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Six South Dakota Rural Water Districts Relocate and Encase Water Lines to Protect Against Potential Hydrocarbon Contamination

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1. ABSTRACT

The Dakota Access Pipeline is a 1,168-mile-long 30-inch diameter steel pipeline that runs from the Bakken / Three Forks oil play in the northwest corner of North Dakota to the Patoka oil terminal in southern Illinois. The pipeline allows for the daily conveyance of 450,000 barrels of light crude oil to markets previously only reached with truck and rail transportation. Although the line eases delivery of domestic oil to the Midwest and East Coast, the alignment of the pipe impacts many existing potable water delivery and distribution systems.

In South Dakota alone, nearly 150 potable water line crossings needed to be addressed. Six rural water utilities, including Web, Mid-Dakota, Kingbrook, Minnehaha, Lincoln, and South Lincoln were transected by the Dakota Access line. The managers from these utilities wanted to continue to provide safe, clean water to their community even in the event of an oil spill. After investigating the potential hydrocarbon contamination issue from national publications and research by South Dakota State University, it was determined that the best protection of the water lines would be achieved by casing them in single, gasketless polyvinyl chloride pipe installed by directional drilling where the Dakota Access line is crossed.

The initiation of the water relocation efforts by the oil pipeline development, the decision process used to determine the best method of protecting water lines at crossings, and the construction methods used for multiple relocations will be discussed, focusing on the protection of potable water from hydrocarbon contamination.

2. INTRODUCTION AND PROJECT BACKGROUND

The Bakken and Three Forks Formations, located largely in the northwest corner of North Dakota and spread into Montana and parts of Canada, consists of shale deposits containing oil and natural gas. The first well to extract this oil was established in 1953 on the Antelope Anticline producing over 5,000 barrels of oil in its first month. From the 1950s to 1960s, 44 vertical wells were constructed in the Antelope Field. Oil companies ventured outside of Antelope Field between 1960 and 1975 to discover the Bakken/Three Forks Pool and later the Bakken Fairway in the 1970s and 1980s. Twenty-six oil fields were formed in the Bakken Fairway aligned along the limits of the Bakken Formation. Advancing technologies increased potential oil production in 1987 with the first horizontally drilled well. This first well, when initially drilled vertically, could produce 217 barrels of oil per day but, when drilled horizontally from the well, could produce 258 barrels of oil per day. The horizontal drilling methods allowed for greater oil extraction in the Elm Coulee Field in Montana discovered in 1996 and the Parshall Field discovered in North Dakota in 2006. Combined advancements in drilling techniques and shale fracture methods allowed for 500 barrels of initial oil production per day in each of the first two Parshall Field wells and greater than 1,000 barrels per day in horizontal wells drilled later on (refer to Figure 1 for maps of well development over the history of the

Bakken / Three Forks Formation). As of 2016, the North Dakota region of the Bakken Formation had over 10,000 producing wells providing approximately one million gallons of oil per day.

