EVALUATION OF TRENCH AND SLOTTED DRAIN MAINTENANCE AND CLEANING – PHASE 1

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16. Abstract

Trench and slotted drains are increasingly being used by ODOT to remove storm water from the roadways. These drains have to be properly cleaned and maintained to prevent vehicles from hydroplaning, eliminate flooding and avoid premature roadway failure. ODOT's current methods for cleaning/maintaining trench and slotted drains take a lot of time and are expensive. This research report documents the current methods that ODOT utilizes for cleaning trench and slotted drains and recommends alternative cleaning methods that can improve safety, production rate and cost effectiveness. Currently, ODOT cleans trench drains manually or using a Sewer Cleaner. The manual process is very labor intensive and expensive while the Sewer Cleaner uses large amounts of water for cleaning. Alternative methods recommended and discussed in the report include Horizontal Directional Drilling (HDD), Horizontal Auger Boring (HAB) and robotic cleaners.

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Executive Summary

The goal of this research is to improve ODOT's current process of maintaining trench/slotted drains. To achieve this goal, the research team evaluated the current ODOT process for cleaning trench/slotted drains, developed a matrix of alternatives for cleaning trench/slotted drains that compares and contrast solutions that are available today and provided recommendations. Currently, ODOT clean trench drains manually or using a Sewer Cleaner. The manual process is very labor intensive and includes unscrewing the grates, removing the debris and re-installing the grates. Field tests conducted in Phase 1 have determined that the manual cleaning process has a production rate of 10 LF/man-hour and an expensive cost of $3.6/LF of drain. Field tests conducted in Phase 1 have determined that the production rate of using a Sewer Cleaner is 6 times faster than the manual cleaning rate. However, there is an environmental concern with using a Sewer Cleaner as large amounts of water are used in cleaning and most of the water is not captured and flows into the storm water drainage network. Furthermore, both the manual process and the current ODOT procedure for using a Sewer Cleaner are not safe as they currently both require ODOT Highway technicians to walk along the drain during cleaning and thus expose them to heavy traffic. Thus a safer, faster, less expensive process that does not use much water and that is capable of cleaning the entire length of the drain from one location is needed. Phase 1 has identified several technologies that can potentially be used to develop such a process. These technologies include Horizontal Directional Drilling (HDD), Horizontal Auger Boring (HAB), cleaning robots and innovative Hydrojetting nozzles.

The use of HDD and HAB technologies to clean drains offer significant environmental benefits over using a Sewer Cleaner as they require substantially less water for cleaning and in some cases can perform the cleaning with no water. Also it has been reported that HDD can have a faster production rate (6 to 12 feet per minute) than a Sewer Cleaner. Cleaning robots are successfully being used to clean and suck settled material in large sewage pipelines. They are remotely controlled from outside, and are equipped with a drilling head and a suction tube that is connected to either a suction excavator or a vacuum truck (Sewer Cleaner). Some models are equipped with water blast nozzles and various auger attachments that break up hard soil for easier suction/removal.

In Phase 2 of the project, the research team recommends testing HDD, HAB and cleaning robots for effectively cleaning trench/slotted drains. Since no cleaning robot that is small enough to fit in the

trench drain exists in the market, the research team recommends working with faculty from the mechanical engineering department and/or robotic companies in Phase 2 to develop a prototype robot. The research team also recommends improving the process of cleaning trench/slotted drains with a Sewer Cleaner. Although the preliminary cost analysis has shown that this process is more expensive than using HDD technology, the research team believes that one reason for the high cost is the low production rate that was achieved during the field tests conducted in Phase 1 because of frequent work stoppages. We recommend that more research be conducted in Phase 2 to further improve the performance of a Sewer Cleaner by designing a stepped cleaning process and using innovative Hydrojetting nozzles that reduce water splashing and eliminate the need for a crew person having to walk along the drain as the cleaning progresses.

Finally, the research team recommends that a trench maintenance plan should be developed and adopted by ODOT. A maintenance plan enable maintenance crews to periodically clean the drains cost-effectively before they become completely clogged in which case they require more expensive cleaning methods or in some cases total replacement with significant cost to ODOT.

Background

Trench and slotted drains are increasingly being used by ODOT to provide surface drainage in roadway depressions along the shoulder or in gore areas. Surface drainage is necessary to remove storm water from the roadway to prevent vehicles from hydroplaning and to eliminate flooding. Trench and Slotted drains are very efficient systems for surface drainage. The narrow continuous gutters adapt well to the surface conditions. They are able to take in large amount of water with great speed. Drainage of large amount of water implies at the same time a great deal of washed out dirt. That is why drains need to be regularly cleaned.

With the increased use of trench/slotted drains on highway reconstruction projects and the reduction of available man hours necessary for maintenance, the drains are not being maintained. When trench and slotted drains are not maintained they can obstruct the necessary and designed flow of storm water from the roadway. That can lead to safety concerns of water and/or ice on the roadway as well as premature roadway failure from saturated subsurface. Without routine maintenance the road grit accumulates in the bottom of the drain and quickly gets root bound by noxious weeds and other vegetation. Once this happens it becomes very difficult to clean the drains. The purpose of this research is to improve the current ODOT process of maintaining trench and slotted drains. This will lead to safer methods for ODOT maintenance crews to complete their work, increase productivity while decreasing labor hours, improve drainage, and improve water quality.

Goals and Objectives of the Project

The overall goal of this project is to evaluate ODOT's current process for cleaning trench and slotted drains and provide best practice recommendations on how to increase efficiency, decrease labor hours, and improve safety, production and cost effectiveness. The objectives of Phase 1 were as follows:

1. Determine the state of current procedures and practices by Ohio DOT and other state DOTs for cleaning trench and slotted drains with a focus on production rates, costs, and best management practices.
2. Identify manufacturers of drain cleaning equipment, interview them to assess experiences and concerns, and recommend appropriate equipment for use in Ohio based on cost, ease of use and production rates.

To achieve these objectives, the following four tasks were completed as shown in Figure 1:

(1) Evaluate the current ODOT process for trench/slot drain cleaning/ maintenance.
(2) Develop a matrix of alternatives that will compare and contrast solutions that are available today and provide a recommendation on the most viable solution
(3) Provide an analysis of current equipment, materials and technology available for handling trench/slot drain maintenance.
(4) Provide an interim report detailing the findings from all the above steps. Recommend solutions for infield testing and analysis

A detailed explanation of the subtasks shown in Figure 1 follows.

1- Evaluate the current ODOT process for trench/slot drain cleaning/ maintenance.

1.1 ODOT Phone Interviews

Before conducting the phone interviews, the research team emailed all ODOT county managers and highway management administrators. A total of 104 emails were sent. The purpose of this short email was to find out which ODOT counties has either trench drains and/or slotted drains on its roads. 57 responses were received with a response rate ratio of 55%. Out of the 57 respondents, 14 have indicated that they have trench and/or slotted drains in their counties as listed in Table 1. All 14 respondents were contacted by phone. 7 returned the phone calls and were interviewed regarding cleaning equipment used, frequency of cleaning, crew size, factors affecting production rate, and safety concerns. The interviews were used to obtain an understanding of current ODOT processes for cleaning trench/slotted drains.

