North American Society for Trenchless Technology (NASTT)
NASTT's 2017 No-Dig Show

Washington, D.C.
April 9-12, 2017

MA-T2-03

Head-to-Head Comparison of Open-Cut vs. HDD: City of Yuma, AZ Water Line Replacement Project

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1. ABSTRACT

In 2016, the City of Yuma, Arizona undertook the replacement of approximately 5,800 L.F. of existing aging and undersized asbestos cement water lines in the vicinity of the downtown core to reduce maintenance and repairs and improve water service levels. The original water lines were installed between 1938 and 1940. Six line segments of existing 2-inch to 6-inch asbestos cement water lines were replaced by 6-inch diameter PVC pipe. To gain a better understanding of the pros and cons of traditional open-cut construction compared to Horizontal Directional Drilling (HDD), the City separated the project into approximately 2,000 L.F. of HDD and 3,800 L.F. of open-cut. Being the same project, it provided an excellent opportunity to study a true head-to-head comparison of the two methods. PVC C900 DR18 was installed using open-cut, while Fusible PVC (FPVC) DR18 was installed by HDD. Data was collected in the field over a two-month period with factors analyzed including comparison of environmental impacts, traffic impacts, and productivity. The results found HDD to have inherent advantages in all three areas when compared to traditional open-cut. The eCalc^{TM} program was used to determine airborne emissions generated during the project by each of the two methods.

2. INTRODUCTION

The City of Yuma, Arizona has a population of just over 93,000 residents and is located in southwestern corner of the State bordering California. In February 2016, the City started the construction of a Downtown Waterline Replacement project to replace their aging 4-inch (100mm) and 6-inch (150mm) asbestos cement waterlines with 6-inch (150mm) PVC pipes. The existing pipes were installed between 1938 and 1940 and had far exceeded their 50-year design life. This paper describes a field research study to capture and analyze site data to compare differences in environmental impacts, traffic impacts, and productivity between traditional open-cut construction and Horizontal Directional Drilling (HDD) installation portions of the project.

The City of Yuma hired Stantec Consulting Services to design the project into two packages for the purpose of evaluating Horizontal Directional Drilling (HDD) versus traditional open-cut construction. This project provided a head-to-head comparison of the two methods being that it is one project in the same local environment. The overall project involved the installation of 3,800 L.F. (1,160m) of 6-inch (150mm) C900, CL 235 DR18 fully restrained PVC water pipe using traditional open-cut construction and 2,000 L.F. (600m) of 6-inch (150mm) C900, CL 235 DR18 fully restrained FPVC water pipe using HDD. The water pipes were installed at a depth of 8 ft (2.4m). Figure 1 illustrates a plan showing the replacement sections, while Table 1 presents a summary of the design lengths of the two technologies.

