or pipe. Entry and exit seals are especially important when high groundwater is anticipated.



**Figure 14. Left: MTBM Launch through Entry Portal. Right: Shoring Removal from Exit Portal in Sheetpile Shaft with Gasketed Seal.**

### **Geotechnical Investigation and Evaluation**

Selection of appropriate trenchless methods is primarily driven by anticipated ground behavior. Soil behavior can be determined through experience with trenchless methods in the anticipated soil types and through both traditional and alternative geotechnical investigation methods.

The geologic setting of the Harvest Water Program in the south-central portion of the Sacramento Valley leads to anticipated ground conditions of sands, silts, and clays, with the potential for some isolated gravel soils. Bedrock, extensive gravels, cobbles, and boulders are unlikely to be encountered so far from the high energy rivers and creeks of the Sierra Nevada and Coast Range mountains. Therefore, the focus of geotechnical investigations for trenchless design on this project should be on the classification of soil stratigraphy, determination of soil consistency and strength, grain-size distribution, and groundwater elevation and variation near each crossing.

The geotechnical data will be used by the C-PMO team and final design teams to assess likely behavior of the ground during trenchless construction and select appropriate trenchless methods to match the anticipated behavior. Heavy focus will be placed on groundwater level and soil permeability, driving decisions between watertight and non-watertight construction methods for both shaft construction and trenchless pipeline installation.

Geotechnical borings should generally be located at or near terminating points of trenchless crossings, e.g. shaft locations. Borings should be offset from the design alignment by 15 to 30 feet, to avoid the potential risk of an abandoned boring presenting an obstruction. Additional intermediate borings are recommended for crossings longer than 500 feet and when geological conditions may be highly variable and challenging; for example, beneath waterways or where

there is a suspected contact between variable soil strata. Past meandering of creeks or rivers will typically lead to more varied ground conditions, often more permeable granular soil deposits, and possibly higher groundwater levels.

Geotechnical boring logs should document the encountered soil type, relative density, and groundwater elevation. Additional testing, such as sieve analyses, friction angle, and Atterberg limits are recommended for samples taken at and near the anticipated pipeline horizon for use in determining appropriate construction methods. Borings should extend below the anticipated design pipe invert by the greater of at least 10 feet or 2 pipe diameters. Borings that terminate above the pipeline invert can lead to costly, inaccurate interpretations and assumptions, as well as differing site conditions claims. Since final design invert elevations are not always fixed or known in advance, deeper borings can provide valuable insights into whether it would be advisable to deepen the crossing, if hydraulic flow requirements permit any flexibility. Deeper borings also help determine shaft shoring and foundation requirements.

It is recommended that at least one piezometer be installed at each proposed trenchless crossing to evaluate seasonal changes in groundwater elevations. Borings that will house piezometers should be near, but not within the shaft footprint. Piezometers should be offset sufficient distance to ensure survival during construction and allow monitoring data to be acquired. If preserved through construction, these piezometers can be used to evaluate the effectiveness of an external dewatering program.

### **Ground Behavior and Method Selection**

Large diameter auger holes and observation pits offer a way to characterize soil behavior, identify the presence of gravel, cobbles, and boulders, and observe groundwater infiltration. During these investigations, a geotechnical engineer can observe the behavior of the vertical cut face to determine if face stability is a concern. Similarly, groundwater pumping tests can identify if groundwater inflows will destabilize the excavation, if a dewatering program is a feasible strategy for dealing with groundwater, or if the infiltration rate and soil behavior indicates that watertight construction methods are necessary. A comprehensive understanding of the anticipated soil behavior is crucial for specifying the appropriate tunneling methods.

Trenchless methods which rely on open-face excavation such as auger boring or open-shield pipejacking can be safely used in ground that will remain stable and produce little to no groundwater inflows. As the ground becomes more unstable, or permeability increases below the water table, closed-face or drilling fluid-supported methods such as microtunneling or HDD become necessary. Ground behavior for trenchless work is typically described using the Tunnelman's Ground Classification system, shown in Table 2. Firm and slow raveling ground are typically suitable ground conditions for auger boring, open-shield pipejacking, and pipe ramming methods. Fast raveling, squeezing, running, and flowing conditions typically require watertight or drilling fluid-supported methods such as microtunneling or HDD. In certain saturated, fast raveling ground, with low permeability, pipe ramming can be used safely if modifications are made to improve the stability of the soil plug maintained inside the casing.

<b>Table 2. General Ground Behavior and Tunnelman’s Ground Classification</b>		
<b>Classification</b>	<b>General Ground Behavior when Exposed in Tunnel</b>	<b>Typical Soil</b>
Firm	Heading can be advanced without initial support.	Hard clays and cemented sands and gravels.
Slow Raveling	Chunks or flakes of material begin to drop out of the arch or face sometime after the ground has been exposed.	Sands with clay or silt binder or fine sands above the water table.
Rapid Raveling	Chunks or flakes of material begin to drop out of the arch or face within a few minutes of exposure.	Sands with clay or silt binder or fine sands below the water table
Squeezing	Ground slowly advances into tunnel without any signs of fracturing. The loss of ground caused by squeeze and the resulting settlement of the ground surface can be substantial.	Soft to stiff clays depending on the degree of overstress, commonly indicated by the value of the stability number.
Swelling	Like squeezing ground, the soil moves slowly into the tunnel, but the movement is associated with a considerable volume increase in the ground surrounding the tunnel.	Highly over-consolidated high plasticity clays.
Cohesive Running	Exposed soil will “run”: like a granulated sugar until the slope angle becomes equal to about 34 degrees. If the run is preceded by a brief period of raveling, the ground is called cohesive running.	Clean, fine, moist sand.
Running	Immediately upon exposure, the soil will “run” like a granulated sugar until the slope angle becomes equal to about 34 degrees.	Clean, coarse or medium sand above the water table.
Flowing	Material with sufficient cohesion to stand for a brief period of raveling before it breaks down and flows as a mixture of soil and water into the heading. The mixture of soil and water flows into the tunnel like a viscous fluid. The material can enter the tunnel from the invert as well as from the face, crown, and walls, and can flow for great distances as it accumulates in the tunnel.	Silt, sand, and gravel beneath the water table without fines to develop appreciable cohesion.

Trenchless pipe alignments at interfaces between significantly dissimilar soil types (e.g. rock and soil) should be avoided. The mixed face condition often results in slow advance rates due to the difficulty of excavating the denser lower layer; meanwhile the more easily excavated upper layer may slough into the face of the machine, resulting in over-excavation which can lead to

settlement. Strategies to avoid mixed face conditions include raising or lowering the pipe elevation to be completely within one soil type, selecting an alternative crossing location, installing a siphon or lift station, or open-cut construction. Although some of these strategies may be unfavorable due to increased construction or maintenance costs, they are often less than the costs incurred for claims, repair of damaged features, and potentially legal costs.

## **Design Criteria**

### **Depth Selection and Settlement**

Trenchless crossing depth is typically determined by seeking the best available soil profile, combined with an assessment of settlement risk to overlying surface features, buried structures, and/or existing utilities. As a starting criterion to avoid settlement damage for pipe jacking installations, designers should look to provide approximately 8 feet of clearance between the top of the trenchless installation and the nearest feature of concern, for trenchless bore diameters of 48 inches or smaller (approximately two bore diameters). For larger installations up to 96 inches, vertical clearance recommendations would be approximately 12 to 16 feet (approximately 1.5 to two bore diameters). In firm/stable ground conditions, these guidelines should provide reasonable mitigation of settlement risks to most overlying features. However, in cases where unfavorable ground conditions, shallow groundwater, unusually deep existing utilities, or especially sensitive features exist, final designers should conduct specific settlement evaluations to check the adequacy of the standard clearance recommendations, or to justify reduced clearances. HDD installations use a larger annulus between the excavated bore and product pipe, resulting in greater settlement potential than pipejacking installations; though the drilling fluid used in HDD fills this annular space, reducing the potential somewhat. HDD bores typically rely on a three to five bore diameters of clearance from overlying features, and mitigation measures such as conductor casing or exposure and physical support of overlying features near the ends of bores where clearance cannot be increased. HDD bores passing close to existing features also warrant specific settlement evaluations. There are many methods available for performing settlement analyses for trenchless installations. One approach that designers may consider is "Analysis and Mitigation of Settlement Risk in New Trenchless Construction", by Wallin, Wallin, and Bennett and published in the proceedings of the NASTT N-Dig Show in 2008.

Analytical models will allow potential settlements to be estimated for individual trenchless crossings, however the other half of the risk evaluation is assessing safe allowable levels of settlement. Table 3 offers starting guidance on allowable settlement values for various types of overlying features. These recommendations are appropriate for standard types of features. However, if the overlying structure or utility is especially sensitive to movement (as for older or brittle structures), has a high consequence associated with any damage (e.g. large water transmission mains, flood control structures, high-speed rail, etc.), or would be costly to repair, tighter settlement limits should be used. It is best practice to coordinate with the owner of any site features that may be subject to settlement to determine acceptable levels of movement.

**Table 3: Allowable Settlement Values for Various Features\***

Feature	Allowable Settlement/Heave (inches)
Railroad Tracks	0.25
City/County Streets	0.5
Underground Utilities	1.00
Unimproved Ground	3.00

Contact grouting should be used after the completion of pipejacking and pipe ramming drives, and should be considered near the ends of HDD bores, to mitigate long-term settlement risks. The specifications should require that casing pipes (or carrier pipes for direct installations) should include lubrication/grout ports in the pipe at intervals of 10 feet or less to allow

injection of low-strength grout to fill the remaining annular space outside of the jacking pipe. Contact grouting should be completed within 48 hours or less after completion of the pipe jacking drive, to reduce the chance for the annulus to squeeze in around the pipe prior to grouting.

### Casing Pipe Requirements

Casing pipe will be required for many of the trenchless crossings for a variety of reasons. Encroachment permit requirements of UPRR and Caltrans require that all carrier pipes be contained within a continuous casing. Certain trenchless methods such as auger boring and pipe ramming require the use of steel casing to withstand installation forces or prevent damage to the carrier pipe. Also, certain types of carrier pipe which may be favored for the transmission or distribution system cannot be safely installed by direct-jacking or HDD pullback. For example, CMLC steel pipe cannot be installed by direct-jacking as the repeated application of axial strain by the jacks would lead to cracking of the mortar. Therefore, casing will be required for crossings where CMLC steel carrier will be installed in a second pass.

For crossings where casing is not required, an additional pipeline material is available that can be safely installed in a single pass, reducing the time and cost associated with installing the carrier within a larger casing. FRP (HOBAS or Flowtite) is available in a configuration that can be installed by pipejacking methods, and can carry internal pressures up to 100 psi. FRP jacking pipe is available in diameters up to 84 inches and can be safely installed using open-shield pipejacking (with measures to protect the interior surface of the pipe from damage) and microtunneling. For projects where FRP is specified to be direct-installed, it is important that the specifications require an appropriate flush jacking pipe joint and that jacking force calculations be submitted by the contractor to demonstrate that the pipe will not be damaged by excessive jacking forces.

Where used, casing thickness for pipe jacking installations can be determined by various factors including long-term soil and live loading (H-20, Cooper E80), jacking force requirements, or permit requirements (Caltrans, AREMA, UPRR). DOT or railroad requirements typically result in the most conservative casing thickness and form the basis of the current BODR recommendations. Table 4 summarizes the casing thickness requirements for specific permitting agencies expected to be involved with the program. Designers may wish to perform specific jacking force and vertical loading analyses to further refine the casing thickness used for non-UPRR crossing locations.

<b>Table 4. Casing Thickness Requirements (inches) for Permitting Agencies for Various Pipe Diameters</b>			
<b>Casing Diameter</b>	<b>Caltrans*</b>	<b>UPRR</b>	<b>AREMA**</b>
<b>≤ 28 inch</b>	0.25	0.4375	0.375
<b>30 to 34-inch</b>	0.50	0.50	0.406 – 0.469
<b>36 to 38-inch</b>	0.50	0.5625	0.469 – 0.50
<b>40 to 42-inch</b>	0.75	0.5625	0.531 – 0.562
<b>44 to 48-inch</b>	0.75	0.625	0.594 – 0.625
<b>50 to 60-inch</b>	0.75	***	0.656 – 0.781
<b>62 to 72-inch</b>	0.75	***	0.812 – 0.938
<b>&gt; 72-inch</b>	***	***	***

*\*For crossings ≥ 150 feet in length*  
*\*\*For coated or cathodically protected casings. Non-coated or protected pipes require thicker casings*  
*\*\*\*Permitting manual does not include minimums for pipe of this diameter or greater*

Pipe ramming installations require thicker casing pipe to withstand repeated impact loading from the hammer. Pipe ramming equipment manufacturer TT Technologies offers the guidance shown in Table 5 regarding minimum recommended casing thickness for various installation diameters. If pipe ramming installations are especially challenging due to length, soil density, or other factors, a specific analysis should be performed to determine the necessary casing thickness. HDD installations require a crossing-specific analysis of pipe installation loads and stresses to determine the necessary thickness to ensure safe installation of both casing (if used) and carrier pipes. Design guidance is provided in ASTM F1962-11 for analysis of loads and stresses for HDPE pipe. Fusible PVC pipe installations can be analyzed using a similar approach, with the substitution of appropriate material parameters.

<b>Table 5: Wall Thickness Recommendations for Pipe Ramming Projects*</b>		
<b>Pipe Diameter (in)</b>	<b>Minimum Wall Thickness (in)</b>	
	<b>Bores &lt; 85 ft</b>	<b>Bores &gt; 85 ft</b>
<b>6</b>	0.25	0.27
<b>12</b>	0.25	0.27
<b>18</b>	0.31	0.39
<b>24</b>	0.39	0.47
<b>30</b>	0.47	0.55
<b>36</b>	0.47	0.62
<b>42</b>	0.59	0.62
<b>48</b>	0.59	0.7
<b>54</b>	0.7	0.78
<b>60</b>	0.75	0.87
<b>72</b>	0.87	1.0
<b>84</b>	1.00	1.25
<b>108</b>	1.125	1.5

\*Source: TT Technologies

Steel casing pipe joints should involve the full thickness of the pipe for pipe jacking and pipe ramming installations. This can be accomplished by full-penetration butt welds made prior to jacking, or through the use of integral press-fit interlocking joint systems (such as Permalok). Partially welded joining approaches have led to telescoping and other types of joint failures on previous pipe jacking projects. Additionally, longitudinally welded pipe is favored for pipe jacking, and should be required for pipe ramming or HDD application. Spiral welded pipe has also resulted in various types of pipe failures on some recent trenchless projects.

It is recommended that carrier pipe installed within steel casing should be supported on casing spacers and encased annular space grout. The casings spacers should serve to allow jacked installation of the carrier pipe into the casing without damage, and should ensure electrical isolation between the carrier pipe and the casing. The casing spacers also facilitate annular space grouting by providing a minimum clearance of 3 inches between the outermost portions of the carrier pipe joints and the inside surface of the casing pipe to allow for free grout flow, and by incorporating hold-downs that prevent the carrier pipe from floating due to buoyant uplift by the fluid grout.

For nominal carrier pipeline diameters smaller than approximately 30 inches, HDD methods allow for the direct installation of HDPE and fusible PVC pipe. (While HDD is capable of installing pipe up to 48 or even 54 inches, bores of this size require very large bend radii that force the bore geometry to be longer and deeper than the crossings on this project require.) HDPE and fusible PVC can accommodate pressures exceeding 200 psi. However, the surface-launched nature of HDD requires greater setback from crossing features to achieve a safe depth, and results in longer overall trenchless lengths than pipejacking methods. The cost-effectiveness of HDD increases with: longer crossings, smaller pipeline diameters, and at locations with high groundwater and unstable soils that would otherwise require the use of expensive microtunneling.

HDD installations require a crossing-specific analysis of pipe installation loads and stresses to determine the necessary thickness to ensure safe installation of both casing (if used) and carrier pipes. Design guidance is provided in ASTM F1962-11 for analysis of loads and stresses for HDPE pipe. Fusible PVC pipe installations can be analyzed using a similar approach, with the substitution of appropriate material parameters.