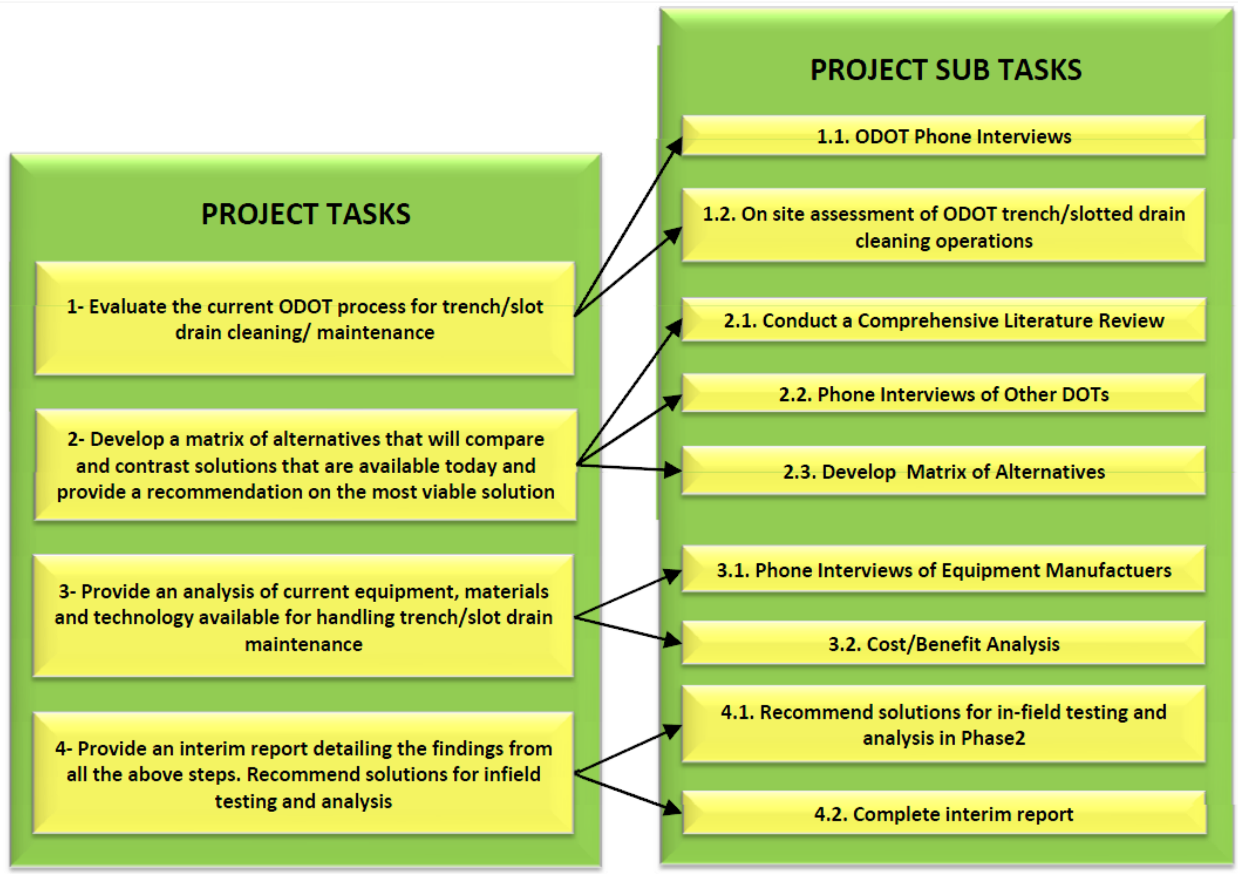

Figure 1. Project tasks and subtasks

Table 1. List of ODOT Counties/Districts that indicated having trench and/or slotted drains in email response

#	County Name	Notes
1	Cuyahoga	Slotted drains on I271 between the express lane and the mainline
2	Highland	One Trench Drain and one Slotted Drain
3	Pike	Have both drains
4	Ross	On 23 South around the 0 - 5 mile markers, also on St Rt 104 near the Ross County Fairgrounds
5	Lawrence	Trench drains
6	Pickaway	One slotted
7	Auglaize	Slotted drains in the parking lot of the USR 33 Rest Areas (never been cleaned). Trench drains inside main facility. They get cleaned regularly
8	Fairfield	Some Slotted Drains on US 33 (never cleaned yet)
9	Summit	90' of slotted drain on I-271 Southbound at the Sr 8 split which is the 18.45 mile marker
10	Ashtabula	One trench drain which was just installed on project
11	Hamilton	Some slotted drains
12	District 2	Trench drains on a new ODOT project on I-75 and the gore area (no experience maintaining them)
13	Coshocton	Slotted drains on US 36 near Roscoe Village
14	Scioto	Have both styles

Below are the questions posed to county managers and transportation managers from the various ODOT county maintenance garages during the phone interviews.

District _____________ County _____________ Phone Number __________________________

Name of contact _________________________ Lane miles maintained ____________________

1. How many linear feet of trench and slotted do you maintain?
2. Do you have experience cleaning trench/slotted drains?
3. What is the typical length of a single installation?
4. What are the typical widths and depths of trench drains in inches?
5. Is it common to have vegetation in clogged drains?
6. How often do you clean trench drains you currently have?
7. What kind of methods you use for trench drain cleaning?
8. What is the production rate of each method (lf/hour)?
9. Where do you get rid of the waste from the cleaning operation?
10. How many people are typically involved in the cleaning operation?
11. Are all the equipment needed in the garage or at the district?

12. What are the limitations of current equipment used?

Interview Results

Table 2 summarizes results from the 7 phone interviews. As shown in Table 2, 2 of the interviewees (Ashtabula County and District 2) have just recently installed their first trench/slotted drain on their roadways and don't have experience yet maintaining the drains. The major findings from the interviews are further discussed in the following subsections. The subsections also include feedback received from Mr. Dan Wise and Mr. Shawn Rostorfer; members of the technical liaison team who were informally interviewed throughout the project.

Frequency of use

Recently, the use of trench/slotted drains by ODOT in roadways has increased. Data provided by Mr. Dan Wise has indicated that

- Since 2013, ODOT installed 33,578 LF of trench drains. Just in District 6 since 2013, ODOT installed 12,570 LF of trench drains.
- Since 2013, ODOT installed 8,236 LF of slotted drains.
- From Feb 2015 to June 2016 ODOT installed 11,510 LF of trench drains. Just in District 6 ODOT installed 9,356 LF.

The interview results have confirmed that the use of trench/slotted drains is going to continue to increase in the future which makes it necessary to develop standard procedures for effectively maintaining/cleaning trench and slotted drains.

Experience in and frequency of cleaning operations

Experience in cleaning trench/slotted drains is very limited in Ohio. Many counties have recently installed these drains for the first time and have not yet had to clean them. Counties that have had these drains for longer typically clean/inspect the drains every year. Without routine maintenance the road grit accumulates in the bottom of the drain and quickly gets root bound by noxious weeds and other vegetation which makes it very difficult to clean. In extremes cases, some slotted drains that were impossible to clean had to be completely replaced with significant cost to ODOT.

Equipment

As shown in Table 2, the predominant equipment used in Ohio for cleaning trench/slotted drains is a sewer cleaner (Vactor-Jet). The sewer cleaner is expensive, which prohibits purchase of a unit for each county. There is currently a relatively small number of sewer cleaners throughout the state and counties report sharing it amongst themselves. The need to share limits the use of the equipment.