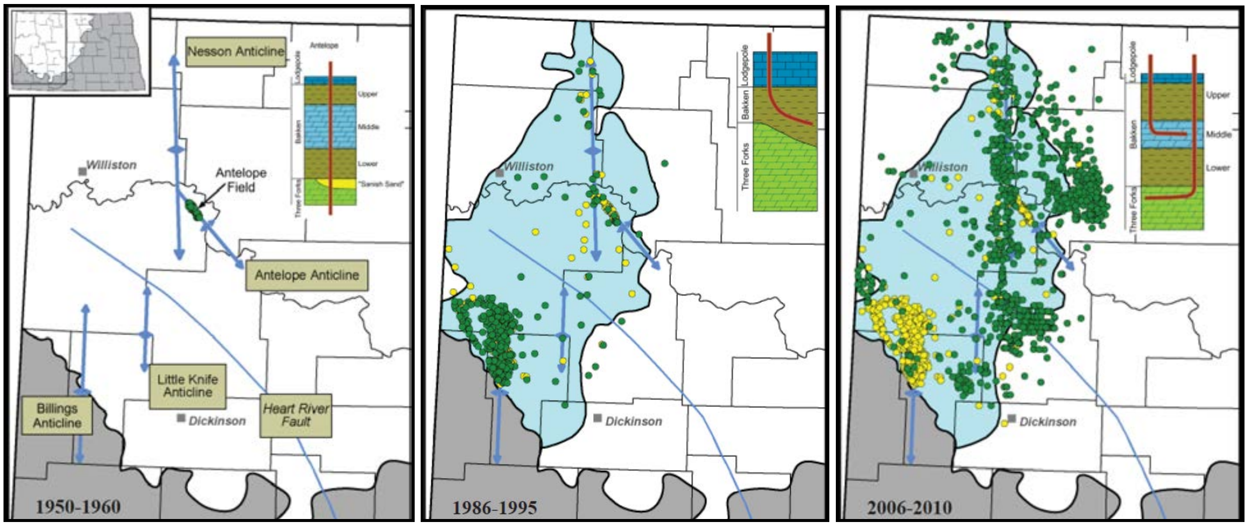

Figure 1. Wells drilled in Bakken / Three Forks Formation over its history.

Per the United States Geological Survey (USGS) assessment in 2013, there are an estimated 7.4 billion gallons of undiscovered oil in the United States portion of the Bakken / Three Forks Oil Formation. Increased production rates require increased transportation efforts to bring the oil out to market at a pace capable of meeting demand. The Dakota Access Pipeline (DAPL) is designed to provide passage of the exponentially growing oil production in North Dakota to an oil terminal in Patoka, Illinois with several connecting lines to provide further conveyance of light crude oil. The pipeline intends to provide a safer means of transporting oil, reducing the amount of freight by railway or truck that can potentially cause environmental damages if an accident were to occur. Per the Manhattan Institute for Policy Research, pipelines result in far fewer spills and injuries than that of railway or road transportation based off recorded incidents between 1992 and 2011. The 30-inch DAPL would span 1,168 miles crossing four states from North Dakota to Illinois and convey approximately 450,000 barrels of oil per day with a capacity up to 570,000 barrels per day, approximately half of the current Bakken / Three Forks Formation’s daily oil production.

On December 15, 2014, Dakota Access, LLC applied to the South Dakota Public Utilities Commission (PUC) for an energy facility permit to construct the DAPL in South Dakota. Shortly after, on April 20, 2015, the South Dakota Association of Rural Water Systems, Inc. (SDARWS) submitted a petition to intervene to the PUC. The South Dakota segment of the DAPL would extend 272 miles through the eastern side of the state and cross 13 counties and 7 rural water districts (Figure 2). The affected water systems included Web, Mid-Dakota, Kingbrook, Minnehaha, Lincoln, South Lincoln, and Lewis & Clark. The SDARWS’s petition requested that the association have the ability to intervene to ensure that any rural water lines crossing the oil line be uniformly designed and environmentally protected.

Dakota Access, LLC did not object and six of the seven rural water districts agreed to adjust their existing water lines to accommodate the DAPL alignment by lowering the lines prior to the DAPL installation. The Lewis & Clark Regional Water System was the only district unable to enter into an agreement due to the system’s 54-inch water line, which provides half of the water supply to the City of Sioux Falls and neighboring communities. Unlike the other six districts that contained water lines significantly smaller than the 30-inch pipeline, the cost to lower this 54-inch water line would exceed that of rerouting the DAPL. For this reason, the DAPL had to adjust their alignment to accommodate the existing water line.

