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Fast-Track Design and Installation of a 30-inch Casing Pipe Crossing of the Ventura River

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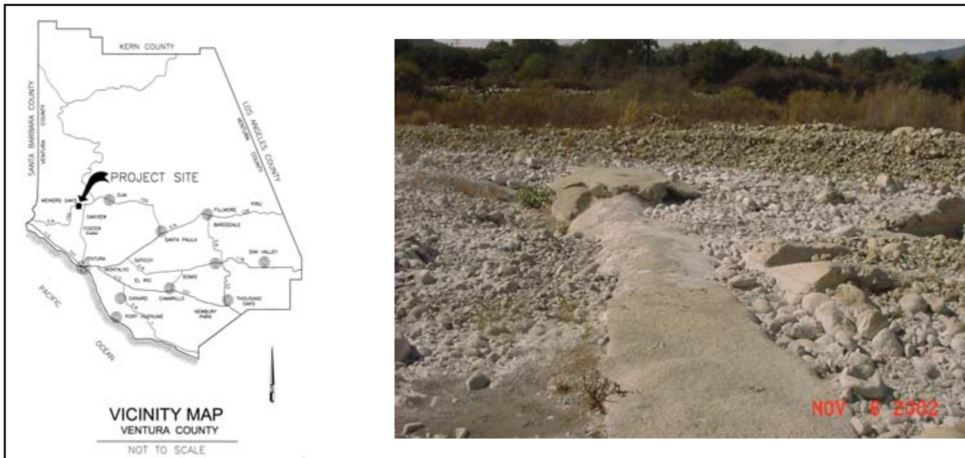
This paper describes how and why a 3300-ft, 30-inch diameter, inverted siphon was constructed in a fast-track manner to convey sewage across the Ventura River. Construction included a combination of horizontal directional drilling and pipe ramming techniques. A particular challenge was getting through alluvial material in the riverbank areas, which are composed of loose sands, gravels, cobbles and boulders, to the more stable mudstone bedrock beneath. Regulations effectively prevented the drilling of exploratory holes within the river prior to construction. An innovative approach to gathering geotechnical data provided invaluable information to design engineers and bidders. Other design, contracting, and construction issues and hurdles are discussed.

THE DYNAMIC ENVIRONMENT

The Ojai Valley Sanitary District owns and operates the wastewater collection system for the Ojai Valley, approximately 15 miles north of Ventura, California. This service territory includes Meiners Oaks, a semi-rural residential area. Since the 1960s, sewage collected from the area was transported across the Ventura River in a shallow, gravity-flow pipe, 18-inches in diameter. Degradation of the riverbed over the years had left the pipe exposed where it crosses the river. Some sections of pipe have washed out during extreme flood events. The pipe was encased in concrete through the river crossing, and through most, but not all of the flood plain. Another vulnerable section of pipe ran along the river's west bank.



In the past, these vulnerabilities were not great concerns because construction, repair, and maintenance work in the flood plain were routinely performed by many different parties. Bulldozers operated in the creek, particularly during emergency events, constructing levees and berms, with minimal regulatory oversight or review. If a pipe was damaged, repairs were made promptly. Sewage lost during extreme flood events did not cause great alarm, considering that the sewage flow was minimal compared to the river flow. Most importantly, Mother Nature took the blame. Of course, those days are gone.

Recently, the District incurred significant expense for environmental projects in the flood plain. They were mandated to mitigate “damage” caused by emergency earthwork—and OVSD’s experience in this area had been actually fairly moderate. Other wastewater agencies have learned that accidental spillage or unauthorized construction work can cost millions in fines and legal costs. In some cases, criminal prosecution has been threatened against agency officials who don’t act to avert spills. The issues became more acute for the District a few years back, when the Ventura River was designated as critical habitat for the southern steelhead trout, an endangered species. This meant that actions that resulted in fish kills were now prosecutable, unless specifically permitted via either a Section 7 consultation or a Habitat Conservation Plan.

Doing any kind of construction work within the river has become a regulatory challenge. Depending on circumstance, construction or maintenance activities in the river now require a Streambed Alteration Agreement from the California Department of Fish and Game, a Section 404 Clean Water Act Permit from the U.S. Army Corps of Engineers, and a Section 401 Clean Water Act Certification from the Regional Water Quality Control Board. In many circumstances, a County Flood Control Encroachment Permit was also necessary for any new construction in the river. None of these permits is easily obtained. Some can take months (if not years) of studies.

For many years, OVSD managers and board members were aware of the risks associated with the river pipelines, as well as the dynamic regulatory environment that seemed to be multiplying the risks. Several studies had examined various alternatives to the gravity pipelines, including the use of a lift station and bridge crossing and alternate pipeline routes. As with many public agencies, it took considerable time and effort to develop a consensus regarding if and how money would be spent. The price tag would be considerable, considering the small number of residents served by the pipeline. Residents of the Ojai Valley are known for their great diversity of opinions, particularly on subjects that affect the community and the natural environment.

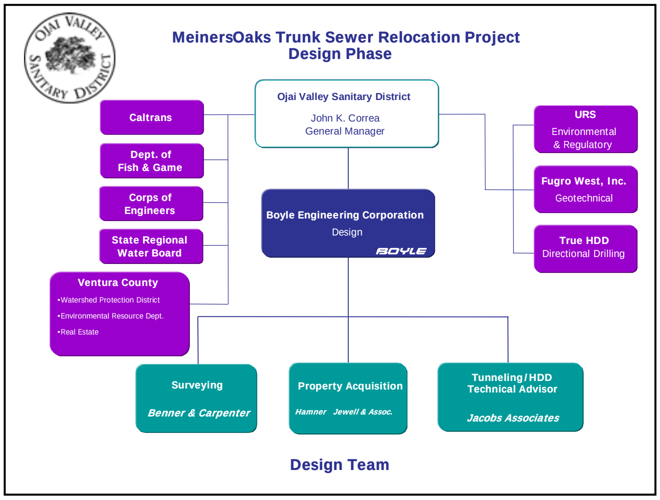
When a recent study indicated that an inverted siphon under the river, installed using the horizontal directional drilling (HDD) process, promised a long-term solution, a consensus for action started to gel. Through the use of the HDD process, work “in the river” could be largely avoided (by going under it), thereby averting much of the regulatory morass. The environmental benefits of this solution also pleased many in the community, helping to strengthen the consensus.

Once a direction was established, the District’s General Manager’s approach was to move as quickly as possible for implementation. If construction could be completed before the next rainy season, the District’s risks would be diminished accordingly. Moving quickly would also reduce the chance that political or regulatory obstacles would emerge, or that the consensus might evaporate.

GEOTECHNICAL AND ENVIRONMENTAL PROJECT APPROACH OVERVIEW

The District explored the general feasibility of the project from geotechnical, technical, and environmental/regulatory perspectives, utilizing the services of Fugro West, True HDD, and URS consultants, respectively. From these studies, the basics of the project were outlined. The project was envisioned as an inverted siphon beneath the Ventura River, replacing both sections of vulnerable pipeline—the section that crosses the river north of the Highway 150 bridge, and the section that is buried in the west bank. The alignment would extend approximately 3300 feet from the eastern abutment of the bridge, across the river to Burnham Road. The alignment would run diagonally at an angle of 50 to 60 degrees with the river. The crossing would consist of a 30-inch or 36-inch casing pipe, housing several small carrier pipes.

