NORTHERN CALIFORNIA PIPE USERS GROUP
www.norcalpug.com

The Northern California Pipe User's Group
19th Annual Sharing Technologies Seminar

Berkeley, CA
February 17, 2011

HDD Successfully Completes Ocean Outfall Project

Glenn Duyvestyn, Ph.D., P.E.
Hatch Mott MacDonald, Inc., Cleveland, OH

ABSTRACT: The Netarts Oceanside Sanitary District (NOSD) completed construction of a 4,100 foot 14-inch dimension ratio (DR) 7.3 high density polyethylene (HDPE) ocean outfall pipeline to convey treated effluent from their existing wastewater treatment plant out to a new diffuser structure bolted onto a rock outcrop on the ocean floor. Horizontal directional drilling (HDD) was selected as the preferred construction method to complete the installation at depths over 200 feet through basalt, mudstone/claystone, fill, sand and gravel. The new longer outfall was required to replace an existing concrete outfall constructed in the late 1970s that suffered from capacity issues, sand infilling, and displaced and offset joints. The longer outfall alleviated on going maintenance issues with the existing outfall due to shifting sands within the surf zone along the majority of the existing outfall. A basalt rock outcrop located in approximately 45 feet of water protruding out above ocean floor sands was chosen as the preferred HDD exit location. Offshore work consisted of towing the entire HDPE pipeline offshore and guiding it into the bore. The HDPE pipe string was fabricated and staged approximately four (4) miles away from the drill rig location and required pulling it down a gravel road, through a fresh water lake, across a cobble, gravel and sand beach, and into the ocean. A tug boat then transported the HDPE pipe to the exit location out in the ocean.

This paper summarizes project constraints, design challenges, and construction issues associated with completing the HDD components of the new outfall.

1. INTRODUCTION

The Netarts Oceanside Sanitary District (NOSD) owns, operates and maintains the wastewater collection, treatment, and disposal system serving the communities of Oceanside and Netarts. It is located on the north coast of Oregon approximately eight (8) miles west of Tillamook (Figure 1) and consists of approximately 22 miles of sanitary sewers, 7 pump stations, a treatment plant, and a treated effluent ocean outfall.

NOSD's prior Pacific Ocean outfall was constructed in 1977 and consisted of approximately 2,800 feet of 16-inch concrete cylinder pipe including a 320-foot diffuser structure. Based on the as-built drawings, the outfall pipeline was constructed at a maximum depth of seven (7) feet below the surface of the seafloor in coarse grained sand. The original pipeline was constructed using traditional open cut and dredging construction techniques across the beach, tidal surf zone and seafloor. The original diffuser structure discharged treated effluent at a water depth of approximately 30 feet.

The area where the original gravity flow outfall pipeline and diffuser was constructed is prone to significant sand movements and heavy surf during storm events. The sand cover across the beach is known to disappear entirely on occasion during seasonal changes and large storms exposing a cobble beach. In addition, long shore drift of sand deposits is known to exist within the surf or tidal zone. As with the beach sands, these same processes were active along the majority of the outfall pipeline. As early as 1981, the outfall diffuser and pipeline had noticeably moved laterally and began giving performance issues. By the late 1990's, sand migration had moved the outfall and diffuser structure approximately 55 feet and buried the diffuser in as much as 15 additional feet of sand. Based on tests, it was believed that only the first outfall diffuser port was operational. The sand cover over the outfall periodically restricted flow to the point that NOSD has had to pump the treated effluent through the outfall. Under worst conditions, pumping was not sufficient and the treated wastewater was discharged into the nearby storm sewer where it flowed across the beach to the ocean.