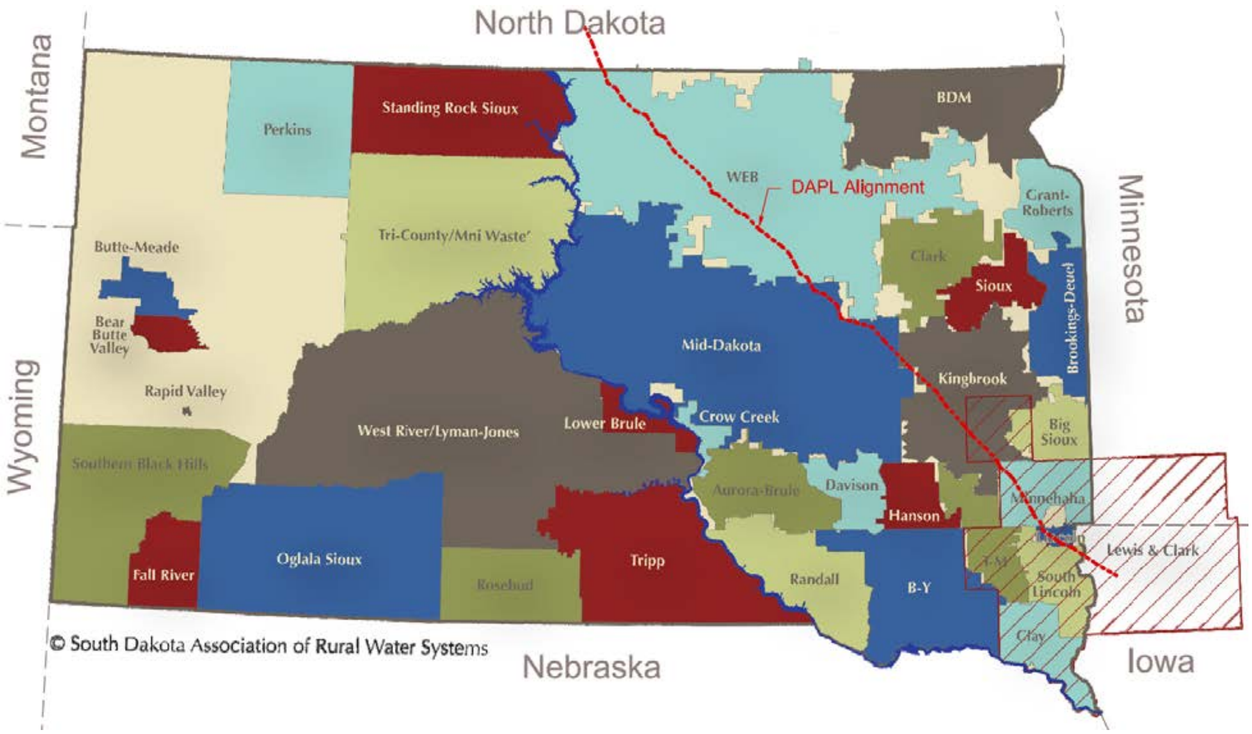

Figure 2. Dakota Access Pipeline Route through South Dakota Rural Water Systems

The DAPL permit was approved by the PUC on November 30, 2015. Dakota Access intended to begin construction at the start of the next year in order to have the entire line completed and in service by the end of 2016. Given this timeline, the six rural water districts that had agreed to relocate their water lines had to immediately begin design to ensure all water line relocations were completed prior to the DAPL's installation. Each district needed to evaluate the best method to protect their water lines from any potential hydrocarbons that could leak into the soil at crossings under the DAPL in the remote case of an oil spill.

3. DETERMINATION OF WATER LINE PROTECTION METHOD

There are two main concerns to consider in an oil pipeline and rural water line crossing: how to protect the rural water supply from contamination in case of a leak in the crude oil line, and how to protect the oil line from any damage potentially incurred by maintenance or repairs to a water line beneath it. One remedy to both issues involves installing a casing pipe on the segments of rural water line that will cross under the crude oil pipeline right of way (ROW) prior to DAPL installation. The encasement provides a barrier between the water supply and the surrounding potentially hydrocarbon-contaminated soil and protects the oil pipeline from soil erosion caused by any leaking water since the water would be carried outside of the right-of-way. Additionally, if the line requires maintenance or a leak needs to be fixed along the water line, the pipe within the casing can be pulled out and reinserted with excavation only required at either end of the encasement instead of at or near the oil pipeline. This method provides cost savings for the DAPL as it eliminates the need for the DAPL to install a thicker pipe in the area of these water lines and the process of pre-lowering the encased water lines removes the majority of utility conflicts during the DAPL installation.