Conceptually, construction of the river crossing could be performed using the directional drilling process. At the center of the river, the pipeline would be approximately 200 feet deep, founded in the mudstone bedrock of the Sespe Foundation. In the riverbank areas, sandy-gravelly material would be encountered, necessitating the driving of a larger (48-inch or 54-inch) casing pipe to prevent caving and the loss of drilling fluid. The gravelly alluvium was expected to range between 25 to 70 feet deep. By confining most construction activities to areas beyond the riverbed, many of the regulatory issues associated with river construction could be avoided.



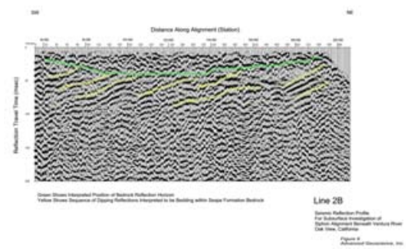
Using a qualification based selection process, the Ojai Valley Sanitary District selected a team led by Boyle Engineering Corporation in early March 2003 to manage the project, prepare drawings, specifications, and estimates, and assist the District and its other consultants in a myriad of associated activities, including hydraulic studies, easement acquisition, permit acquisition, supplemental geotechnical exploration, and environmental documentation.

CRITICAL DESIGN ISSUES

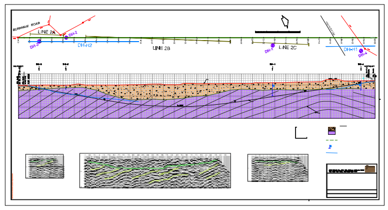
The following were the critical issues, and the approach taken in for resolution.

Geotechnical Characterization. Obtaining accurate geotechnical information and performing an accurate site characterization was crucial. The District retained Fugro West to perform initial investigations but no borings within the river area could be obtained due to the regulatory obstacles. In the river area, Fugro used geophysical methods to determine, within a certain range, the depth to bedrock, but steeply incised channels cut within the bedrock material could be missed. The geophysical studies had limited capability to distinguish between the easy-to-drill mudstone and relatively hard sandstone lenses present in the Sespe formation. Understanding the subsurface conditions was one of the most important factors in minimizing the risks associated with constructing the river crossing. The selection of the tools and equipment would depend on these conditions and would greatly impact the cost and time required to make of the crossing.

Geophone Cable



Seismic Reflection Profile



Cross Section

Alluvial Deposits

Basically, two different geological conditions were identified, alluvium and Sespe formation. The alluvium consisted of largely uncemented sand, gravels, cobbles and boulders. The boulder materials could be very hard and as large as small buildings. This would be the major obstacle to an HDD approach. The Sespe formation, on the other hand, was nearly ideal for HDD; with a consistency like very densely packed soil, this bedrock material was layered in strata that would be quite favorable. Occasional interbedded layers of hard sandstone were expected within the Sespe.

Because the District faced severe regulatory hurdles regarding drilling test holes in the River, the team proposed an innovative approach. Test HDD borings were drilled from each end of the proposed siphon, outside of the restricted area. The test borings paralleled the proposed alignment and profile, extending as far under the river as time and budget allowed. An HDD contractor was hired for one week of service with a medium-sized rig. Fugro logged the cuttings, and videotaped the process. The driller maintained a production log. The District's drilling consultant, True HDD, kept notes regarding production, tools and equipment—all information was provided to the bidders.

An extremely important discovery made during this "trial HDD" investigation: the need for "surface casing" (i.e., the casing rammed through the alluvium) was less than originally assumed. Conditions encountered during trial indicated that the alluvial material was not as unstable as initially believed. On the south side of the siphon, it appeared that with the proper construction, drilling, reaming and pullback methods it would be possible to drill without surface casing. Surface casing was now only planned for the top 50 feet of alluvium, on the north end of siphon, to reduce the potential for damage to existing utilities and a paved road. This reduction in casing requirements favorably impacted the construction budget. Final specs required less than half of what was originally planned.

The trial drilling provided contractors with the subsurface data that was much more relevant to the HDD drilling process than conventional test holes would have been. Also, the information from the trial drilling was useful in several ways, not only was the casing length reduced, the estimated construction costs were thought to be reduced by $500,000.

HDD Technical Specifications. Boyle and its subconsultant, Jacobs Associates evaluated equipment requirements, entry and exit points, lay down areas, pipe materials, and drill path to complete the work. This task began with a thorough evaluation of the horizontal directional drilling methods that were available. Some considerations in this regard were as follows:

- River crossings through similar or longer distances have been performed successfully with equipment rated at 850,000 lb-force of pull back capacity. The number of drilling companies owning drill rigs with appropriate pull back capacity would be limited.
- Fugro's preliminary investigations had indicated that the Sespe formation had adequate density and enough fine-grained material to allow for a drill hole to stay open for the time required to pull the pipe into it. Because of the density and stiffness of the fine-grained material, the behavior of the ground was ideal for drilling – weak enough for straightforward drilling and steering, yet stiff enough to remain open during each subsequent ream. The bore path to negotiate beneath the alluvium had to be able to handle the minimum radius associated with pipe materials.
- Steel pipe was recommended for the pull back. While HDPE might work, the risk associated was deemed to great. With steel, additional force could be applied, and (if needed) a pipe ramming tool could be used for assistance.

Surface Casing Design. Several options were available for installation of the surface conductor casing (i.e., the casing through the alluvium). Longer installation (e.g. greater than 100 to 200 feet) is most commonly done prior to installation of the directional drill pilot hole as the potential to damage the drill steel with the casing is high. An alternative approach was to install the pilot hole and then drive the conductor casing as the hole is reamed. Either approach was considered to be acceptable. The casing is set to line and grade then rammed into the ground by a compressed air hammer system.

For installation in advance of the pilot hole drilling the surface casing may need to be telescoped as the anticipated length may be long for a single driven casing. Telescoping the casing might entail driving approximately 200 feet with a larger diameter casing (approximately 60 inches) followed by installation of a slightly smaller diameter (approximately 54 inches). Each of these casings could be cleaned during the driving operation by forward reaming with the HDD equipment, with flight augers, with bucket auger, or manually if necessary (if a large rock gets stuck in the casing). If the second casing becomes immobilized before reaching bedrock, then a third casing of 48-inches could be used.

Alternatively, the casing could be driven over the pilot hole, this is required if the casing is to be installed on the exit side of the HDD bore as the ability to steer into a pre-installed casing is unreliable. For long applications where the casing is driven over the pilot hole drill string, back reaming can be done to remove the materials and guide the casing in the right direction.

A final decision regarding installation method was to be made by the contractor. As previously discussed, the trial HDD test borings provided critical data to evaluate how much casing would be required, and whether casing of the exit hole would be needed. In order to facilitate the bidding of alternative approaches, Jacobs recommended that the contractor be allowed to drill the pilot hole from either side of the crossing. Site constraints, however, dictated that the casing laydown would have to occur on the north side of the siphon, with the rig position on the south side for the pullback.

HDD and 30-inch Casing Design. After the surface conductor casing(s) was installed to a depth of 100 feet, a 48-inch hole was excavated using a 12-inch pilot hole and two reams (27" and 48") and then a 30-inch steel bore casing was installed. Based on general guidelines, the diameter of the reamed hole is 1.5 times the bore casing diameter. However, because the hole was expected to be stable in Sespe formation and with the surface conductor casing in the alluvium, a smaller diameter reamed hole was deemed to be acceptable. It was expected that 3 to 4 reaming cycles would be needed to achieve the necessary diameter for the casing installation; however only two were required. Following the last reaming operation and cleaning of the hole, the 30-inch steel bore casing was installed. The steel casing was connected to the drill steel, and then pulled in behind a pulling head attachment.