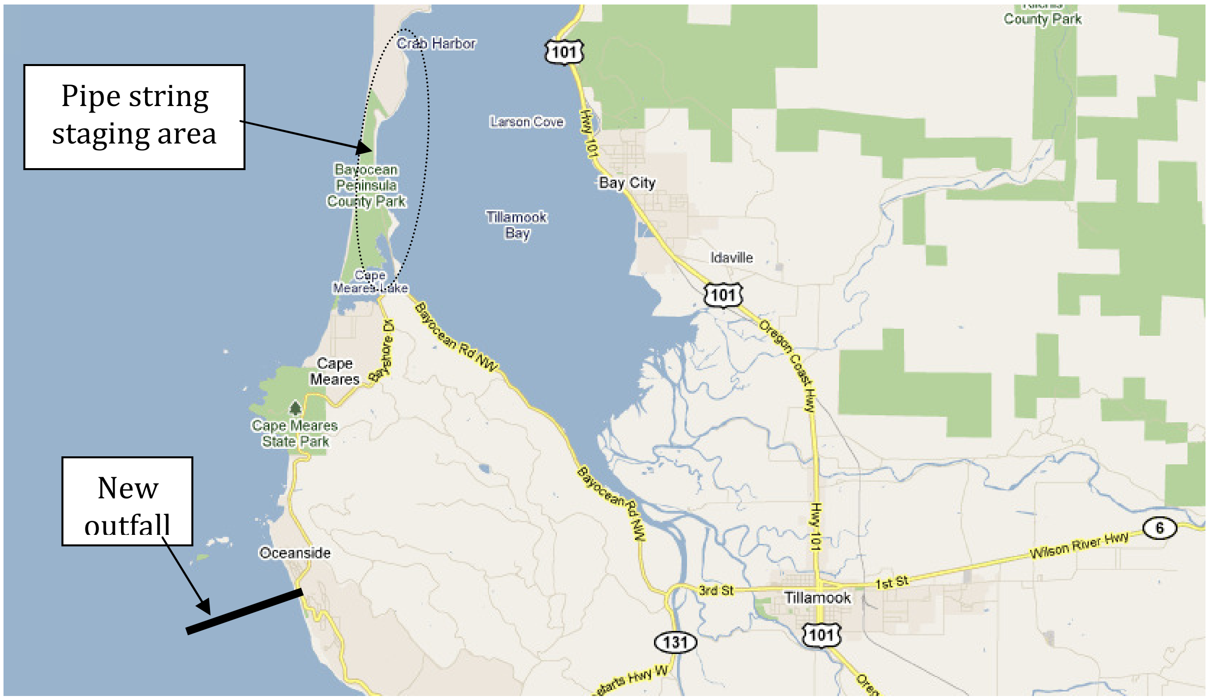

Figure 1. Project location.

NOSD, under agreement with the Oregon Department of Environmental Quality (DEQ), initiated design of a new outfall pipeline and diffuser structure to replace the failed outfall pipeline and to eliminate discharges into the nearby storm sewer. Requirements of the new replacement outfall included a deeper, longer, and more reliable installation with a required design life of at least 50 years. The key to success of this project included designing the installation within more favorable materials beyond the surf zone where most of the active sand movement occurred.

Horizontal directional drilling (HDD) was selected as the preferred method of construction based on its smaller environmental impact, its ability to install the new pipeline within bedrock materials that are more favorable for a long-term solution than within the shifting ocean floor sands, and its decreased dependence on marine work (in comparison to open cut/dredging construction techniques).

2. GEOTECHNICAL CONDITIONS

The geotechnical conditions at the project site were characterized through a review of available geologic maps and reports, borehole investigations, and bathymetry and geophysical surveys. The local and regional geology is characterized by complex depositional and erosional processes in the project area. The geophysical survey was performed to identify the soil/bedrock interface. Sidescan sonar and seismic reflection profiling were performed to identify surficial features on the seafloor and to determine the thickness of the surficial sediments on the ocean floor. This information was used to identify potential target exit locations within exposed bedrock areas. The depth of the bedrock below sea level ranged from

20 feet in the near shore portion of the survey to approximately 63 feet near the end of the existing outfall. Seismic velocities obtained during surveying indicated the presence of sandstone, siltstone and/or mudstone below the surveyed locations. Diving surveys of submerged exposed bedrock materials on the ocean floor identified the bedrock as basalt. These exposed outcrops are similar to the basalt outcrops that project above the sea level north of the project site (Figure 2).

Five distinct geologic units were identified at the project site. These included, from the ground surface downward in order of increasing age, fill materials, stable dune deposits, beach/shelf deposits, Grande Ronde Basalt, and Astoria Formation. The fill materials range in thickness from zero feet to 52 feet and consist of loose to very dense silty gravelly sand. The stable dune deposits consist of dense to very dense fine to medium grained sand and overly the Astoria and Grande Ronde Basalt. The beach/shelf deposits consist of similar sands with gravels and cobbles beneath. These deposits represent areas experiencing sand transport within the surf zone and offshore continental shelf.