Furthermore, the sewer cleaner such as a Vactor-Jet, is a large piece of equipment, and usually requires lane/shoulder closures to use. It cannot be driven off the pavement due to its weight. The sewer cleaner also requires the use of large volume of water which is mixed with the sediments built up in the drains and is carried to the stormwater system; this is not in compliance with current EPA standards particularly if the resulting water from the cleaning operation is drained to a stream or a wetland. Also the use of high pressure water from the sewer cleaner creates a large mess as the water escapes through the holes in the top grates.

Table 2. Survey Results for Equipment Usage

Questions	Answers						
County/District	Highland	Ross	Lawrence	Fairfield	Scioto	Ashtabula	District 2
How many linear feet of trench and slotted do you maintain?	Not Available	5 Miles	Not Available	200 feet	4,500 feet	Not Available	Not Available
Do you have experience cleaning trench/slotted drains?	Yes	Yes	Yes	Yes	Yes	No	No
What is the typical length of a single installation?	Not Available	55 feet	100 feet	Not Available	Not Available	Not Available	Not Available
Typical widths and depths of trench drains in inches?	W: 8-1/2 D: 18	W: 10 D: 12-16	W: 6-10 D: 6-8	Not Available	W: 4-5 D:8-10	Not Available	Not Available
Is it common to have vegetation in clogged drains?	Yes	Yes	No	Not Available	Yes	Not Available	Not Available
How often do you clean trench drains you currently have?	1/Year	1/Year	As needed or 1/year		Inspect 1/year		
What kind of methods you use for trench drain cleaning?	Vac-Con Air pressure	Vac-con	VAC-CON	VAC-CON	VAC-CON		
What is the production rate of each method (lf/hour)?	Not Available	Not Available	Not Available				
Where do you get rid of the waste from the cleaning operation	Landfill	Waste Site	Test and let other companies handle it	Approved site	Approved site		
How many people are typically involved in the cleaning operation	4-6	3-5	6-7		4-5		
Are all the equipment needed in garage or at district	Garage and District	District do Maintenance	Garage		District		
Limitation of current equipment	No	No	No		Slow, mess		

Standard Procedures

Currently there are no standard procedures for maintaining trench/slotted drains. Although most counties that provided feedback on equipment used have indicated the use of a sewer cleaner for cleaning, production rates are not known. Without knowing production rates, it is difficult to adequately plan for maintaining the drains with the available resources.

1.2 On site assessment of ODOT trench/slotted drain cleaning operations

In order to complement the information obtained from the phone interviews, the research team conducted 3 site visits to better understand challenges related to cleaning trench/slotted drains and to observe current cleaning operations in Ohio and to evaluate possible cleaning methods identified as a result of the literature review. The visits served to observe cleaning methods first hand, including crew composition, equipment usage and maintenance, and environmental measures taken. Table 3 provides more information about the date and location of the site visits.

Table 3. Summary of Site Visits and Demonstrations

Date	District	County	Description
9/16/2016	6	Franklin	• Tour of several ODOT installations of trench/slotted drains • Demonstration of various types of trench drains
10/12/2016	6	Franklin	• Observe ODOT`s current practices for cleaning trench/slotted drains • Evaluate possible cleaning methods identified as a result of the literature review
10/26/2016	6	Franklin	• Evaluate a Sewer Cleaner with a Water Recycling System • Evaluate different types of ENZ nozzles to clean trench drains

First site visit on 9/16/2016

The first site visit on 9/16/2016 consisted of a tour of several ODOT installations of trench/slotted drains in Franklin County, as well as a demonstration of the various types of trench drains and the ease of removing the grates from different types. Figure 2 shows several installations of drains around Franklin county. As shown in the figure, Trench and slotted drains are commonly installed in roadway depressions along the shoulder or in gore areas. They are typically installed in these locations as a result of shallow pavement cross slopes that cannot be drained into a ditch or catch basin. Many of the areas where trench/slotted drains are installed experience high traffic throughout the day and in many cases high speeds which present a challenge to safely clean the trenches.

Figure 2- Various installations of trench and slotted drains in Franklin County, Ohio

As shown in Figure 3, the drains over time collect different types of debris including grit and leaves. Drains that are not maintained on a regular basis become completely clogged and obstruct the necessary and designed flow of storm water from the roadway. That can lead to safety concerns of water and/or ice on the roadway as well as premature roadway failure from saturated subsurface. Furthermore, without routine maintenance the road grit accumulates in the bottom of the drain and quickly gets root bound by noxious weeds and other vegetation as shown in Figure 3. The presence of vegetations makes the drain harder to clean.

Figure 3- Debris and vegetation in trench drains

Figure 4 shows different styles for trench drains. Some trench drains are monolithic and have no removable grates. In another style of drains, the grates are screwed to the drain body. For this style, it is usually a painstaking job to unscrew and screw again grates; screws get rusty or lost and the job has to be performed on the knees which can cause workers getting hurt.

In a third style of drains as shown in Figure 4, locking rods are used to provide a firm linkage between the grates and the drain body. For this style, it is easier to remove and re-install the grates. A special tool as shown in Figure 5 permits easy locking of the drain cover and unlocking while the crew member is an upright position.

Monolithic drains

Screwed Grates

Grates attached with locking rods

Figure 4. Different style of drains

Figure 5. Tool to remove grates attached with locking rods

Second site visit on 10/12/2016

The purpose of the second visit on 10/12/2016 was to observe ODOT`s current practices for cleaning trench/slotted drains and to evaluate possible cleaning methods identified as a result of the literature review. Demonstrations of various cleaning operations were performed using a mechanical drain (plumber's snake), compressed air and a sewer cleaner (Vactor Jet). In addition a 30 ft section of the trench drain was cleaned manually to calculate the production rate of manual cleaning. Description and summary of cleaning methods observed are provided in the sections below.

Manual cleaning:

Three crew members participated in the manual cleaning process. As shown in Figure 6, the process consisted of unscrewing the grates, removing the debris and loading it in buckets, cleaning around the drain with a blower and re-installing the grates. The crew was able to clean 30 linear feet of drain in 1 hour. In other words 3 man-hours were needed to clean 30 ft which amount to a production rate of 10ft/man-hour.

1-unscrewing grates 2-removing debris 3-loading debris in buckets 4-cleaning around drain with a blower 5- Installing grates

Figure 6- Manual cleaning of trench drains

Compressed air:

Compressed air was tested for cleaning a short section of trench drain. As shown in Figure 7, an ODOT personnel used compressed air to blow the debris out of the drain. The compressed air was not capable of completely removing the debris from the drain and as shown in Figure 7, debris from the drain scattered everywhere around the drain creating an unacceptable mess. Because of these limitations, it was concluded that compressed air is not a viable method for cleaning trench drains.

Figure 7- Use of compressed air in cleaning drains

Mechanical Drain (Plumber's snake):

As shown in Figure 8, a mechanical drain was tested for cleaning a short section of a trench drain to evaluate if it can loosen hard dirt accumulated in nearly fully clogged drains. However, because the drain was not completely full of debris, as the cable rotated, it rode on the top of the sediments and was unable to clear up clogging from inside the drain. Due to this observed limitation, it was concluded that the mechanical drain is not a viable method for cleaning trench drains.

Figure 8- Use of mechanical drain in cleaning trench drains

Sewer Cleaner:

A sewer cleaner was tested for cleaning a trench drain. As shown in Figure 9, the water jet nozzle was placed in the drain and the suction tube was placed behind it, also in the drain. Because the suction tube diameter is larger than the drain, a special extension hose was specially made to fit in the drain. Another option is to place the suction tube in the catch basin connected to the trench drain as will be demonstrated in a following section. The intent of placing the suction tube directly in the drain as opposed to placing it in the catch basin is to try to capture as much water used for cleaning the drain as possible. However it was observed that a significant amount of water was not captured by the suction tube and was discharged to the catch basin.