Specifications called for the hole and casing pipe to be filled with an adjusted density drill mud, to minimize the buoyancy of the casing so that the casing friction is minimized. When the casing is in place, a specially designed drill mud would then be used to fill the outside of the casing to solidify the annular space between the casing and the drill hole. This was not anticipated to be necessary with the surface conductor casing in place as the HDD hole in the Sespe formation was anticipated to be stable, and because there are no critical structures above the alignment.

Hydraulic Design, Flow Conditions, and Velocities. The hydraulic design of the siphon carrier pipes was targeted for the following cases:
- Current dry-weather peak flows
- Current wet-weather peak flows
- Future dry-weather peak flows
- Future wet-weather peak flows

A key consideration was keeping the siphon pipes clean. To do this, the siphon pipes must be sized with capacity for handling the peak flows, while maintaining adequate velocities during non-peak times, so that the pipes are self cleaning, both now and in the future. Fortunately, there was plenty of elevation difference from one end of the siphon to the other so that adequate velocities were attainable under all flow conditions.

There are many different opinions regarding the velocities needed to clean pipe. A 1986 AWWA guide suggests that a minimum of 2.5 ft/s is required, 5 ft/s is desired, and that perhaps 12 ft/s is needed to flush sand and silt from river undercrossings. A 1997 study indicated that 6 ft/s is needed to remove sediments and biofilms. A 1994 report from the University of Alberta postulated that boundary shear, rather than velocity is the parameter that is most important in determining how effective flushing is in removal of biofilm or other adherent material.

More recent work by the AWWA Research Foundation looked at flushing velocities using computational fluid hydraulics, bench tests, and field tests at 11 utilities. Conclusions from these studies are as follows:
- **Particle size.** The typical size of most sediment particles does not significantly affect the velocity required to lift and transport the sediment. However, as noted below, when material reaches cobble size and larger, size becomes an important factor.
- **Specific gravity.** While the specific gravity of the sediment is important in theory, the actual specific gravity of sediment found in pipe did not vary significantly. For sediment with a specific gravity of 2.5 to 3.5 (this would include sand and pipe corrosion products) a velocity of 2.5 ft/s is required to lift and transport the majority of sediment.
- **Pipe roughness.** The roughness of the pipe has a profound effect on our ability to flush it clean. If the pipe has smooth walls (such as with HDPE) there is little benefit to flushing more than 3 ft/s . At this level, 95 percent of the pipe wall is cleaned and all sediment is suspended and removed. If the pipe is slightly scaled, benefits reach a plateau at about 4 ft/s (1.2 m/s), with about 90 percent of the pipe wall cleaned. However, for severely scaled pipe, flows of 5 ft/s (1.5 m/s) were effective in cleaning only about 73 percent of the surface. Where the pipe is heavily scaled, areas of zero flow velocity will exist within recesses in the scale, even with very high flows.
- **Sediment Settling Velocities.** Factors that affect the settling of particles suspended in water are: the size, shape, and specific gravity of the suspended particles; the temperature and viscosity of the water; and the velocity of the water. Using Fluid Mechanics, we can calculate the settling velocities for spherically-shaped particles using Stoke's Law or Newton's Law. (Stoke's law applies for Reynolds number less than 1, and Newton's law applies for Reynold's numbers greater than 2000. A transition area exists in the intermediate area.)

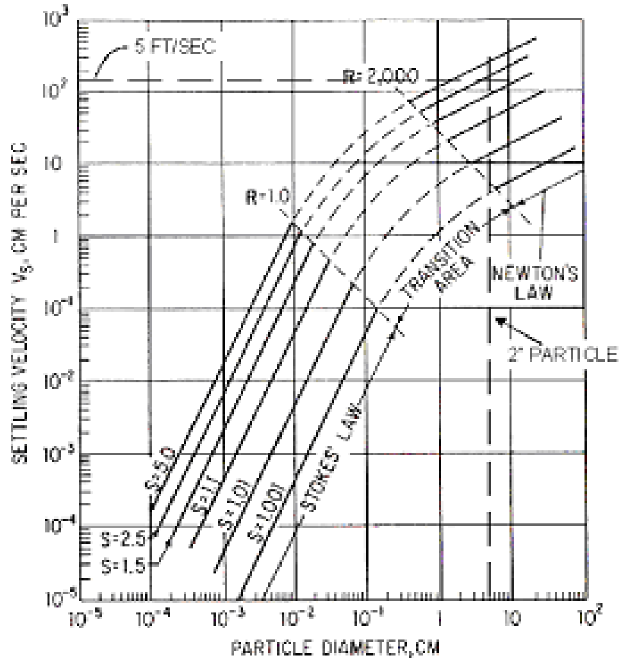


Figure 1

Figure 1[1] shows the settling velocities for various particle sizes and specific gravities. This chart confirms that a velocity of 5 feet per second will keep particles 2 inches and smaller in suspension.[2] This chart also shows that sand sized particles require very little velocity (~ 0.3 ft/sec) to remain suspended. It should therefore be fairly easy to flush coffee grounds and other common wastewater sediment (small in size and with low specific gravity) from the pipelines.

Velocities of 3 to 5 ft/s are often set forth as goals for siphon design, and appear to be reasonably in line with most of the research performed to date. Although velocities this high may not be needed to remove small, loose sediment from smooth wall pipe, the velocities required to remove adherent materials from smooth pipe are not at all certain. And certainly where the pipe is scaled, there will be a benefit to a higher velocity in creating turbulence that helps lift sediment and scour material from the deeper recesses.

The following hydraulic design criteria was adopted for the design of the inverted siphon:

1. The scour velocity (at least 3 feet per second) should occur at least once per day.
2. The maximum velocity should not rise above 10 feet per second.
3. The inlet structure should be designed to intercept rocks and other heavy debris that is larger than 1 inch.
4. Minimizing the slope of the exit pipeline should also allow non-suspended particles to “roll” out of the siphon. Standard practice in the industry is to limit the slope to 15 percent.

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[1] From Standard Handbook for Engineers, 1976, Fredrick Merritt. Chart is based on water at 10 degrees C.
[2] Assumes a specific gravity of 2.5. This corresponds to material with a dry weight of approximately 150 pcf.

Siphon Maintenance. In addition to designing the siphon facilities to intercept large debris and to maintain cleaning velocities, Boyle offered several recommendations to aid in siphon maintenance:

- The carrier pipes should be rated for pressures above the normal operating range, and pig-launching ports would be provided. This would enable the District to flush the lines under pressure, with and without cleaning pigs.[3]
- The slope of the pipeline entering the outlet facility should (ideally) not exceed 15 percent. A mild slope, along with a velocity of at least three feet per second will remove most sediment from the siphon.
- The channel to the inlet pipe should be designed to avoid submerging it, otherwise grease and other floating material can accumulate in the upstream manhole.
- Provisions are needed to divert flow from one pipe to another, to allow for cleaning. Also if one barrel becomes plugged, the flow should automatically spill into another barrel.
- A bar screen or rock-catcher box should be provided to insept large sediment that might settle into the bottom of the siphon.
- The inlet and outlet manholes should be designed to minimize turbulence. Not only is this important in minimizing the release of odors and gas, but will make it easier to perform the cleaning and other maintenance operations that would be needed.
- HDPE was selected for the carrier pipe. Not only is HDPE resistant to corrosion, but its abrasion resistance is superior to harder materials, such as concrete and steel.