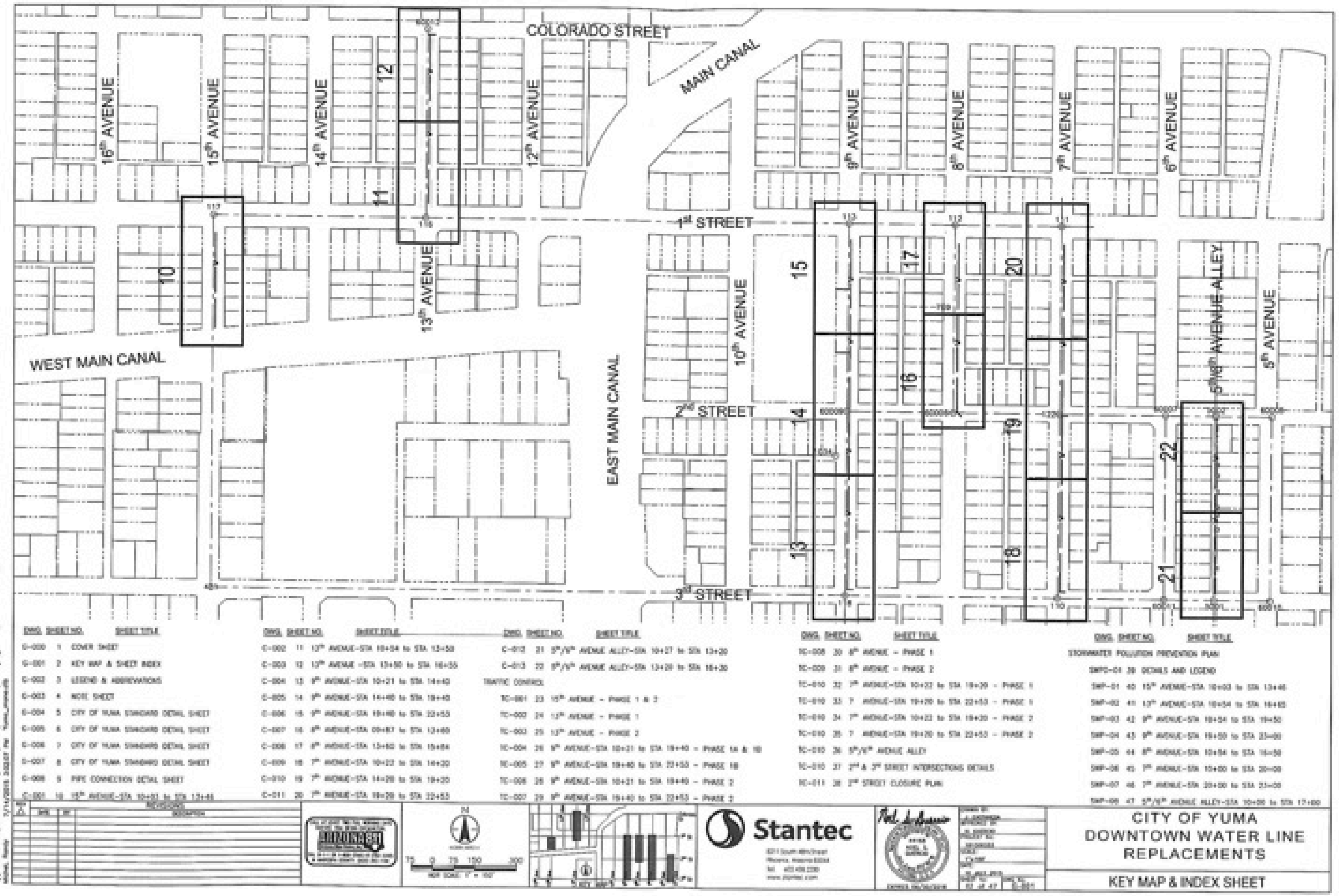

Figure 1. Water line replacement sections in downtown Yuma, AZ

Table 1. Summary of replacement locations and design lengths

Installation Method		Location	Design Length
Horizontal Directional Drilling	Phase I	8th Avenue	700 L.F.
	Phase II	7th Avenue	1300 L.F.
Open Cut	Phase III	5th/6th Avenue Alley	675 L.F.
	Phase IV	9th Avenue	2000 L.F.
	Phase V	13th Avenue	725 L.F.
	Phase VI	15th Avenue	400 L.F.

3. EQUIPMENT ANALYSIS

Data collection included visiting the jobsite over a two-month period between February to March 2016 and collecting real time data on equipment usage and activity characteristics. This involved recording information on all specific equipment used on the project including model year, engine hours, load factor, horsepower, and percent utilization. Emissions are calculated based on specific equipment and respective activities to provide actual emissions and productivities. Equipment information for the open-cut and HDD installations is shown as in the following section.

3.1 Open-Cut Construction Equipment

The open-cut construction portion of the project that was analyzed in this study involved replacements at three locations: 1) 9th Avenue (April 4-6); 2) 13th Avenue (March 17); and 3) 15th Avenue (March 16). Table 2 presents information on the equipment used on each of the three open-cut sections. The Case 590 Super L excavator used in the project is shown in Figure 2.