The Astoria Formation consists of sandstones, mudstones, and siltstones. This formation is structurally juxtaposed against and beneath the Grande Ronde Basalt. In the project area, bedding planes of the Astoria formation dips seaward at an angle between 10 to 28 degrees. The Astoria Formation underlies the fill and beach deposits. The Astoria Formation was encountered from an elevation of -10 feet below sea level to -98 feet below sea level corresponding to the termination elevation of one of the boreholes.

The Grande Ronde Basalt forms the bedrock basement beneath the offshore portion of the outfall site. A fresh sample of this material collected from exposed bedrock outcrops offshore indicated unconfined compressive strengths of approximately 22,000 psi. An important characteristic of this bedrock material is its inherent magnetic properties, which was not discovered until the pilot bore had been advanced approximately 3,000 feet.

Figure 2. Photograph of exposed Grande Ronde Basalt Outcrops north of the project site

3. DESIGN CHALLENGES

The challenges associated with the design of an ocean outfall are much greater in scope than those associated with a typical or traditional HDD installation. The increased challenges are attributed to the inability to routinely access one end of the installation. Specific design challenges accompanying this project included:

- **Limited geotechnical information.** While boreholes were used to characterize the site soils and bedrock conditions in the vicinity of the beach and near shore (covering only the first 300 to 500 feet of the 4,100-foot long installation), the offshore geotechnical information was inferred from diving surveys of exposed outcrops on the ocean floor, geophysical surveys along the alignment (that only identified the soil/bedrock interface), and available geotechnical maps in the project vicinity.

- **Presence of fill materials at the proposed HDD rig entry location**. These materials were identified as potentially containing voids and preferential fluid flow pathways. A steel conductor casing was incorporated to avoid loss of drilling fluids to the potential voids and preferential flow pathways.

- **Presence of a 40-foot high cliff immediately adjacent to Netarts Oceanside Highway.** This cliff was located within 160 feet of the drill rig entry location.

- **Need for a conductor casing.** A 210-foot long steel conductor casing was incorporated into the design at the HDD entry location to support the fill materials to a depth of 67 feet and provide a pathway for drilling fluids to return to the drill rig location as opposed to finding their own path to the beach (i.e. frac out). The casing was designed to be seated into the bedrock located at an elevation of 12 feet below sea level. This casing strategy was designed based on hydrofracturing pressure and required drilling fluid pressure analyses. Maintaining drilling fluid returns was of high importance since the bore was designed within bedrock materials and would require significant quantities of drilling fluids to complete. The diameter of the casing was determined by the Contractor to coincide with their installation/reaming strategy.
- **Large elevation difference between HDD entry and exit locations.** The difference in elevation between the HDD entry location and the exposed bedrock outcrop (target exit location) on the bottom of the ocean was approximately 110 feet. The elevation of the target exit location was 50 to 55 feet below sea level. The large elevation difference mandated a pilot bore and reaming strategy to maximize drilling fluid returns for processing and re-use. If the pilot bore were to be completed in its entirety, drilling fluids pumped during the subsequent reaming pass(es) would likely drain towards the ocean. Aside from the environmental impact of losing this volume of mud to the ocean, a water source of between of 400 to 550 gallons per minute would also be needed to avoid drilling delays.

- **Small on-shore staging area.** The topography of the HDD entry location was very confined and required excavation and leveling to provide sufficient room to stage the required equipment (Figure 3).

- **Potential air entrapment within the outfall pipeline.** NOSD wanted a reliable pipeline that would serve the needs of the District for many years. To avoid air entrapment within an HDD installed pipeline, the profile of the bore was designed as a continuous downward sloping pipeline (with a grade of -0.873 percent) from the HDD entry location to a distance of approximately 3,300 feet coinciding with the location where the bore would then be steered upward toward the HDD target exit location. This downward slope provided the added benefit of using gravity acting on the drill pipes to help provide a bearing pressure at the face of the tooling and bedrock materials, as opposed to solely relying on the thrust capability of the drill rig to apply the required force to excavate the hard bedrock materials.