RISK ASSESSMENT, MANAGEMENT, AND CONTROL

Throughout the project, Boyle and the other consultants worked closely with the owner to manage project risks and associated impacts on construction schedule and cost. Examples of these risks include breaching the alluvium in the bore, encountering a highly cemented layer in the Sespe formation, and the pipe getting stuck on pull back.

Boyle's subconsultant, Jacobs Associates developed a "Risk Registry" to identify potential risk, track mitigation measures, and monitor the progress associated with the risk elements. This was a valuable tool to make sure risk issues are clearly defined, allocated, and monitored as the project proceeds. **Appendix A** shows the risk matrix that was developed for this project.

Risks were also effectively managed by the following:

- **Contractor prequalification.** The HDD/pipe ramming bidders were prequalified utilizing procedures recently made permissible by new provisions in state law.
- **Unit price bid items.** The schedule of bid items allowed for changes during the construction process, as needs arise.
- **Geotechnical Basis Report.** A report documenting the expected conditions upon which bidders were to base their bids was prepared.
- **Partnering.** The partnering attitude of Boyle and Ojai Valley Sanitary District was evident to bidders at the outset—a gourmet barbeque was provided at the pre-bidders conference.

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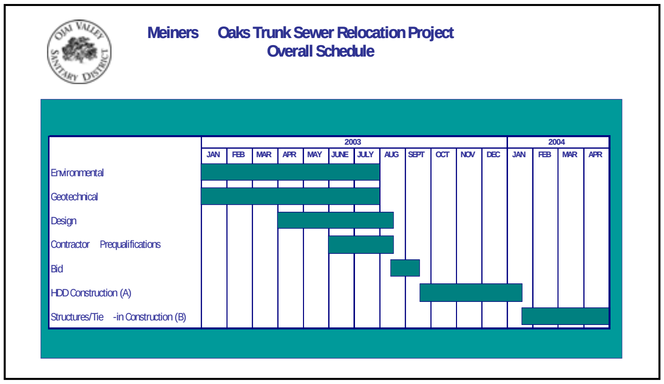
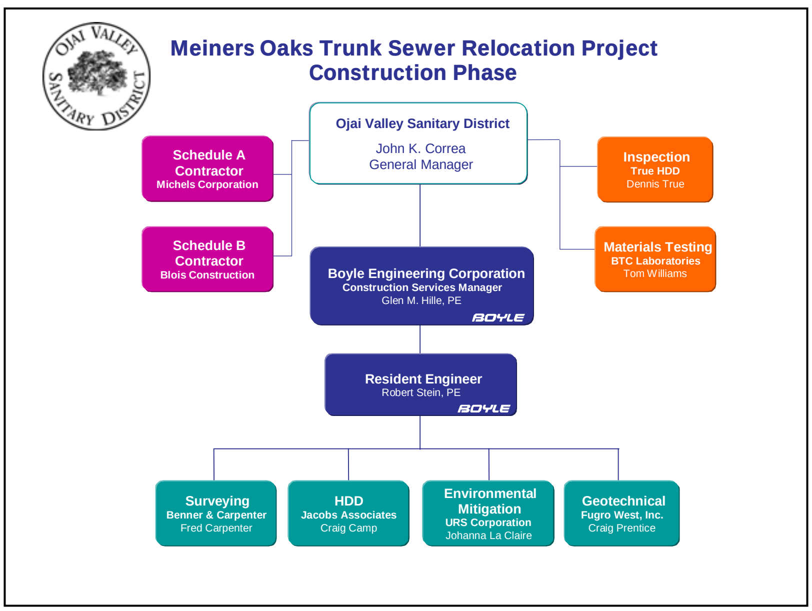
[3] Pigs are cylindrical or bullet shaped pieces of foam that are forced through a pipeline under pressure. As the pig travels, adherent material is scoured from the pipe walls and any sediment in the pipe is pushed out. While most pigs utilize a foam core, many have a plastic shell. Some have abrasive material such as Velcro, carbide straps, or wire bushes embedded in the shell to assist in scale removal. However, in this case, simple swabs (uncoated urethane foam cylinders) are likely to be all that is needed to remove adherent material from the smooth-wall HDPE pipe. It is recommended that pigs with very abrasive materials be avoided.

CONSTRUCTION PHASE

In adherence to the District's ambitious schedule, plans and specifications were prepared in just four months. Separate contracts for the siphon and inlet/outlet facilities were awarded on September 23, 2003. Michels Corporation of Brownsville, Wisconsin was awarded the siphon work, which included the HDD and pipe ramming tasks. Blois Construction, a local contractor, was awarded the inlet and outlet facilities construction. Blois' work commenced upon completion of Michels work. Approximately three months were scheduled for each contractor.



The District retained the design team during the construction phase to support the construction management personnel.



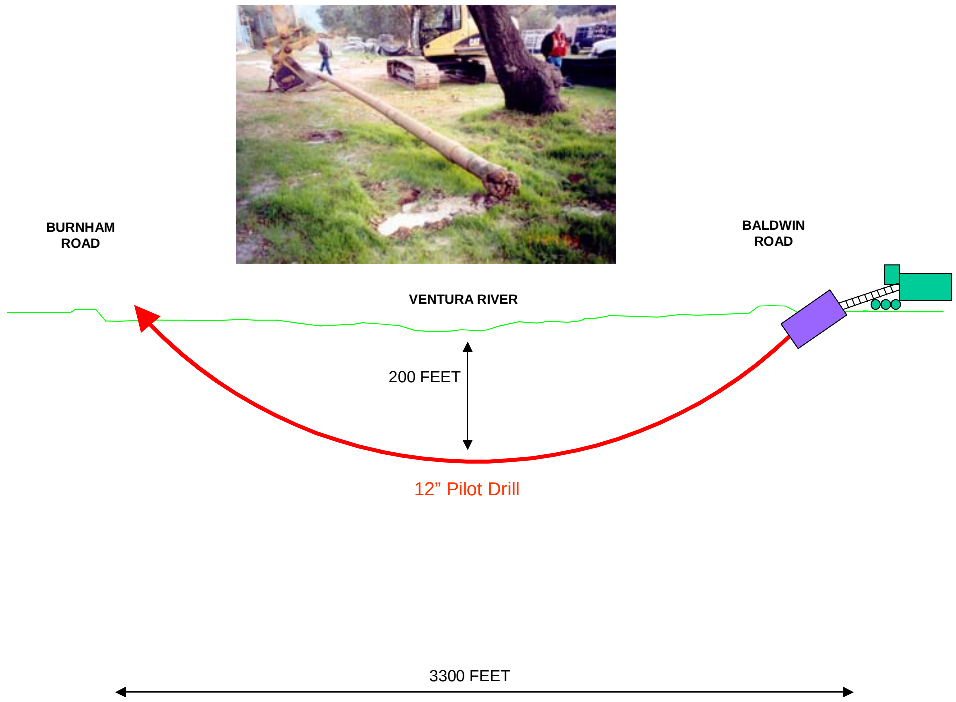
Michels approached the work similarly to the vision of the design team but incorporated cost reduction concepts that included the following:

