EFFECTIVE AND ECONOMICAL CLEANING OF PIPES AND UNDERDRAINS

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16. Abstract		
The Ohio Department of Transportation (ODOT) maintains 43,000 lane miles of roadway in order to allow the public to safely and efficiently travel throughout Ohio. Pavement conditions play a major role in the efficiency and safety of the traveling public, as well as public opinion towards ODOT. The public's increasing demand to have roadways clear of potholes and cracks motivates ODOT to explore various methods of extending the lifespan of the roadways without an increase in budget. ODOT currently spends approximately $523 million dollars on pavement projects and an additional $25 million on maintaining the roadways (not including snow and ice operations) in the fiscal year 2015 (ODOT, 2015). One method that may increase the service life of pavement is to reduce the amount of standing water on the roadways by cleaning pipes and underdrains. The results of this project will provide ODOT with a cleaning method necessary for maintaining pipes and underdrains that may be more efficient than he current practices of ODOT. In addition, the project provides recommendations for equipment that is specialized in cleaning smaller pipes and drains that will utilize an existing ODOT vehicle located at the Portage County Garage in District 4.		
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Customary Unit	SI Unit	Factor	SI Unit	Customary Unit	Factor
Length			Length		
inches	millimeters	25.4	millimeters	inches	0.039
inches	centimeters	2.54	centimeters	inches	0.394
feet	meters	0.305	meters	feet	3.281
yards	meters	0.914	meters	yards	1.094
miles	kilometers	1.61	kilometers	miles	0.621
Area			Area		
square inches	square millimeters	645.1	square millimeters	square inches	0.0016
square feet	square meters	0.093	square meters	square feet	10.764
square yards	square meters	0.836	square meters	square yards	1.196
acres	hectares	0.405	hectares	acres	2.471
square miles	square kilometers	2.59	square kilometers	square miles	0.386
Volume			Volume		
gallons	liters	3.785	liters	gallons	0.264
cubic feet	cubic meters	0.028	cubic meters	cubic feet	35.314
cubic yards	cubic meters	0.765	cubic meters	cubic yards	1.308
Mass			Mass		
ounces	grams	28.35	grams	ounces	0.035
pounds	kilograms	0.454	kilograms	pounds	2.205
short tons	megagrams	0.907	megagrams	short tons	1.102

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DOT – Department of Transportation

ft – Foot or Feet

gpm – Gallons Per Minute

lbs - Pounds

ODOT – Ohio Department of Transportation

psi – Pounds Per Square Inch

PVC – Polyvinyl Chloride

VJT – Vacuum Jet Truck

CHAPER I INTRODUCTION

The Ohio Department of Transportation (ODOT) maintains 43,000 lane miles of roadway in order to allow the public to safely and efficiently travel throughout Ohio. Pavement conditions play a major role in the efficiency and safety of the traveling public, as well as public opinion towards ODOT. The public's increasing demand to have roadways clear of potholes and cracks motivates ODOT to explore various methods of extending the lifespan of the roadways without an increase in budget. ODOT currently spends approximately $523 million on pavement projects and an additional $25 million on maintaining the roadways (not including snow and ice operations) in the fiscal year 2015 (ODOT, 2015).

One method to preserve the pavement conditions on the roadways is to reduce the amount of standing water left on the roads. Water on roadways not only damages pavement but also creates unsafe conditions for the traveling public. To combat standing water, drainage systems are implemented along roadways. Drainage systems consist of underdrains, culverts, catch basins, and ditch line trenches as presented in Figure 1.1.

(a) Underdrain

(b) Culvert

(c) Catch Basin

(d) Ditch Line Trench

Figure 1.1: Samples of Various Drainage System Components – (a) Underdrain, (b) Culvert, (c) Catch Basin, & (d) Ditch Line Trench.

An underdrain is a 50 to 200 feet (ft) long pipe that runs perpendicular to the main sewer line of the roadway. The pipe has a diameter ranging from four to six inches with a pipe entry located 10 to 100 feet from the nearest roadway. A culvert is a tunnel carrying water under a road and is an open drain. Catch basins, or storm drain inlets, are typically a box-like structure moving the water from the top of the road surface into the sewer line system while allowing water to be retained during heavy flows. Ditch line trenches run parallel to the roadway. Unfortunately, the drainage systems tend to gather more than just water. The draining water carries debris and sediment into these drains causing a reduction in water flow through the pipe or drain. These blockages require the cleaning of pipes and drains in order to remove the water properly from the roadway. Optimizing the methods and equipment used to conduct these cleanings will extend the lifespan of pavement at a reduced cost.

ODOT's current method to clean these pipes is to use a Vacuum Jet Truck (VJT). The VJT is a massive piece of equipment retrofitted with a pump connected to a water tank, and a vacuum system connected to a debris tank as presented in Figure 1.2.

Figure 1.2: Vacuum Jet Truck.

This truck is able to assist with cleaning all aspects of the drainage system since it is able to vacuum up debris and push high-pressured water through to remove blockages. This equipment is very versatile and, therefore, appealing to agencies such as ODOT. Unfortunately, most VJTs have a high capital cost of approximately $500,000 depending on capacity and attachments. This high capital cost affords each ODOT district the ability to purchase one or two VJTs. For routine cleanings, sharing a VJT may work reasonably; however, during periods of heavy rainfall or massive snow melting events, problems with drainage may occur in multiple counties at the same time. Additionally, due to the truck's massive size, it must park on the shoulder of a roadway requiring additional ODOT employees to conduct traffic control, which in turn reduces the traffic flow on that roadway and exposes ODOT employees to the motorized public. The truck's location on the shoulder may also reduce the cleaning efficiency for underdrains due to the hose controllers being located on the truck (not at the operator's end), restricting the operator's ability to change pressure settings. Though the VJT is ideal for some drainage maintenance, it may be over-designed for maintenance that does not require all the various capabilities. This is especially true for underdrains, which do not require the vacuum hose or debris storage tank.