Table 2. Details of equipment used for open-cut installation

Name	Model	Power	Activities
Excavator	2012 Case 590 Super L (4T-390)	95 hp	1. Excavation of trench 2. Backfilling of trench 3. Lifting of pipe and layout
Hand Compactor	2014 Lancin 196CC	5.5 hp	Compaction of backfill
Truck	2015 Dodge Ram 3500	383 hp	Transport
Truck	2015 Form F350	385 hp	Transport
Water Truck	2002 Chevrolet C6500	207 hp	Dust control

Figure 2. Case 590 Super L excavator

2.1 Horizontal Directional Drilling Equipment

The HDD portion of the project that was analyzed in this study involved the replacements at three locations: 1) 8th Avenue between 1st and 2nd Streets (February 9-10; 2) 7th Avenue between 1st and 2nd Streets (February 11); and 3) 7th Avenue between 2nd and 3rd Streets (February 12). Table 3 presents the information on the equipment used on each of the three sections. The Vermeer D24x40A rig used in the project is shown in Figure 3.

Table 3. Details of equipment used for HDD installation

Name	Model	Power	Activities
HDD Rig	2000 Vermeer D24x40A	125 hp	1. Pilot bore 2. Pre-reaming 3. Pullback and Pipe Installation
Excavator	2012 Case 590 Super L (4T-390)	95 hp	Excavation of entry & exit pits
Vacuum Truck	Vacmasters System 4000	127 hp	Potholing existing utilities
Fluid Mixing System	Vermeer 2000 Gallon Mud Mixer	16 hp	Mixing of drilling fluid
Truck	2008 Ford F650	330 hp	Transport of vacuum equipment
Truck	1993 Kenworth T800	450 hp	Transport of mixing system
Water Truck	2002 Chevrolet C6500	207 hp	Dust control
Truck	Kenworth W900	600 hp	Transport of HDD rig

Figure 3. Vermeer D24x40A HDD rig

4. ENVIRONMENTAL CALCUATION OF AIRBORNE EMISSIONS

An emission calculator tool was developed in MS Excel using Visual Basic coding. E-Calc™ estimates emissions [i.e., hydrocarbons (HC); carbon monoxide (CO); nitrogen oxide (NOx); particulate matter (PM); carbon dioxide (CO_2); and sulfur oxide (SOx)] from underground utility projects based on EPA-approved methodology. Required input data can be obtained from daily progress reports or productivity estimates, while equipment-specific information should be acquired from the contractor. Non-road equipment data include: power; model year; engine technology; useful hours and cumulative hours to date; fuel characteristics such as type and sulfur content; and activity characteristics such as representative equipment cycle, power used, and hours of use. The data required to calculate emissions generated from on-road transportation equipment include: model year; gross vehicle weight; mileage; fuel characteristics such as type and sulfur content; and activity characteristics such as altitude of operation, number of trips, one way distance, and return distance.

As with any software tool, the accuracy of output information depends on the accuracy of the input data. The calculator is a tool intended for contractors, engineers, and owners to obtain an estimate of the environmental impact of their proposed underground utility project. The tool provides a comparison of emissions generated from two possible installation methods with default information available for four typical utility construction methods: 1) horizontal directional drilling; 2) trenchless pipe replacement; 3) trenching; and 4) traditional open-cut. It should be noted that the tool is portable and can be applied to any construction process that incorporates machinery and equipment such as water main replacement technologies studied in this research. This software tool has been used for evaluating numerous trenchless technology options (Ariaratnam and Sihabuddin, 2009; Matthews et al. 2014).

The emission factor is the basic tool for estimating emissions. It is usually expressed as the weight of pollutant emitted divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. The emission factors are used to determine the emissions from equipment or machineries that burn fuel. The general equation provided in document EPA/454/R-95/015 (EPA, 1997) is:

$$E = A \times EF \times \left[1 - \left(\frac{ER}{100} \right) \right] \qquad (1)$$

Where;

E = emissions

A = activity rate

EF = uncontrolled emission factor

ER = overall emission reduction efficiency, %

(ER is the product of the control device destruction or removal efficiency and the capture efficiency of the control system)

The activity rate is a function of the specific activity under consideration. The activity rate determination is based on the emission factor, which was calculated based on the test data ratings. If the emission factor is expressed as the weight of pollutant released for a volume of fuel consumed by the activity, the activity rate should be the measurement of the volume of fuel consumed by that activity (Sihabuddin and Ariaratnam, 2009).