- **HDPE pipe staging area.** Staging the 4,100-foot long high density polyethylene (HDPE) outfall pipeline in one continuous pipe string was not possible in the vicinity of the project site. While the beach presented an ideal location, permission from Oregon State Parks could not be obtained due to a previous project where an HDPE pipe string sat on a beach for several months due to difficulties completing the installation. Permission was received to stage the product pipe along a non-motorized trail/road in the vicinity of Tillamook Bay, approximately 4.5 miles away from the project site. However, this staging site would require moving the entire fabricated HDPE product pipe approximately 4,300 feet down a gravel road, across a 4,500-foot long fresh water lake, across a 200-foot barrier island, and across a 300-foot beach. From the beach, a tug boat picked up a tow line to transport the product pipe out into the ocean to the project site.

Figure 3. Photograph of staging area next to existing wastewater treatment plant.

- **4,100-foot HDD installation.** The required flow diameter of the new outfall pipeline was 10 inches. To provide sufficient strength to resist the installation loads, the dimension ratio (DR) of the HDPE product pipe was selected as 7.3. Based on these conditions, the outer diameter of the iron pipe size (IPS) HDPE pipeline was 14 inches. The manufacturer's allowable installation load for this pipe diameter and DR rating was approximately 94,000 lb. The predicted HDD installation loads were on the order of 55,000 to 60,000 lbs.

- **Marine operations.** While HDD minimizes the amount of marine work, it does not eliminate it entirely. Marine operations are required to verify exit location, connect the pipe string to the drill pipe, and to construct the diffuser structure. The work window for such activities is limited to the summer months due to rough sea conditions during other times of the year.

- **HDD contractor qualifications.** The complexities of this project required an experienced HDD contractor to complete the work. For this reason, all prospective bidders were required to submit qualifications of their company, superintendent, and drill rig operator along with their bids.

A simplified version of the design plan and profile for the outfall pipeline is provided in Figure 4. The chosen HDD entry location was in the vicinity of the wastewater treatment plant located on the east side of the Netarts – Oceanside Highway. Where possible, flexibility was built into the bore to allow the HDD contractor to modify their drilling and reaming strategies during the HDD process. Bending radii were selected to allow steel casing pipe and to address difficulties steering towards the target exit location approximately 4,100 feet away from the drill rig.

An exposed bedrock outcrop was selected as the preferred exit target to allow installation of the diffuser structure on the outcrop. In doing so, the structure would not be exposed to the shifting sand conditions that led to the demise of the initial outfall pipeline and diffuser structure.