Due to some of the limitations with the VJT, the goal of this research is to examine alternative cleaning processes for underdrains to increase the efficiency of production while reducing cost. Some of the key limitations of the VJT to remedy with an alternative method are:

- Allowing the hose system to be controlled at the end of the hose rather than on the truck which may be far from the underdrain,
- A smaller unit that may be placed away from the road closer to the pipe, which reduces the need for traffic control and traffic delay,
- A more economical system to allow more units to be acquired and less issues in sharing the equipment, and
- Still meeting the effectiveness of the VJT when cleaning underdrains.

In order to determine the optimal method and equipment for cleaning underdrains, the following objectives for this research project are:

- Objective One – Create a matrix of current practices of ODOT and other state departments of transportation (DOT),
- Objective Two – Determine efficient and economical means or equipment to clean pipes, and
- Objective Three – Recommend potential solutions for an in-field evaluation to be done in Phase Two.

As outlined in the objectives, this report consists of three chapters. Chapter One is the introduction which explains the current issues and reasons for the research. Chapter Two describes the current practices, and includes a literature review, a national survey, and an in-state survey. Chapter Three makes the recommendations for methods to improve pipe and underdrain cleaning.

CHAPER II STATE OF PRACTICE

The goal of this chapter is to present ODOT with the current state of the practice for underdrain cleaning and maintenance. The state of the practice will enable ODOT to compare its methods with methods used by other states and municipalities. This chapter is divided into three sections:

- Section One – National Survey,
- Section Two – In-State Survey, and
- Section Three – Synthesis of State of the Practice.

These sections may allow an adequate overview for cleaning and maintaining underdrains.

2.1 National Survey

The national survey is created with the intention to gather information on the current best practices on cleaning underdrain pipes at the national level. These current practices include details on the main equipment used to clean pipes and underdrains, the lifespan of the main equipment, alternative equipment that may be used, the process of cleaning underdrains with various types of equipment, and any recommendations pertaining to the equipment or cleaning process. Figure 2.1 below presents all the states that answered the survey questions.

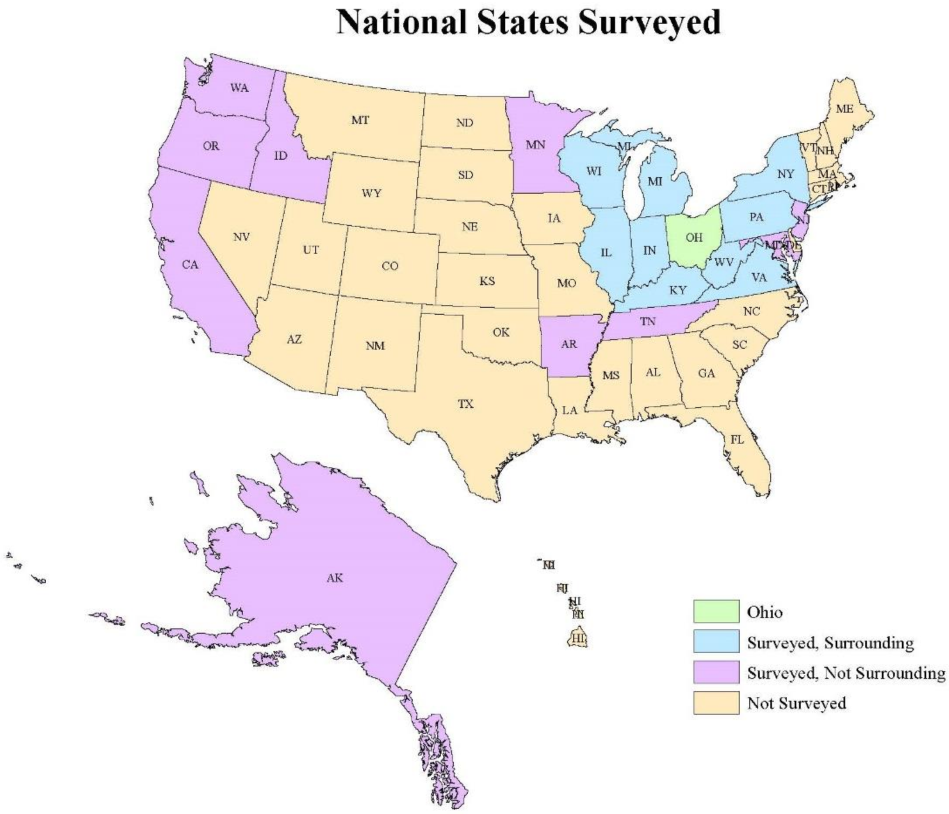


Figure 2.1: States Surveyed for Current Practices; 19 States Total Surveyed.

As seen in Figure 2.1, a total of 19 states were surveyed about their underdrain maintenance. Though it is important to speak with states all across the county, the information provided by the states surrounding Ohio may be more relatable to Ohio. For example, western states periodically experience droughts, and therefore, tend to move away from systems which require excessive water. This makes sense in those states; however, Ohio doesn't experience the same issues; therefore, their goals and methods may not align with those of ODOT. Note that all other states were contacted multiple times without success. The survey questions and responses are summarized in Table 2.1 below. The responses to the questions have been quantified and compiled for the purposes of comparison.