For example, in the case of emission factors expressed in terms of g/hp-hr, the activity needs to be measured in terms of power (hp) consumed and duration (hr) of the activity that emits the pollutants. If the emission factor is expressed in terms of g/gal, then the activity rate should be the measure of gallons of fuel burned. A sample output emissions calculation screen from eCalc^{TM} is shown in Figure 4, while the summary screen is shown in Figure 5.

Table 4 presents a comparison of airborne emissions from the open-cut and HDD installations. These show the inherent environmental benefits of the HDD options. For example, converting emitted emissions to a normalize value shows HDD to have produced less than a third of CO2 emissions compared to traditional open cut. Overall, the HDD option emitted approximately 23% airborne emissions compared to open cut.

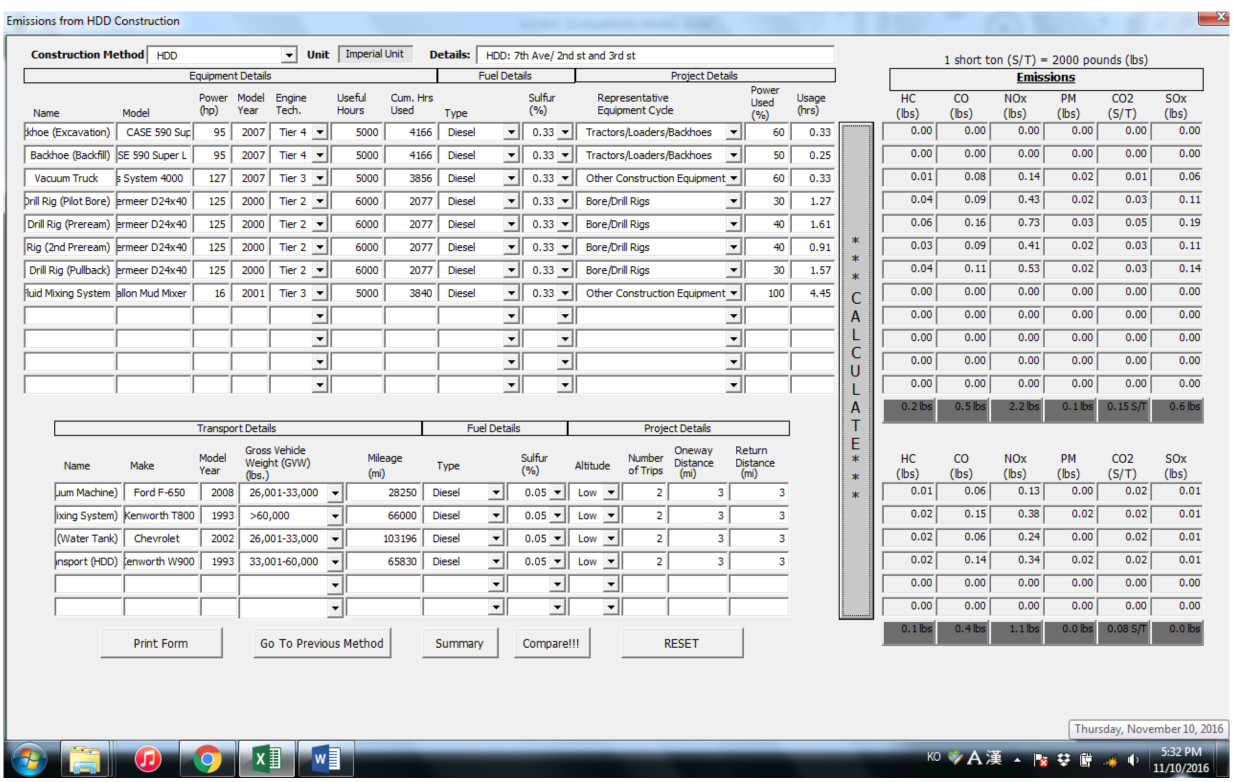

Figure 4. Sample HDD output emissions calculation screen

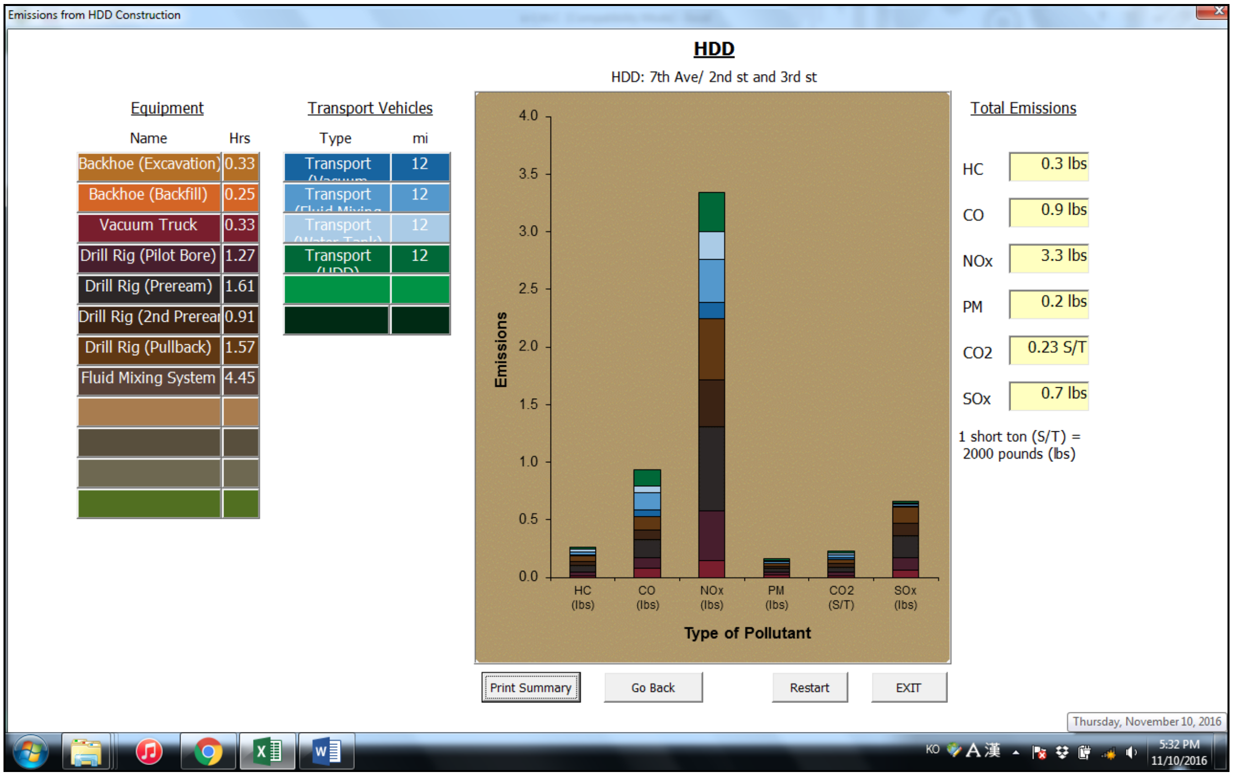

Figure 5. Sample HDD emissions summary screen

Table 4. Emission comparison

Installation Method	Installation Length Monitored	HC (lbs)	CO (lbs)	NOx (lbs)	PM (lbs)	CO2 (S/T)	SOx (lbs)