It was observed that the sewer cleaner is capable of cleaning the trench drain. The nozzle used had a good propel thrust and was able to break down the hardened debris and clean the drain. However, as shown in Figure 9, the nozzle used splashed a significant amount of water from the top holes in the grates. The large amount of splashed water can cause a safety hazard for drivers using the road and for ODOT crews.

A wooden board was used to limit the amount of water splashed. The wooden board was effective in reducing splashed water in this case but may be difficult to use on other projects where traffic is heavier. Furthermore, a significant amount of debris cleaned from the drain escaped through the holes in the grates and ended up on the pavement next to the drain as shown in Figure 10. This debris will have to be removed either manually or using a street sweeper and disposed of safely. If left on the pavement, it will quickly move back and settle in the drain with any rain.

In summary, the sewer cleaner was shown to be a potential viable method for cleaning trench drains. However there were several concerns with using the sewer cleaner that need to be addressed. These are:

- Significant amount of water used for cleaning
- Significant amount of splashing
- Debris accumulating on the pavement next to the drain. This debris will have to be removed requiring additional resources and equipment.

After contacting sewer cleaner manufacturers and nozzle manufacturers and discussing these concerns, the research team concluded that some of these concerns can potentially be improved using different types of nozzles and/or sewer cleaners. To evaluate the potential improvements, the research team scheduled a field test on 10/26/2016.

1-Placing Nozzle in Drain

2- Placing Suction tube in drain

Figure 9- Use of sewer cleaner in cleaning trench drains

Figure 10- Debris cleaned from the drain

Third visit on 10/26/2016

The purpose of this visit was to evaluate the capabilities of a Sewer Cleaner with a Water Recycling System and different types of ENZ nozzles to clean trench drains. The research team wanted to find out:

1. If the water recycling system can significantly reduce the amount of water used for cleaning.
2. If certain models of ENZ nozzles significantly reduce the amount of splashing and reduce the amount of debris accumulating on the pavement next to the drain after cleaning.

A water recycling system in a sewer cleaner reuses water for cleaning after filtering it. This reduces the amount of contaminated water that is discharged to the storm water network and also allows for uninterrupted line cleaning as it eliminates the need for periodically filling up the sewer cleaner with water. The Vactor 2100 Plus® Water Recycling System shown in Figure 11 was tested during this site visit.

Figure 11- Vactor 2100 Plus® Water Recycling System

Also during the site visit and as shown in Figure 12, two different water jet nozzles were tested: ENZ Flounder and ENZ Chisel Point. The ENZ flounder is suited to clean flat pipes and channels. The flat design combined with the rounded corners and edges provides the tool with good gliding properties. The ENZ chisel point, with its very strong concentrated forward jets and the sharp cutting edges, is capable of tearing through tough blockage.

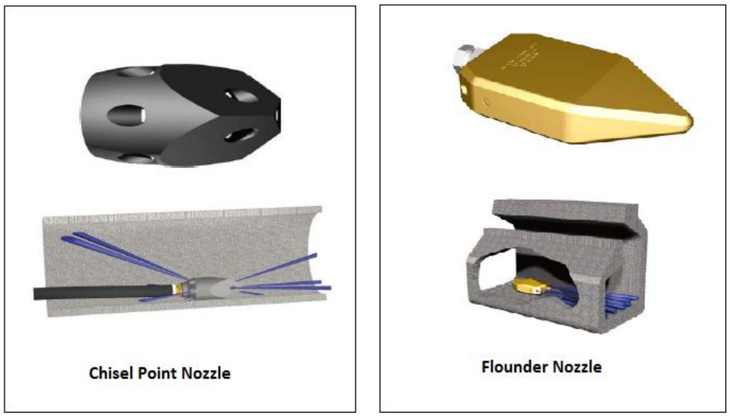

Figure 12- ENZ nozzles

A wooden board was used to control splashing. A string was attached to the board to allow a crew member to pull the board as the nozzle advances inside the drain as shown in Figure 13.

Figure 13- Crew member pulling wooden board

When the Flounder nozzle was used, the splashing was significantly reduced as shown in Figure 14. The Flounder however was unable to tear through tough blockage because it didn't produce a concentrated forward jet. The Chisel Point nozzle was able to easily cut through all blockages but increased water splashing.

Figure 14- Reduced splashing when using Flounder nozzle

As shown in Figure 15, the suction tube was placed in the catch basin connected to the trench drain. The suction tube wasn't able to capture a lot of the water used for cleaning because the pipe connected to the trench drain was much higher than the other pipes connected to the catch basin. It is important to note that the fact the suction tube was not capable of capturing most of the cleaning water renders the water recycling capability of the sewer cleaner less useful. It was thus concluded that a water recycling system is not necessarily needed for trench drain cleaning.

Figure 15- Suction tube placed in catch basin

The entire cleaning was completed in one hour and used about 1000 gallons of water. 180 feet of trench drains were cleaned thoroughly. This amounts to a production rate of 180 feet per hour and water consumption of 5.5 gallons per linear feet. Several stops occurred during work to change nozzles and when the crew member pulling the wooden board was unable to keep up with the nozzle moving up the drain. The field test has confirmed the viability of using the sewer cleaner for cleaning trench drains. The cleaning production rate achieved was 6 times faster than the manual cleaning rate. However, it is recommended that more research be conducted in phase 2 to further improve the process by designing a stepped cleaning process and identifying a suitable nozzle that eliminates the need for a crew person having to pull a wooden board. It is the research team's judgment that pulling a board to control splashing is not very safe particularly in high traffic areas. Nozzles' manufacturers such as ENZ can typically work with their customers to manufacture a suitable nozzle. It is recommended that in phase 2, the research team work with nozzle manufacturers to develop a nozzle whose spray pattern of the water jets prevent any water from splashing up directly eliminating water splashing and the need to clean up around work areas.

2- Develop a matrix of alternatives that will compare and contrast solutions that are available today and provide a recommendation on the most viable solution

2.1 Conduct a Comprehensive Literature Review

The literature review focused on trench/slotted drains' cleaning operations, factors affecting selection of cleaning method and best practices for cleaning trench/slotted drains.

Trench/slotted drains' cleaning operations and procedures

The literature review has identified potential methods of cleaning trench/slotted drains. Many of these methods were evaluated during the site visits are discussed in section 1.2. These cleaning methods are:

1. Manual cleaning
2. Flushing with water
3. Mechanical drain cleaning
4. Hydrojetting
5. Using a sewer cleaner

These methods are further discussed in the following subsections.

Manual Cleaning

When trench drains are cleaned manually as shown in Figure 16, most of the grates are first removed. Maintenance crews then remove debris from the drain manually with shovels or brushes. The size and shape of the shovel used will vary based on the drain's shape and size. The manual method is one of the methods recommended by the Tahoe Regional Planning Agency for cleaning trench drains with removable grates (TRPA BPM Handbook 2014).

Figure 16. Manual Cleaning of Trench drains

Although manual cleaning methods do not require expensive equipment, they are very labor intensive. Manual methods may also lead to possible injuries resulting from dropping grates on toes or back injuries resulting from improperly carrying heavy weight.