Table 2.1: National Survey Summary Table.

	Total States		**Surrounding States**	
	Count	**Percent**	**Count**	**Percent**
Question and Responses	19		9	
Equipment Currently Use				
Vacuum Jet Truck	10	52%	4	44%
Hydro-Jet / Jetter	8	43%	4	44%
Sewer / Drain Flusher	1	5%	1	12%

Equipment Cost				
Vacuum Jet Truck $300,000 - $500,000	6	32%	1	11%
Hydro-Jet / Jetter - $60,000	2	11%	1	11%
Sewer / Drain Flusher - $250,000	1	5%	0	0%
Did Not Know	10	52%	7	78%
Lifespan of Equipment				
10-12 years	3	16%	2	22%
15 years	3	16%	0	0%
20+ years	5	26%	1	11%
Did Not Know	8	42%	6	67%
Equipment After Lifespan				
Sold at Auction	12	63%	4	44%
Did Not Know	7	37%	5	56%
Alternate Cleaning Equipment				
Backhoe & Shovels	3	16%	1	11%
Bucket Machine	2	11%	0	0%
Sewer Cleaner	2	11%	1	11%
Water / Jetter Trailer	9	46%	2	22%
None	3	16%	5	56%
Additional Equipment Needed				
Standard Dump Truck	2	11%	0	0%
Standard Pickup Truck	2	11%	2	22%
None	15	78%	7	78%
Procedure to Find Underdrains				
Mapped Locations	4	21%	1	11%
Visual Inspection	2	11%	0	0%
Did Not Know	13	68%	8	89%
Step if Underdrain Not Found				
Excavate / Dig Up	3	16%	1	11%
Mark as Not Found	1	5%	0	0%
Did Not Know	15	78%	8	89%
Concern with Main Equipment				
Maintenance	1	5%	1	11%
Getting Stuck Off-road	2	11%	0	0%
Equipment Too Big for Pipe	3	16%	0	0%
No Concerns	13	68%	8	89%
Improve Cleaning Equipment				
Additional Attachments	1	5%	1	11%
Better Off-road Equipment	1	5%	0	0%
More Underdrain Maintenance	4	21%	0	0%
No Improvements Needed	13	69%	8	89%

Concern with Cleaning Process				
Regularly Scheduled Maintenance	1	5%	0	0%
Equipment Stuck Off-road	2	11%	0	0%
Refilling Water Tanks	2	11%	0	0%
No Concerns	14	73%	9	100%
Recommendation for Cleaning Process				
Custom Alternative Equipment	1	5%	0	0%
Equipment Inspections	2	11%	0	0%
Larger Water Tank	1	5%	0	0%
Regular Pipe Maintenance	2	11%	1	11%
No Recommendations	13	68%	8	89%

Note: Survey conducted fall/winter 2016.

The research team understands the importance of speaking with states across the country since new techniques may be learned. The questions were answered to the best of the phone interviewees' abilities. The interviewees were mainly equipment managers at the district or region level at the states' departments of transportation.

The phone conversions have revealed many interesting findings. Table 2.2 provides some of the key findings from the national survey.

Table 2.2: Key Findings from National Survey.

State DOT	Other Key Points from National Survey
Alaska	Has a map of all underdrains throughout the state. Only owns VJT; therefore uses water to flush out pipes. Does not clean pipes properly.
Arkansas	Cleans with a Sewer Drain Flusher. Known to get stuck if going off-road to clean underdrains. Notes that square connections in underdrain clog more frequently than smooth curves.
Indiana	VJT is main equipment; uses a power rodder to clean pipes with diameter < 8". Purchases water to fill tank and also pays to properly dispose of waste.
Pennsylvania	Hydro-Jet is used to clean underdrains and catch basins. Requires standard pickup truck to pull hydro-jet on a trailer. Due to low funding and small budget, hydro-jet is best bang-for-buck to clean.
Washington	Created a custom-built vehicle to clean longer pipes. Typically uses VJT to clean all pipes.

Note: More information about the survey responses is available upon request. Survey conducted fall/winter 2016.

Some of the key findings from the national survey include the Alaska DOT owning a map of every underdrain location in the state, the Arkansas DOT cleaning underdrains with a sewer drain flusher known to get stuck when cleaning off-road pipes, the Pennsylvania DOT cleaning pipes with a hydro-jet trailer due to low funding for maintenance in their budget, and the Washington DOT creating a custom vehicle to clean longer underdrain pipes which the VJT cannot clean properly. A few contacts recommended looking into various nozzles and attachments that are used to prevent problems when clearing tree roots. These data may assist the research team when determining the optimal method and equipment ODOT should implement for underdrain cleaning. More details are provided in Section 2.3 of this report.

2.2 In-State Survey

In order to further understand the equipment used for cleaning pipes, an in-state survey was also conducted. This survey was conducted through phone interviews between the research team and municipalities, contractors, and vendors. The focus of the surveys was to identify the main equipment used to clean pipes, the equipment used to clean smaller diameter pipes, and problems that arise when cleaning pipes.

2.2.1 Municipalities

The first point of contact for the research team was the municipalities within the state of Ohio. There were 157 out of 648 municipalities that provided information. Note that the municipalities for which no data were available were contacted several times without success. Table 2.3 presents the questions and responses from the municipalities that provided data.

Table 2.3: Survey Questions and Reponses from Municipalities.