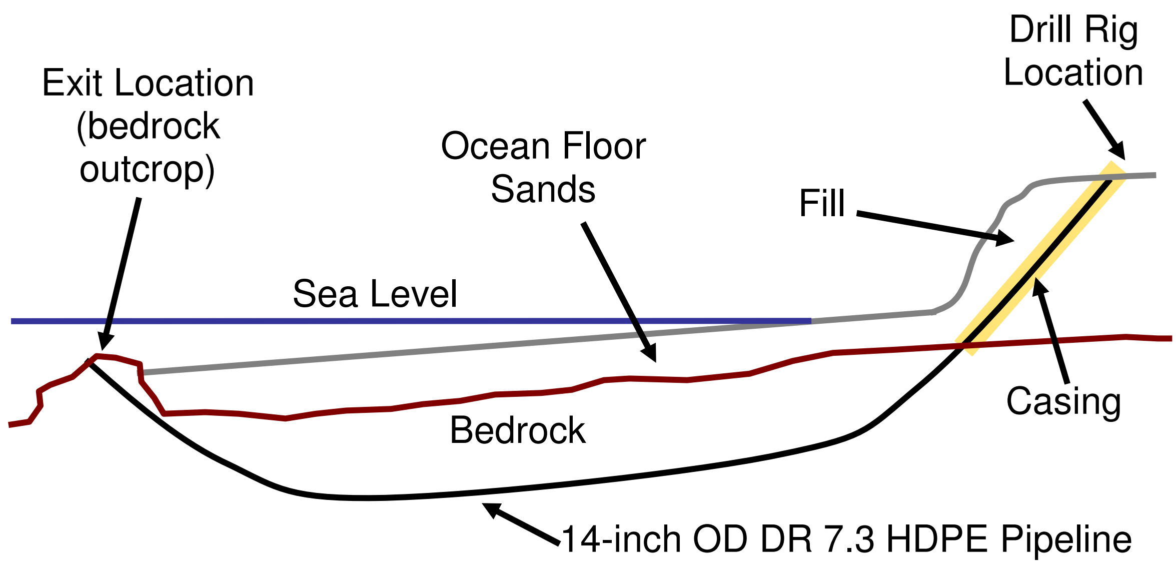

Figure 4. Simplified plan and profile of outfall pipeline

4. CONSTRUCTION CHALLENGES

The Contractor's HDD plan of work included installing the conductor casing, then initiating their 9 7/8-inch pilot bore, followed by a 21-inch forward ream with a split bit hole opener, followed by an 18-inch swab pass, and finally installation of the 14-inch OD DR 7.3 HDPE product pipe.

Maximizing drilling fluid returns during the pilot bore and reaming process was a key factor in the successful completion of this project. As stated earlier, if the pilot bore would have been fully completed prior to reaming, drilling fluids would be lost to the ocean instead of being collected for separation and re-use. To maximize drilling fluid returns, the contractor elected to stop their pilot bore short of the target exit location and initiate their reaming pass to complete as much of the bore as possible with drilling fluid returns. The pilot bore was then re-started. In this manner, only the reaming portion of the bore yet to be drilled saw a loss in drilling fluids to the ocean.

Specific construction challenges related to the HDD component of this project included (in order of occurrence):

- **Conductor casing installation issues.** The design required the installation of approximately 210 feet of conductor casing to support the fill materials and provide a pathway for the drilling fluids to return to the drill rig for reclamation and reuse. A pneumatic hammer was used to ram the steel 24-inch steel conductor pipe into the ground along the 18-degree HDD entry angle. As the casing pipe was rammed into the ground, frictional forces acting on the outside of the casing pipe and within the casing pipe limited progress to a rate of 6 to 8 minutes per foot. When the production rate slowed to this rate, the Contractor elected to cut the casing and cleanout the spoil within the casing pipe to reduce the frictional forces acting on the inside of the conductor casing. Cleaning was accomplished using the drill rig to advance a 12 foot long auger flight connected to the drill pipe (Figure 5). In total, approximately 202 feet of the conductor casing was installed in 7.5 days.

- **Maintaining fluid returns during pilot bore drilling.** The mudstones of the Astoria formation clogged the drilled pilot bore on numerous occasions during the initial stages of the pilot bore. When drilling fluid returns ceased, the Contractor elected to pull back and re-establish slurry flow. This cyclic process was completed until a distance of 460 feet, at which time the Contractor elected to install a temporary casing to help eliminate the build up of cuttings contributing to the stoppages in the slurry flow. To facilitate an inner casing pipe, the Contractor elected to ream the completed portion of the bore to 18-inches and install a 12-inch diameter steel casing pipe. This smaller diameter casing was thought to help convey/transport drilling fluid returns to the drill rig due to higher flow velocities associated with the smaller diameter casing (in comparison to the 24-inch steel starter/conductor casing). This approach was very successful in maintaining slurry flow during the pilot bore drilling phase of the work.

Figure 5. Photograph of auger flight used to remove spoil from inside conductor casing

- **Tooling issues.** Approximately 1,700 feet into the pilot bore, the mud motor developed a serious issue and blew apart at the adjustable bent sub. When the drill string was removed from the bore, the first 12 feet of the motor and drill bit assembly were missing. The Contractor elected to try to fish the missing section of motor and drill bit from the bore. However, after three unsuccessful days, the Contractor elected to pull back 200 feet and complete a kick-off of a new pilot bore that would pass beneath the missing mud motor. The result was a new bore alignment approximately 200 feet below sea level as opposed to the design depth of 140 feet at the deepest point. The re-directed pilot bore was drilled without any incident.