The DAPL was not the first pipeline to carry crude oil through South Dakota. Construction of the Keystone pipeline by TransCanada Pipelines began in May 2008 to convey approximately 590,000 barrels of oil per day from the Hardisty terminal in Alberta to the Midwest markets in the United States. Similarly, this oil pipeline crossed through six rural water districts in South Dakota (not the same six as the DAPL alignment), requiring water line relocations in each system. Each district installed the water line crossings per designs they felt would appropriately protect the water line. Five of the water systems chose to install the crossings with polyvinyl chloride (PVC) casings; of these five, four used restrained joint PVC pipe and one used fused PVC pipe (FPVCP) casings. Upon completion of these relocations, the districts requested that their design choices be verified with testing to determine whether they had chosen the best casing materials to protect the water supply from hydrocarbon permeation. The U.S. Department of Transportation Pipeline and Hazardous Safety Administration, the Regional Water System Research Consortium, and the South Dakota Department of Environmental and Natural Resources funded this research to provide insight for future rural water line and oil pipeline crossings such as the ones being planned at the time for a Keystone XL pipeline.

The research was conducted by the Water and Environmental Engineering Research Center at South Dakota State University (SDSU). Only plastic pipe materials were considered in the experiment. Plastic was more likely to be used in actual applications in South Dakota due to the familiarity of water systems with plastic materials, its relatively low cost in comparison to metal casing materials, its ability to be installed using horizontal directional drill (HDD) technology, and its corrosion resistance that eliminates cathodic protection measures. Previous studies had been performed to test the effects of hydrocarbons on polyethylene (PE) and PVC pipes and gaskets but these tests exposed the materials to gasoline and the organic chemical compounds of benzene, toluene, ethylbenzene, and xylene (BTEX) contained within gasoline; these were products of processed crude oil, but not crude oil itself. One study by the Water Research Foundation found PVC to be impermeable to typically encountered levels of gasoline and BTEX contamination, whereas PE pipe was permeated regardless of the concentration of gasoline and BTEX in the surrounding soils; the pipe was considered to be permeated when the water sample within the pipe exceeded the U.S. EPA minimum contamination levels. The study recommended specific gaskets for use in contaminated soils to lessen permeation at any pipe or fitting joints.

The investigation conducted at SDSU determined the impact of crude oil on varied plastic pipe materials and elastomeric gaskets, testing not only the permeation of the oil but the impact of the contamination on the pipe's strength. The plastic pipe materials tested included FPVCP, restrained joint PVC, and fusible high density polyethylene (HDPE). Both compression and tensile tests were performed according to ASTM D2412 and D638 standards, respectively, on un-jointed (segments without a joint) PVC and HDPE pipe exposed to crude oil over a 24-week period. The PVC pipe did not show a significant difference in either tensile or compression strength over the exposure period to crude oil when compared to the pipe sample exposed to water (set up as a baseline). The HDPE sample showed a slight decrease in both tensile and compression strength when compared to the baseline, indicating potential for further decline in strength in time periods exceeding 24 weeks. The permeability of crude oil through un-jointed HDPE and PVC pipe was measured over 18 weeks of exposure to oil-saturated sand. Hydrocarbons did not permeate the PVC pipe wall but permeation of the HDPE pipe wall occurred 9 to 12 weeks into the test.

SDSU's study also analyzed polyisoprene and nitrile butadiene rubber (NBR) gaskets used in restrained joint PVC pipe. The first is a standard gasket material found in most applications, and the second is typically called for in applications involving contaminated soils. Tensile strength tests were performed on both gasket materials at intervals over 165 days of crude oil exposure. Both gasket materials exposed to oil displayed a reduction in tensile strength compared to that of the gaskets submerged in water, with polyisoprene gaskets losing an average of 19% and NBR gaskets losing 27%. To test the permeability of a restrained joint PVC coupling, the same setup was used as in the un-jointed pipe tests. On average the joint with a polyisoprene gasket was permeated in 9 weeks and the joint with the NBR gasket was permeated in 5 weeks.