Question and Response	**Count**	**Percentage**
	157	
Routine Cleaning of Pipes		
Yes	52	33%
Yes, Contracted Out	41	26%
As Needed	24	15%
No	14	9%
No, Culverts Only	3	2%
No, Ditch lines Only	18	11%
No, Culverts and Ditch lines	4	3%
Did Not Answer	1	1%
Equipment Used To Clean Pipes		
Vacuum Jet Truck	61	38%
Hydro-Jet / Jetter	16	10%
Backhoe and Man Power	26	16%
Fire Truck	9	6%
Auger	1	1%
Bucket Machine	1	1%
Rodder	1	1%
Tractor	1	1%
Did Not Know (Contracted)	41	26%
Routine Cleaning Of Underdrains		
Yes	16	10%
As Needed	23	15%
No	37	23%
Do Not Have Underdrains	81	52%
Equipment Used To Clean Underdrains		
Vacuum Jet Truck	15	9%
Hydro-Jet / Jetter	14	9%
Backhoe and Man Power	8	5%
Fire Truck	1	1%
Did Not Know	38	24%
Do Not Have Underdrains	81	52%

Note: Survey conducted fall/winter 2016.

The interviewees were facility managers and engineers at each of the municipality facilities. The team understood that surveying municipalities from across the state was more beneficial for research purposes than surveying only select municipalities as more new knowledge may be gained through this process.

As shown in Table 2.3, 26% of municipalities contract out their routine pipe cleaning. Additionally, 38% of them use a VJT and 10% use a hydro-jet. On top of that, 10% routinely clean out their underdrains, while 52% don't have underdrains in their service area. Table 2.4 summarizes the key findings from the survey.

Table 2.4: Municipalities Survey Results.

Key Points	Key Findings of the Municipality Survey
Main Equipment Used to Clean Pipes	38% of municipalities use the VJT to clean pipes, 26% hire a contractor to clean pipes, 16% use a backhoe, 10% use a hydro-Jet, 6% use a fire truck with a modified hose attachment, The remaining municipalities use rodding machines, bucket machines, augers, or preventative methods using street cleaners.
Equipment Used to Clean Underdrains	26% of municipalities hire a contractor to clean smaller pipes, 9% use a hydro-Jet, 6% use manpower or fire trucks with a modified hose attachment, 9% use VJT. All the municipalities that have a hydro-jet use it to clean smaller pipes if any of these pipes are located within their jurisdiction. Municipalities that use a VJT to clean smaller pipes hire a contractor if the VJT cannot reach the pipe.
Problem Areas	The VJT cannot travel off-road to clean smaller pipes. 46% municipalities that have underdrains lack portable equipment to clean pipes with an entry located off the road, which causes them to hire a contractor.

Note: More information about the survey responses is available upon request. Survey conducted in fall/winter 2016.

The results show that the municipalities use a variety of equipment to clean pipes. The majority of them use a VJT. Many smaller municipalities desire to purchase a VJT, but at the present time, do not have the funds to purchase it. Many municipalities indicated that the VJT has difficulty reaching off-road pipes, which is similar to issues that ODOT has experienced. All municipalities that currently own a hydro-jet use it for smaller pipes exclusively. Of the municipalities which have underdrains in their service areas, 46% hire a contractor to clean small pipes located off the road due to the lack of equipment available at certain locations.

2.2.2 Contractors

Particular municipalities provided the contact information for the contractors. The research team spoke to 21 of the contractors out of the total of 43 called. The contractors provided information regarding the equipment that they use to clean pipes. Table 2.5 presents a summary of the survey questions and responses from the pipe cleaning contractors used by many municipalities.

Table 2.5: In-State Survey of Contractors Summary of Pipe Maintenance.

		Count	**Percent**
Questions and Responses		21	
Vacuum Jet Truck To Clean Pipes			
	Yes	13	62%
	No	7	33%
	Did Not Answer	1	5%
Pipe Specifications Cleaned By Vacuum Jet Truck			
	> 6"	12	57%
	Non-Storm Pipes	3	15%
	Did Not Answer	6	28%
Hourly Rate for Vacuum Jet Truck			
	$180/hour	1	5%
	Multiple Determining Factors	2	10%
	Not Able To Answer	18	85%
Jurisdiction Of The Pipes Cleaned			
	Northeast Ohio	3	15%
	Northwest Ohio	1	5%
	No Jurisdiction	17	80%
Equipment Used To Clean 4"-6" Pipes			
	Hydro-Jet	18	85%
	Vacuum Jet Truck	1	5%
	Combination	1	5%
	Did Not Answer	1	5%
Why Use Alternative Equipment In Place Of Vacuum-Jet Truck?			
	Vacuum Jet Truck Is Too Big	20	95%
	Vacuum Jet Truck Cannot Reach Off-road	1	5%
Initial Cost Of This Equipment Used To Clean Smaller Pipes?			
	$25,000-$50,000	1	5%
	Not Able To Answer	20	95%

Hourly Rate For Using Alternate Equipment?			
	$140-$275 per hr.	2	10%
	$1000 per day	1	5%
	Determined After Inspection	1	5%
	Not Able To Answer	17	80%

Note: Survey conducted fall/winter 2016.

As presented in Table 2.4, 62% of contractors utilized a VJT; however, when asked about 4" to 6" pipe cleanings, 85% utilize a hydro-jet. Table 2.6 summarizes the findings of the key questions asked.

Table 2.6: Contractor Survey Results.

Key Points	**Key Findings from Ohio Contractor Survey**
Main Equipment Used to Clean Pipes	62% of contractors surveyed use the VJT to clean pipes. 24% use only the hydro-jet. All of the contractors clean pipes higher than 8 inches when using the VJT.
Equipment Used to Clean Smaller Pipes	85% use the hydro-jet to clean smaller pipes. 5% of the contractors use a Combination Trailer due to the buildup of gravel around the entry of the pipe.
Problem Areas	VJT cannot reach the pipe entry due to the large size of the truck or the large size of the hose. High pressure output of the VJT may damage the pipe.