#### UPRR Encroachment Permits

There are 6 locations along the project alignment where crossings of UPRR ROW are anticipated – three along the transmission pipeline alignment, and three within the distribution system. Pipeline crossings of UPRR require that an encroachment permit be obtained. UPRR has several requirements in their Encroachment Permit manual that are relevant to the planning and design of trenchless crossings beneath the tracks. First, all crossings carrying liquids require that the carrier pipe be installed within a steel casing that is at least 2 inches larger than the largest outside diameter of the carrier pipe, or 10% larger, whichever is greater. The casing must have welded joints, or joints that are otherwise watertight. Depth of the crossing shall be a minimum of 5 feet below the base of the closest rail. Casings shall extend at a minimum beyond the limits of the UPRR ROW, but must also extend the greater of 30 feet or twice the depth plus 20 feet beyond the centerline of each outside track. Shafts must be located a minimum of 30 feet from the centerline of the nearest track, and outside of the ROW. UPRR prefers crossings to be made at 90 degrees to the track alignment, but will tolerate up to 45 degrees if required due to site restrictions. No crossing should be located within 150 feet of any railroad bridge or other important structures. Finally, casing pipe must have a minimum thickness in accordance with the information listed in Table 15.

#### Jacking Forces

Designers should conduct estimates of jacking forces necessary to complete each trenchless crossing. For installations involving steel casing, the casing pipe will almost certainly have greater

jacking capacity than necessary to complete the bore, based on other performance criteria. However, there are three components to the jacking system that must be evaluated: the jacking pipe, the hydraulic jacks and frame (contractor submittal issue), and the thrust block and soils behind the jacking shaft. Any one of these three components may be the weak link the jacking system, and may require additional design considerations to address potential issues. For short crossings with very stiff/dense ground, jacking forces may not be a substantial issue. However, for longer crossings, shallow installations or those in areas of weak soils, designers need to consider requiring thicker jacking pipe, intermediate jacking stations, automatic lubrication systems, high-capacity jacks, or ground improvement outside of shafts.

### Work Areas

The following are guidelines on the typical work areas necessary for various trenchless construction methods. In addition to simply proving the square footage recommended, other considerations should be addressed when designers are laying out trenchless crossings. Work areas need to provide a minimum width of approximately 30 feet to allow cranes or other lifting equipment to operate safely with outriggers extended. As the diameter of the installation increases, so will the overall work area needs to accommodate larger pipe and large equipment. Even when the minimum width is met, the work area may be very inefficient to work in if lifting equipment cannot swivel 180 degree to pick up pipe or other equipment from behind. In this case, a higher capacity crane will likely be needed to reach across the shaft to pick up loads, possibly requiring additional width for larger outriggers. Fifty feet of minimum width allows a much more efficient work area. Another consideration for lifting equipment is the presence of overhead obstructions. Overhead lines, trees, traffic light arms, etc. can obstruct the movement of lifting equipment and make work areas impractical. Microtunneling work sites need to allow for placement of the control container next to the jacking shaft, and need to allow access for dump trucks to the separation plant for hauling of spoil.

When laying out work areas consideration should be made for traffic flow, and access for residents, businesses, schools, etc. Crossing lengths may need to be extended to move work areas away from critical access locations. Additionally, work area layout in roadways needs to take into account the space occupied by traffic control barriers (k-rail), signs, cones, etc. The work area needed for trenchless construction is measured inside traffic control features.

### Standard Specifications

The C-PMO team will be providing standard specification sections to serve as a starting point for designers to use during final design of trenchless crossings on individual transmission and distribution line segments. These technical specification sections are anticipated to include:

- Water Control for Shafts and Tunnels
- Shaft Excavation and Support
- Portal Stabilization
- Auger Boring
- Open-Shield Pipejacking
- Microtunneling
- Pipe Ramming

- Horizontal Directional Drilling (HDD)
- Steel Casing Pipe
- Settlement Monitoring
- Contact Grouting
- Installation of Carrier Pipe in Casing

### **Evaluation of Trenchless Construction Alternatives at Identified Trenchless Crossings**

As part of the alignment validation effort, both the HWP transmission main and distribution system alignments were reviewed to identify potential trenchless construction locations. Generally, trenchless construction has been identified at railroad crossings, crossings of water ways, crossings of large box culverts, or to reduce traffic impacts at major intersections or road crossings. A total of 18 potential trenchless construction locations have been identified as shown in Figure 15 and are summarized in Table 6. Further evaluation and analysis will need to be conducted by the Final Designer to confirm the exact trenchless locations, limits of trenchless construction, trenchless construction methods, and design details.

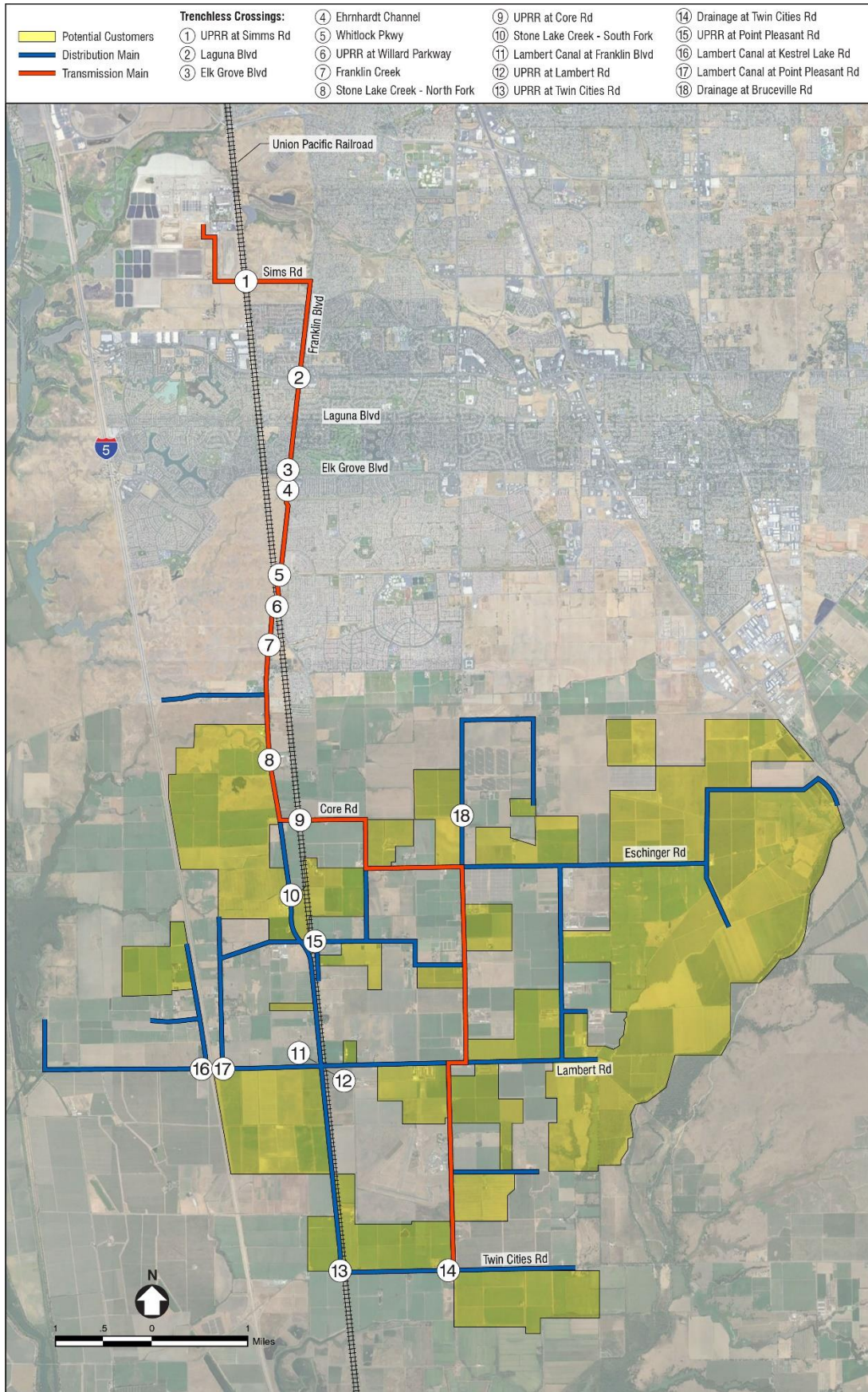


Figure 15. Locations of 18 Potential Trenchless Crossings for Harvest Water Program

Table 6. Summary of Trenchless Crossings							
#	Crossing Name	Location	Approx. Carrier Pipe Diameter	Approx. Casing Pipe Diameter	Preliminary Anticipated Trenchless Method	Approximate Crossing Length	Crossing Notes
1	UPRR @ Sims Road	1,400' E of Sims Road / Dwight Road	66"	84"	Microtunneling	500'	UPRR Permit Required, Road Closure Required
2	Laguna Boulevard	Franklin Boulevard / Laguna Boulevard	66"	*	Open-Shield Pipejacking	250'	Lane Closures/Traffic Control Required
3	Elk Grove Boulevard	Franklin Boulevard / Elk Grove Boulevard	66"	*	Open-Shield Pipejacking	300'	Lane Closures/Traffic Control Required
4	Ehrhardt Channel	700' S of Franklin Boulevard / Elk Grove Boulevard	66"	*	Microtunneling	175'	Lane Closures/Traffic Control Required, Groundwater Likely
5	Whitelock Parkway	Franklin Boulevard / Whitelock Parkway	66"	*	Open-Shield Pipejacking	400'	Lane Closures Required
6	UPRR @ Willard Parkway	1,600' S of Franklin Boulevard / Whitelock Parkway	66"	84"	Open-Shield Pipejacking	150'	UPRR Permit Required
7	Franklin Creek	1,500' N of Franklin Boulevard / Bilby Road	66"	*	Microtunneling	300'	Private Easements Likely Required, Groundwater Likely
8	Stone Lake Creek - North Fork	3,200' N of Franklin Boulevard / Core Road	66"	*	Microtunneling	200'	Private Easements Likely Required, Groundwater Likely
9	UPRR @ Core Road	1,000' E of Franklin Boulevard / Core Road	60"	78"	Microtunneling	250'	UPRR Permit Required, Road Closure Anticipated, Groundwater Likely
10	Stone Lake Creek - South Fork	2,700' N of Franklin Boulevard / Point Pleasant Road	48"	*	Microtunneling	150'	Road Closure Anticipated, Groundwater Likely

11	Lambert Canal @ Franklin Boulevard	100' N of Franklin Boulevard / Lambert Road	42"	*	Microtunneling	250'	Road Closure Anticipated, Private Easements Likely Required, Groundwater Likely
12	UPRR @ Lambert Road	100' E of Franklin Boulevard / Lambert Road	30"	48"	Microtunneling	275'	UPRR Permit Required, Road Closure Anticipated, Private Easements Likely Required, Groundwater Likely
13	UPRR @ Twin Cities Road	200' E of Franklin Boulevard / Twin Cities Road	24"	42"	Auger Boring	200'	UPRR Permit Required, Road Closure Anticipated
14	Drainage @ Twin Cities Road	400' W of Bruceville Road / Twin Cities Road	24"	*	Horizontal Directional Drilling	800'	Road Closure Anticipated, Groundwater Likely
15	UPRR @ Point Pleasant Road	500' E of Franklin Boulevard / Point Pleasant Road	18"	36"	Auger Boring	200'	UPRR Permit Required, Road Closure Anticipated
16	Lambert Canal @ Kestrel Lake Road	100' N of Lambert Road / Kestrel Lake Road	18"	*	Microtunneling	150'	Road Closure Anticipated, Groundwater Likely
17	Lambert Canal @ Point Pleasant Road	100' N of Lambert Road / Point Pleasant Road	18"	*	Microtunneling	150'	Road Closure Anticipated, Groundwater Likely
18	Drainage @ Bruceville Road	2,900' N of Bruceville Road / Eschinger Road	16"	*	Horizontal Directional Drilling	500'	Road Closure Anticipated, Groundwater Likely

\*Casing not required, pending method selection and carrier pipe material. Minimum recommended casing diameter is 18 inches larger than nominal carrier pipe inner diameter, if casing is used.

Visual site reconnaissance was conducted on May 19 and August 7, 2020 to evaluate site conditions, including sensitive features and existing utilities which could impact feasibility of various trenchless methods. In addition to the site reconnaissance, a preliminary desktop evaluation was conducted using limited available geotechnical, utility, and site information. This preliminary evaluation considered expected ground conditions, available work area, likelihood of groundwater, pipe diameter, length, and constructability to determine viable trenchless construction methods and make initial recommendations. The methods considered for HWP include auger boring, open-shield pipejacking, microtunneling, pipe ramming, and horizontal directional drilling (HDD). The following discussion provides additional consideration for each trenchless crossing location that should be incorporated into the Final Design. As-built drawings of crossings, where found, are attached to this technical memorandum.

### Crossing #1: UPRR at Sims Road

While running east within the Sims Road ROW, the 66-inch diameter transmission line will pass beneath a set of UPRR tracks, approximately 1,400 feet east of the intersection with Dwight Road. In addition to the railroad, the proposed trenchless crossing will pass beneath a drainage ditch running parallel to the tracks, approximately 160 feet to the east as shown in Figure 16. Flows in the drainage ditch appear to cross Sims Road in a shallow culvert. The crossing is located within the Bufferlands area surrounding the SRWTP which consists of flat, undeveloped grasslands. The UPRR tracks cross on an embankment that is approximately 8 feet higher than the surrounding ground. Sims Road is a two-lane paved road running at the same elevation as the surrounding land and rising gently to cross the railroad at-grade.



Figure 16. Proposed Trenchless Crossing of UPRR at Sims Road

There are several existing utilities running perpendicular to the proposed crossing including: two PG&E gas lines and a SMUD gas line, two water lines, MCI fiber optic running in the UPRR ROW, underground telephone, and a sanitary sewer line. There is also a gravity sewer that runs parallel to the crossing within Sims Road. Overhead SMUD 230kV transmission lines and 12kV

distribution lines also run perpendicular to the crossing, east of UPRR. As-builts obtained from Regional San indicate that the gravity sewer line running east of the railroad has an invert depth approximately 25 to 30 feet below grade.

Two geotechnical borings have been completed by Shannon & Wilson for the Sims Road crossing, one on each side of the UPRR tracks. SWB-1 and SWB-2 each encountered approximately 8 to 10 feet of loose to medium dense sandy fill overlying further loose to medium dense sands and cohesive sands to approximately 14 feet below ground surface (bgs), near the railroad embankment. Both borings then encountered stiff to hard sandy clay and silt extending to approximately 28 feet bgs. The remaining depth explored (~45 feet bgs) consisted of varied layers of sand, silt, and clay of medium dense and stiff to hard consistency. Groundwater was encountered in both borings at a depth of 33 feet bgs.

UPRR encroachment permit requirements for pipeline crossings call for continuous steel casing surrounding the carrier pipe being installed. It is anticipated that the 66-inch CMLC steel carrier pipe will require an 84-inch OD steel casing to allow for safe installation and grouting of the annular space. To provide approximately two diameters of clearance beneath the UPRR tracks on the embankment, it is expected that the crown of the 84-inch diameter casing pipe would be installed a minimum of 8 feet below the surrounding ground. Further utility research and potholing work is needed to determine the depth of existing utilities, to allow a settlement risk evaluation to be made. Based on the conditions encountered in the borings performed to date, the most advantageous soil horizon appears to be the stiff to hard sandy clay soils between 14 to 28 feet bgs. This horizon is located above the groundwater encountered in both borings, and would be expected to exhibit firm ground behavior.

While a crossing of the UPRR ROW and drainage ditch could be completed with approximately 300 feet of trenchless installation, the crossing is proposed to extend approximately 500 feet to avoid open cut crossings of the multiple gas and water lines located west of the tracks.

Based on the proposed length, diameter, and anticipated ground conditions, potentially feasible trenchless methods include: open-shield pipejacking, and microtunneling. The crossing is too large in diameter for auger boring, and the length and hard ground conditions make pipe ramming a risky alternative. Additionally, if the elevation of existing utilities allows the tunnel horizon to remain above the groundwater and permeable sands below approximately 30 feet bgs, then the capabilities of microtunneling will be unnecessary. Therefore, the most likely construction method for this crossing is considered to be open-shield pipejacking. Non-watertight tunneling methods could be combined with non-watertight shaft methods such as slide rails, soldier piles and lagging, or liner plate. More capable, and costly, methods such as interlocking sheetpiles or secant piles should be unnecessary. However, further evaluations will be necessary during final design to assess the risks presented to the existing sanitary sewer. Depending on the exact elevation, the new HWP casing may be able to pass just above the existing sewer to stay within the more favorable soils above groundwater. If risks to both the UPRR tracks and the sewer cannot be mitigated, the crossing may need to be lowered into the saturated and permeable soils where watertight trenchless methods would be required.