Flushing with water

This procedure is aligned with manufacturers' recommendations. One manufacturer, ACO, recommends in their site installation manual the following procedure:

1. Remove grates
2. Remove debris from channel
3. Flush channels with water or high pressure washer.
4. Repair damaged surfaces, if necessary, with an appropriate ACO repair kit.
5. Renew joint seals as required.
6. Empty rubbish baskets and clean out pipe connections.
7. Re-install rubbish baskets.
8. Re-install grates, ensuring they are locked in place.

As shown in Figure 17, flushing with water is labor intensive: first, maintenance crews have to manually remove the majority of the grates, and then they have to remove the debris from the channel, flush with water and re-install the grates. Depending on the trench drain types, the grates could be bolted on both sides and may have to be unscrewed for removal and screwed again for installation. The grates are heavy and have to be carefully handled by maintenance crews to avoid injuries such as injuries resulting from dropping grates on toes or back injuries resulting from improperly carrying heavy weight. Such injuries may results in workers' compensation claims and workdays' loss. Also the grates may have to be marked after removal to facilitate their installation in the correct position.

Figure 17. Cleaning Trench Drains by Flushing with Water

Mechanical drain cleaning

A mechanical drain cleaner is also called a plumber's auger, or drain snake. As shown in Figure 18, a mechanical drain cleaner uses an electric motor to twist a cable into the drain by mechanical force. As the cable rotates, it clears up clogging and removes debris from inside the drain. Special attachments for a mechanical drain cleaner can cut through tree roots and remove some types of foreign objects from a drain. The mechanical drain cleaning method is one of the methods recommended by California DOT for cleaning drains (CDOT 2014).

Figure 18. Cleaning a Trench Drain by a Mechanical Drain Cleaner

Hydrojetting

Hydrojetting or high pressure water jetting is an efficient and economical way to clean drain blockage. The typical composition of a hydro jetting unit (also called hydrojetter or jet rodder) includes a hose, nozzle, water pump and water tank. Using flexible hoses, water is propelled under varying pressures into the drain. As shown in Figure 19, forward and reverse jets direct powerful cleaning throughout the entire drain providing 360 degree coverage. The back-firing jets on a hydrojetter nozzle pull the jetter line into clogged drain. The high pressure water jetting penetrates and emulsifies grease, breaks up sludge and debris, pulverizes trees and shrubs, and flushes out the system, leaving the drains clean and free of obstruction.

Figure 19 Cleaning a Trench Drain by a hydrojetter

Hydrojetting is one of the methods recommended by California DOT for cleaning trench drains (CDOT 2014). Texas DOT also recommends hydrojetting for cleaning trench/slotted drains and have included in its "Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges" specific requirements for using hydrojetting; Texas DOT require a self-contained, single-unit vehicle with a high-pressure water pump capable of pumping at least 60 gpm at 2,000 psi with at least 500 ft of hose and a water storage tank of at least 1,300 gallon capacity (TDOT, 2004).

Hydrojetting is capable of cleaning trench and slotted drains efficiently without removing the majority of the grates. Hydrojetting clean the drain more thoroughly and effectively than mechanical drain cleaning which only forms a hole in the clogged area as a temporarily solution but does not scour the perimeter of the drain. Since hydrojetting completely removes all obstructions from the drain, fewer cleaning is required. Furthermore, a hydrojetter can unclog a drain faster than when a mechanical drain is used. In addition, if blockage is caused by sludge buildup that has hardened, a mechanical drain cleaner may not be effective and a hydrojetter should be used. Hydrojetting costs more than a mechanical drain cleaner but depending on the situation can be more economical overall since cleaning intervals is typically increased.

Using a Sewer Cleaner

A sewer cleaner, as shown in Figure 20, is a truck that combines high-pressure water jetting and a high-flow vacuum to break up blockages in drains, flush out debris and scour drains clean to restore and maintain normal flow. Using a sewer cleaner is one of the methods recommended by The Tahoe Regional Planning Agency for cleaning trench drains (TRPA BPM Handbook 2014). Using a sewer cleaner is expensive and should only be used when all other methods are not appropriate; typically in case of trench drains that have never been cleaned and are completely clogged up after years of service. A sewer cleaner has been used by Michigan DOT to clean a long run of trench drains (20,000 lf) that have not been cleaned during its entire 10 years of service.

Figure 20. Cleaning a Trench Drain by a Vactor-jet

Factors affecting selection of cleaning method

The literature review and the research team's previous experience with trench/slotted drains have identified several factors that need to be considered when deciding which drain cleaning method should be adopted for a particular project. The factors are listed and further discussed in the following subsections.

Degree of blockage

Some drains have accumulated an abundance of road grit because they have not been regularly maintained and as a result are completely blocked. For those drains, it may be necessary to pump out the large amount of road grit as it rises up from the drain and a sewer cleaner may have to be used. For drains that are regularly inspected and maintained, a less expensive high pressure washer with high flow rates can potentially do the cleaning.

Location

The location of the trench/slotted drain will affect the type of debris accumulated in the drains. If the drain is installed near a forest, the debris collected in the drain will primarily be composed of falling leaves. Drains installed in cities will accumulate more dirt. The type of debris and degree of blockage will impact the selection of the cleaning method as was discussed in the previous section. The impact on traffic will also be affected by the location of the drains. Drains located in congested urban areas have to be cleaned in a speedy manner to reduce impact on traffic. Furthermore, if the drains are located in high traffic areas (e.g. interstate bridges), methods that require movement of crew members along the drain (i.e. manual methods) will not be adequate. In such cases, the cleaning method should enable the crew to clean the entire length of the drain from a starting point (e.g. catch basin) that is located away from the heavy traffic and bring all the debris back to the starting point.

Drain types

Some trench drains are monolithic and have no removable grates. For these drains, manual cleaning is not an option.

Drain length

Length of trench drain installations can vary from less than 20 ft to more than 20,000 lf. Shorter installations are typically used on exit ramps and across roads uphill of intersections. Long installations are used along highways constructed in flat areas. Shorter installations of trench/slotted drains can be more appropriately cleaned manually and may not justify the mobilization of large and expensive equipment. Long installations on the other hand should be cleaned with mechanical equipment to shorten the duration of the cleaning operation and to reduce the impact on traffic.

Best Practices for cleaning trench/slotted drains

The literature review has revealed several best practices including the following:

- The best way to know if trench drain systems are functioning properly is to observe and inspect them visually, especially during and immediately after rain or snowmelt events when higher flows put more stress on the drains. According to Washington State DOT, the entire drainage system should be generally inspected at least twice a year (WSDOT 2013). Inspections should cover: Grates and locking devices, Pits and rubbish baskets, adjacent paving.

- A trench maintenance plan should be adopted. A maintenance plan enable maintenance crews to periodically clean the drains cost-effectively before they become completely clogged in which case they require more expensive cleaning methods or in some cases total replacement. Although trench/slotted drain manufacturers understand the importance of a maintenance plan, they typically don't publish recommended maintenance schedules because the frequency of required maintenance will vary from one installation to another. New trench drains installations should initially be checked/cleaned twice per year and based on observation, the frequency of their cleaning can be properly determined.
- Planning the job should be done well in advance the drain cleaning operation to ensure that when equipment and men arrive at the job site the drain can be cleaned correctly and efficiently. Planning should include visiting and inspecting the site to determine the correct type of equipment needed and the proper cleaning procedures (IRF 2010).
- Proper traffic control devices should be used to alert drivers that road maintenance is being performed and to help prevent traffic from interfering with the job (NYDOT 2009)

2.2 Phone Interviews of Other DOTs

The research team contacted various state DOTs and municipalities to request information about their trench/slotted cleaning procedures. Each DOT was asked about their drain cleaning process, and information was gathered about frequency of use of trench/slotted drains, equipment used, crew sizes and production rates. The sections below highlights information obtained from other DOTs.