Note: More information about the survey responses is available upon request. Survey conducted in fall/winter 2016.

All of contractors use the VJT to clean pipes that are greater than eight inches in size. Multiple contractors state that the VJT is less effective than a hydro-jet in cleaning small off-road pipes. When it comes to pipes with a smaller size the majority of contractors use the hydro-jet trailer.

2.2.3 Vendors

In some cases the contractors provided contact information for multiple vendors. Seven out of the ten vendors the research team contacted provided information about the equipment used to clean pipes. Table 2.7 provides information about the survey questions and results.

Table 2.7: In-State Survey Summary of Sewer-Maintenance Vendors.

		Count	Percent
Questions and Responses		8	
Equipment to Best Clean Underdrains			
	Hydro-Jet / Jetter	8	100%
Equipment Tank Sizing			
	Small (low flow/low pressure)	3	38%
	Medium (lasts longer than a few minutes)	4	50%
	Did Not Answer	1	12%
Why Specific Pump Pressure When Cleaning			
	Properly Clean Without Damaging	8	100%
Disadvantages of Equipment			
	Tank Too Small	2	25%
	Trailer Not As Mobile	4	50%
	Did Not Answer	2	25%
Advantages of Equipment			
	Trailer May Carry Large Tank	1	12%
	Truck Mount Is More Mobile	4	50%
	Did Not Answer	3	38%
Volume and pressure relationship			
	Volume Will Not Affect Pressure	4	50%
	Volume Will Affect Pressure	2	25%
	Did Not Answer	2	25%
Diameter of Hose on Equipment			
	3/8"	4	50%
	1/2"	1	12%
	Did Not Answer	3	38%
Length of Hose on Equipment			
	200 feet	2	24%
	300 feet	3	38%
	500+ feet	3	38%
Pressure Nozzle Attachment for Equipment			
	May Attach Or Has A Pressure Nozzle	3	38%
	Does Not Have Pressure Nozzle	1	12%
	Did Not Answer	4	50%
Jet Mounted to a Frame, Easily Installed on Truck			
	Yes	6	76%
	No	1	12%
	Did Not Answer	1	12%

Note: Survey conducted fall/winter 2016.

As seen in Table 2.7, all vendors recommend a hydro-jet when cleaning underdrains. The hydro-jet's smaller size and mobility make it ideal for cleaning underdrains according to the vendors. Also, the underdrains do not require all the capabilities of some of the other equipment for pipe cleaning, such as the vacuum functions on the VJT. Additional key points from the vendor survey are summarized in Table 2.8.

Table 2.8: Vendor Survey Results.

Key Points	Key Findings from Vendors Survey
Main Equipment to Clean Pipes	Each vendor recommends using a VJT when cleaning pipes that are over 12 inches.
Equipment Used to Clean Smaller Pipes	All of the vendors recommend the use of the hydro-jet to clean pipes smaller than 12 inches.
Problem Areas	The VJT is too large to travel off the road. The further off the road the pipe entry is located, the lower the VJT's cleaning efficiency will be. The VJT has a higher probability of damaging smaller pipes due to the large amount of pressure output.

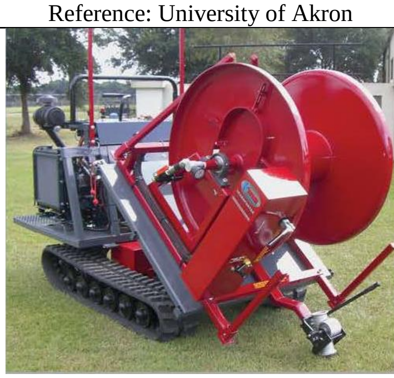
Note: More information about the survey responses is available upon request. Survey conducted in fall/winter 2016.

The vendors all recommended using the VJT to clean any pipe with a diameter over 12 inches and the hydro-jet for all pipe diameters under 12 inches. A majority of the vendors state the VJT should not be used for pipes located off the road and have smaller diameters.

2.3 Synthesis of State of the Practice

The national and in-state surveys suggest that five separate pieces of equipment have been identified for cleaning pipes. The pieces of equipment are a bucket machines, a combination trailer, an easement machine, a hydro-jet, and a rodding machines. Table 2.9 illustrates the types of equipment and their features.

Table 2.9: Types of Alternative Equipment.

Types of Alternative Equipment	
 Reference: Sreco Flexible	**Bucket Machine** A bucket machine is a trailer mounted or fixed piece of equipment. The machine operates with a bucket attached to a pulley that may be lowered into a manhole or pipe system. The bucket machine extracts the waste out of pipe and the waste is then pulled up on a conveyor belt with a cradle shaker at the top. The waste is eventually dumped into the back of a truck.
 Reference: University of Akron	**Combination Trailer** A combination trailer is a trailer mounted machine with a vacuum and pump system. The combination trailer is essentially a smaller version of the VJT and may be modified with an optional filtration system.
 Reference: KWMI Equipment Machine	**Easement Machine** An easement machine may be mounted on the bed of a truck or transported to the site using a trailer. The easement machine is a hose reel mounted on treads. The hose is connected to the water supply and may travel up to 600 ft to any off-road pipe entry. The weight of the machine is distributed throughout the treads allowing for minimal to no damage to the site.
 Reference: Cam Spray	**Hydro-Jet** A hydro-jet is a trailer or truck mounted pump system which uses the flow of water to push the obstruction from the pipe.
 Reference: Sewer Equipment Co. of America	**Rodding Machine** A rodding machine is a cart, truck, or trailer mounted machine. The rodding machine uses a cable with a head extension to push the obstruction through the pipe or pull the obstruction out of the pipe.