The jacking shaft could be located on either side of the crossing. Light traffic volumes on Sims Road, and redundant access via Dwight Road and Laguna Boulevard, will allow full closure of the road to install the transmission line within the roadway. The paved portion of Sims Road is approximately 35 feet wide in this area, so the large jacking and receiving shafts necessary for the casing installation will occupy most of the road width. Work areas must remain within the disturbed roadway footprint, as disturbance to the surrounding Bufferlands will not be allowed. The exact horizontal alignment will be largely influenced by the sanitary sewer that also crosses the UPRR tracks at this location. The available work area between the existing pasture fences is 50 feet wide. To provide the standard recommended work area of 15,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft, the allowable work area should be 300 feet long and 160 feet long, respectively.

#### Crossing #2: Laguna Boulevard

The 66-inch diameter transmission alignment runs south along Franklin Boulevard and crosses through a major intersection at Laguna Boulevard as shown in Figure 17. The tentative crossing location is within the travel lanes of Franklin Boulevard; both Franklin Boulevard and Laguna Boulevard are 6-lane roads with additional multiple turn lanes. The topography is generally flat through the intersection.

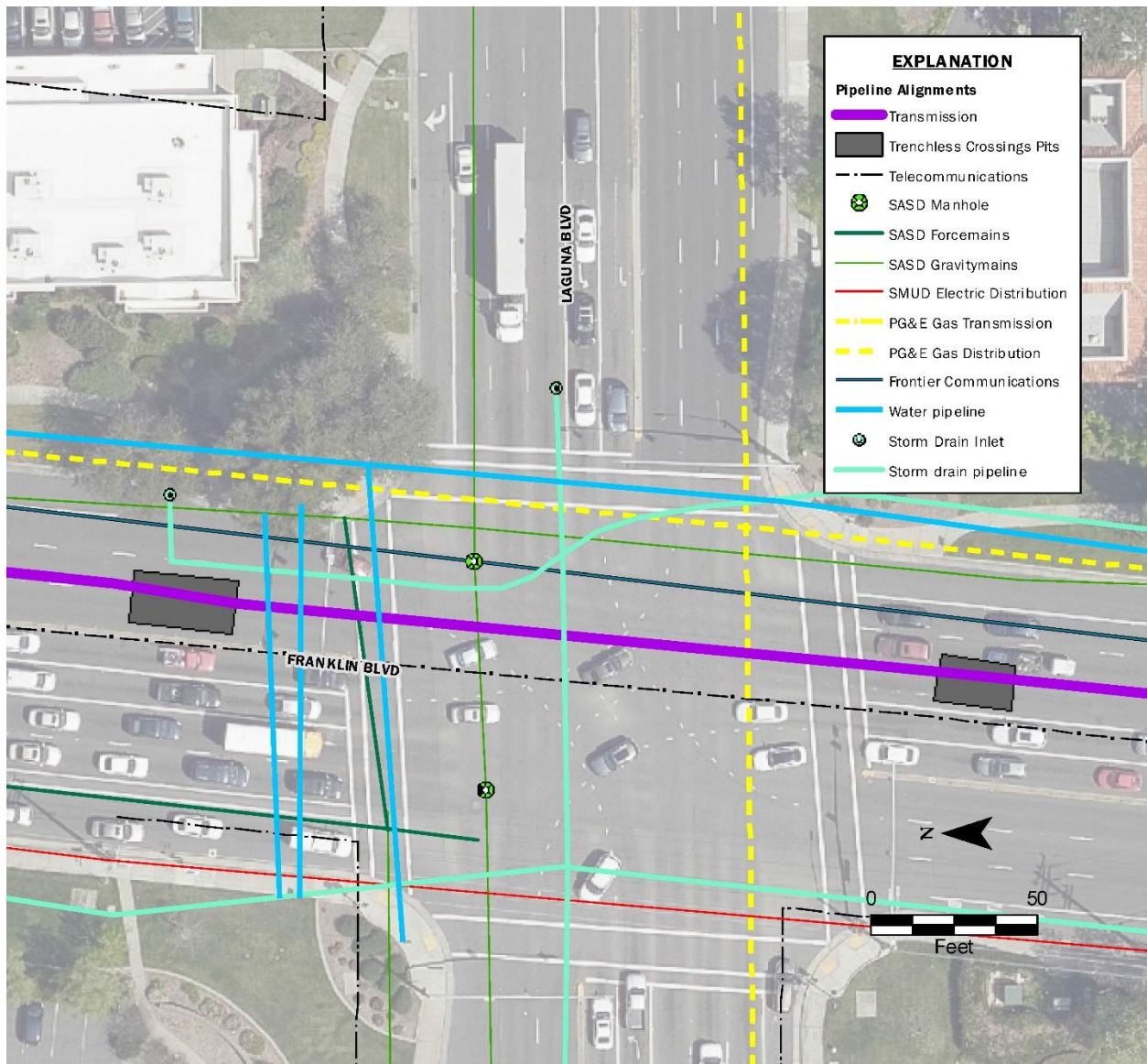


Figure 17. Proposed Trenchless Crossing of Laguna Boulevard at Franklin Boulevard

There are many existing utilities within both Franklin Boulevard and Laguna Boulevard. The transmission main will cross three watermains, two SASD sewer lines, a storm drain, and a PG&E gas distribution line. The alignment runs roughly parallel to a telecom line to the west, and an SASD sanitary sewer and a storm drain to the east.

The C-PMO team will perform one geotechnical boring at this crossing location to make a preliminary assessment of ground conditions. It is anticipated that at least one additional geotechnical boring will be performed during the final design phase. In advance of the completion of this boring, it is assumed that conditions at this crossing will consist of relatively stable cohesive sands, silts, and clays, with groundwater located approximately 30 feet below ground surface.

It is anticipated that 66-inch CMLC steel carrier pipe would require an 84-inch OD steel casing to allow for safe installation and grouting of the annular space. Alternatively, FRP could be used as a carrier pipe, which can be direct-installed without a casing by open-shield pipejacking or microtunneling. To provide approximately two diameters of clearance beneath the roadways, it is expected that the shaft inverts necessary for installation of the 84-inch diameter casing pipe or 69-inch OD FRP would be a minimum of 17 to 24 feet below the road surfaces. Further utility research and potholing work is needed to determine the depth of existing utilities, and to perform a settlement risk evaluation.

The anticipated trenchless crossing would likely pass beneath all the existing utilities with shafts set back from the intersection to manage traffic impacts along Laguna Boulevard and through the intersection. Exact shaft locations will be determined by location of existing utilities and specific traffic control plans based on analysis of traffic usage and open-lane priorities. The anticipated crossing length would be approximately 250 feet.

Based on the proposed length, diameter, and currently anticipated ground conditions, potentially feasible trenchless methods include: open-shield pipejacking and microtunneling. The crossing is too large in diameter for auger boring, and the noise impacts make pipe ramming an unfavorable alternative. Additionally, if the elevation of existing utilities allows the tunnel horizon to remain above groundwater then the capabilities of microtunneling should be unnecessary. Therefore, the most likely construction method for this crossing is considered to be open-shield pipejacking. Non-watertight tunneling methods could be combined with non-watertight shaft methods such as slide rails, soldier piles and lagging, or liner plate. More capable, and costly, methods such as interlocking sheetpiles or secant piles should be unnecessary. The jacking shaft could be located on either side of the crossing.

Necessary work areas at both shaft locations will require lane closures along Franklin Boulevard, likely near the median. To provide the minimum recommended work area of 15,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft, the allowable work area should be approximately 50 feet wide by 300 feet long and 40 feet wide by 200 feet long, respectively.

### Crossing #3: Elk Grove Boulevard

The 66-inch diameter transmission alignment continues south along Franklin Boulevard and crosses through a major intersection at Elk Grove Boulevard, as shown in Figure 18. The tentative crossing location is within the travel lanes of Franklin Boulevard; both Franklin Boulevard and Elk Grove Boulevard are 6-lane roads with additional multiple turn lanes at this location. The topography is generally flat at the intersection.



Based on the proposed length, diameter, and currently anticipated ground conditions, potentially feasible trenchless methods include: open-shield pipejacking and microtunneling. The crossing is too large in diameter for auger boring, and the noise impacts make pipe ramming an unfavorable alternative. Additionally, if the elevation of existing utilities allows the tunnel horizon to remain above the groundwater then the capabilities of microtunneling would be unnecessary. Therefore, the most likely construction method for this crossing is considered to be open-shield pipejacking. Non-watertight tunneling methods could be combined with non-watertight shaft methods such as slide rails, soldier piles and lagging, or liner plate. More capable, and costly, methods such as interlocking sheetpiles or secant piles should be unnecessary. The jacking shaft could be located on either side of the crossing, however limitations in available roadway width to the north favor the southern shaft as the jacking shaft. Necessary work areas at both shaft locations will require lane closures along Franklin Boulevard, likely near the median. To provide the standard recommended work area of 15,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft, the allowable work area should be approximately 45 feet wide by 330 feet long and 35 feet wide by 230 feet long, respectively.

#### Crossing #4 Ehrhardt Channel

The 66-inch diameter transmission alignment continues south along Franklin Boulevard and crosses under the box culvert for the Ehrhardt Channel as shown in Figure 18. The tentative crossing location is within the travel lanes of Franklin Boulevard; Franklin Boulevard has two south-bound lanes and three north bound lanes at this location. Franklin Boulevard is generally flat at the intersection; the Channel invert is approximately 10 feet below the road surface and runs through a box culvert under Franklin Boulevard. The as-builts for the box culvert indicate that the box-culvert extends approximately 12 feet beneath Franklin Boulevard.

Several existing utilities run along Franklin Boulevard: a water line, PG&E gas distribution line, and multiple SMUD electrical lines run along the eastern shoulder; a gas and fiber optic line run along the center of Franklin Boulevard; and a telecommunications line runs along the western shoulder. In addition, three utilities – a Frontier Communications line, a SMUD electrical line, and a storm drain - transition from the western shoulder to the eastern shoulder just north of the channel.

Two geotechnical borings will be performed at this crossing location to make a preliminary assessment of ground conditions. In advance of the completion of these borings, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water within the canal.

It is anticipated that 66-inch CMLC steel carrier pipe would require an 84-inch OD steel casing to allow for safe installation and grouting of the annular space. Alternatively, FRP could be used as a carrier pipe, which can be direct-installed without a casing by open-shield pipejacking or microtunneling. To provide approximately two diameters of clearance beneath the box culvert, it is expected that the shaft inverts necessary for installation of the 69-inch FRP or 84-inch diameter casing pipe would be a minimum of 28 to 35 feet below the road surface. Further utility

research and potholing work is needed to determine the depth of existing utilities, and to conduct a settlement risk evaluation to both utilities and the box culvert.

The anticipated trenchless crossing would pass beneath the box culvert with shafts set back a sufficient distance from the utilities to minimize the risk of damage. Exact shaft locations will be determined by location of existing utilities and specific traffic control plans based on analysis of traffic usage and open-lane priorities. An additional consideration for this crossing is maintaining access to an emergency vehicle access road to the east for the Laguna Estates neighborhood. The anticipated crossing length would be approximately 175 feet.

Based on the proposed length, diameter, and currently anticipated high groundwater conditions, the most likely feasible trenchless method is microtunneling. If low-permeability soils are encountered in the geotechnical borings, open-shield pipejacking may be feasible. The crossing is too large in diameter for auger boring, and the noise impacts make pipe ramming an unfavorable alternative. If watertight trenchless methods are deemed necessary, watertight shaft construction methods such as interlocking sheetpiles or secant piles would be required. The jacking shaft would likely be located on the northern side of the crossing where Franklin Boulevard is wider, providing more space for the required equipment.

Necessary work areas at both shaft locations will require lane closures along Franklin Boulevard, likely near the median. To provide the standard recommended work area of 15,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft, the allowable work area should be approximately 45 feet wide by 330 feet long and 35 feet wide by 230 feet long, respectively.

#### Crossing #5 Whitelock Parkway

The 66-inch diameter transmission alignment runs parallel to Franklin Boulevard, approximately 50 feet off the eastern shoulder and crosses diagonally under the three-way intersection of Franklin Boulevard, Willard Parkway, and Whitelock Parkway and ends in the one-lane south-bound Franklin Boulevard spur which is west of Willard Parkway as shown in Figure 19. The topography is generally flat at the intersection.

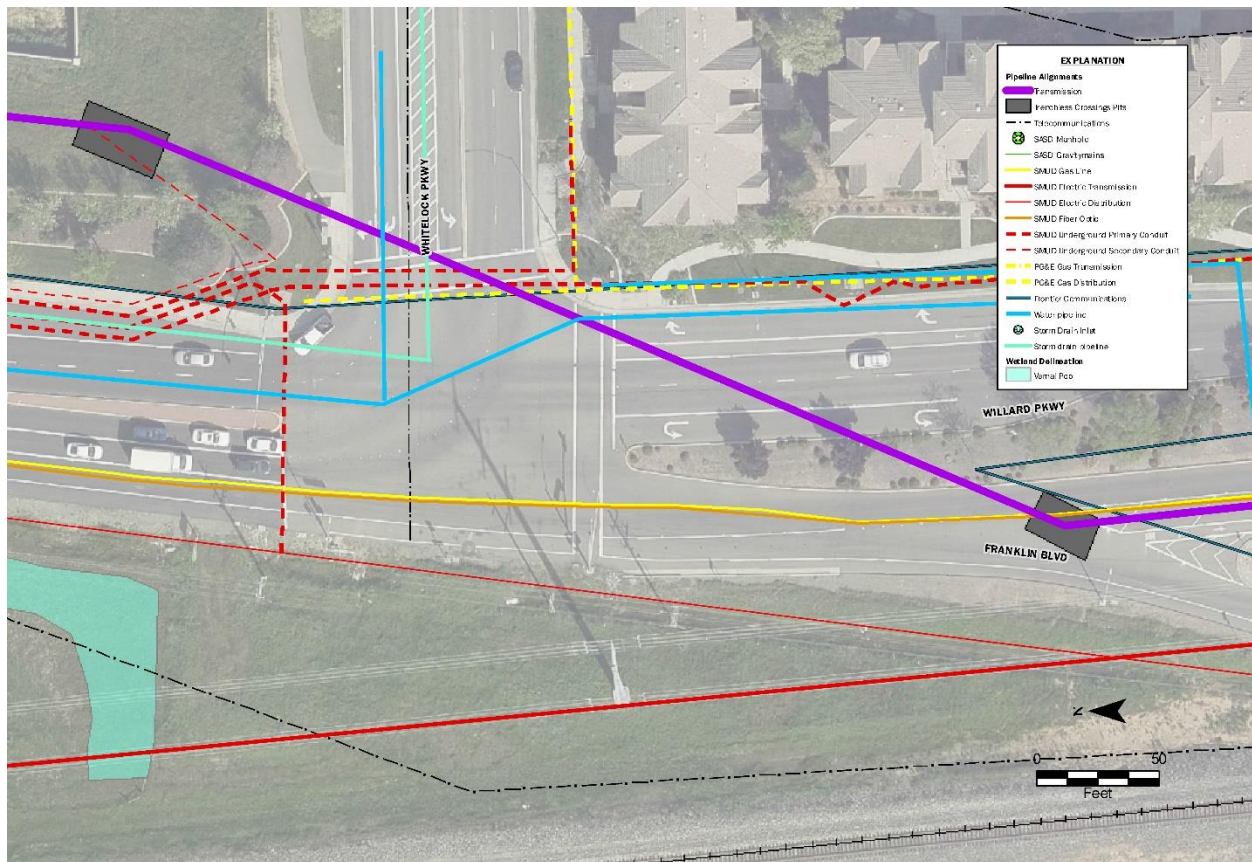


Figure 19. Proposed Trenchless Crossing of Whitelock Parkway at Franklin Boulevard

Multiple existing utilities run through the large intersection. The alignment crosses two watermains, a storm drain, SMUD electrical conduit, PG&E gas distribution line, a SMUD fiber optic line, and a SMUD gas line. Other utilities near the shaft locations include multiple SMUD electrical lines along the western shoulder of Franklin Boulevard north of the intersection, and a Frontier Communications line and electrical transmission line near the southern end of the crossing.

One geotechnical boring will be performed at this crossing location to make a preliminary assessment of ground conditions. It is anticipated that at least one additional geotechnical boring will be performed during the final design phase. In advance of the completion of this boring, it is assumed that conditions at this crossing will consist of stable cohesive sands, silts, and clays, with groundwater located approximately 30 feet below ground surface.

It is anticipated that the 66-inch CMLC steel carrier pipe will require an 84-inch OD steel casing to allow for safe installation and grouting of the annular space. To provide approximately two diameters of clearance beneath the road surface, it is expected that the shaft inverts necessary for installation of the 84-inch diameter casing pipe would be a minimum of 24 feet below the road surface. Further utility research and potholing work is needed to determine the depth of existing utilities and to perform a settlement risk evaluation.