Florida

- Florida has a significant amount of trench drains. It currently maintains more than 100 miles of those drains and plans to install more in the future.
- The drains get clogged and gets root bound by noxious weeds and other vegetation
- Trench drains get inspected every 2 years
- Equipment used include pressure washer, side blower and a Sewer Cleaner.

Pennsylvania

- Pennsylvania has only a limited amount of trench/slotted drain installations
- The drains are cleaned manually, or by a Sewer Cleaner.
- A subcontractor is usually hired to clean the drains and adequately dispose the waste.

Virginia

- Virginia has only a limited amount of trench/slotted drain installations
- The drains are cleaned by a sewer cleaner, pressure washer, or culvert cleaning equipment.
- A subcontractor is usually hired to clean the drains and adequately dispose the waste.

Massachusetts

- Massachusetts clean their trench/slotted drains every 2 years
- The drains are cleaned by a sewer cleaner.
- Cleaning of the drains is done in house.
- Debris removed from the drain is disposed of in approved decant facilities.
- A crew of 4 to 6 people performs the cleaning.

2.3 Develop Matrix of Alternatives

Information obtained as part of the previous research tasks was summarized in a matrix of alternatives for cleaning trench/slotted drains as shown in Figure 21. Only the cleaning methods that have potential have been listed in the matrix. Cleaning methods that were deemed inappropriate were excluded. The methods that were excluded are:

- Using compressed air: This method was excluded because of its limitations as observed during the second site visit that took place on 10/12/2016
- Using a mechanical drain: This method was excluded because of its limitations as observed during the second site visit that took place on 10/12/2016
- Flushing with water: This method was excluded because of its limitations as observed during the second site visit that took place on 10/12/2016
- Hydrojetting: Hydrojetting is very similar to using a sewer cleaner with the exception that the the hydrojectter doesn't have suction capabilities that allow for the collection of the water used in cleaning. This method was excluded after talking to the technical liaison team as they expressed concerns about the environment if the large amount of water used in Hydrojetting is not captured and is all allowed to be discharged in the stormwater drainage system.

As shown in Figure 21, the matrix of alternatives provides information on applicability, safety considerations, impact on the environment, and production rates if applicable. Two methods have been added to the matrix although they have not been field tested nor demonstrated during the site visits. These 2 methods are (1) Horizontal Directional Drill Technology and (2) Horizontal Auger Boring and are further explained below.

Horizontal Directional Drill (HDD) Technology

Horizontal directional drilling or HDD, is a trenchless method of installing underground pipe, conduit, or cable by using a surface-launched drilling rig as shown in Figure 22. Some companies have been using HDD to clean culvert and drains (Custome crews 2016, Harr Technologies 2016). These companies claim that they can effectively and efficiently clean clogged culverts and drains to like new condition at a fraction of the cost of other methods. The use of HDD technology offers many advantages including control of water injection/pressure as well as the ability to span any length of culvert simply by adding drill rods.

Figure 22. Installing pipes using a HDD rig

Method	Description	Applicability	Prodution Rate and Crew Requirement	Impact on Traffic	Environmental Impact	Safety/Health Concerns
Manual Cleaning	Manual cleaning operations consists of unscrewing bolts on and removing all grates, cleaning out dirt with shovel, re-installing all grates, screwing bolts and site cleaning.	It is applicable for all types of trench drains whose grates can be removed. Is feasible only if traffic conditions allows for crew members safely perform work along the entire length of drain. Not applicable for slotted drains and monolithic trench drains.	1 man hour to clean 10ft of trench drain (Observed). A 3 persons crew will clean 30 ft/hour	Requires closing of lane(s) adjacent to drains	Low environmental impact since no water is used.	Manual cleaning has to be performed on the knees which can cause back injuires. Other injuries may result from dropping grates on toes or back injuries resulting from improperly carrying heavy weight.
Sewer Cleaner	Using different types of nozzles as water jetting head to jet through the drain channel to have it thoroughly cleaned. Also, vaccum hose is used to collect the waste generated from cleaning.	Applicable for both trench drains and slotted drains.	180 ft / hour observed. Production rates can possibly by increased by further research in Phase 2.	Requires closing of lane(s) adjacent to drains. Large size of sewer cleaner causes a significant impact on traffic.	Large amount of water used in cleaning. Most of the water is not captured and flow into the storm water drainage network.	Safety rules and procedures for operating large equipment should be followed
Horizontal Directional Drills	Trenchless method of installing underground pipe, conduit, or cable by using a surface-launched drilling rig . Some companies have been using HDD to clean culvert and drains.	Applicable for both trench drains and slotted drains.	3-12 feet/minute (based on manufacturer information) depending on size/power of HDD rig and its ability to automatically load drilling rods.	Low impact on traffic since all cleaning will be performed from one cleaning location	Very little environmental impact, only a small amount of water may be needed.	Safety rules and procedures for operating large equipment should be followed
Horizontal Auger Boring	Continuous flights of augers are rotated and simultaneously pushed into the ground. As the length of auger is advanced into the hole, a new auger section is connected. As the bore progresses the ground is cut and the auger flights convey the material back to the starting point (cleanout location).	Applicable for both trench drains and slotted drains.	No production rate were available. Recommend field testing in Phase 2 to determine production rates	Low impact on traffic since all cleaning will be performed from one cleaning location	Very little environmental impact because it is a nearly dry operation.	Safety rules and procedures for operating large equipment should be followed

Figure 21. Matrix of Alternatives

If HDD is used successfully to clean drains there might be no need to close the lanes adjacent to the trench drains. The cleaning tools used with HDD technology are made of mild steel so that they won't damage the drains' bodies. One advantage of HDD compared to using a sewer cleaner is the significant reduction of water needed for cleaning. The amount of water that may be needed if HDD is used is a very small fraction (3-5%) of what is needed by the sewer cleaner. The HDD cleaning process can be completed in some cases completely dry without adding water. In other cases small amount of water can be added to loosen hard blockages. Also it has been reported that HDD can have a fast production rate (6 to 12 feet per minute) depending on the debris and the drill used (Harr Technologies 2016); a large drill such as a 10x15 Vermeer drill will be faster then a mini skid steer with a roto witch attachment.

Horizontal Auger Boring

Horizontal auger boring provides a safe method of boring a hole horizontally or cleaning a culvert. Continuous flights of augers as shown in Figure 23 are rotated and simultaneously pushed into the ground. As the length of auger is advanced into the hole, a new auger section is connected. As the bore progresses the ground is cut and the auger flights convey the material back to the starting point (cleanout location).

Figure 23. Horizontal Auger Boring

3- Provide an analysis of current equipment, materials and technology available for handling trench/slot drain maintenance.

3.1 Interviews of Equipment Manufacturers

The research team assembled a list of 4 manufacturers that design and produce equipment that the previous project's tasks have shown their potential for effectively cleaning trench slotted drains. Each manufacturer was phone-interviewed regarding their various models. The interview addressed maximum length of drain that can be cleaned, speed of cleaning/drilling, equipment cost and required training. Summary of the results of the phone interviews are included in Table 4. More information about the 4 manufacturers is provided in the following sections.