- Casing size reduction (36" to 30"),
- Deletion of mud return line,
- Increased influent slope,
- Tailings disposed locally,

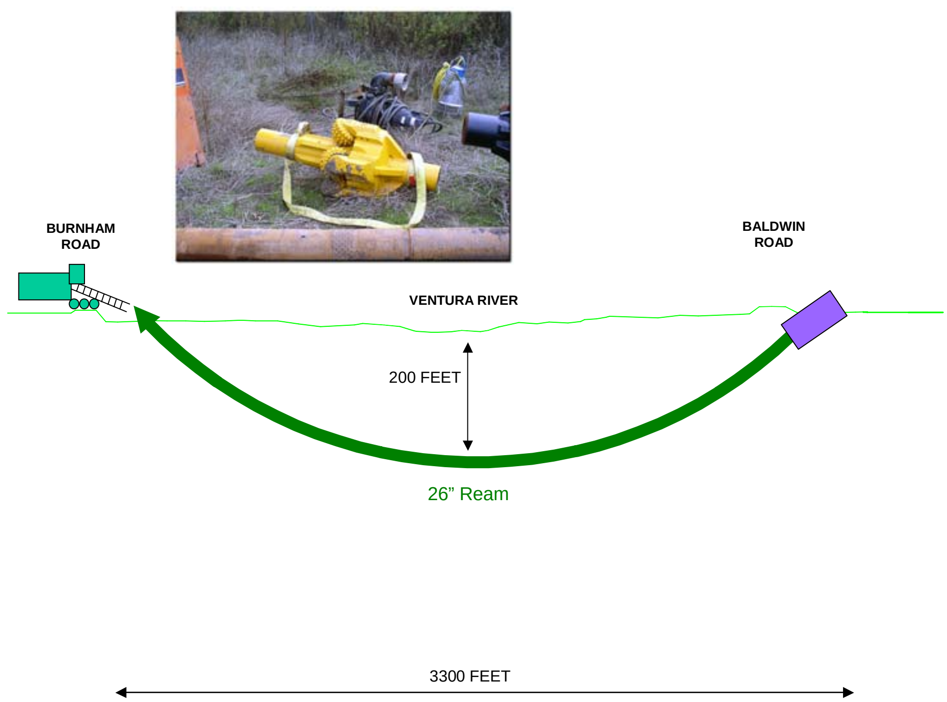
SIPHON CONSTRUCTION SEQUENCE

Step 1

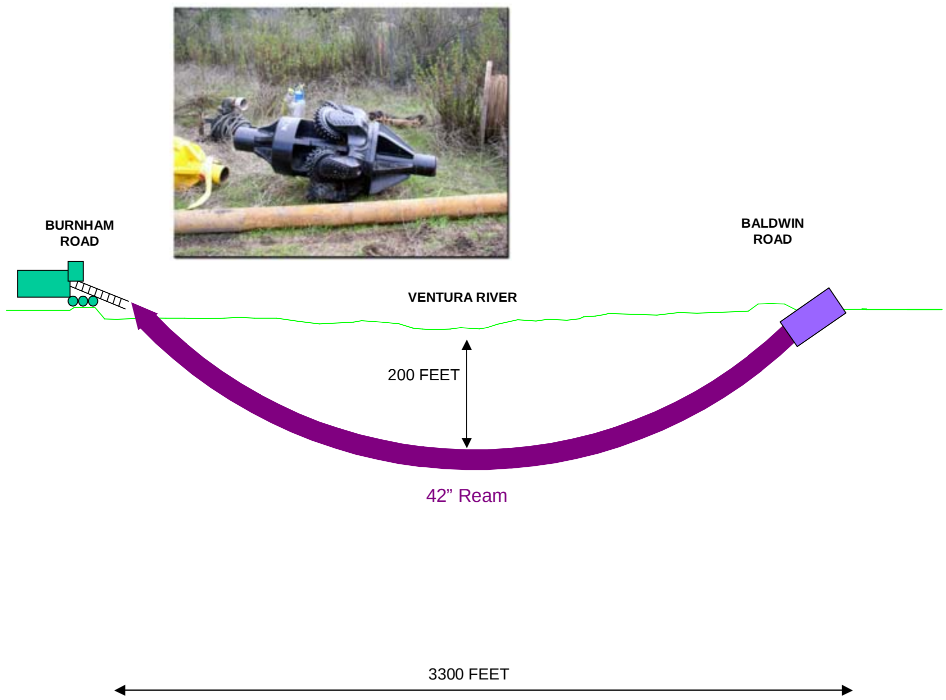
Step 2


BURNHAM
ROAD
BALDWIN
ROAD
VENTURA RIVER
200 FEET
12" Pilot Drill
3300 FEET

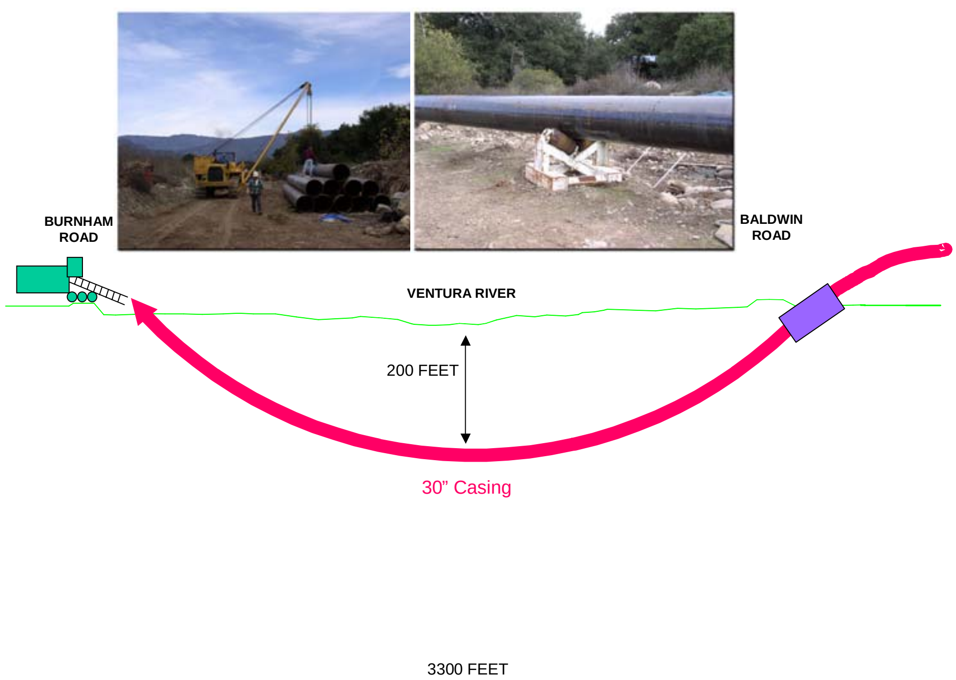
Step 3


BURNHAM
ROAD
BALDWIN
ROAD
VENTURA RIVER
200 FEET
26" Ream
3300 FEET

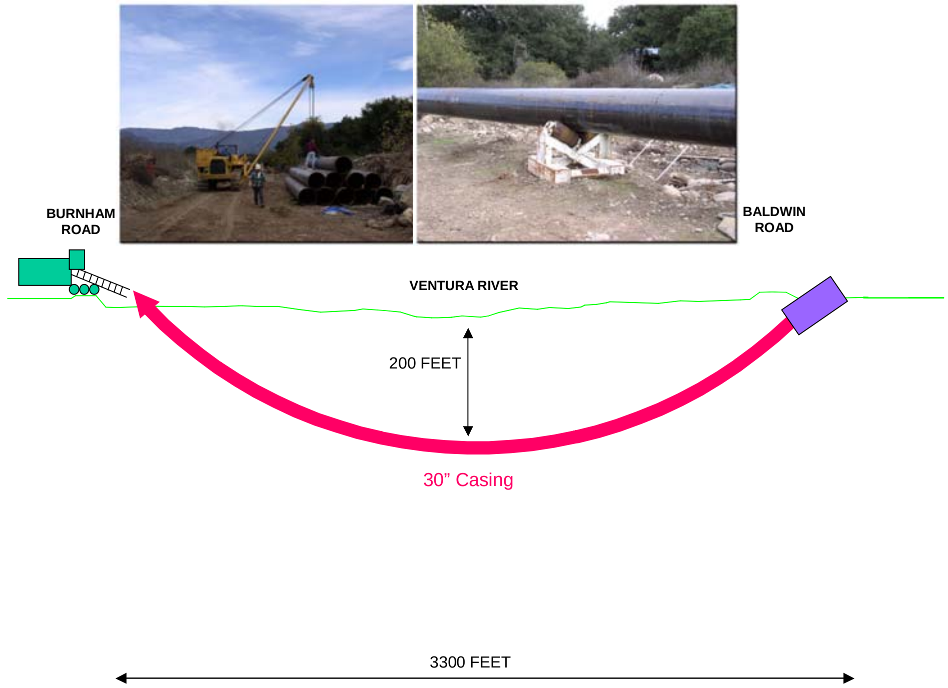
Step 4


BURNHAM ROAD
BALDWIN ROAD
VENTURA RIVER
200 FEET
42" Ream
3300 FEET

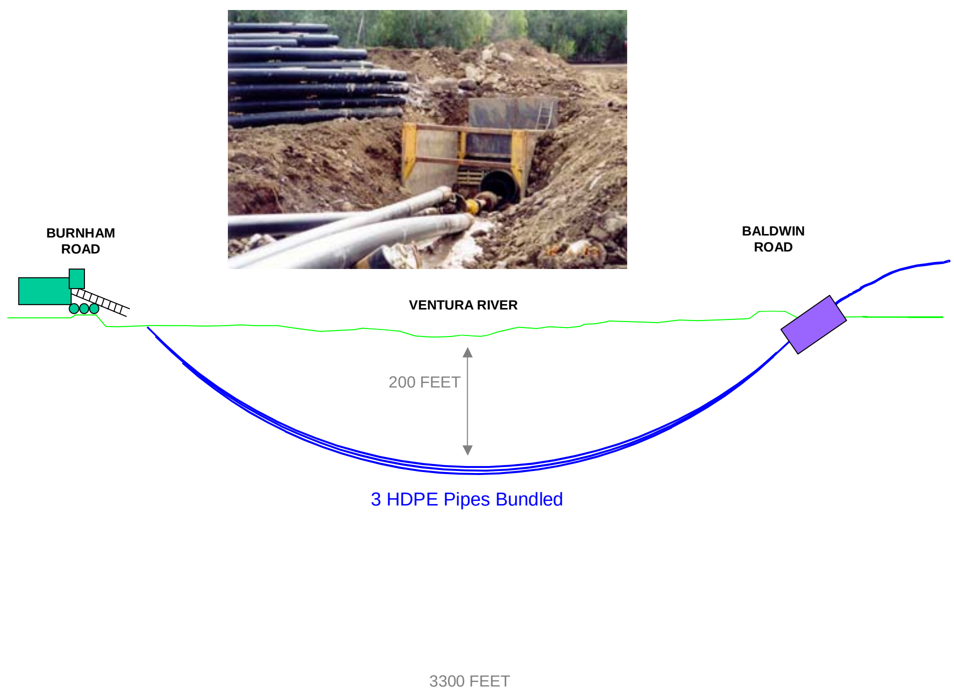
Step 5


BURNHAM ROAD
BALDWIN ROAD
VENTURA RIVER
200 FEET
30" Casing
3300 FEET

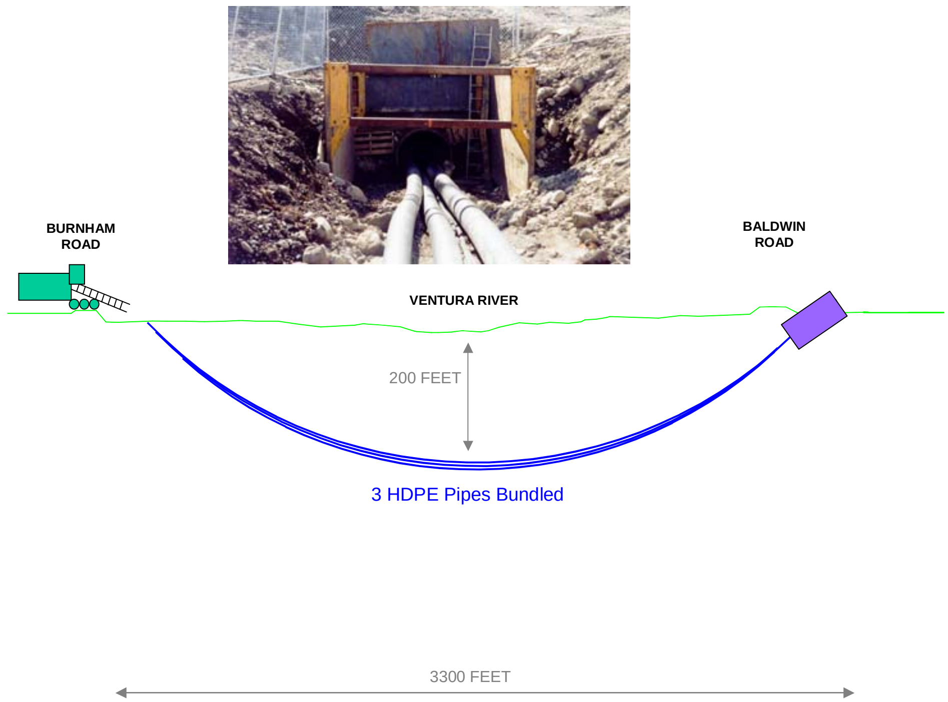
Step 6


BURNHAM ROAD
BALDWIN ROAD
VENTURA RIVER
200 FEET
30" Casing
3300 FEET

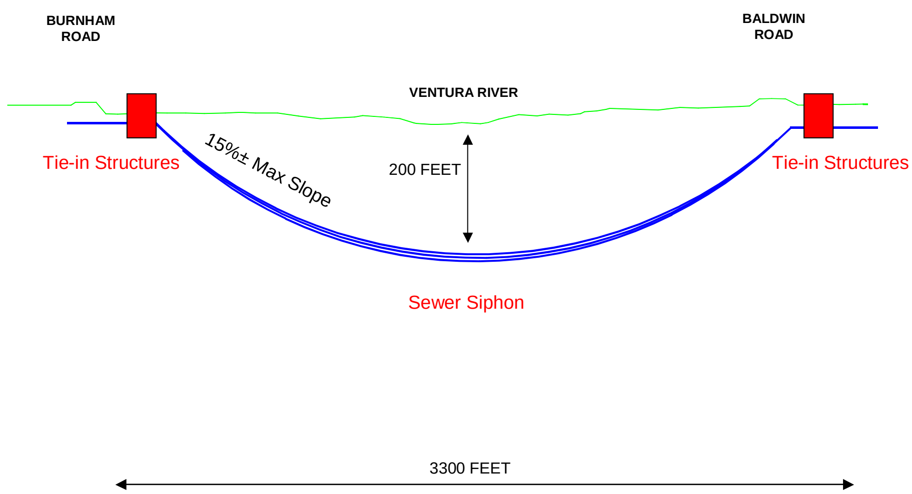
Step 7


BURNHAM ROAD
BALDWIN ROAD
VENTURA RIVER
200 FEET
3 HDPE Pipes Bundled
3300 FEET

Step 8



Step 9

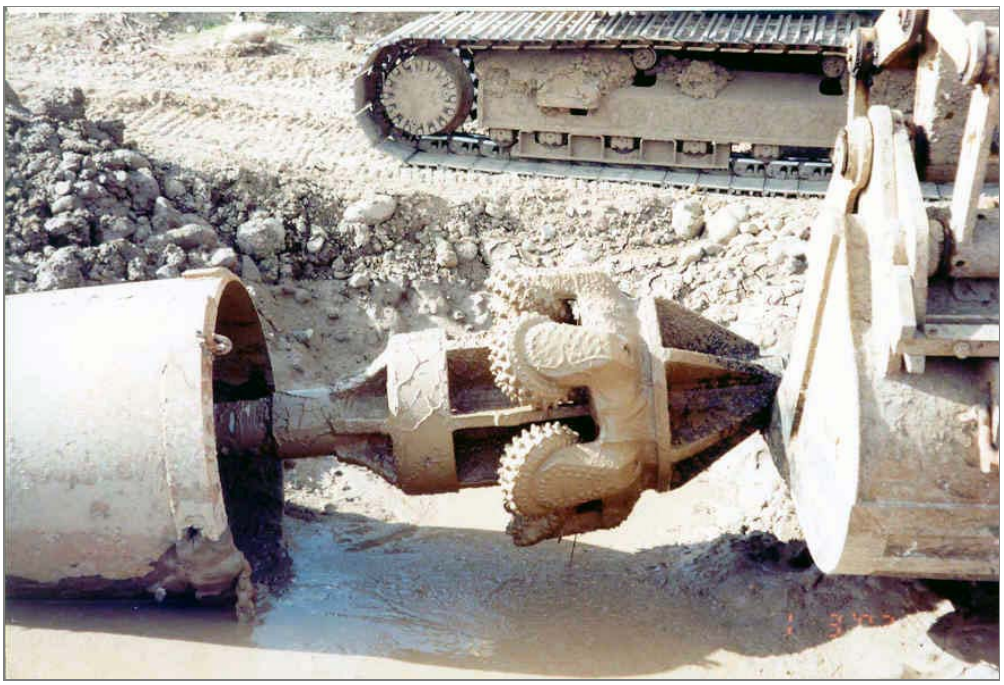


Step 10

Surface Casing
48" – 150'
2 weeks

Pilot Drill from the North
12± inch
2 weeks

First Back Ream
27± inch
1 week



Second Back Ream & Clean
42± inch
2 weeks

Casing Pull Back
30" – 3,200± feet
1 day

HDPE Carrier Pipe Assembly,
Installation and Casing Grouting
2 weeks

Outlet Structure and Piping
4 weeks

Inlet Structure and Piping
8 weeks

Completion and Testing

COST SUMMARY

Meiners Oaks Trunk Sewer Relocation Project
Project Costs

Environmental/Geotechnical/Design	$.45 M
Construction	$4.4 M
Construction Phase Engineering & CA	$.25 M
Change Orders (to date)	$0.0 M
Total	**$5.2 M**

CONCLUSIONS

- Use project development experts
    - Proactive attitude
    - Successful project experiences