The anticipated trenchless crossing would pass beneath the intersection with the northern shaft located in the green space northeast of the crossing and the reception shaft located on the Franklin Boulevard spur road. Shaft locations should be selected to avoid impacts to the multiple existing utilities. The anticipated crossing length would be approximately 400 feet.

Based on the proposed length, diameter, and currently anticipated ground conditions, potentially feasible trenchless methods include open-shield pipejacking and microtunneling. The crossing is too large in diameter for auger boring, and the length and noise make pipe ramming an unfavorable alternative. Additionally, if the elevation of existing utilities allows the tunnel horizon to remain above the groundwater then the capabilities of microtunneling would be unnecessary. Therefore, the most likely construction method for this crossing is considered to be open-shield pipejacking. Non-watertight tunneling methods could be combined with non-watertight shaft methods such as slide rails, soldier piles and lagging, or liner plate. More capable, and costly, methods such as interlocking sheetpiles or secant piles should be unnecessary. The jacking shaft would likely be located on the northeast side of the crossing where more work area is available outside the roadway.

The standard recommended work area of 15,000 square feet at the jacking shaft could be accommodated using the 75-foot wide green area outside the Monterrey Village neighborhood running parallel to Whitelock Parkway and the 50-foot wide green area parallel to Franklin Boulevard. To provide 8,000 square feet at the reception shaft, a road closure of the Franklin Boulevard spur near the intersection with southbound Willard Parkway will be required. The allowable work area should be approximately 35 feet wide by 230 feet long. It is assumed that southbound Franklin Boulevard traffic could be re-routed to share the current northbound Franklin Boulevard to southbound Willard Parkway merge ramp.

#### Crossing #6 UPRR at Willard Parkway

The 66-inch diameter transmission alignment continues down the southbound lanes of Willard Parkway, parallel to the UPRR tracks. Approximately 1,600 feet south of the intersection with Whitelock Parkway, the alignment turns to the west and crosses beneath the UPRR right-of-way and then continues down Franklin Boulevard to the southwest as shown in Figure 20. The topography is mostly flat, with the UPRR tracks on an approximately 6-foot embankment.

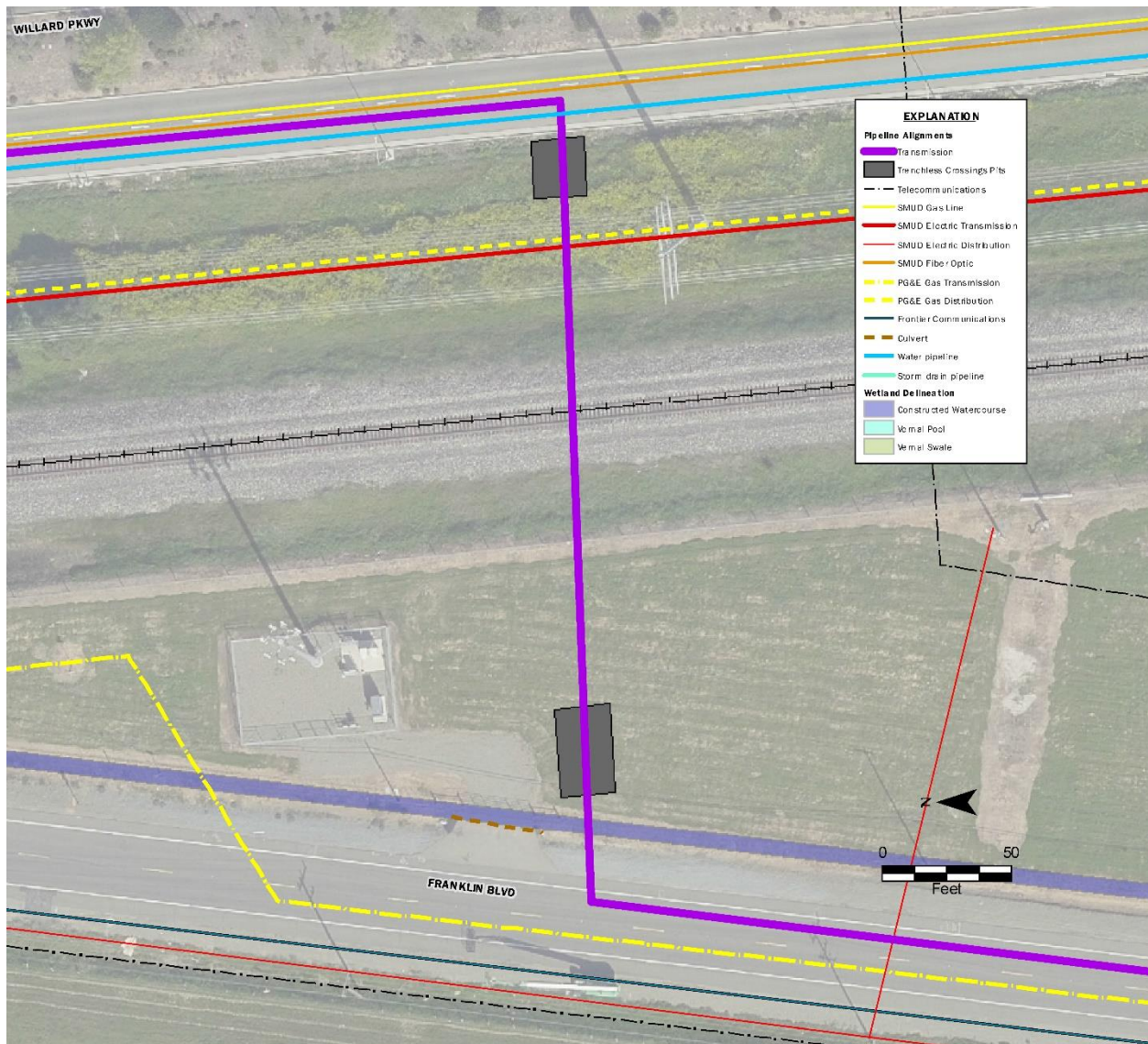


Figure 20. Proposed Trenchless Crossing of UPRR at Franklin Boulevard

Several existing utilities run within Willard Parkway, including gas, fiber optic, and water lines. There is also an overhead electrical system along the western shoulder of Willard Parkway. In the green area between Willard Parkway and the UPRR right-of-way, the alignment crosses a PG&E gas distribution line and a SMUD electrical distribution line. An overhead electrical line runs along the eastern shoulder of Franklin Boulevard. A cellular tower lies between the UPRR right-of-way and Franklin Boulevard north of the planned trenchless crossing.

Two geotechnical borings will be performed at this crossing location to make a preliminary assessment of ground conditions. In advance of the completion of these borings, it is assumed that conditions at this crossing will consist of stable cohesive sands, silts, and clays, with groundwater located approximately 30 feet below ground surface.

The 66-inch CMLC steel or FRP carrier pipe will require an 84-inch OD steel casing to adhere to UPRR permit requirements and to allow for safe installation and grouting of the annular space.

To provide approximately two diameters of clearance beneath the UPRR embankment, it is expected that the shaft inverts necessary for installation of the 84-inch diameter casing pipe would be a minimum of 18 feet below the surrounding ground. Further utility research and potholing work is needed to determine the depth of existing utilities, to allow a settlement risk evaluation to be made.

The anticipated trenchless crossing would pass beneath the UPRR right-of-way with the eastern shaft located in the green space west of Willard Parkway and east of the UPRR ROW, and the western shaft located in the green space between the UPRR ROW and Franklin Boulevard. Shaft locations should be selected to avoid impacts to the multiple existing utilities and to shorten the crossing as much as possible without encroaching on UPRR right-of-way. The anticipated crossing length would be approximately 150 feet.

Based on the proposed length, diameter, and currently anticipated ground conditions, potentially feasible trenchless methods include: open-shield pipejacking, microtunneling, and pipe ramming. The crossing is too large in diameter for auger boring. If the elevation of existing utilities allows the tunnel horizon to remain relatively shallow, the larger shafts associated with pipe ramming may not be cost prohibitive, and the short length would be suitable for that method. If the pipeline horizon can be located above the groundwater then the capabilities of microtunneling would be unnecessary. Therefore, the most likely construction method for this crossing is considered to be either pipe ramming or open-shield pipejacking. Non-watertight tunneling methods could be combined with non-watertight shaft methods such as slide rails, soldier piles and lagging, or liner plate. More capable, and costly, methods such as interlocking sheetpiles or secant piles should be unnecessary. The jacking shaft would likely be located on the western side of the crossing where more work area is available and there are less complications from overhead utilities.

The standard recommended work area of 15,000 square feet at the jacking shaft could be accommodated using the green area between UPRR and Franklin Boulevard. The recommended 8,000 square feet of work area at the reception shaft, could be accommodated using the green area between Willard Parkway and UPRR. Closures to Franklin Boulevard or Willard Parkway should not be necessary to provide work area for the trenchless crossing at this location.

#### Crossing #7 Franklin Creek

The 66-inch diameter transmission alignment continues down Franklin Boulevard where it crosses Franklin Creek (Figure 21), which often runs dry in the summer. Franklin Boulevard is generally flat in this area, with the creek passing beneath the road through a pair of box culverts. The creek invert is approximately 10 to 12 feet below the road surface.

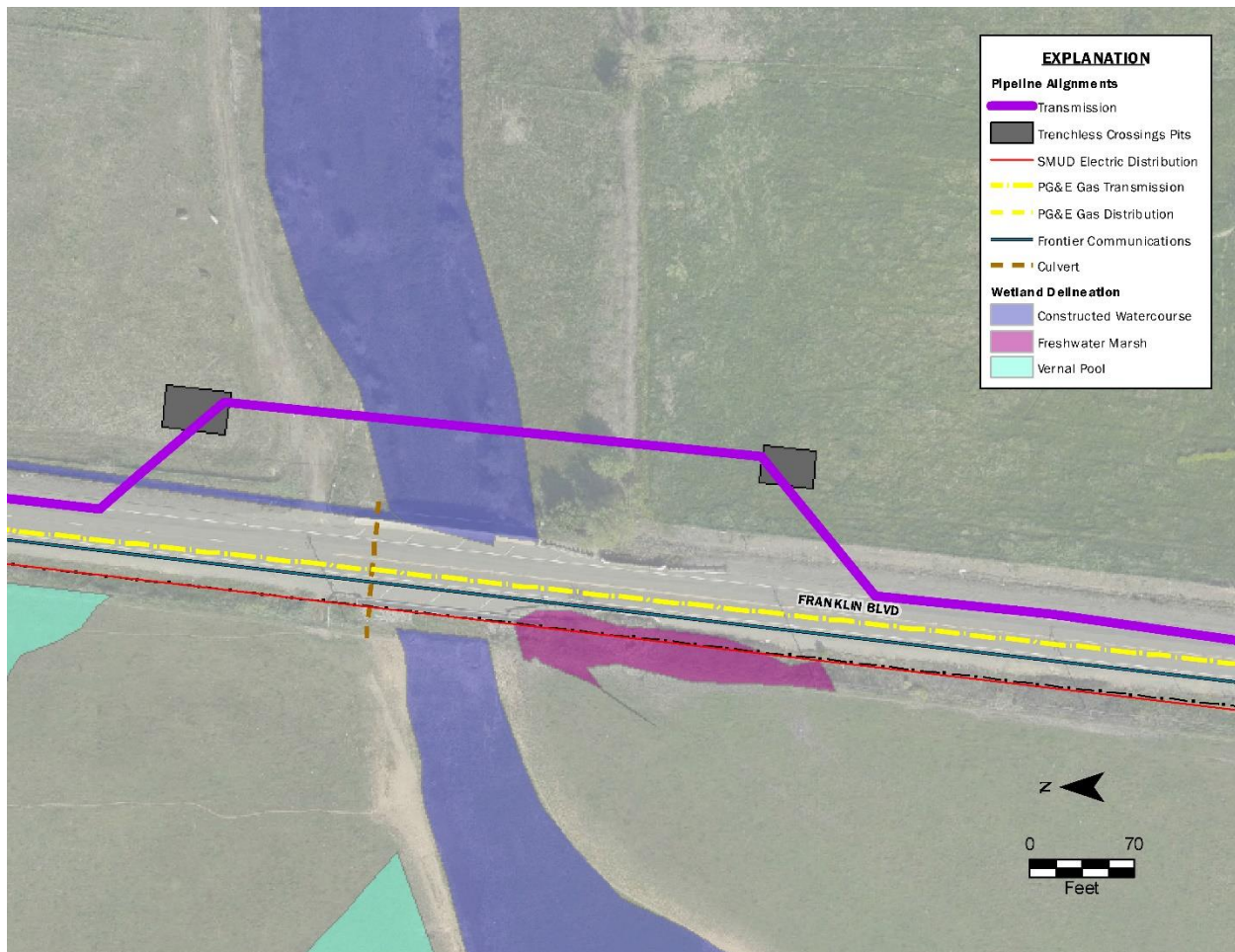


Figure 21. Proposed Trenchless Crossing of Franklin Creek at Franklin Boulevard

Several existing utilities run within Franklin Boulevard including a water line, a gas distribution line and an electric distribution line. An overhead telecommunications line runs along the western shoulder of Franklin Boulevard and an overhead electrical line runs along the eastern shoulder of Franklin Boulevard at this location. A drainage ditch also parallels Franklin Boulevard to the east and empties into the creek.

The C-PMO team will perform one geotechnical boring at this crossing location to make a preliminary assessment of ground conditions. It is anticipated that at least one additional geotechnical boring will be performed during the final design phase. In advance of the completion of this boring, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water within the creek.

It is anticipated that 66-inch CMLC steel carrier pipe would require an 84-inch OD steel casing to allow for safe installation and grouting of the annular space. Alternatively, FRP could be used as a carrier pipe, which can be direct-installed without a casing by open-shield pipejacking or microtunneling. To provide approximately two diameters of clearance beneath the creek invert, it is expected that the shaft inverts necessary for installation of the 69-inch OD FRP or 84-inch

diameter casing pipe would be a minimum of 27 to 34 feet below the surrounding ground surface. Geotechnical data would be necessary to determine the required depth beneath the creek bottom to avoid granular soils and to allow a settlement risk evaluation to be made.

The anticipated trenchless crossing would be offset approximately 100 feet to the east of Franklin Boulevard to avoid impacting the box culvert/bridge foundation. Both shafts would be located in the fields to the east of Franklin Boulevard. It is likely that permanent easement would be necessary for this crossing. Shafts should be set back sufficiently from the creek to avoid creating a direct water connection from the creek to the shaft. The offset of the shafts from the creek will be determined by permeability of the soils. The anticipated crossing length would be approximately 300 feet.

Based on the proposed length, diameter, and anticipated groundwater conditions, microtunneling is likely the most feasible trenchless construction method. It is anticipated that groundwater will be encountered under the creek which can result in face instability for open-shield. The currently anticipated unstable granular soils at the trenchless crossing make pipe ramming undesirable. The crossing is too large in diameter for auger boring. If the geotechnical investigations indicate that the pipeline can be located in non-permeable soils or above the groundwater table, then open-shield pipejacking or pipe ramming may be feasible. Therefore, the most likely construction method for this crossing is considered to be microtunneling. Watertight shaft construction methods such as interlocking sheetpiles or secant piles would likely be necessary. The jacking shaft could likely be located on either side of the creek for this crossing. The standard recommended work area of 15,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft could be accommodated by acquiring temporary easement in the fields north and south of the crossing. Closures to Franklin Boulevard are unlikely to be necessary to provide work area for the trenchless crossing at this location.

#### Crossing #8 Stone Lake Creek – North Fork

The 66-inch diameter transmission alignment continues down Franklin Boulevard where it crosses the north fork of Stone Lake Creek as shown in Figure 22. Franklin Boulevard is generally flat with the creek passing beneath Franklin Boulevard through a box culvert. The creek invert is approximately 6 to 8 feet below the road surface.