- **Tracking the pilot bore.** The contractor elected to use a TruTracker guidance system to track the down hole tooling during pilot bore drilling. The contractor elected to setup two coils. The first coil set along the beach with a length of approximately 1,200 feet. A second proposed coil was to be installed on the ocean floor between distances of 3,300 and 3,700 feet away from the drill rig. During construction, the Contractor did not elect to deploy their second coil until they had already drilled approximately 3,600 feet. Up to this distance, azimuth and inclination readings from down hole tooling appeared to be consistent. However, a noticeable change in the azimuth readings between successive drill pipes was observed prompting discussions on whether active interference was distorting readings. The cuttings processed at the separation plant were also noted as being slightly magnetic. At the time, the steering subcontractor believed the bore was approximately 20 feet right of the planned alignment. To verify the bore location, the Contractor elected to perform a gyroscopic survey of the 3,600-foot long drilled bore. This survey suggested that the bore was actually 65 feet left of design alignment. However, questions were raised as to the calibration of the gyroscopic survey tooling prior to insertion into the bore. To better determine the deviation in line, the contractor elected to install his ocean floor coil and sample where he already drilled. This survey suggested that the bore was 55 feet left of the design alignment.

- **Steering issues upon discovery of magnetic bedrock.** With only 500 feet remaining to drill until reaching the intended exit location, the Contractor produced a new revised alignment and was confident he could still hit the intended exit location. Unfortunately, the survey tooling was not calibrated properly (high-sided) and during the next 120 feet of drilling, the survey tooling was miss-oriented by 170 degrees. This meant that the down hole tooling was directed left instead of right and down instead of up during this additional 120 feet. By the time the mistake was realized, the bore was much further left and low in elevation with only 380 feet left to drill. The Contractor elected to continue drilling instead of pulling back and re-drilling a portion of the bore. He thought that he could still hit the target outcrop but would be a little longer than the intended exit location. Continuing the pilot bore, the Contractor drilled to a distance of approximately 3,935 feet when returns decreased significantly. Wanting to avoid loosing returns for the reaming pass, the Contractor stopped their pilot bore and tripped out to prepare to ream the completed portion of the bore to its final 21-inch diameter.

- **Reaming issues.** To aid in the reaming process, the Contractor elected to use a mud motor with a zero degree bend to turn the reamer. In doing so, the Contractor was able to eliminate the need for the drill rig to produce the entire torque to rotate the hole opener and enlarge the 3,925-foot long bore to a diameter of 21-inches. Drilling fluid pumping rates of 400 to 550 gallons per minute were used to rotate the hole opener. Approximately 3,400 feet into the forward ream, consistent stalling out of the reamer was observed. Concerned about the condition of the mud motor and the hole opener, the Contractor elected to pull out of the bore and examine the bottom hole assembly. Once out of the bore, it became apparent that the hole opener was partially to blame for the stalling as it was heavily worn with several teeth missing and its cones could be moved from side to side and up and down with any effort. A new reamer was fitted to a new mud motor and the reaming process continued without incident to a distance of 3,935 feet.

- **Maintaining fluid returns.** Maintaining drilling fluid returns during the reaming process proved to be difficult at times. While no frac outs or lost returns occurred, the drilling fluid returns would cease momentarily while clay slugs were pushed out of the bore approximately every 100 feet. The Contractor reacted to the stoppage in drilling fluid returns by pulling back and clearing any blockages within the bore with the reamer assembly. The clay slugs measured 24-inches in diameter and up to 30 feet in length (Figure 6). Once cleared, full drilling fluid returns were again received at the drill rig.

- **Prematurely exiting the ocean floor - missed exit location.** Upon completion of the forward ream to a distance of 3,935 feet, the pilot bore recommenced towards the exit location. The Contractor continued to steer as much as he could to the right while concurrently steering up. The Contractor still believed he could hit the intended exit target location. At a distance of approximately 4,070 feet, resistance or face pressure at the drill bit decreased significantly indicating that the drill bit was no longer in bedrock materials. The Contractor advanced the drill bit approximately 40 more feet and a diver was called to the site to survey the actual exit location. The survey indicated that the exit location was approximately 30 feet left and 30 feet short of the intended outcrop location.

  The Contractor was asked to verify conditions and determine the thickness of the ocean floor sands at the exit location and determine the impacts to construction schedule should a decision be made to pull back and re-drill a portion of the pilot bore. The target exit location was to be used to house the diffuser structure regardless of which whether the bore would be used as drilled or if the bore were to be re-drilled. Considerations included the thickness of the ocean floor sands, whether dredging could be used to remove the sands to allow fastening of the outfall pipeline, the ocean conditions and remaining construction season/weather window, and feasibility and schedule impacts should the bore be re-drilled.