SDSU's report concluded that the three casing pipes studied would all make good candidates for the casing material at rural water and crude oil pipe crossings if only the pipe strength were considered. Yet the permeability of restrained PVC's joint and HDPE's pipe wall would be cause for rejection, making FPVCP the safest casing pipe choice for oil pipe crossings (Table 1).

Table 1. Factors affecting casing pipe selection at rural water pipe crossings of crude oil pipelines.

Decision Parameter	Restrained Joint PVC	Fusible HDPE	FPVCP
Pipe Tensile Strength	Accept	Accept ? (slight strength decrease)	Accept
Pipe Compressive Strength	Accept	Accept ? (slight strength decrease)	Accept
Pipe Wall Permeability	Accept	Reject	Accept
Joint Permeability	Reject	Jointless	Jointless
Overall	Reject	Reject	Accept

The Regional Water System Research Consortium involved in the crude oil pipe crossing study is partly supported by the SDARWS and many of its rural water systems and water development districts. As intended, this research provided guidance to rural water systems and South Dakota engineers tasked with designing rural water line crossings of the multiple new crude oil lines proposed for construction, setting a precedent that influenced engineers to specify materials per the conclusions found.

4. DESIGN OF RURAL WATER LINE CROSSINGS

The SDARWS was formed as a means of uniting the multiple rural water districts in South Dakota to prevent duplicate efforts in legislation, research, and design. This group provided a communication conduit by which ideas and experiences could be shared between members. Upon approval of SDARWS's petition to intervene in April 2015, the six rural water districts affected by the DAPL installation began design of their rural water system relocations. DGR Engineering designed the water line relocations for the Web, Kingbrook, and Lincoln rural water systems. Bartlett & West Engineers, Inc. designed the Mid-Dakota rural water relocations. The Minnehaha and South Lincoln systems were designed in-house by the utility and their selected contractor. Although the design engineers varied between water systems, all six water systems chose to use restrained joint PVC water line with an FPVCP casing at all DAPL crossings. The similarity in design attests to SDARWS's effectiveness in sharing experience and research between districts.

The DAPL was to be installed with a depth of cover ranging from minimums of three to five feet depending on the area, similar to the depths of the existing rural water systems in South Dakota, prompting relocations and deepening of water lines at the crossings. The DAPL had not yet been installed through South Dakota so technically open trench installation was a possibility for these relocations. However, in trying to create a large clearance from the intended DAPL alignment, the trench depths would potentially reach over 20 feet. For this reason, HDD methods would be implemented to install the casing pipes in all six water systems, allowing the casing to reach the desired clearance under the oil line while the installation setup remained at the surface.

The casing pipe sizing was consistent throughout the rural water systems with a set casing size for each carrier pipe size, typically providing a 2-inch or greater clearance from the outside diameter of the coupling on the restrained joint PVC carrier pipe to the inside diameter of the casing (Table 2). Internal debeading of each joint was required on all casing pipes to prevent any minor 'catching' when the carrier pipe and spacers were installed.

Table 2. Required casing pipe size for each water line size.

Nominal Water Line Size (in)	Nominal Casing Size (in)
2 & 3	6
4	8
6	10
8	12
10	16
12	18