Horizontal Directional Drilling	1,580 L.F.	1.1	5.3	13.7	0.7	0.98	1.3
	Emissions/Unit (x10^{-3})	**0.7**	**3.4**	**8.7**	**0.4**	**0.6**	**0.8**
Open-Cut	945 L.F.	2.1	27.4	18,2	3.7	1.81	5.7
	Emissions/Unit (x10^{-3})	**2.2**	**29.0**	**19.3**	**3.9**	**1.9**	**6.0**

*Note: 1 S.T. = 2,000 lbs

5. TRAFFIC IMPACTS

Numerous researchers have cited reduction in traffic impacts as a major benefit of adopting trenchless technologies such as HDD (Tighe et al. 1999; Gilchrist and Allouche, 2005). Being in a residential neighborhood near the downtown core, it was important to minimize traffic impacts and inconvenience to the local residents. The sections with installations using traditional open-cut construction involved closure of the entire street to traffic as shown in Figure 6. Conversely, only half of the street was closed during the HDD installations as shown in Figure 7, thus enabling traffic flow. This further demonstrates an advantage of utilizing trenchless methods, particularly in urban areas. In this project, the City of Yuma planned on replacing the entire deteriorated pavement. Generally, only minimal sections of pavement at the entry and exit pits require replacement when employing HDD.