  Based on the information provided by the Contractor, an alternative design was developed for constructing the portion of the outfall pipeline between the actual and intended HDD exit location. The biggest factor in deciding to use the actual HDD bore was the current weather window and ocean conditions. If re-drilling were to be completed, the project would have been delayed approximately eight (8) months as the storm season and rough ocean conditions had begun. At the time, the Contractor had provided information that the thickness of the sand was only 7 feet deep and that his marine contractor was equipped with a dredging unit and could remove the sand to allow the outfall pipeline to be fastened to the underlying bedrock materials. This portion of the bore was reamed to its final diameter without incident and with no drilling fluid returns.

Figure 6. Photograph of clay slugs during reaming process

- **Product pipe fabrication.** The 14-inch DR 7.3 IPS HDPE product pipeline was fabricated along a limited access road along a spit between the Pacific Ocean and Tillamook Bay. Once fabricated, the entire 4,120-foot pipe string was moved approximately 4,500 feet down the road, across a 4,000 foot long fresh water lake and up onto the beach (Figure 7). From here, a tow line was attached to the HDPE pipe and taken off shore to a tug boat and the pipe string was towed to the HDD exit location.

Figure 7. Photographs during product pipe transportation prior to installation

- **Connecting HDPE pipe string to the drill pipe.** Weather conditions and poor visibility on the ocean floor delayed attaching the HDPE pipe string to the drill pipe. To complicate matters, the divers misplaced the Contractor's swivel delaying the product pipe installation. During the time required to fabricate a new swivel, the HDPE product pipe was damaged at the back of the work boat used to support the exit site work activities. The damaged pipe required cutting and re-welding the pipe string together. In all, connecting the product pipe to the drill pipe string took six (6) days. A photograph of the work boat used to install the HDPE product pipe and to fabricate the diffuser structure is shown in Figure 8.

Figure 8. Photograph of the offshore work boats used to support HDD activities and construct the outfall diffuser

- **Swabbing of the bore.** During the delay in connecting the product pipe to the drill string, the Contractor swabbed the last 400 feet of the bore. The swab was completed with an 18-inch barrel reamer. Swabbing stalled out the reamer on numerous occasions during each swabbing pass. From all drilling records and the drill rig reaction during swabbing, it appears as though the barrel reamer collected gravel and cobble sized particles within the ocean floor sand and that these particles stalled out the barrel reamer within the bedrock portion of the bore as the reamer fought to pass these objects.

- **Pipeline installation.** The product pipe installation commenced at 3:05 PM on Thursday, September 11th, 2008 and was completed at 2:30 AM Friday, September 12th, 2008 (Figure 9). During the initial 120 feet of the pullback process, the barrel reamer did stall in a similar manner as it did during the swab pass. The reamer was freed by pushing a few feet forward when it locked up. The majority of the drill pipes were pulled within 1 to 3 minutes each. The maximum installation load was approximately 65,000 lbs. Drilling fluid returns were observed at the drill rig with 575 feet remaining to be installed despite the 110-foot elevation difference between the HDD entry and exit locations. The occurrence of drilling fluid returns at this distance was predicted during the design phase of the project using the method described in Duyvestyn (2009).

Figure 9. Photograph of completed installation of product pipe

5. SUMMARY

The complexities associated with this HDD project presented significant design and construction challenges. Despite these challenges, the Contractor was able to complete the installation and provide a new replacement outfall pipeline to convey treated effluent. The new HDD outfall pipeline will provide the longevity and reliability required of this project. Greater details for this project can be found in Duyvestyn et al. (2010).

6. REFERENCES

Duyvestyn, G.M., 2009. “Comparison of predicted and observed HDD installation loads for various calculation methods,” Proceedings of the International and North American No-Dig 2009 Conference, Paper B-1-01, North American Society for Trenchless Technology, Toronto, Ontario, Canada, May-April, 2009.

Duyvestyn, G.M., Yarnall, J., and Mello, D., 2010. “HDD completes ocean outfall in extremely challenging conditions,” Proceedings of the North American No-Dig 2010 Conference, Paper E-1-04, North American Society for Trenchless Technology, Chicago, Illinois, USA, May 2-7, 2010.