Note: There may be other options; however, these are the alternatives mentioned in surveys. Additionally, many agencies or companies custom build their own systems.

Each of the alternative equipment has respective advantages and disadvantages. The process of analyzing each piece of equipment will provide additional information that will aid in identifying the precise equipment that will be necessary for the cleaning of underdrains. Table 2.10 provides the advantages and disadvantages of the alternative equipment.

Table 2.10: Alternative Equipment Analysis.

Alternative Equipment	Advantages	Disadvantages	Summary
Bucket Machine	Smallest equipment Easy transportation Minimum manpower for operation	Mounting is required for operation Long setup time Dangerous	Time consuming method that is mainly used for larger pipes than a typical underdrain utilizing a small crew. Safety is also an issue for this particular equipment selection.
Combination Trailer	Large water tank Water recirculation Hydro-excavating	Produces large amount of waste Equipment is heavy Only applicable on/near road Hose must be transported to pipe	Large, immobile equipment that essentially reduces to a hydro-jet due to its inability to use the vacuum system.
Easement Machine	Highest mobility Handles 34”-46” gates Transports hose to pipes Minimal setup time Minimal to no damage to site	Requires a water source	Extremely mobile and efficient equipment that requires minimal set up time and site damage. The easement machine, though, requires a water source to be hooked which has proved problematic.
Rodding Machine	Light weight Cleans pipes when temperatures are below freezing Removes roots efficiently	Rod may break off in pipe Rod must be transported to pipe Retrieving roots from main pipeline Only applicable on/near road	The rodding machine is extremely powerful, lightweight, and may even be used in below freezing temperatures. It is also immobile and can even break off inside a pipe causing more blockage.

Hydro-Jet	Large water tank High mobility Lowest cost	Hose must be transported to pipe	The hydro-jet is a cost efficient option that is also very mobile and carries a large water tank to allow for extended time cleaning pipes. The hose must be transported to the pipe but with the mobility of the system this problem has an easy solution.

Notes: These data are gathered from survey information presented in Chapter Two of this report.

As presented in Table 2.10, there are multiple advantages and disadvantages with the alternative equipment used to clean underdrains. However, when reviewing the summaries, it appears that the hydro-jet has minor disadvantages when applied to cleaning underdrains.

As previously mentioned, all vendors recommended a hydro-jet as well as 85% of contracts for cleaning an underdrain. Alternatively, the hose of the hydro-jet may be easily transported to the entry of the underdrain. The pressure may be adjusted by securing a power washer attachment to the end of the hose, unlike the VJTs that ODOT currently uses. An overwhelming number of municipalities and contractors use the hydro-jet for cleaning underdrains located in far proximity from the roadway due to its mobility and functions.

CHAPER III RECOMMENDATIONS

Throughout Chapter 2, the VJT has been suggested to clean any pipe that is 12 inches in diameter or higher that are located in close proximity to the roadway. It has been determined through the survey results, as presented in Chapter 2, that a hydro-jet is advised to clean underdrains due to its small size and its ability to operate off the road. A hydro-jet, as presented in Table 2.9, consists of a water tank, a pump, and hose. Since these basic components may be acquired at multiple vendors, some agencies or contract companies may select to assemble their own hydro-jet instead of purchasing a pre-built one. Once the review of the state of the practice, as discussed in Chapter 2, suggests that a hydro-jet is the optimal selection for cleaning underdrains, the research team contracted customers and vendors of the hydro-jet to discuss component-specific questions. Table 3.1 presents the findings of these phone conversations.

Table 3.1: Analysis of Hydro-Jet Components.

Key Points	**Key Findings of the Customers and the Second Vendors Survey**
Tank Specifics	The tank size for cleaning underdrains is between 300 and 400 gallons.
Pump Specifics	The pump will have a maximum pressure of 4,000 pounds per square inch (psi), but typically only 2,000 psi is needed to clean underdrains. The typical flow used to clean underdrains is 12 gallons per minute (gpm).
Hose Specifics	The hose is 200 feet long with a diameter of ½ of an inch.
Relations Between Components	The more debris in the pipe, the more pressure will be needed. As the flow in the hose increases, the pressure in the hose decreases. An increase of the flow in the hose will cause the tank to drain faster.

Note: More information about the survey responses is available upon request. Survey conducted in fall/winter 2016.

The specifications and relationships between the hydro-jet components will assist the research team in determining what type of hydro-jet is necessary. Note that these specifications are not finite, and may be changed based on the agencies' discretion. For example, the size of the tank will determine how many underdrains may be cleaned before the tank must be refilled. Therefore, an agency treating a small service area may not have to travel far to refill and may choose a smaller size tank. However, agencies with a larger service area may not want to increase their tank size to reduce the deadhead time for refilling the tank. Table 3.2 presents the decision matrix for the hydro-jet.

Table 3.2: Decision Matrix of Hydro-Jet Components.