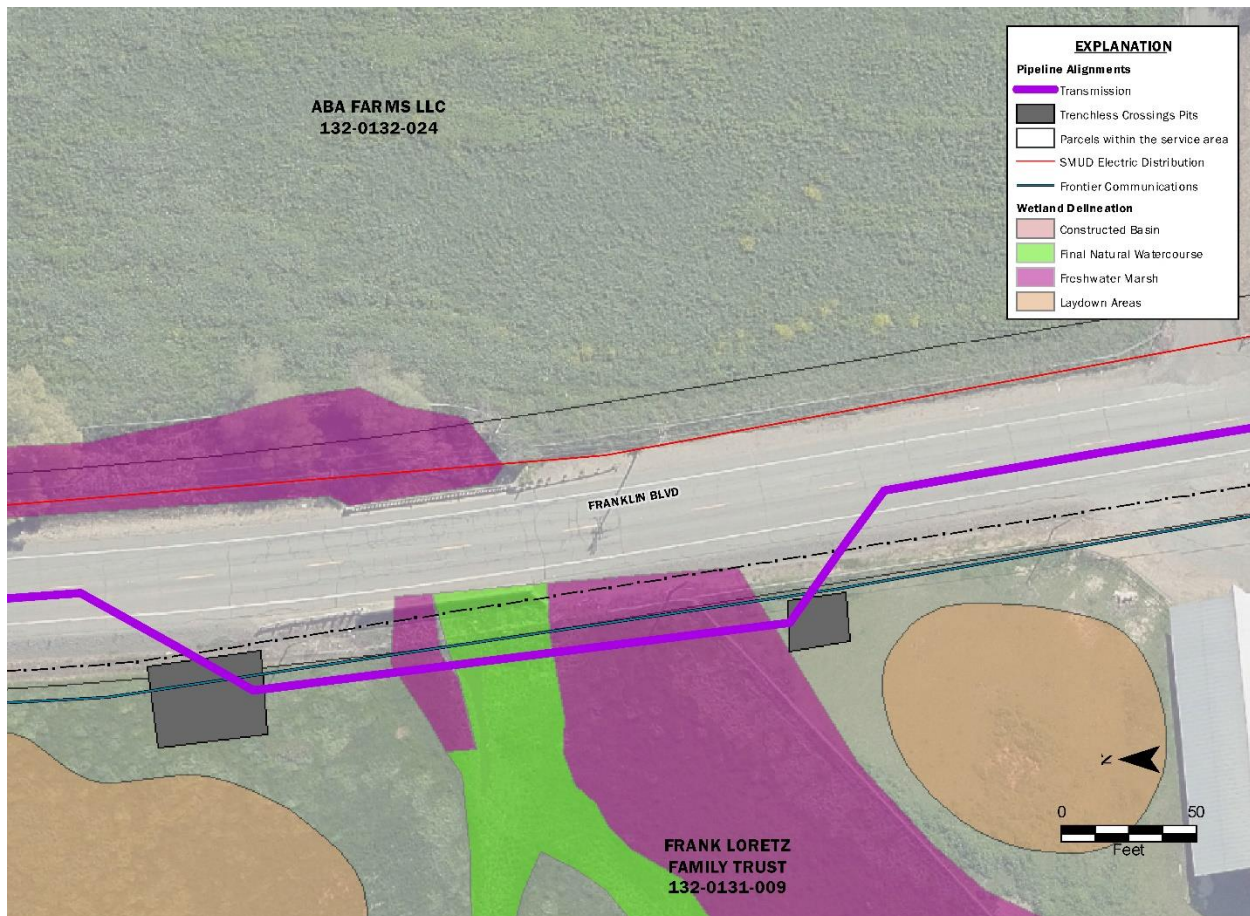


Figure 22. Proposed Trenchless Crossing of the North Fork of Stone Lake Creek at Franklin Boulevard

Several existing utilities run within Franklin Boulevard including a SMUD electric distribution line on the eastern shoulder, and overhead Frontier Communications line on the western shoulder. A drainage ditch also parallels Franklin Boulevard to the east and empties into the culvert under Franklin Boulevard.

The C-PMO team will perform one geotechnical boring at this crossing location to make a preliminary assessment of ground conditions. It is anticipated that at least one additional geotechnical boring will be performed during the final design phase. In advance of the completion of this boring, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water within the creek.

It is anticipated that 66-inch CMLC steel carrier pipe would require an 84-inch OD steel casing to allow for safe installation and grouting of the annular space. Alternatively, FRP could be used as a carrier pipe, which can be direct-installed without a casing by open-shield pipejacking or microtunneling. To provide approximately two diameters of clearance beneath the creek invert, it is expected that the shaft inverts necessary for installation of the 69-inch OD FRP or 84-inch diameter casing pipe would be a minimum of 27 to 30 feet below the surrounding ground surface. Geotechnical data would be necessary to determine the required depth beneath the creek bottom to avoid granular soils and to allow a settlement risk evaluation to be made.

The anticipated trenchless crossing would be offset approximately 25 feet to the west of Franklin Boulevard to avoid impacting the box culvert bridge foundation. Both shafts would be located in the fields to the west of Franklin Boulevard. It is likely that permanent easement would be necessary for this crossing. Shafts should be set back sufficiently from the creek to avoid creating a direct water connection from the creek to the shaft. Offset of the shafts from the creek will be dependent on the permeability of the ground conditions. The anticipated crossing length would be approximately 200 feet.

Based on the proposed length, diameter, and currently anticipated groundwater conditions, microtunneling is likely the most feasible trenchless construction method. It is anticipated that groundwater will be encountered under the creek which can result in face instability for open-shield pipejacking and pipe ramming. The crossing is too large in diameter for auger boring. If the geotechnical investigations indicate that the pipeline can be located in non-permeable soils or above the groundwater table, then open-shield pipejacking or pipe ramming may be feasible. Therefore, the most likely construction method for this crossing is considered to be microtunneling. Watertight shaft construction methods such as interlocking sheetpiles or secant piles would likely be necessary. The jacking shaft could likely be located on either side of the creek for this crossing.

The standard recommended work area of 15,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft could be accommodated by acquiring temporary easement in the fields north and south of the crossing. Closures to Franklin Boulevard are unlikely to be necessary to provide work area for the trenchless crossing at this location. Intermittent traffic flaggers may be necessary for trucks exiting and entering the roadway.

#### Crossing #9 UPRR at Core Road

The 66-inch diameter transmission alignment turns east off of Franklin Boulevard onto Core Road where it crosses the UPRR right-of-way as shown in Figure 23. The UPRR tracks are on an approximately 4-foot embankment above the surrounding ground, and at-grade with Core Road. A constructed water retention basin lies south of Core Road, to the east of the UPRR tracks. A drainage ditch lies parallel to the UPRR tracks to the east but terminates north of Core Road.

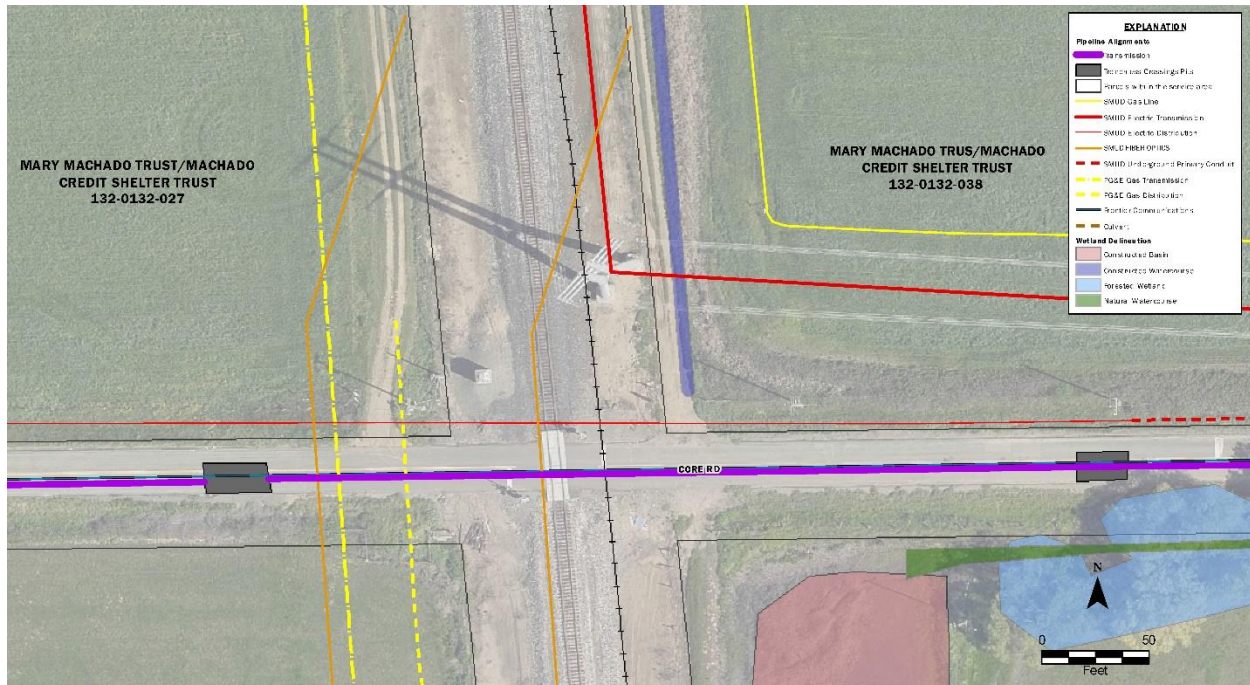


Figure 23. Proposed Trenchless Crossing of UPRR at Core Road

Several existing utilities run parallel to the UPRR tracks including a two PG&E gas lines and two SMUD fiber optic lines. Overhead electrical lines run along the northern shoulder of Core Road and transition to underground approximately 300 feet east of the UPRR tracks.

The C-PMO team will perform two geotechnical borings at this crossing location to make a preliminary assessment of ground conditions. In advance of the completion of these borings, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water in the basin to the southeast.

The 66-inch CMLC steel or FRP carrier pipe will require an 84-inch OD steel casing to allow for safe installation and grouting of the annular space. To provide approximately two diameters of clearance beneath the UPRR tracks, it is expected that the shaft inverts necessary for installation of the 84-inch diameter casing pipe would be a minimum of 24 feet below the road surface. Further utility research and potholing work is needed to determine the depth of existing utilities, to allow a settlement risk evaluation to be made.

The anticipated trenchless crossing would lie within Core Road to avoid impacting the wetlands to the north and south of Core Road. Both shafts would be located in Core Road and would likely require a full road closure. Shafts should be set back at least 30 feet from the center of the UPRR tracks and outside the UPRR right of way, while maintaining as short a crossing as possible. The anticipated crossing length would be approximately 250 feet.

Based on the proposed length, diameter, and currently anticipated groundwater conditions, microtunneling is likely the most feasible trenchless construction method. It is anticipated that groundwater will be encountered, due to the adjacent wetlands, which can result in face

instability for open-shield pipejacking and pipe ramming. The crossing is too large in diameter for auger boring. If the geotechnical investigations indicate that the pipeline can be located in non-permeable soils or above the groundwater table, then open-shield pipejacking or pipe ramming may be feasible. Therefore, the most likely construction method for this crossing is considered to be microtunneling. Watertight shaft construction methods such as interlocking sheetpiles or secant piles would likely be necessary. The jacking shaft could likely be located on either side of the creek for this crossing.

The standard recommended work area of 15,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft could be accommodated by closing Core Road. Work areas for the jacking and reception shaft would be approximately 30 feet wide by 500 feet long and 30 feet wide by 270 feet long, respectively.

#### Crossing #10 Stone Lake Creek – South Fork

The northeast section of the distribution alignment runs along Franklin Boulevard and crosses the South Fork of Stone Lake Creek (See Figure 24) approximately 2,700 feet north of the intersection with Point Pleasant Road. The distribution line is anticipated to be approximately 42-inches in this section of the alignment. The unlined creek invert is approximately 8 feet beneath Franklin Boulevard and appears to have seasonal flows, running mostly dry in the summer. As-built drawings of the bridge show abutments for the foundation extend approximately 10 feet beneath the road surface. A residence is located west of Franklin Boulevard just south of the creek. The northern shaft could be centered within Franklin Boulevard, but the southern shaft should be located on the eastern side of Franklin Boulevard to limit impacts to the residence. Franklin Boulevard is mostly flat at the crossing location with the surrounding ground at grade.

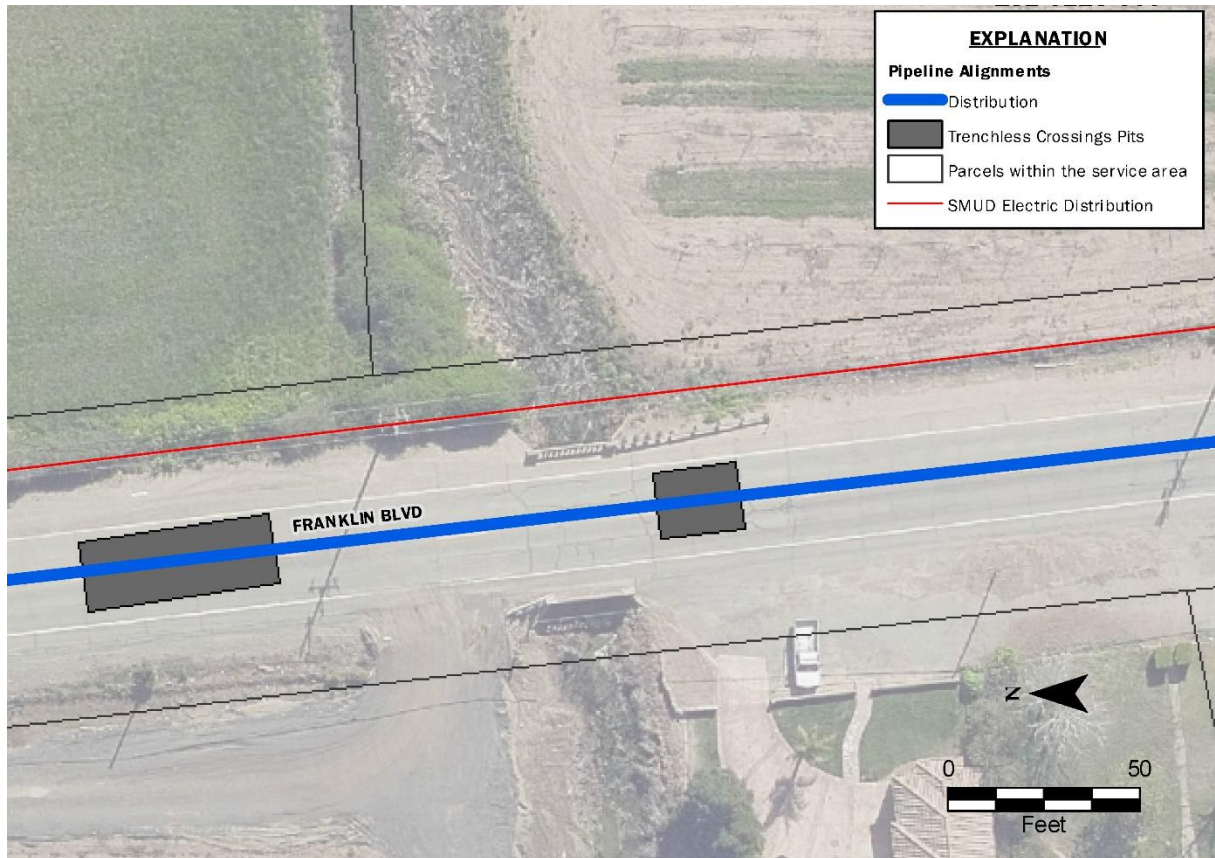


Figure 24. Proposed Trenchless Crossing of the South Fork of Stone Lake Creek at Franklin Boulevard

The only identified utility at this crossing is an overhead electric line running along the eastern shoulder of Franklin Boulevard.

The C-PMO team does not have plans to perform geotechnical borings at this crossing location. It is recommended that the final design team anticipate completing a geotechnical boring on each side of the crossing to make an accurate assessment of ground conditions. In advance of the completion of these borings, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the water level in the creek.

It is anticipated that 42-inch CMLC steel carrier pipe would require 60-inch OD steel casing to allow for safe installation and grouting of the annular space. Alternatively, FRP could be used as a carrier pipe, which can be direct-installed without a casing by open-shield pipejacking or microtunneling. To provide approximately two diameters of clearance beneath the bridge foundation, it is expected that the crown of the 45-inch OD FRP or 60-inch diameter casing pipe would be installed a minimum of 17 to 20 feet below the Franklin Boulevard. Evaluation of the geotechnical properties will be necessary to determine the appropriate alignment depth to evaluate settlement risk to the bridge foundation structures. The anticipated length of the crossing is approximately 150 feet to provide adequate clearance between the shafts and the bridge foundations.

Based on the proposed length, diameter, and anticipated ground conditions, potentially feasible trenchless methods include: auger boring, pipe ramming, open-shield pipejacking, and microtunneling. However, due to the required depth to avoid damaging the bridge foundations combined with the likely high groundwater and source of recharge from the creek, watertight construction methods are likely necessary. Therefore, the most likely construction method for this crossing is considered to be microtunneling in combination with watertight shaft methods, such as interlocking sheetpiles or secant piles. The jacking shaft would be located on the northern side of the crossing to limit impacts to the residence on the south side, as well as limit impacts from the overhead electric line.