Other aspects of the design varied by water system based on the preference of the utility. In previous designs for the Keystone pipeline, the five systems that used a casing required between 6 and 20-foot vertical clearances from the casing pipe to the Keystone oil line, and casing lengths ranging from 100 to 340 feet. A range of vertical and horizontal clearance requirements were also seen through the six systems in the DAPL alignment. The minimum vertical clearance allowed was 5 feet but the majority of systems actually preferred and designed for a clearance from 7 to 10 feet. The required casing length needed to protect the water line depended on the buffer zone and easements of the DAPL, the angle at which the water line crossed the DAPL, and the bending radius of the casing pipe. The DAPL has a permanent 50-foot easement along its entire length, so in all of the water systems the HDD was designed such that the bore did not curve back to the surface until outside of that easement. Additionally, with the exception of the Mid-Dakota design (one of the earliest designs completed), there was generally a 100-foot buffer zone to either side of the DAPL. All connections from the bored water line back to the rest of the water line were made outside of this buffer, making for a minimum casing length of 200 feet in instances where the water line crossed the oil line at a 90° angle. The minimum required casing length increased as the angle with the oil line decreased in order to encase the entire length within the buffer zone. The Mid-Dakota design did not include this buffer but did require a minimum casing length of 165 feet when crossing at a 90° angle. Mid-Dakota used the same procedure of increased casing lengths at smaller crossing angles, giving one 690-foot casing designed for a 7° crossing angle. Extra casing exceeding these minimum lengths depended on the bend radius of the casing pipe, i.e. the distance needed to curve the casing pipe back to standard depths.

5. PROJECT BIDDING

The designs for each water system were completed and advertised for bid by summer 2015. Although designs between systems were similar, each water system's relocation project was bid separately by each rural water district. The bid forms for each project included line items for the utility (a.k.a. DAPL) and road crossings broken up by carrier pipe size and crossing type. Each item included the cost of the casing pipe, carrier pipe and accessories, assembly, and installation. The remaining items in the bid form consisted of PVC pipe to be trenched and all necessary tie-ins back to the existing water line after relocating the line.

The northernmost water systems, Web and Mid-Dakota, bid in July 2015 and were awarded to Dakota Directional. The Minnehaha and South Lincoln systems were bid privately and were awarded to Gator Brothers Boring. The Kingbrook and Lincoln systems bid in September 2015 with the Kingbrook project awarded to Halme, Inc. and the Lincoln relocations awarded to Winter Brothers Underground, Inc. Construction began on all systems in fall 2015 with the goal to complete all relocations by January 2016, when start of the DAPL construction was initially scheduled.

6. CONSTRUCTION

As these are rural water line relocations, the majority of the DAPL crossings are located in pastures or agricultural land. Therefore, both traffic control and site preparation were minimal. The open land allowed for unobstructed pipe layout and drill rig setup (Figures 3 & 4). However, given the extensive open areas, the majority of the water line crossings were spread out with several miles between them, requiring constant onsite mobilizations of drilling and FPVCP fusion equipment.

Figure 3. Casing pipe fusion in South Lincoln Rural Water System.

Figure 4. Casing pipe layout in Kingbrook Rural Water System.

Casing pipes in Kingbrook, Minnehaha, Lincoln, and South Lincoln were fused and debeaded by the FPVCP supplier's technicians. Casings in Web and Mid-Dakota were fused, debeaded, and installed by Dakota Directional. Dakota Directional won relocation projects in two of the six water systems but these two accounted for half of the rural water line crossings of the DAPL in South Dakota. In order to keep on the intended schedule, Dakota Directional bought their own fusion machine and was fusion trained by the FPVCP supplier. By fusing the casing themselves, the contractor did not need to coordinate between two companies, giving them the freedom to relocate, assemble, and install encased water lines on their own schedule.

The combined Web and Mid-Dakota projects required over 70 drill and fusion locations and the same number of equipment mobilizations. These drills stretched over 150 miles from Pollock, South Dakota along the northern boundary of the state to Yale, South Dakota at the edge of the Mid-Dakota rural water system. Construction of these two system's relocations started in October 2015 and required work through the winter in order to guarantee completion prior to the DAPL installation. Dakota Directional built a trailer with an awning and swing-out doors to protect against wind and rain when fusing each casing (Figure 5).

Figure 5. Fusion setup by Dakota Directional in Web Water Development.

Casing pipe joints required internal debeading for all water systems to yield a smooth surface for the restrained joint PVC water line to be pulled through. As each 45-foot length of pipe was fused to the next, the bead created in the new joint was removed using a debeading tool (Figure 6).