    - Multi-discipline culture
    - Qualifications based selection
- Owner involvement
    - Land/ROW
    - Environmental
    - Permits
- Find the project execution experts
    - Prequalified contractors
    - Partnered approach
    - Resolve issues ahead of contractor
    - Facilitate

Appendix A

Ojai Ventura River Crossing
Risk Registry

Risk ID	Risk	Undesirable event	Consequence	Likelihood	Effect	Degree of Risk	Risk Control Measure(s)	Residual Hazard	Responsible Party
Alpha-numeric identifier	Describe the risk which could occur.	Describe what happens as a result of the identified risk.	Describe the impact of the undesirable event on the project.	Use likelihood chart to estimate probability of event.	Use effect chart to estimate cost impact.	Use the severity chart to evaluate degree of risk.	Identify methods to mitigate or control the risk.	Describe what impact still exists given the implication of the risk control measures.	Establish who is responsible for mitigating the risk and who ultimately "owns" the risk and residual hazard.
C-1	Under Qualified Contractor	The Contractor will have difficulty completing the project.	The project could fall behind schedule and budget as a result of an inexperienced Contractor.	3	4	High	The pre-qualification approval process should include minimum experience requirements.	The Contractor may appear qualified but could still not be able to complete the project.	The Designer is responsible for mitigation and the Contractor for all risks
C-2	Under Qualified Crew	The Crew will have trouble doing complex tasks.	The project could fall behind schedule and budget as a result of an inexperienced Crew.	3	3	Medium	Incorporate minimum Crew qualifications into the specifications.	The crew qualification could be insufficient.	The Designer is responsible for mitigation and the Contractor for all risks.