A full closure of Franklin Boulevard is likely to be required at this crossing to provide adequate work area for both jacking shafts. The portion of Franklin Boulevard south of the bridge could remain open for residential access only. Traffic could be detoured to the east to Ed Rao Road, running parallel to Franklin Boulevard, via Core Road to the north and Point Pleasant Road to the south. The available work area between the fences on either side of Franklin Boulevard is approximately 50 feet wide. To provide the standard recommended work area of 20,000 square feet at the jacking shaft, the allowable work area should be 400 feet long. For the reception shaft, the work area will need to provide a travel lane at least 12 feet wide for residential access. Therefore, the work area at the reception shaft will be approximately 40 feet wide and 250 feet long to provide the recommended 10,000 square feet of work area.

#### Crossing # 11 Lambert Canal at Franklin Boulevard

The distribution alignment continues south along Franklin Boulevard and crosses the Lambert Canal approximately 200 feet north of the intersection with Lambert Road, as shown in Figure 25. To limit impacts to Lambert Road, the trenchless crossing is anticipated to continue south of Lambert Road. The distribution line is anticipated to be approximately 42-inches in this section of the alignment. The unlined creek invert is approximately 8 to 10 feet beneath a bridge in Franklin Boulevard and appears to have seasonal flows, running mostly dry in the summer. An abandoned AT&T facility is located west of Franklin Boulevard south of Lambert Road. The northern shaft would likely be located within Franklin Boulevard; the southern shaft could be located within the abandoned AT&T facility to limit impacts to traffic on Franklin Boulevard south of the intersection. If easement cannot be acquired for the AT&T lot, the jacking shaft would be located within Franklin Boulevard south of the intersection with Lambert Road. Franklin Boulevard is mostly flat at the crossing location with the surrounding ground at grade.

For feasibility level cost estimating it was assumed there would be two separate trenchless installations. There are likely opportunities for significant cost savings with the crossing to combine two shafts as a single shaft. The final designer should evaluate this and other cost savings concepts.

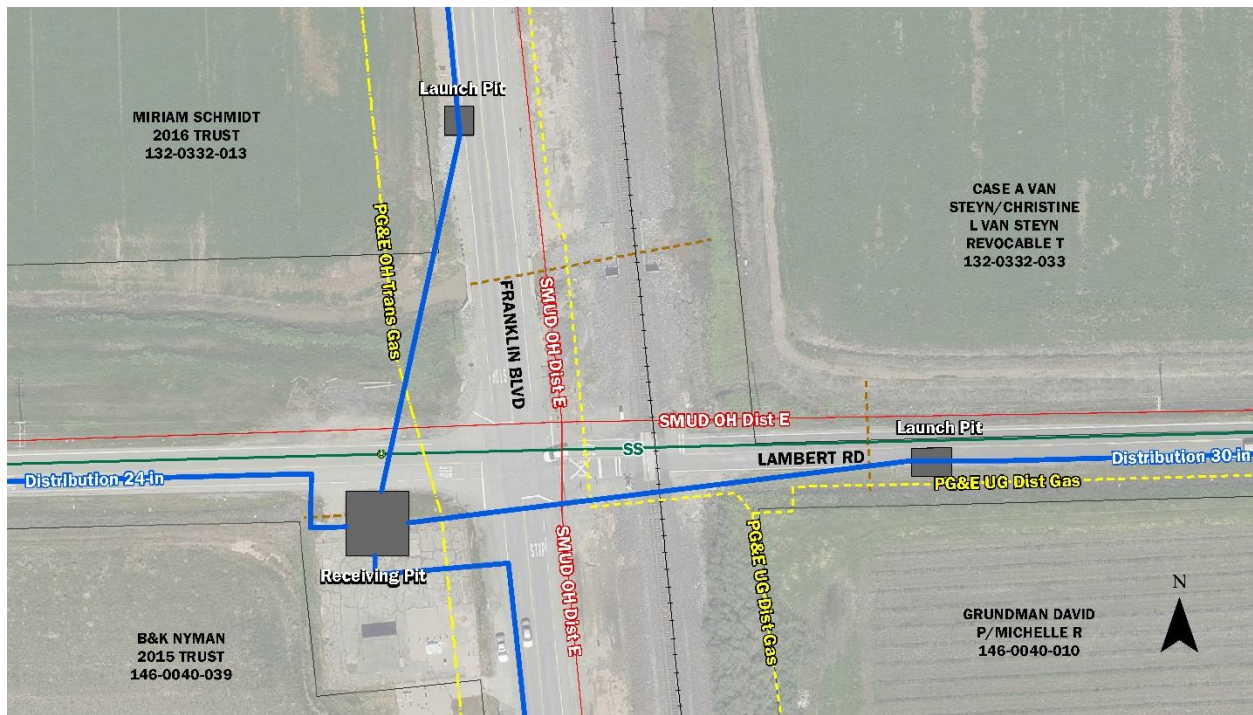


Figure 25. Proposed Trenchless Crossing of Lambert Canal at Franklin Boulevard and Franklin Bouelvard at Lambert Road

Several existing utilities lie parallel to Franklin Boulevard at this location. An overhead electrical and underground PG&E gas distribution line lie on the eastern shoulder of Franklin Boulevard, while an existing overhead telecommunications line and PG&E gas transmission main lie on the western shoulder. Two utilities lie within Lambert Road including an overhead electric line on the northern shoulder and a sewer in the westbound lane.

The C-PMO team will perform one geotechnical boring on the southern side of this crossing location to make a preliminary assessment of ground conditions. It is recommended that the final design team perform an additional boring north of the canal to verify conditions at the northern shaft. In advance of the completion of these borings, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the water level in the channel.

It is anticipated that 42-inch CMLC steel carrier pipe would require 60-inch OD steel casing to allow for safe installation and grouting of the annular space. Alternatively, FRP could be used as a carrier pipe, which can be direct-installed without a casing by open-shield pipejacking or microtunneling. To provide approximately two diameters of clearance beneath the Franklin Boulevard, it is expected that the crown of the 45-inch OD FRP or 609-inch diameter casing pipe would be installed a minimum of 8 to 10 feet below the Franklin Boulevard. Evaluation of geotechnical conditions and the bridge foundation structures will be necessary to determine the appropriate alignment depth to evaluate settlement risk. In addition, the alignment depth will need to evaluate settlement risk of crossing beneath the PG&E transmission line and the sewer in Lambert Road. The anticipated length of the crossing is approximately 250 feet to provide adequate clearance between the northern shaft and the bridge foundations and to keep the

southern shaft work area south of Lambert Road. It is likely that the shaft south of Lambert Road could be a common shaft for the trenchless crossing of the UPRR tracks along Lambert Road (Crossing #12).

Based on the proposed length, diameter, and anticipated ground conditions, potentially feasible trenchless methods include: auger boring, pipe ramming, open-shield pipejacking, and microtunneling. However, due to the required depth to avoid damaging the bridge foundations combined with the likely high groundwater and source of recharge from the creek, watertight construction methods are likely necessary. Therefore, the most likely construction method for this crossing is considered to be microtunneling in combination with watertight shaft methods, such as interlocking sheetpiles or secant piles. The jacking shaft would be located on the southern side of the crossing within the AT&T abandoned lot to keep the shaft and work area out of Franklin Boulevard and Lambert Road.

A full closure of Franklin Boulevard is likely to be required at this crossing to provide adequate work area for the northern shaft. The portion of Franklin Boulevard south of the Lambert Road could remain open if the AT&T lot can be used to construct the shaft. The AT&T lot is approximately 100 feet wide by 100 feet long. To provide the standard recommended work area of 20,000 square feet at the jacking shaft, an additional 10,000 square feet of work area would be required, preferably within the field adjacent to the AT&T lot. If however, easement within the AT&T lot cannot be acquired, it is likely that a full closure of Franklin Boulevard will be required south of Lambert Road to provide adequate work area to construct the shaft and conduct trenchless activities. The approximate work area for the alternate jacking shaft location would be approximately 50 feet wide by 400 feet long. The available work area between the fences on either side of Franklin Boulevard is approximately 50 feet wide. For the reception shaft, the work area be approximately 50 feet wide and 200 feet long to provide the recommended 10,000 square feet of work area.

#### Crossing #12 UPRR at Lambert Road

The distribution alignment crosses the UPRR right-of-way on Lambert Road just east of the intersection with Franklin Boulevard. To limit impacts to Franklin Road, the trenchless crossing is anticipated to extend to the west of Franklin Boulevard. The distribution line is anticipated to be approximately 30 inches in this section of the alignment. The UPRR tracks are on a slight embankment, but is at grade when they cross Lambert Road. An abandoned AT&T facility is located west of Franklin Boulevard south of Lambert Road which could be used for a shaft location, likely a common shaft with the trenchless crossing of Lambert Canal (Crossing #11). If easement cannot be acquired for the AT&T lot, the jacking shaft would be located within Franklin Boulevard south of the intersection with Lambert Road. The eastern shaft would likely be located within Lambert Road. Lambert Road and the surrounding ground is mostly flat at the crossing location with a slight rise in grade on either side up to the UPRR tracks. See Figure 25 above.

Several existing utilities lie parallel to Lambert Road at this location. An overhead electrical line lies on the northern shoulder of Lambert Road and sewer force main runs in the westbound lane. The trenchless stretch will likely cross multiple utilities within Franklin Boulevard, including an overhead electric and gas transmission main on the eastern shoulder of Franklin Boulevard, and

a PG&E gas transmission main on the western shoulder of Franklin Boulevard. In addition, a culvert crosses Lambert Road approximately 125 feet east of UPRR.

The C-PMO team will perform two geotechnical borings at this crossing location to make a preliminary assessment of ground conditions. In advance of the completion of these borings, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the water level in the channel.

The 30-inch CMLC steel or FRP carrier pipe will require a 48-inch OD steel casing to satisfy UPRR permit conditions and to allow for safe installation and grouting of the annular space. To provide approximately two diameters of clearance beneath the UPRR tracks, it is expected that the crown of the 48-inch diameter casing pipe would be installed a minimum of 8 feet below Lambert Road. Evaluation of existing utilities and ground conditions will be needed to evaluate the settlement risk to utilities and the UPRR tracks.

The anticipated length of the crossing is approximately 275 feet to provide adequate clearance between the eastern shaft and the culvert as well as to keep the western shaft work area west of Franklin Boulevard. It is likely that the shaft west of Franklin Boulevard could be a common shaft for the trenchless crossing of the Lambert Canal along Franklin Boulevard (Crossing #11).

Based on the proposed length, diameter, and anticipated ground conditions, potentially feasible trenchless methods include: auger boring, pipe ramming, open-shield pipejacking, and microtunneling. However, due to the likely high groundwater and source of recharge from the channel, watertight construction methods are likely necessary. Therefore, the most likely construction method for this crossing is considered to be microtunneling in combination with watertight shaft methods, such as interlocking sheetpiles or secant piles. The jacking shaft would be located on the western side of the crossing where there is a larger work area available.

A full closure of Lambert Road is likely to be required at this crossing east of the UPRR tracks to provide adequate work area for the eastern shaft. The portion of Lambert Road west of Franklin Boulevard could likely remain open. The AT&T lot is approximately 100 feet wide by 100 feet long. To provide the standard recommended work area of 20,000 square feet at the jacking shaft, an additional 10,000 square feet of work area would be required, preferably within the field adjacent to the AT&T lot. If however, easement within the AT&T lot cannot be acquired, it is likely that Franklin Boulevard would be required south of Lambert Road to provide adequate work area to construct the shaft and conduct trenchless activities. The approximate work area for the alternate jacking shaft location would be approximately 50 feet wide by 400 feet long. The available work area on Lambert Road is approximately 25 feet wide. For the reception shaft, the work area be approximately 25 feet wide and 400 feet long to provide the recommended 10,000 square feet of work area.

#### Crossing #13 UPRR at Twin Cities Road

A portion of the distribution pipeline system runs south down Franklin Boulevard, before turning east on Twin Cities Road. Approximately 175 feet east of Franklin Boulevard, the 24-inch

diameter distribution pipeline crosses beneath the UPRR ROW as shown in Figure 26. An irrigation ditch runs along the east side of the UPRR ROW, and turns to run east along the north side of Twin Cities Road. It appears there may be a culvert passing beneath Twin Cities Road, east of the UPRR ROW, connecting the irrigation ditches north and south of the road.

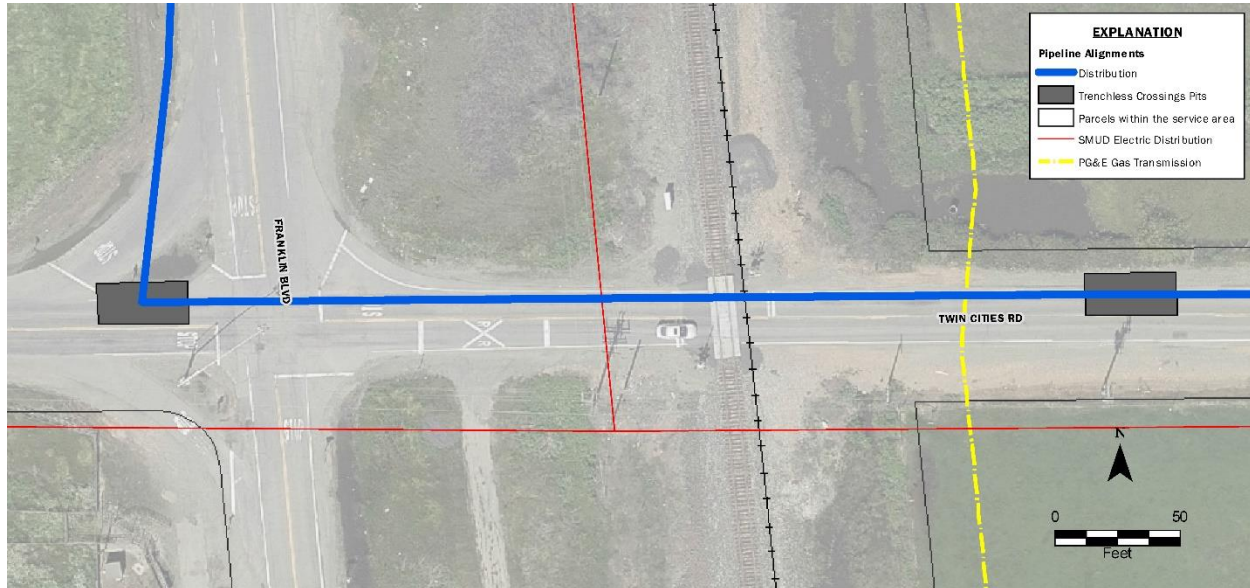


Figure 26. Proposed Trenchless Crossing of UPRR at Twin Cities Road

Overhead electric runs along the west side of the UPRR ROW and along the south side of Twin Cities Road. A PG&E gas lines runs along the east side of the UPRR ROW, approximately 100 feet east of the tracks.

No borings are planned for this crossing location during the BODR phase. It is anticipated that two borings would be advanced near this location during the final design phase. In advance of the completion of borings at this location, it is assumed that conditions at this crossing will consist of stable cohesive sands, silts, and clays, with groundwater located approximately 30 feet below ground surface.

The 24-inch carrier pipe will require a 42-inch OD steel casing to satisfy UPRR permit requirements and to allow for safe installation and grouting of the annular space. To provide approximately 2.5 to 3 diameters of clearance beneath the UPRR tracks, it is expected that the shaft inverts necessary for installation of the 42-inch diameter casing pipe would be a minimum of 12 feet below the road surface. Further utility research and potholing work is needed to determine the depth of existing utilities, to allow a settlement risk evaluation to be made.

The anticipated trenchless crossing would lie within Twin Cities Road to avoid impacting private property. Both shafts would be located within the roadway and would likely require a full road closure. Shafts should be set back at least 30 feet from the center of the UPRR tracks and outside of UPRR right-of-way, while maintaining as short a crossing as possible. The anticipated crossing length would be approximately 200 feet.

Based on the proposed length, diameter, and currently anticipated ground conditions, potentially feasible trenchless methods include: auger boring, microtunneling, and pipe ramming. If the elevation of existing utilities allows the tunnel horizon to remain relatively shallow, the larger shafts associated with pipe ramming may not be cost prohibitive, and the short length would be suitable for that method. However, auger boring would likely provide the most cost-effective approach. If the pipeline horizon can be located above the groundwater then the capabilities of microtunneling would be unnecessary. Therefore, the most likely construction method for this crossing is considered to be auger boring. Non-watertight tunneling methods could be combined with non-watertight shaft methods such as slide rails, soldier piles and lagging, or liner plate. More capable, and costly, methods such as interlocking sheetpiles or secant piles should be unnecessary. The jacking shaft would likely be located on the western side of the crossing where more work area is available and impacts to the residence located east of the tracks could be reduced.