Figure 6. Internal debeading of FPVCP casing [internal debeading tool (left); debeading process (right)]

Aside from weather delays expected in winter construction, the drilled crossings were installed without issue. Due to the expansive work area, geotechnical conditions varied from clay to sand to rock, but no soil encountered posed a problem that hindered installation. Each crossing was drilled to the depths required to meet the 7 to 10-foot clearance under the future DAPL. Drill depths ranged from 12 feet to as deep as 23 feet in the Web relocations. Once drilled, the casing pipe was pulled through the final bore hole after drilling and reaming (where required for the larger sized casings), followed by installation of the restrained joint PVC rural water line (Figure 7). The water line was protected at the exit and entrance of the casing using standard end seals and sleeves attached to the carrier pipe.

Figure 7. Casing and water line installation [installed casing pipe (left); insertion of carrier into casing (right)]

In total, over 40,000 feet of encased water lines were installed in the six rural water system relocations in South Dakota. Table 3 describes the project details in each rural water district and Table 4 summarizes the total crossing lengths by size and system. The majority of the relocation projects were finished by the allotted deadline of January 2016. The Web relocations, the system with the highest number of crossings, finished in March 2016, just after its revised deadline that had been extended due to weather.

Table 3. Overview of crossing details in each rural water system crossed by the DAPL.

Rural Water System	No. of DAPL Crossings	Water Pipe Diameters	Casing Length	Engineer	Contractor
Web	51	2 – 10 inch	220 – 550 feet	DGR Engineering	Dakota Directional
Mid-Dakota	22	2 – 8 inch	165 – 690 feet	Bartlett & West Engineers, Inc.	Dakota Directional
Kingbrook	33	3 – 12 inch	220 – 420 feet	DGR Engineering	Halme, Inc.
Minnehaha	17	2 – 6 inch	240 – 300 feet	In-House	Gator Brothers Boring
Lincoln	12	2 – 8 inch	260 – 300 feet	DGR Engineering	Winter Brothers Underground Inc.
South Lincoln	12	2 – 6 inch	220 – 300 feet	In-House	Gator Brothers Boring

Table 4. Total encased rural water lines crossing DAPL alignment in South Dakota.

Rural Water Line	**2 & 3-inch**	**4-inch**	**6-inch**	**8-inch**	**10-inch**	**12-inch**	**TOTAL**
Casing	**6-inch**	**8-inch**	**10-inch**	**12-inch**	**16-inch**	**18-inch**	
Rural Water System	**Encased Pipe Length (feet)**						
Web	9,985	2,300	1,085	290	330		13,990
Mid-Dakota	7,930	280	450	205			8,865
Kingbrook	6,705	855	945	315	360	765	9,945
Minnehaha	2,160	1,710	630				4,500
Lincoln	270		1,710	1,440			3,420
South Lincoln	1,890	270	630				2,790
TOTAL	28,940	5,415	5,450	2,250	690	765	**43,510**

7. CONCLUSION

The SDARWS and research by SDSU played a large role in orchestrating a semi-cohesive design through the six rural water systems directly impacted by the DAPL installation. Each rural water line is shielded from potential hydrocarbon contamination at crude oil pipeline crossings by a gasketless, PVC casing found to be impermeable to hydrocarbons when immersed in crude oil. This casing barrier protects the rural water line for 165 feet at minimum, with the majority of encased crossings exceeding 200 feet. The water line is also protected by the 7 to 10-foot clearance between the oil line and the water line's casing.

Very few challenges arose during construction. The only issues delaying construction involved the seasonal timing of construction and the multiple mobilizations of equipment due to the multi-mile distance between many of the crossings. Winter weather in South Dakota caused some project delays but for the most part it was a relatively light winter. Crews also benefited from this timing since the majority of the alignment was located in farmlands; crops had already been harvested, providing plenty of layout space and access to the rural water lines.

All rural water line relocations were completed just before the start of spring 2016. Dakota Access intended to start construction of the DAPL in early 2016 but didn't actually begin until spring 2016. As of November 2016, 87% of the DAPL was completed; however, due to conflicts in North Dakota, potential rerouting of the pipeline pushed the construction into 2017. South Dakota rural water systems will be equipped for its initiation once completed.

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