System Component	Classification	Truck	Space Required on Trailer Weight/Weight Limit (Pounds, lbs)	Cost
Tank (select one of the following options)	Small (100-200 gallons)	1/2 ton meets specification	20 sq. ft. (2,000 lbs)	$220 ± $35
	Medium (200-400 gallons)	1/2 ton meets specification	25 sq. ft. (3,500 lbs)	$500 ± $210
	Large (400+ gallons)	3/4 ton meets specification	30 sq. ft. (>3,500 lbs)	$750 ± $290
Hose (select one of the following options)	Small (200 feet)	1/2 ton meets specification	4 sq. ft. (170 lbs)	$2,000
	Medium (300 feet)	1/2 ton meets specification	4.5 sq. ft. (175 lbs)	$2,000
	Large (400 feet)	1/2 ton meets specification	5 sq. ft. (200 lbs)	$2,500
Pump (select one of the following options)	Low Flow (12-18gpm)	1/2 ton meets specification	1.5 sq. ft. (25 lbs)	$10,000
	High Flow (40gpm)	1/2 ton meets specification	3 sq. ft. (45 lbs)	$16,000
Σ of costs not including trailer				
Trailer Selection	Standard	1/2 ton meets specification	100 sq. ft. (<5,000 lbs)	$2,000 ± $150
	Heavy Duty	3/4 ton meets specification	140 sq. ft. (5,000-12,000 lbs)	$3,150 ± $410
Σ of costs including trailer				

Notes: As shown above, choose one tank, hose and pump from the selections listed. The weight of a tank includes fully-filled water. Standard Trailer is 6.4' x 16' and the Heavy Duty Trailer is 7' x 20'. Trailers are needed to be stored under cover upon return the garage. 1/2 ton and 3/4 ton trucks are currently a part of ODOT's fleet. One truck from its current fleet is to be used for this project. Baffling is recommended more as the capacity of the tank increases due to safety concerns. Additional cost may be needed to purchase nozzle attachments. Values without standard deviation mean there is only one data point at this time.

As presented in Table 3.2, the factors that influence the decision in determining what type of hydro-jet is needed include:

- Tank size,
- Hose length,
- Pump flow or pressure, and
- Nozzle attachments.

Tank size will dictate the size requirements of the trailer and, hence, the truck needed to tow the trailer since the tank will require the most square-footage on the trailer and will add the most weight to the system. Ideally, the hydro-jet should be able to be towed with one of ODOT's current vehicles to reduce costs. As presented in the decision matrix in Table 3.2, ODOT's current fleet has ½ and ¾ ton vehicles to use for underdrain cleaning. Tank size will also dictate the number of underdrains that may be cleaned before refilling. A smaller tank may only allow two to four underdrains to be cleaned depending on how much blockage and the length. A medium-sized tank may allow four to eight underdrains to be cleaned while a larger tank would clean greater than eight on average. As previously discussed, the location of the underdrains with respect to a refilling station should guide ODOT on the proper tank size for its garage and service area.

The pump will be related to the material of the underdrain maintained by ODOT and the amount of blockage. The two types of material that sewer pipes are made of are metal and polyvinyl chloride (PVC). The metal pipes are older and have a higher probability of corrosion than PVC pipes. The more corrosion in a pipe, the less pressure the pipe may withstand. Additionally, the amount of contaminants influences the pressure. The more contaminants there are, the more pressure is required. There is also an increased risk of detaching the nozzle or lodging the hose in the pipe when more contaminants are present.

The hose length will be determined by the distance of the location of underdrains from the roadway. According to the vendors, an agency such as ODOT wouldn't want a hose less than 200 ft. However, in discussions with ODOT personnel, they would like at least 300 ft. Theses specifications should be discussed with ODOT personnel since they have a large knowledge base of their service area.

Nozzle attachments may be needed to remove certain obstructions in the underdrain pipe. ODOT has expressed interest in reviewing various types of hose attachments. Certain attachments may be superior under certain underdrain conditions and may increase the efficiency of underdrain maintenance. Attachments include but aren't limited to: chain cutters, drill turbines, square stock corkscrew, small root saw, or sand shoes which may be used to clean distinct types of debris. For example, it is common for plant roots to penetrate pipes and restrict water flow. Using only high-pressured water will not remove these roots; instead, a square stock corkscrew or small root saw may be required to remove the roots.

3.1 Phase Two Recommendation

Currently ODOT utilizes a VJT to clean all pipes including underdrains. The VJT is ideal for larger pipes and when a vacuum system is need, such as cleaning a catch basin. However, it has been discovered that utilizing a hydro-jet for the underdrain cleaning may be more beneficial. The capital cost and life span of a piece of equipment may be a driving factor for purchasing that equipment. The VJTs have a larger capital cost than hydro-jets; however, they may last longer. Table 3.3 presents these data on capital costs.

Table 3.3: Cost to Own Vacuum Jet Truck Compared to Hydro-Jet Based On Capital Cost and Life Span.

	Capital Cost	**Lifespan**	**Yearly Cost to Own**
Vacuum Jet Truck	\$500,000 ± \$50,000	15 ± 3	\$46,780 ± \$11,420
Purchased Large Hydro-Jet	\$85,000 ± \$3,650	10 ± 2	\$10,900 ± \$2,440
Purchased Medium Hydro-Jet	\$33,350 ± \$6,500	10 ± 2	\$4,280 ± \$1,260
Purchased Small Hydro-Jet	\$18,500 ± \$2,100	10 ± 2	\$2,370 ± \$580

Note: Monte Carlo Simulation was run 500,000 times to determine these values. Additionally, the vendors feel the lifespan of the hydro-jet may be longer.

When comparing capital cost of the equipment as well as the lifespan, the largest hydro-jets are 4.3 times less expensive to own than VJTs. It should be noted that there may be added costs associated with the use hydro-jets since their tank capacity is much smaller than the VJT. However, if utilizing the medium or large hydro-jet and if ODOT employees work six hours in the field (one hour to set up and travel to site, and another hour at end of day to travel back to the garage and clean up), one full tank may last the entire day of cleaning underdrains. It should be noted that the VJT is still needed for maintaining other parts of the drainage system. However, investing in a hydro-jet may allow underdrains to be cleaned more frequently and will reduce the wear and tear on the VJT, which may then be utilized for larger jobs. Therefore, when cleaning underdrains, it may be cost effective to invest in a hydro-jet.