The standard recommended work area of 8,000 to 10,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft could be accommodated by closing Twin Cities Road near the crossing. Work areas for the jacking and reception shaft would be approximately 30 feet wide by 300 feet long and 30 feet wide by 270 feet long, respectively.

#### Crossing #14 Drainage at Twin Cities Road

A portion of the distribution system runs east and west along Twin Cities Road. Approximately 400 feet west of Bruceville Road, the 24-inch pipeline will pass beneath an unnamed drainage, shown in Figure 27. The drainage runs parallel to Bruceville Road, on the west side of the road north of the crossing, and then turns to flow west along the north side of Twin Cities Road. Approximately 400 feet west of Bruceville Road, the drainage crosses beneath Twin Cities Road through a box culvert or small bridge structure, spreading into a broad wetland area south of the road. The bottom of the drainage appears to be approximately 6 feet below the road surface.

For feasibility level cost estimating an auger bored construction method would be used. There are likely opportunities for significant cost savings with a horizontally directionally drilled construction installation, though it would be longer than an auger bore. The final designer should evaluate both methods and develop the most cost effective, feasible method.

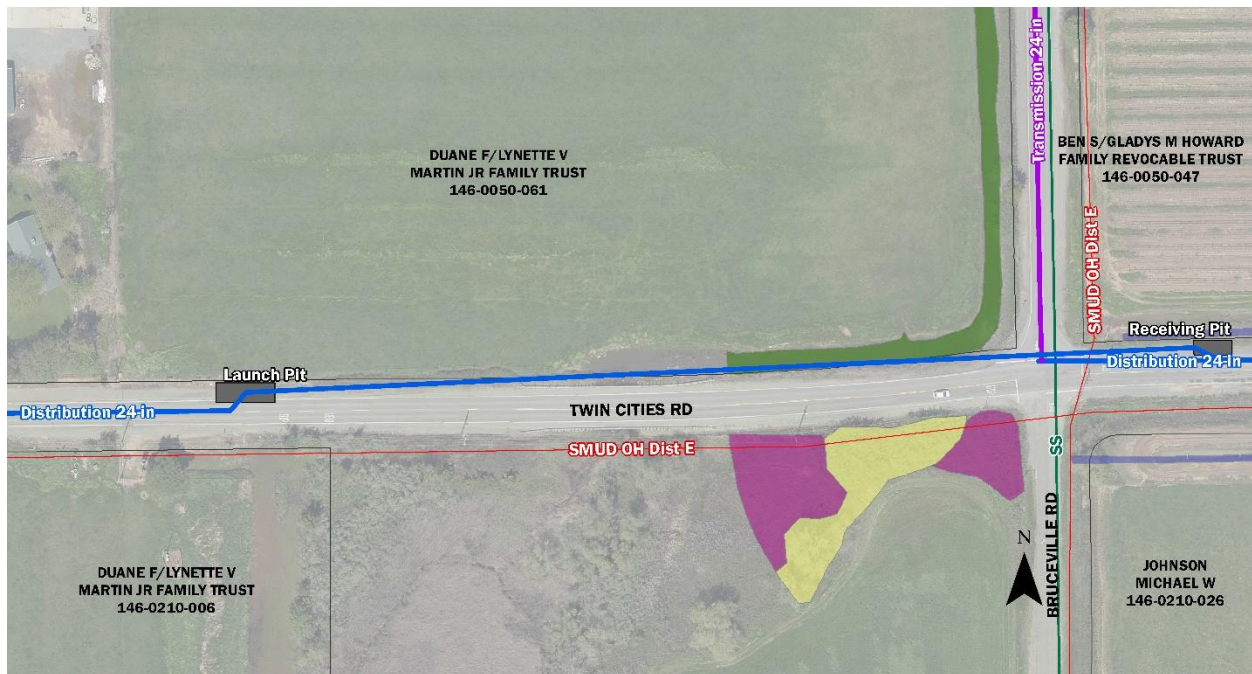


Figure 27. Proposed Trenchless Crossing of Drainage at Twin Cities Road

The only known utilities in the area are overhead electric service running along the south side of Twin Cities Road and telephone running along the north side.

No borings are planned for this crossing location during the BODR phase. It is anticipated that two borings would be advanced near this location during the final design phase. In advance of the completion of borings at this location, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water in the drainage.

It is anticipated that the 24-inch carrier pipe could be installed directly using HDD methods and HDPE pipe. To provide approximately 20 feet of clearance beneath the creek bottom to reduce risk of hydrofracture, it is expected that the bore would need to be at least 500 feet long. However, if the crossing length were increased to 800 feet, the trenchless construction could continue east beyond the intersection of Twin Cities Road and Bruceville Road, reducing traffic disruption at this location. Further utility research and potholing work is needed to determine if any other underground facilities are present that need to be considered. Hydrofracture and settlement analyses would then be used to confirm the necessary depth, and resulting length, of the crossing.

The anticipated trenchless crossing would lie within Twin Cities Road to avoid impacting the wetlands to the north and south of the road. The bore could be advanced in either direction, however the entry/rig location will likely require full closure of the road. The exit/pipe layout side of the bore could likely be completed along the shoulder and a small portion of one lane, allowing two-way traffic to continue with a shift of lanes.

Based on the proposed length, diameter, and currently anticipated groundwater conditions, HDD is likely the most feasible trenchless construction method. It is anticipated that groundwater will be encountered, due to the drainage and adjacent wetlands, which can result in face instability for auger boring and pipe ramming. Microtunneling could also be used in to complete the crossing in the anticipated ground conditions, however this may require the use of an oversized casing as the smallest microtunneling installations are 24 to 30 inches in diameter. Additionally, the typical unit cost of microtunneling and the cost of watertight shafts would be significantly higher than for an HDD installation. If the geotechnical investigations indicate that the pipeline can be located in non-permeable soils or above the groundwater table, then auger boring or pipe ramming may be feasible. Therefore, the most likely construction method for this crossing is currently considered to be HDD.

The recommended work area for this crossing is approximately 6,000 to 8,000 square feet at the rig location / entry point and 2,000 to 3,000 square feet near the exit location, with an additional 500 to 800 feet of narrow space on the road shoulder for pipe layout. The rig work area would require approximately 200 feet of Twin Cities Road to be closed. The exit side area could be kept to the shoulder and a small portion of one lane of the road, and approximately 200 feet long. To reduce disruption to the residence located west of the crossing, it is suggested that the entry point be located just east of the intersection with Bruceville Road.

#### Crossing #15 UPRR at Point Pleasant Road

A portion of the distribution pipeline system runs east and west along Point Pleasant Road. Approximately 500 feet east of Franklin Boulevard, the 18-inch diameter distribution pipeline crosses beneath the UPRR tracks, shown in Figure 28. The UPRR line has split into a set of two parallel tracks at this location.

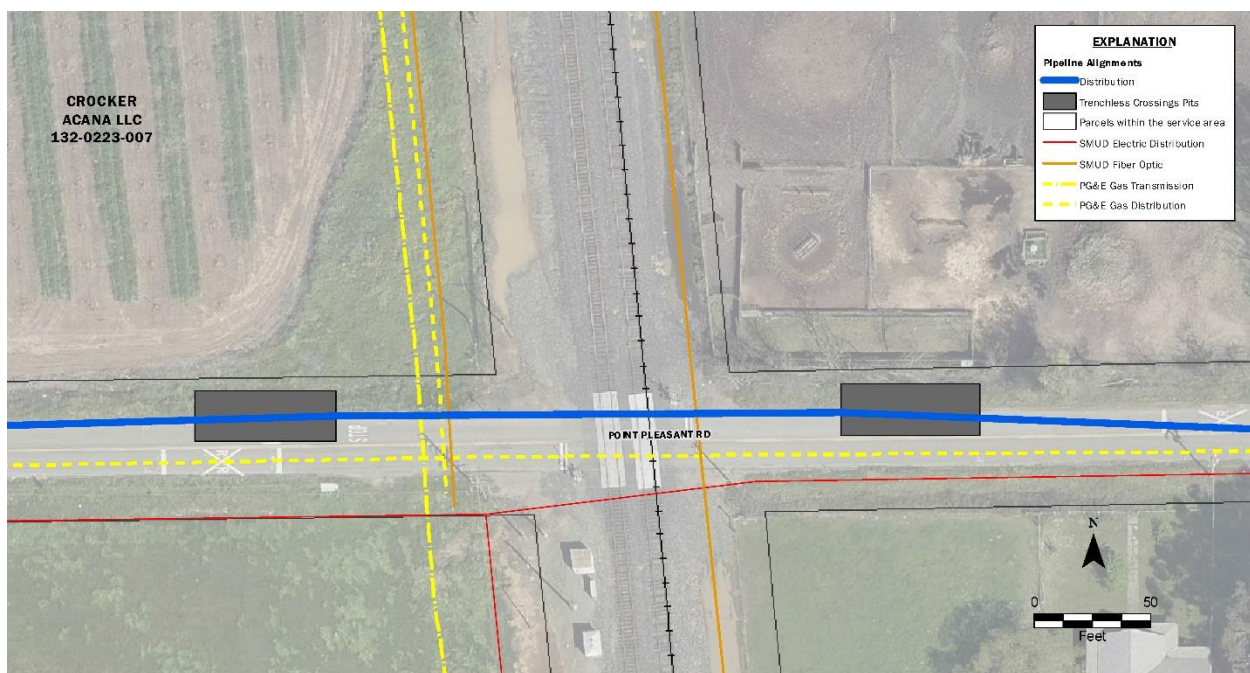


Figure 28. Proposed Trenchless Crossing of UPRR at Point Pleasant Road

There are several existing utilities at the crossing location including two PG&E gas lines running parallel with the UPRR ROW, and a third gas line running along the south side of Point Pleasant Road. SMUD fiber optic lines run along each side of the UPRR ROW, as well as overhead electric on the west side of the tracks. Finally, overhead electric is also running along the south side of Point Pleasant Road.

No borings are planned for this crossing location during the BODR phase. It is anticipated that two borings would be advanced near this location during the final design phase. In advance of the completion of borings at this location, it is assumed that conditions at this crossing will consist of stable cohesive sands, silts, and clays, with groundwater located approximately 30 feet below ground surface.

It is anticipated that the 18-inch carrier pipe will require a 30-inch OD steel casing to allow for safe installation and grouting of the annular space. Casing will be required at this location to meet UPRR permit requirements. To provide approximately 2.5 to 3 diameters of clearance beneath the UPRR tracks, it is expected that the shaft inverts necessary for installation of the 30-inch diameter casing pipe would be a minimum of 11 feet below the road surface. Further utility research and potholing work is needed to determine the depth of existing utilities, to allow a settlement risk evaluation to be made.

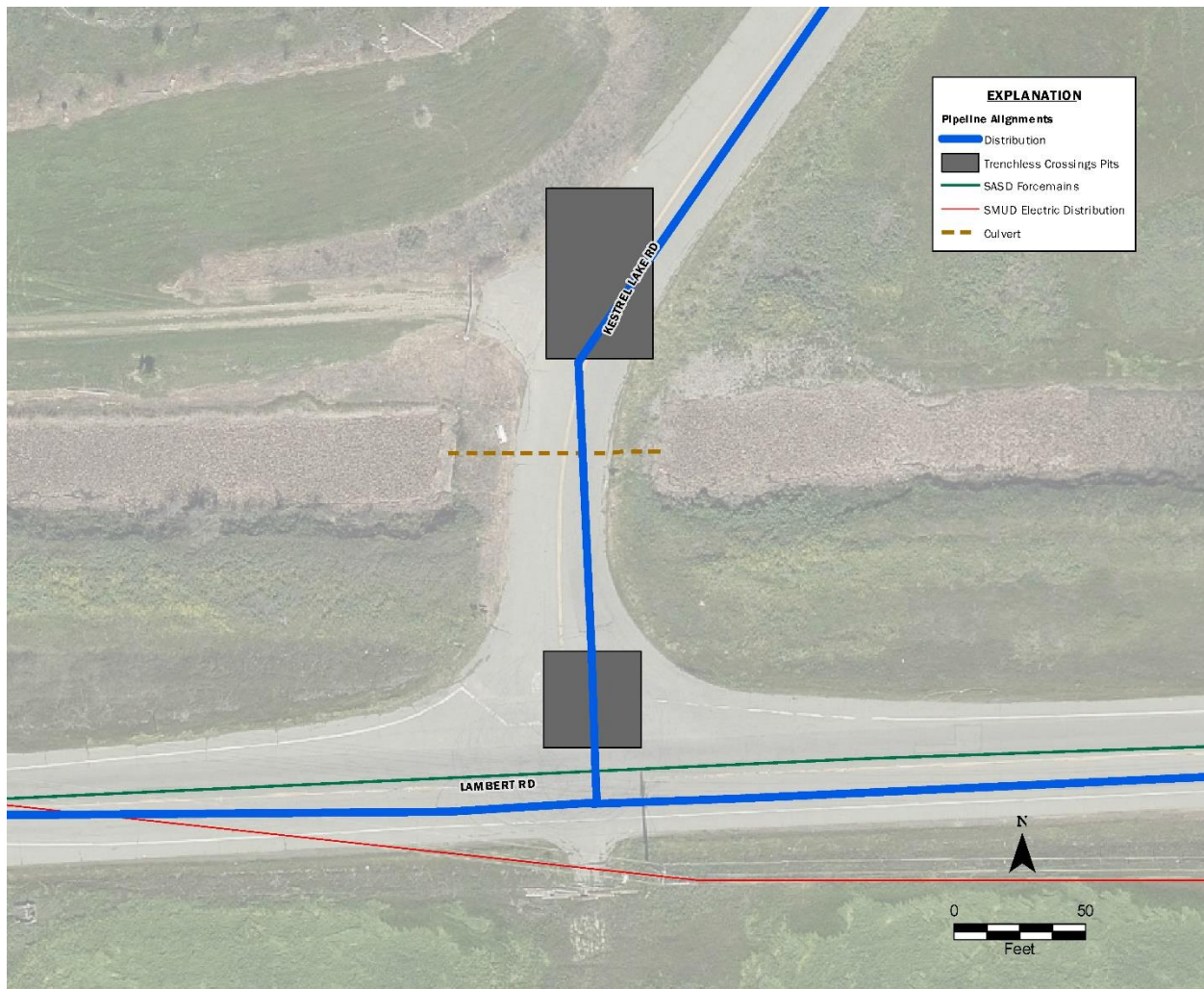
The anticipated trenchless crossing would lie within Point Pleasant Road to avoid impacting private property. Both shafts would be located in Point Pleasant and would likely require a full road closure. Shafts should be set back at least 30 feet from the center of the UPRR tracks and outside of UPRR right-of-way, while maintaining as short a crossing as possible. The anticipated crossing length would be approximately 200 feet.

Based on the proposed length, diameter, and currently anticipated ground conditions, potentially feasible trenchless methods include: auger boring, microtunneling, and pipe ramming. If the elevation of existing utilities allows the tunnel horizon to remain relatively shallow, the larger shafts associated with pipe ramming may not be cost prohibitive, and the short length would be suitable for that method. However, auger boring would likely provide the most cost-effective approach. If the pipeline horizon can be located above the groundwater then the capabilities of microtunneling would be unnecessary. Therefore, the most likely construction method for this crossing is considered to be auger boring. Non-watertight tunneling methods could be combined with non-watertight shaft methods such as slide rails, soldier piles and lagging, or liner plate. More capable, and costly, methods such as interlocking sheetpiles or secant piles should be unnecessary. The jacking shaft would likely be located on the western side of the crossing where more work area is available and impacts to the residence located east of the tracks could be reduced.

The standard recommended work area of 8,000 to 10,000 square feet at the jacking shaft and 8,000 square feet at the reception shaft could be accommodated by closing Point Pleasant Road near the crossing. Work areas for the jacking and reception shaft would be approximately 30 feet wide by 300 feet long and 30 feet wide by 270 feet long, respectively.

### Crossing #16 Lambert Canal at Kestrel Lake Road

The distribution pipeline system runs west along Lambert Road toward Interstate 5. Approximately 500 feet west of I-5, an 18-inch diameter spur pipeline turns north on Kestrel Lake Road and crosses beneath an irrigation canal/drainage that is running along the north side of Lambert Road, shown in Figure 29. The drainage appears to cross beneath Kestrel Lake Road through a set of three 48- to 60-inch diameter culverts, with invert elevations approximately 6 to 8 feet below the surrounding ground.