Harr Technologies

Harr Technologies has developed a method for cleaning and restoring clogged and damaged culverts using HDD technology. Harr has developed a set of tools and attachments for a horizontal directional drill (HDD). The tools as shown in Figure 24 come in several sizes to accommodate for different diameter culvers and include:

- A box pull bucket. The operator drills a pilot hole through a clogged culvert, connects a pull bucket to the drill pipe on the other end, and pulls back unwanted debris.
- A round pull bucket designed for round culverts. It works in a similar manner as the box pull bucket. An operator drills a pilot hole through a clogged culvert, connects a pull bucket to the drill pipe on the other end, and pulls back unwanted debris.
- A push bucket designed to push material out the far end of the culvert. Unlike pull bucket, a push bucket is connected to the drill stem at the beginning and it is pushed down a culvert, consequently forcing debris and material out of a culvert. It can also function as a scoop removing material bucket full at a time.
- A barrel Reamer: Barrel reamer is designed to loosen and remove heavy material located in the culvert. By utilizing rotational force and push force of horizontal directional drill, a barrel reamer is pushed trough a culvert while rotating. This allows to loosen compressed debris and forces it out of a culvert.
- A brush designed to fine clean a culvert.

Table 4. Summary of results of manufacturers' phone interviews

	Harr Technologies	Porta Mole	little beaver	ENZ
Type of Equipment	Culvert tools used for Horizontal Boring	Horizontal Boring	Horizontal Boring	Nozzle
Is it a completed system for boring	No-requires HDD drill (i.e. vermeer or ditch witch)	Yes	Yes	No-nozzles used with Sewer Cleaner
Has product been previously used for trench drain or culvert cleaning?	Yes	Yes	No	Yes
Recommended products for applications	Different tools including barrel reamer, push bucket, pull bucket & Forward arituculating reamer tool	TM9 , TM11	MDL-5H	Flounder
Type of drain product is suitable for	All types	Round – anywhere from ¾ " to 24"	Not for drains	All types
How long (in linear feet) can the equipment reach	Depends on type of HDD drill used in the cleaning	good to 150 ft	N/A	Depends on hose length on Sewer Cleaner
What is the typical speed of drilling	6-12 feet per minute depending on HDD drill used	3-5 feet per minute with light resistance or 1 - 2 feet per minute with hard resistance	Varies	
How much does the product cost	Culvert cleaning tools cost $300-1000 each. Cost of HDD extra	$7500.00 to $20,000.00	$2,700.00 - $5,000.00	Nozzles cost $500-1000 each. Cost of Sewer cleaner extra
How much training is needed for crew members	Simple tool / training can be provided over the phone	4-6 hours recommended	Very little	Very little

- A forward articulating reaming tool which uses an internal coil to draw debris into a holding cylinder so it can be removed from the drainage structure. The tool is attached and rotated by an HDD drill. As the drill moves forward with the tool rotating, debris is loaded inside the cylinder. Once the cylinder is loaded, the HDD drill backs up until the tool exits the structure; then reverses rotation to remove the debris.

Figure 24. Harr Technologies tools and attachments to HDD drills (Source: http://www.harrtech.com/)

Portamole

As shown in Figure 25, the portamole is a compact lawn-mower size horizontal boring machine that has been used to clean culverts. The machine uses a 5-9 hp motor to drive a drill stem at 600 rpm. A small stream of water goes through the stem to cool the bit and flush out the cuttings. Different bits allow drilling through virtually any rock or soil. The Porta-Mole can be purchased for less than $7,500. When the boring is underway, forward speed is controlled by a hand winch mounted on the machine. Porta mole small sizes allows a 3 person crew to load it and unload it by hand. Because the bore stem is flexible, it operates at ground level. Crews do not need to spend time digging and filling large access holes. Porta-Mole™ Boring Machines can easily be transported in a small truck or can be purchased with a complete Trailer Package that includes a 16' Double Axle Trailer, Water Tank, and Water Pump.

Figure 25. Portamole Horizontal boring unit (Source: http://www.portamole.com/)

Little Beaver

The Little Beaver is a small boring unit that is used to make small straight horizontal bores. As shown in Figure 26, the Little Beaver offers two types of boring attachments: the dry-type horizontal boring attachment uses a 5 foot long by 3 inch diameter auger to drill under sidewalks for conduit water pipe or irrigation installation.

The little beaver wet type horizontal boring attachment uses standard schedule 80 three-quarter inch water pipe, a special swivel adapter and a drill bit to bore horizontal holes up to 50 feet in length. The special water drill bit is screwed on the leading end of the water pipe. As many sections of water pipes to complete the hole may be assembled. As the drill bit loosen soil the stream of water coming out of the bit carries spoil from the hole keeping the hole flushed and open.

The little beaver has not been previously used to clean culvert/drains and has a limited reach (50 feet). It has been excluded from further analysis.

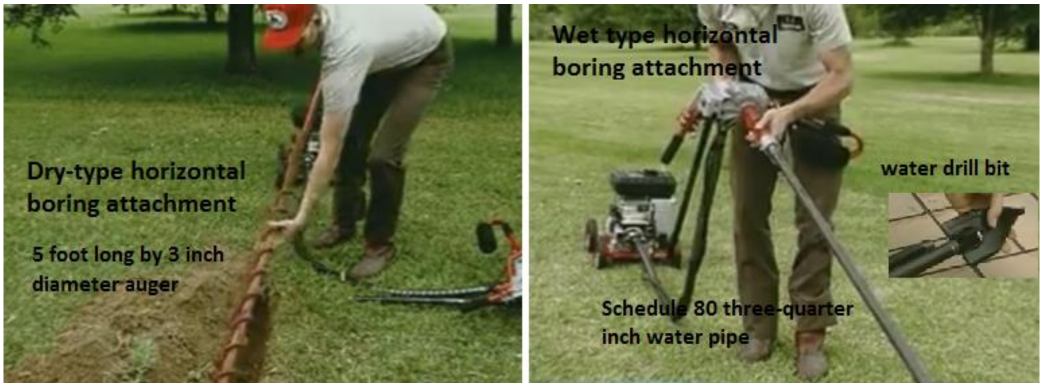

Figure 26. Little Beaver boring attachments (Source: http://www.littlebeaver.com/)

ENZ

ENZ offers a large range of high quality pipe cleaning tools that are used in conjunction with Hydrojetting equipment. The research team has already tested two different ENZ nozzles during the third site visit as discussed in section 1.2. The ENZ representative has indicated that the company can customize their existing nozzles to meet their customers' needs. For example, he noted during the third site visit that the Flounder nozzle can be modified by adding a high pressure forward jet that is capable of tearing through tough blockage while keeping the water splashing to a minimum.

3.2. Cost/Benefit Analysis

To be able to perform a cost benefit analysis of the recommended equipment, the cost of the manual method had to be first determined as follows:

3.2.1 Cost of Manual method of cleaning

The hourly crew wages were obtained from ODOT as follows:

- Highway Tech (with overhead): $36/hr

As was indicated in section 1.2, the second site visit has calculated the manual cleaning method has a production rate for 10ft/ manhour. Thus it costs $3.6 to clean a linear feet of trench drain.