Figure 6. Closure of entire street for open-cut

Figure 7. Partial street closure for HDD installation

6. PRODUCTIVITY ANALYSIS

Productivity data was collected onsite for both the HDD and open-cut installations. All activities were timed by a stopwatch to gain a better understanding of all tasks associated with both installation methods. Since the installation lengths were not the same, all values were normalized to productivity shown in linear feet per minute (L.F./min). As shown in Table 5, HDD achieved an average productivity of 1.91 L.F./minute compared to traditional open-cut, which achieved an average productivity of 0.43 L.F./minute. This translates to HDD achieving productivity greater than four times that of open cut. It should be noted that productivity did not consider surface replacement such as paving or other tasks. The City of Yuma decided to repave all of the streets regardless of installation method and thus we did not consider restoration in the analysis. If considered, much more time would have been dedicated to surface restoration with the open-cut method. Productivity was measured as the time from excavation to final installation of the PVC pipe. In the case of open-cut, this included compaction of the backfill material.

Horizontal Directional Drilling was able to achieve more than four times the productivity rate as traditional open-cut. This may be attributed to the ability of HDD to navigate horizontally once the drill rod is inserted into the ground. Furthermore, improved accuracy of the tracking equipment and tooling enables for more accurate installation, thereby reducing the likelihood of striking an existing buried utility. Furthermore, the contractor was required to pothole and confirm the depth of all existing utilities that crossed the path of the PVC pipe installation.

Table 5. Productivity comparison

Installation Method	Location	Installation Length Monitored	Time for Completion (minutes)	Date	Productivity (L.F./minute)
Horizontal Directional Drilling	8th Avenue	520 L.F.	242	Feb. 8-9	2.15
	7th Avenue	1,060 L.F.	639	Feb. 10-11	1.66
				AVERAGE	**1.91**
Open-Cut	15th Avenue	70 L.F.	321	March 16	0.22
	13th Avenue	175 L.F.	385	March 17	0.45
	9th Avenue	700 L.F.	1,103	April 4-6	0.63
				AVERAGE	**0.43**

7. CONCLUSIONS

This paper described a field research study to capture and analyze site data comparing differences in environmental impacts, traffic impacts, and productivity between traditional open-cut construction and Horizontal Directional Drilling (HDD) portions of a replacement project of existing asbestos-cement waterline in Yuma, Arizona. The project was unique in that it provided a head-to-head comparison of the two methods in the same local environment. The field study involved assessing the installation of 945 L.F. (288m) of 6-inch (150mm) C900, CL 235 DR18 fully restrained PVC water pipe using traditional open-cut construction and 1,580 L.F. (482m) of 6-inch (150mm) C900, CL 235 DR18 fully restrained FPVC water pipe using HDD.

Field emissions data was collected and inputted into the eCalc™ software. The results found the HDD option to have emitted approximately 23% of airborne emissions compared to open cut. Furthermore, converting emitted emissions to a normalize value found HDD to have produced less than a third of CO2 emissions.

As expected, traffic impacts were minimized with the HDD option. The sections with installations using traditional open-cut construction involved closure of the entire street to traffic. Conversely, only half of the street was closed during the HDD installations, thus enabling traffic flow.

Overall productivity was much higher with the HDD option. The analysis found HDD achieved an average productivity of 1.91 L.F./minute compared to traditional open-cut, which achieved an average productivity of 0.43 L.F./minute. This translates to HDD achieving productivity greater than four times that of open cut. It is worth noting that surface restoration was not included in the analysis because the City of Yuma planned to repave all of the streets regardless of installation method.

8. REFERENCES

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