C-3	Drilling Fluid Mud Man	The Contractor does not have a qualified mud man on site.	Control of drill mud is not sufficient and does not meet the project requirements.	4	3	High	Require that the Contractor have a pre-qualified Mud Man and Manufactures Representative on site	The mud man could always be under qualified.	The Designer is responsible for mitigation and the Contractor for all risks.
C-4	Prequalification Appeal	The Contractor appeals the prequalification.	The project is delayed for the appeal.	3	2	Medium	Prequalification is in accordance with California law and includes an appeal process.	The appeal process could still delay the project start.	The Designer is responsible for mitigation and the Owner for all risks
C-5	Equipment	The Contractor's equipment may not be sufficient for the job.	The project could fall behind schedule and budget as a result of insufficient equipment.	3	3	Medium	The specifications should include an equipment approval process and require minimum equipment Standards.	The equipment may be poorly maintained.	The Designer is responsible for mitigation and the Contractor for all risks.
C-6	Back-up Equipment	The Contractor does not have spar parts for crucial equipment.	If crucial equipment fails and the failed part is not readily available, it may delay the project.	4	3	High	Require the Contractor to have major components for crucial equipment available.	A part on crucial equipment not anticipated to fail could break and still delay the project.	The Designer is responsible for mitigation and the Contractor for all risks.