**Figure 29. Proposed Trenchless Crossing of Lambert Canal at Kestrel Lake Road**

The only known utilities located in the area of this crossing are overhead electric running along the south side of Lambert Road, south of the crossing and an SASD sanitary sewer force main also running within Lambert Road.

No borings are planned for this crossing location during the BODR phase. It is anticipated that one or two borings would be advanced near this location during the final design phase. In advance of the completion of borings at this location, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water in the irrigation canal/drainage.

No permit requirements necessitate the use of casing at this crossing location. However, the only potentially feasible trenchless method that could directly install the 18-inch carrier pipe is HDD, which is not considered a practical option for this crossing due to geometry constraints. To achieve a safe depth beneath the drainage, an HDD bore would likely need to be approximately 500 feet long. Lambert Road runs perpendicular to the crossing location approximately 100 feet to the south. Therefore, an HDD bore would have to begin well south of Lambert Road, in private farmland. Both auger boring and pipe ramming require the use of steel casing to prevent damage to the product pipe; and microtunneling can only directly install carrier pipe as small as 24 inches in diameter. Therefore, it is assumed that the 18-inch pipeline will be installed in a 30-inch casing pipe at this location. To provide approximately two to three diameters of clearance beneath the irrigation canal, it is expected that the shaft inverts necessary for installation of the 30-inch casing pipe would be a minimum of 18 feet below the road surface. Further utility research and potholing work is needed to determine the depth of existing utilities, to allow a settlement risk evaluation to be made.

The anticipated trenchless crossing would lie within Kestrel Lake Road to avoid impacting private property. Both shafts would be located in the road and would likely require a full road closure. Shafts should be set back sufficiently from the drainage, while maintaining as short a crossing as possible. Offset of shafts from drainage will depend on the permeability of the soils and easement acquisition. The anticipated crossing length would be approximately 100 to 150 feet.

Based on the proposed length, diameter, and currently anticipated groundwater conditions, microtunneling is likely the most feasible trenchless construction method. It is anticipated that groundwater will be encountered, due to the surface water in the irrigation canal, which can result in face instability for auger boring and pipe ramming. If the geotechnical investigations indicate that the pipeline can be located in non-permeable soils or above the groundwater table, then auger boring or pipe ramming may be feasible. Therefore, the most likely construction method for this crossing is currently considered to be microtunneling. Watertight shaft construction methods such as interlocking sheetpiles or secant piles would likely be necessary. The jacking shaft could likely be located on either side of the creek for this crossing, however keeping the larger required work area on the south side of the crossing would reduce impacts to the residence located just north of the drainage.

The standard recommended work area of 15,000 square feet at the jacking shaft could be accommodated by using an approximately 200-foot width of the 75-foot wide unused area located between Lambert Road and the irrigation ditch/drainage. The recommended 8,000 square feet at the reception shaft could be accommodated by closing approximately 200 feet of Point Pleasant Road.

#### Crossing #17 Lambert Canal at Point Pleasant Road

The distribution pipeline system runs west along Lambert Road toward Interstate 5. Approximately 600 feet east of I-5, an 18-inch diameter spur pipeline turns north on Point Pleasant Road and crosses beneath an irrigation canal/drainage that is running along the north side of Lambert Road, shown in Figure 30. The drainage appears to cross beneath Point Pleasant

Road through a set of three 48- to 60-inch diameter culverts, with invert elevations approximately 6 to 8 feet below the surrounding ground.

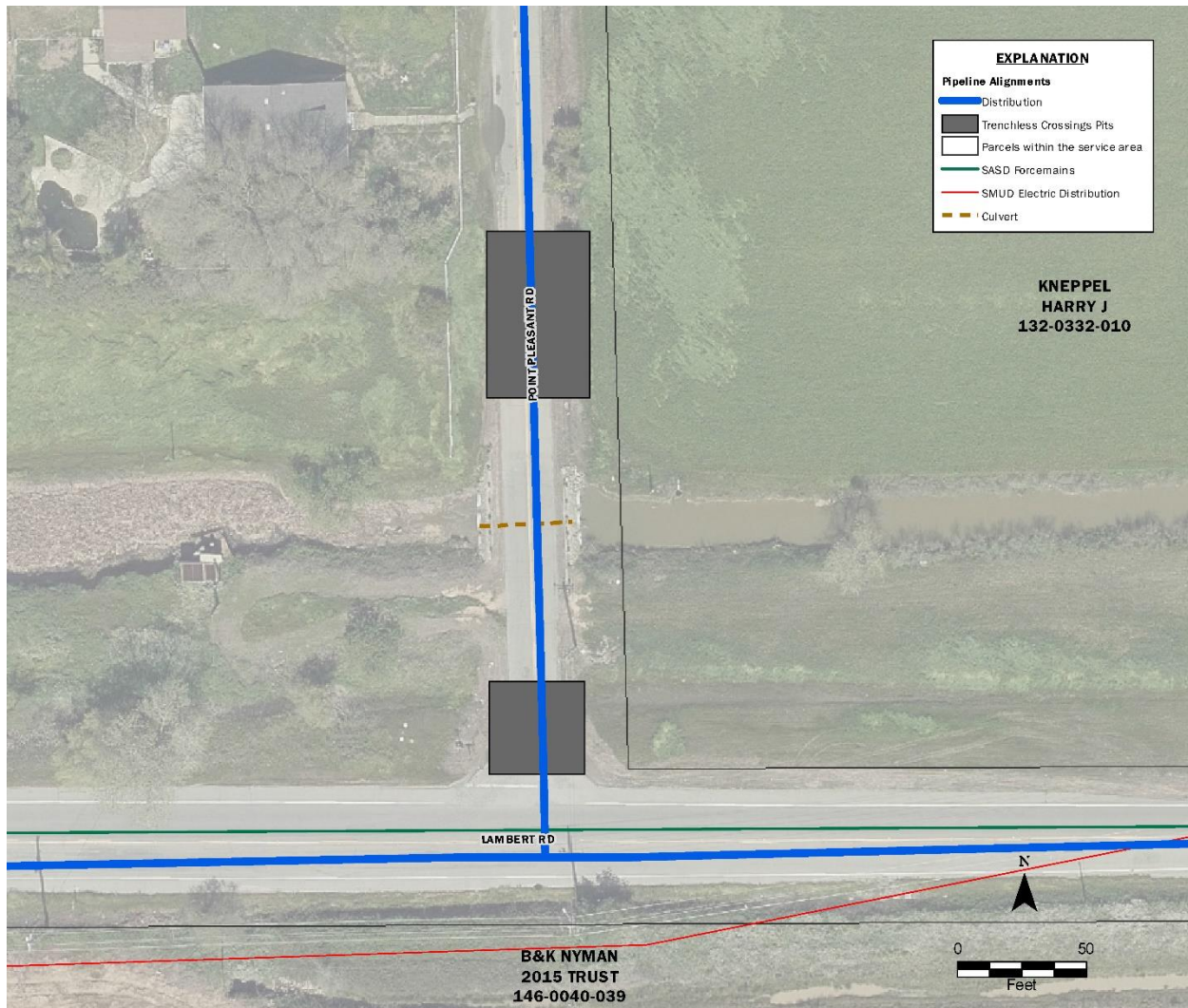


Figure 30. Proposed Trenchless Crossing of Lambert Canal at Point Pleasant Road

The only known utilities located in Point Pleasant Road are overhead power and telephone running along the east side of the road. Additional overhead electric runs along the south side of Lambert Road, south of the crossing. A SASD sanitary sewer force main also runs south of the crossing within Lambert Road.

No borings are planned for this crossing location during the BODR phase. It is anticipated that one or two borings would be advanced near this location during the final design phase. In advance of the completion of borings at this location, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water in the irrigation canal/drainage.

No permit requirements necessitate the use of casing at this crossing location. However, the only potentially feasible trenchless method that could directly install the 18-inch carrier pipe is HDD,

which is not considered a practical option for this crossing due to geometry constraints. To achieve a safe depth beneath the drainage, an HDD bore would likely need to be approximately 500 feet long. Lambert Road runs perpendicular to the crossing location approximately 100 feet to the south. Therefore, an HDD bore would have to begin well south of Lambert Road, in private farmland. Both auger boring and pipe ramming require the use of steel casing to prevent damage to the product pipe; and microtunneling can only directly install carrier pipe as small as 24 inches in diameter. Therefore, it is assumed that the 18-inch pipeline will be installed in a 30-inch casing pipe at this location. To provide approximately two to three diameters of clearance beneath the irrigation canal, it is expected that the shaft invert necessary for installation of the 30-inch casing pipe would be a minimum of 18 feet below the road surface. Further utility research and potholing work is needed to determine the depth of existing utilities, to allow a settlement risk evaluation to be made.

The anticipated trenchless crossing would lie within Point Pleasant Road to avoid impacting private property. Both shafts would be located in the road and would likely require a full road closure. Shafts should be set back sufficiently from the drainage, while maintaining as short a crossing as possible. Distance of shafts from the drainage will be determined by permeability of ground conditions. The anticipated crossing length would be approximately 100 to 150 feet.

Based on the proposed length, diameter, and currently anticipated groundwater conditions, microtunneling is likely the most feasible trenchless construction method. It is anticipated that groundwater will be encountered, due to the surface water in the irrigation canal, which can result in face instability for auger boring and pipe ramming. If the geotechnical investigations indicate that the pipeline can be located in non-permeable soils or above the groundwater table, then auger boring or pipe ramming may be feasible. Therefore, the most likely construction method for this crossing is currently considered to be microtunneling. Watertight shaft construction methods such as interlocking sheetpiles or secant piles would likely be necessary. The jacking shaft could likely be located on either side of the creek for this crossing, however keeping the larger required work area on the south side of the crossing would reduce impacts to the residence located just north of the drainage.

The standard recommended work area of 15,000 square feet at the jacking shaft could be accommodated by using an approximately 200-foot width of the 75-foot wide unused area located between Lambert Road and the irrigation ditch/drainage. The recommended 8,000 square feet at the reception shaft could be accommodated by closing approximately 200 feet of Point Pleasant Road.

#### Crossing #18 Drainage at Bruceville Road

As the distribution pipeline system progresses up Bruceville Road, approximately 3,000 feet north of Eschinger Road, the 16-inch pipeline will pass beneath an unnamed drainage as shown in Figure 31. The drainage runs parallel to Bruceville Road, on the west side of the road north of the crossing, and along the east side of the road south of the crossing. The drainage crosses beneath the road in a box culvert or under a small bridge structure, approximately 6 feet below the roadway and surround ground surface.

For feasibility level cost estimating an auger bored construction method would be used. There are likely opportunities for significant cost savings with a horizontally directionally drilled construction installation, though it would be longer than an auger bore. The final designer should evaluate both methods and develop the most cost effective, feasible method.

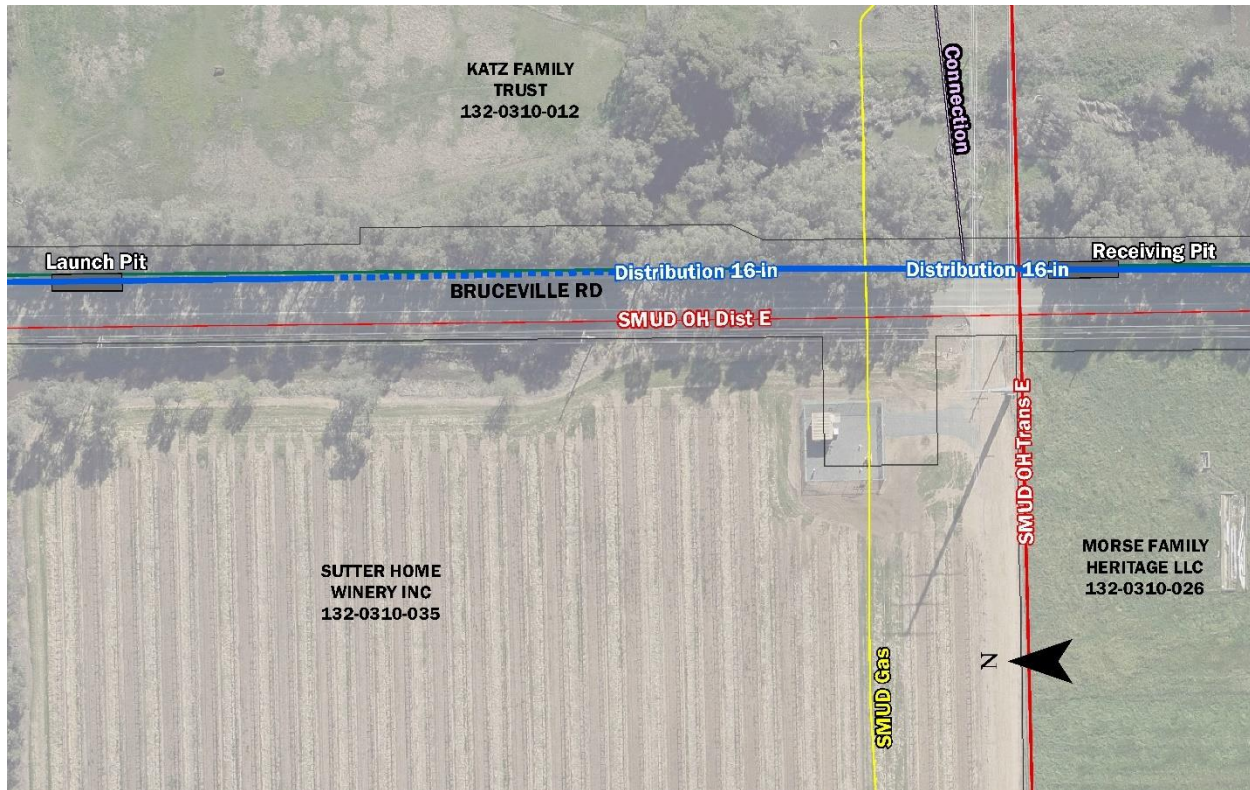


Figure 31. Proposed Trenchless Crossing of Drainage at Bruceville Road

SMUD overhead electric lines run along the west edge of Bruceville Road; an SASD sanitary sewer force main runs along the eastern edge. A Frontier Communications fiber optic line runs parallel to the east side of Bruceville Road, approximately 25 feet off the edge of the roadway. A SMUD gas line crosses perpendicular to Bruceville Road, approximately 175 feet south of the drainage, and enters a valve lot on the west side of the road.

No borings are planned for this crossing location during the BODR phase. It is anticipated that two borings would be advanced near this location during the final design phase. In advance of the completion of borings at this location, it is assumed that conditions at this crossing will consist of potentially unstable cohesive sands, silts, and clays, with groundwater located near the ground surface, influenced by the surface water in the drainage.

It is anticipated that the 16-inch carrier pipe could be installed directly using HDD methods and HDPE pipe. To provide approximately 20 feet of clearance beneath the creek bottom to reduce risk of hydrofracture, it is expected that the bore would need to be approximately 500 feet long. Further utility research and potholing work is needed to determine the exact location of the SASD forcemain, and the depth of the SMUD gas line. Hydrofracture and settlement analyses would then be used to confirm the necessary depth, and resulting length, of the crossing.

The anticipated trenchless crossing would lie within Bruceville Road to avoid impacting the wetlands to the east and west of the road. The bore could be advanced in either direction, however the entry/rig location will likely require full closure of the road. The exit/pipe layout side of the bore could likely be completed in a single lane, allowing one-way traffic flow.

Based on the proposed length, diameter, and currently anticipated groundwater conditions, HDD is likely the most feasible trenchless construction method. It is anticipated that groundwater will be encountered, due to the drainage and adjacent wetlands, which can result in face instability for auger boring and pipe ramming. Microtunneling could also be used in to complete the crossing in the anticipated ground conditions, however this would require the use of an oversized casing as the smallest microtunneling installations are 24 to 30 inches in diameter. Additionally, the typical unit cost of microtunneling and the cost of watertight shafts would be significantly higher than and HDD installation. If the geotechnical investigations indicate that the pipeline can be in non-permeable soils or above the groundwater table, then auger boring or pipe ramming may be feasible. Therefore, the most likely construction method for this crossing is currently considered to be HDD.

The recommended work area for this crossing is approximately 6,000 to 8,000 square feet at the rig location / entry point and 2,000 to 3,000 square feet near the exit location, with an additional 500 feet of narrow space on the road should for pipe layout. The rig work area would require approximately 200 feet of Bruceville Road to be closed. The exit side area could be kept to one lane of the road, and approximately 200 feet long.

AS-BUILT DRAWINGS OF CROSSING LOCATIONS

Location 1 – UPRR @ Sims Road

Location 4 – Ehrhardt Channel

Location 7 – Franklin Creek

Location 8 – Stone Lake Creek – North Fork

Location 10 – Stone Lake Creek – South Fork