3.2.2 Hourly cost of recommended equipment

The hourly ownership cost were calculated as explained below. The calculated hourly costs were compared to rental costs found on the internet to ensure accuracy. Ownership costs are those costs which accrue whether or not the equipment is used. For ODOT, the ownership cost is the purchase price. The hourly ownership cost can then be calculated by dividing the purchase price by (an expected use rate per year multiplied by the useful life of the equipment). It should be noted that both the expected use rate per year and the equipment's useful life will have a significant impact on the outcome of the cost analysis and therefore should be carefully determined. The research team got feedback on both the expected use rate and the equipment useful life from the equipment manufacturers as shown in Table 5.

Table 5. Calculating hourly cost of recommended equipment

	Sewer truck	**Vermeer D10x15 with Harr tools**	**Skid Steer HDD with Harr tools**	**Portamole**
Expected use rate per year (hrs/year)	300	100	100	100
Useful life (years)	10	10	10	5
Purchase Price ($)	350000	150000	45000	10000
Hourly ownership cost ($/hr)	116.67	150	45	20
Yearly maintenance costs ($)	2000	1000	500	200
Hourly maintenance/repair costs ($/hr)	6.67	10	5	2
Total hourly costs ($/hr)	123	160	50	22

3.2.3 Comparative Cost Analysis of Proposed Equipment

Once the hourly costs of the proposed equipment are calculated, a comparative cost analysis comparing the proposed equipment can be performed by knowing the production rate of each process, the required crew composition, hourly rate of the equipment used, and crew wages.

The production rates of the various equipment and how these rates were determined are shown in Table 6:

Table 6. Production rates of recommended equipment

	Sewer cleaner	**Vermeer D10x15 with Harr tools**	**Skid Steer HDD with Harr tools**	**Portamole**
Production rate (feet per minute)	3	10	6	3
Source of Production rate information	Observed	Manufacturer	Manufacturer	Manufacturer
Feet of drain cleaned per hour	180	600	360	180

The water used by each method is also needed to calculate the cost of cleaning drains. The water consumption is shown in Table 7.

Table 7. Water consumed by recommended equipment

	Sewer cleaner	Vermeer D10x15 with Harr tools	Skid Steer HDD with Harr tools	Portamole
Water used in gallons per feet	5.5	0.3	0.3	0.7
Source of water consumption information	Observed	Manufacturer	Manufacturer	Manufacturer
Cost of water ($/LF) (assuming 0.8 c/gallon)	0.044	0.0024	0.0024	0.0056

The production rates, the water consumption and the hourly equipment and crew costs were used to calculate the cost of cleaning drains ($/LF) using the various equipment as shown in Figures 27, 28, 29 and 30.

Sewer truck			
	$/hr	#	Total ($/hr)
Sewer truck	123.33	1	123.33
Highway Tech.	36	4	144
Total Hourly Cost			$ 267.33
Production Rate (feet/hour)			180
Cost per feet (excluding water)			$ 1.49
Total Cost per feet			$ 1.53

Figure 27. Cost of cleaning drains ($/LF) using a sewer cleaner

Skid Steer HDD with Harr tools			
	$/hr	#	Total ($/hr)
Skid Steer	50.00	1	50.00
Highway Tech.	36	4	144
Total Hourly Cost			$ 194.00
Production Rate (feet/hour)			360
Cost per feet (excluding water)			$ 0.54
Total Cost per feet			$ 0.54

Figure 28. Cost of cleaning drains ($/LF) using a skid steer HDD drill with rotowitch & Harr tools

Vermeer D10x15 with Harr tools			
	$/hr	#	Total ($/hr)
Vermeer D10x15	160.00	1	160.00
Highway Tech.	36	4	144
Total Hourly Cost			$ 304.00
Production rate (feet/hour)			600
Cost per feet (excluding water)			$ 0.51
Total Cost per feet			$ 0.51

Figure 29. Cost of cleaning drains ($/LF) using a Vermeer D10x15 with Harr tools

Portamole			
	$/hr	#	Total ($/hr)
Portamole	22.00	1	22.00
Highway Tech.	36	4	144
Total Hourly Cost			$ 166.00
Production Rate (feet/hour)			180
Cost per feet (excluding water)			$ 0.92
Total Cost per feet			$ 0.92

Figure 30. Cost of cleaning drains ($/LF) using a Portamole

4- Provide an interim report detailing the findings from all the above steps. Recommend solutions for infield testing and analysis

4.1- Recommend solutions for infield testing and analysis

In Phase 2 of the project, the research team recommends using an HDD drill with Harr technologies' tools to clean trench and slotted drains. It should be noted that there is a large number of HDD drills in the market with varying power and initial costs ($30,000 to $150,000). The preliminary cost analysis performed for two HDD drills has shown that the Vermeer D10X15 has similar cleaning costs per linear feet of drain to the skid steer HDD drill. However more research should be performed in Phase 2 to determine which HDD drill is more appropriate for cleaning drains. Initial cost should not be the only factor used in the selection process since the added torque power of larger HDD drills will increase speed and enable the cleaning of longer drains from one cleanout location without the need to move the drill. The added torque power will also allow the research team to investigate the use of continuous flights of augers to convey the debris from the drain back to the clean out location. Mr. Dan Wise has already developed a prototype auger that can be used in this application as shown in Figure 31.

Figure 31. Prototype of augers to clean drains

The research team suggests that before spending money to purchase the HDD drill ($150K in case of the Vermeer D10x15 drill), that in Phase 2, we rent the unit and work with Mr. Bob Harr of Harr Technologies to ensure that the HDD process will work for cleaning the drains. We already contacted Mr. Harr and he is willing to provide a demonstration of how his tools can be used in conjunction with an HDD drill to clean trench/slotted drains.

The research team also recommends improving the process of cleaning trench/slotted drains with a sewer truck. Although the preliminary cost analysis has shown that this process is more expensive than using HDD technology, the research team believes that one reason for the high cost is the low production rate that was achieved during the third site visit because of frequent work stoppages. We recommend that more research be conducted in phase 2 to further improve the performance of a sewer truck by designing a stepped cleaning process and identifying a suitable nozzle that eliminates the need for a crew person having to pull a wooden board. It is the research team's judgment that pulling a board to control water splashing is not very safe particularly in high traffic areas. Nozzles' manufacturers such as ENZ can typically work with their customers to manufacture a suitable nozzle. It is recommended that in phase 2, the research team work with nozzle manufacturers to develop a nozzle whose spray pattern of the water jets prevent any water from splashing up directly which would eliminate the need for using a wooden board to cover the top holes of the grates and the need to clean up around work areas.

The research team recommends that in Phase 2, a trench maintenance plan should be developed and adopted by ODOT. A maintenance plan enable maintenance crews to periodically clean the drains cost-effectively before they become completely clogged in which case they require more expensive cleaning methods or in some cases total replacement with significant cost to ODOT.

As part of Phase 1, the research team conducted a preliminary evaluation of using cleaning robots to clean trench drains. Cleaning robots such as the one shown in Figure 32 are successfully being used to clean and suck settled material in large sewage pipelines (larger than 30” in diameter), manifolds and tunnels. They are remotely controlled from outside, and are equipped with a drilling head and a suction tube that is connected to either a suction excavator or a vacuum truck (Sewer Cleaner). Some models are equipped with water blast nozzles and various auger attachments that break up hard soil for easier suction/removal.

Since no cleaning robot that is small enough to fit in the trench drain exists in the market, a preliminary cost analysis for this technology could not be performed. However, the research team recommends working with faculty from the mechanical engineering department and/or robotic companies in Phase 2 to develop a prototype robot for cleaning drains.

Figure 32. Prototype of augers to clean drains (Source: http://www. suction-excavator.com)

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