When reviewing purchasing a hydro-jet compared to designing and building one, the research team determined that there are more advantages to building the system. One advantage to building the system in-house is that it may be designed to meet specific garage needs. Even within ODOT, one county's needs might not be the same as another since the service areas will differ throughout the state. Using the decision matrix presented in Table 3.2, a preliminary cost analysis was conducted to determine if purchasing a system is more economically. Table 3.4 presents some of the results.

Table 3.4: Probability that the Built System will be More Expensive than the Purchased System.

Purchased System	Built Components	Probability Built >Purchased
Small Tank with Standard Trailer		
Small Hydro-Jet System	Small Hose, Pump Low Flow	12% Chance it will Cost More
	Medium Hose, Pump Low Flow	12% Chance it will Cost More
	Large Hose, Pump Low Flow	15% Chance it will Cost More
	Small Hose, Pump High Flow	80% Chance it will Cost More
	Medium Hose, Pump High Flow	80% Chance it will Cost More
	Large Hose, Pump High Flow	85% Chance it will Cost More
Medium Tank with Standard Trailer		
Medium Hydro-Jet System	Small Hose, Pump Low Flow	<1% Chance it will Cost More
	Medium Hose, Pump Low Flow	<1% Chance it will Cost More
	Large Hose, Pump Low Flow	<1% Chance it will Cost More
	Small Hose, Pump High Flow	4% Chance it will Cost More
	Medium Hose, Pump High Flow	4% Chance it will Cost More
	Large Hose, Pump High Flow	5% Chance it will Cost More
Large Tank with Heavy Duty Trailer		
Large Hydro-Jet System	Small Hose, Pump Low Flow	0% Chance it will Cost More
	Medium Hose, Pump Low Flow	0% Chance it will Cost More
	Large Hose, Pump Low Flow	0% Chance it will Cost More
	Small Hose, Pump High Flow	0% Chance it will Cost More
	Medium Hose, Pump High Flow	0% Chance it will Cost More
	Large Hose, Pump High Flow	0% Chance it will Cost More

Note: A labor rate of $17.50 ± $3.00, for 2-3 days with 2-3 employees was used in order to capture the cost to build the hydro-jet system. A Monte Carlo simulation was ran 500,000 times to determine the probability of cost difference. The cost of a small hydro-jet is $18,500 ± $2,100, medium hydro-jet is $33,350 ± $6,500, and large hydro-jet is $85,000 ± $3,650. A small and medium tank will only require a standard trailer while the large tanks would require a heavy duty trailer.

As seen in Table 3.4, when using the lower flow pump for a smaller tank, the probability of it costing more than a purchased hydro-jet, despite the hose size, ranges from 12-15%. Therefore, it makes sense to build a custom system. However, selection of a higher flow pump will have an 80-85% probability that it will cost more to build a custom system than purchasing a commercial one. There is a high probability that building a hydro-jet in-house with a medium-sized tank will be less expensive than purchasing one. Note that this probability estimate was based on the assumption that a medium-sized tank will only require a standard trailer. Additionally, it will be most cost effective to build a custom system if it utilizes a large tank. Note that this preliminary cost analysis doesn’t include the cost of baffling in the large tank or an increase in build time compared to the small and medium systems. An additional benefit to building a system is the ability to design with the end-users in mind: in this case, ODOT employees, whose knowledge of the procedure will allow the system to be built around their specific needs.

Upon reviewing the cost analysis and the service area throughout ODOT counties, the research team recommends that building a medium-sized system (with medium-sized tank) would be most cost-effective for ODOT. This system would require a standard trailer and a ½ ton vehicle to tow. Such vehicles are readily available at ODOT. The medium-sized tank would allow more underdrains to be cleaned than the smaller-sized tank would and it is more cost-effective to build than compared to the smaller-sized tank. The hose and pump sizes will be designed to meet ODOT’s needs.

Reducing the cost of the system fabrication may be achieved by implementing equipment currently present at ODOT locations. Traditionally more hydro-jet systems are developed using a trailer. One problem with a trailer is some areas may be difficult to get to. One potential solution is to implement an ODOT hook lift truck. A hook lift truck has the ability to exchange between truck bodies allowing for additional versatility. Figure 3.1 presents the hook lift truck located in Portage County.

Figure 3.1: Portage County's Hook Lift Truck.

The research group may work together with ODOT to modify a pre-existing swap loader truck frame for the custom built hydro-jet. As mentioned on page 19 of this report, a medium size system requires a ½ ton vehicle. The swap loader allocates more than enough capacity to mount a medium system. The system may include at least a 300 gallon tank size with a hose length of 300 ft. The pump may be modified to operate at variable speeds with the ability to reach a maximum capacity of 4,000 psi at twelve gpm. This may allow the system to provide enough pressure and flow to clean any amount of loose contaminants present in pipes smaller than twelve inches. In addition to the hydro-jet components, the swap loader will have enough room to mount a toolbox to store additional equipment, such as nozzles. The nozzles may increase the pressure of the system when removing tight contaminants. According to the contractor survey result in Chapter 2, Table 2.3; some pipes may require a vacuum system. If needed, the swap loader may be able to incorporate a vacuum system. After the design of the swap loader is laid out, local fabricators such as; Porter Metal and Cenweld may provide additional information regarding the pricing of each component and the fabrication of the system.

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