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D-1	The HDPE Pipe Sizes are Under Capacity	The pipes will not handle the maximum flows.	The flow could back up.	3	4	High	Install an extra 10" HDPE pipe inside the casing.	The flows could still exceed the capacity of the 10" HDPE pipe some day.	The Designer is responsible for mitigation and the Owner for all risks.
D-2	Miss Alignment of the Directional Drill to the Siphon Structure	The directional drill becomes off alignment and is unable to connect with the siphon structure.	The directional drill is unable to connect with the siphon structure and the project needs to be redesigned.	3	3	Medium	The design has a built in 50 foot tolerance.	The Contractor still misses the siphon structure with the built in tolerance.	The Designer is responsible for mitigation and the Contractor for all risks.
D-3	Small Diameter Conduit	The conduits installed in the directional drill leave no room for future installations.	Other Owners run the risk of having to repeat this project in the future to accommodate additional installations.	2	1	Low	Add extra blank conduits to the installation.	The pipe has a limited amount of space.	The Designer is responsible for mitigation and the Owner all risks.
D-4	Odor Control	The sewer produces an undesirable odor.	The site and surrounding neighborhoods have a bad odor.	5	4	High	Install manholes and vent structures.	Limited odors still occur.	The Designer is responsible for mitigation and the Owner for all risks
D-5	Bar Screen	Bar screen openings pass material that could become lodged in the siphon.	The siphon doesn't perform properly and flow backs up.	3	4	High	Make the bar screen openings smaller.	The bar screen openings could become clogged if the openings are too small.	The Designer is responsible for mitigation and the Owner for all risks.

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E-1	Environmental Mitigation Measures	Contractor doesn't follow the approved mitigation measures.	The Contractor is found to be in non compliance with the environmental impact report. He will risk job shut down and project delays.	3	3	Medium	Incorporate Mitigation measures into the specifications.	Contractor could still violate specifications.	The Designer is responsible for mitigation and the Contractor for all risks.
E-2	Frac-Out	A frac-out, the loss of fluid to the surface will discharge drill mud to the surface.	A frac-out could make the ground surface muddy.	4	2	Medium	Have an environmental monitor who walks the pipeline alignment and require the contractor to notify the resident engineer of frac-out indications.	A frac-out might not be visible if the river water has high turbidity.	The Designer is responsible for mitigation, the Contractor for all risks, and the Owner the remaining residual.
E-3	Excessive Noise and Vibration on Site	The noise and vibration from the equipment could be very high.	The noise and vibrations could disturb the surrounding residential neighborhoods.	5	2	High	Reference the Federal Standards in the specifications, require provisions for a sound wall, and noise/vibration monitoring.	The measures still do reduce noise levels down to Federal Standards and residence may continue to complain.	The Designer is responsible for mitigation and the Owner for all risks.
E-4	Contamination to Aquifer	The drill mud could silt up the aquifer.	The drill mud could ultimately lower the aquifer permeability and contaminate the ground water.	2	1	Low	The contamination of aquifer might be so small it is insignificant. Incorporate into the specifications, as a preventive measure, a NFS 60 bentonite seal for the bore hole.	Some claim could be made that the aquifer is contaminated.	The Designer is responsible for mitigation and the Owner for all risks.

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E-5	Draining of Aquifer	The bore hole could allow water to drain out of the aquifer.	The Aquifer water level could drop at the wells.	3	2	Medium	Use a bentonite well seal grout as final backfill at bore.	It is difficult to predict ground conditions.	The Designer is responsible for mitigation and the Owner for all risks.

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G-5	Formation Variable Strength	The strength of the formation is variable.	The equipment may have a difficult time breaking down both soft and hard material.	4	3	High	Specify strength range and prepare GBR.	Bid may go up.	The Designer is responsible for mitigation and the Owner and contractor for all risks.
G-6	Groundwater fluctuations	The ground water elevation fluctuates during construction.	Lower groundwater decreases the stability of the borehole and mud.	3	3	Medium	Specify wide groundwater fluctuation range.	Bid may go up.	The Designer is responsible for mitigation and the Owner and contractor for all risks.
G-7	Size of Boulders	The size of the boulders may be larger than anticipated in the geotechnical investigation.	The equipment may not be able to handle extra large boulders.	4	3	High	Specify wide boulder size range.	Bid may go up.	The Designer is responsible for mitigation and the Owner and contractor for all risks.
G-8	Borehole Stability	The bore hole is unstable.	If the hole collapses the drill steel could become stuck. Extensive surface settlement could also occur.	3	3	Medium	Require that the contractor have a pre-qualified Mud Man and Manufactures Representative on site.	The bore hole always has a chance of becoming unstable.	The Designer is responsible for mitigation and the Contractor for all risks
G-9	Specified Conductor Casing Length is Insufficient	The length of the conductor casing specified is not sufficient.	More conductor will need to be ordered and could possible delay the project.	2	3	Medium	Describe the logic of the minimum specified conductor casing amount and allow the Contractor to install more at their discretion. GBR passes hole stability risk to contractor	They complete as specified and the bore hole is still unstable or head is lost. Bid may go up.	The Designer is responsible for mitigation and the Owner and Contractor for all risks

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PL-1	Debured Pipe	The burs on the inside of the pipe are not removed prior to installation.	The pipe is hydraulically less effective and CCTV could get stuck on the burs.	4	3	High	Incorporate into the specifications that prior to installation the pipe must be debured, under go a CCTV and pressure testing.	It is difficult to remove the burs after the pipe is installed.	The Designer is responsible for mitigation and the Contractor for all risks.
U-2	Bore hole collapses and damages utility	The utility is damaged while bore is being removed.	The utility is damaged.	3	3	Medium	Specify a conductor casing to protect utilities.	Vibration could still damage the pipe when it is exposed	The Designer is responsible for mitigation and the Contractor and Owner for any damage.
U-3	Casing Vibration	The vibration created by the conductor casing installation could damage water pipes and clay conduits.	The damage of sewage pipe and water pipes could potentially wash out.	2	2	Medium	Monitor vibration, inspect pipes continuously, have stand by byepass pumping, and evaluate pipes after operation is complete.	Vibration monitoring may not be sensitive enough and pipes may still be damaged.	The Designer is responsible for mitigation and the Owner for all risks.
U-4	Road Settlement	The road settles as a result of bore hole collapse.	The damaged road could cause traffic problems	2	2	Medium	Incorporate CalTrans Permitting into the specifications.	CalTrans will require the road to be repaired.	The Designer is responsible for mitigation and the Owner for all risks.
U-5	Broken Sewer Pipe	Pipes on and around the site could potentially be broken during construction.	Broken pipes take time and money to repair. They can also contaminate the surrounding environment and inconvenience nearby neighborhoods.	2	3	Medium	Have available and ready for quick setup by-pass pumpes.	A pipe could break when the site is inactive and not be fixed till the start of the following shift.	The Designer is responsible for mitigation and the Owner for all risks

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U-6	Broken Water Pipe	Pipes on and around the site could potentially be broken during construction.	Broken pipes take time and money to repair. They can also inconvenience nearby neighborhoods.	2	3	Medium	Have a representative from the water district on site during excavations.	Broken water pipes will still inconvenience nearby neighborhoods.	The Designer is responsible for mitigation, the Water District will be responsible for all repairs and Owner will be for all risk.
W-1	Flood	The river inundates the 100yr flood plane.	Water fills the on-site channel and limits site access.	1	3	Medium	Require that the Contractor bid the project as if there were water in the channel at all times.	The Contractor's bid will be higher than originally anticipated and there is still risk that a flood could occur greater than the anticipated 100yr average.	The designer is responsible for mitigation, the Contractor for any damage caused by a flood less than the 100yr average and the Owner for anything greater than the 100yr average.

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