EFFECTIVE AND EFFICIENT ROADSIDE DITCH CLEANING USING BMPS FOR EROSION AND SEDIMENT CONTROL

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16. Abstract

The goal of this research is to improve ODOT's current process of maintaining ditches. The research team evaluated current procedures that ODOT utilize for roadside ditch cleaning and conducted field tests to evaluate alternates to current procedures. Field tests of the Ditchmaster (DM) 800, a ditcher that uses a horizontal rotating auger to remove spoil material, have revealed its inability of cleaning ditches that have wet and sticky soil. This is considered a major limitation as it limits its use for "emergency" ditching. In spite of this significant limitation, the benefits of the DM resulting from a better production rate, and a more environmentally friendly ditch configuration can potentially make it a useful component of an integrated ditch maintenance system (IDMS). Field tests of temporary erosion control products (TECPs) have revealed the potential benefits of using such products in controlling erosion of the slopes and bottoms of the ditches after cleaning. A manual was developed to familiarize highway maintenance personnel with best practices for installation, recommended application rates and selection methods of TECPs.

17. Keywords

Roadside ditches, erosion and sedimentation control, hydraulic mulches, ditchers.

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Executive summary

ODOT maintains approximately 43,000 lane miles of roadside ditches creating significant constraints on budgets and labor. The goal of this research is to improve ODOT's current process of maintaining ditches. To achieve this goal, the research team first evaluated the conventional methods that ODOT currently utilizes for roadside ditch cleaning. Such conventional methods which utilize a mini-excavator or a Gradall were found to be expensive ($15,285 per mile), and create deep V-shaped ditches that are prone to erosion and may destabilize the ditch's slopes.

To reduce the difficulties associated with current ODOT ditch maintenance procedures discussed above, the research team developed a matrix of alternatives that compared and contrasted solutions that are available today and recommended testing the Ditchmaster Model (DM) 800 effectiveness in cleaning ditches. The DM800 uses a horizontal rotating auger to remove spoil material from ditch bottoms and it produces a shallow and relatively smooth round ditch bottom. The preliminary cost analysis estimated that the DM800 will cut the cost/mile of cleaning a ditch to $5,954/mile.

Field tests of the DM have revealed its inability of cleaning ditches that have wet and sticky soil. This is considered a major limitation as it limits its use for "emergency" ditching to relieve flooding during seasonal rain storms or spring thaw runoff. Although the revised cost/mile for cleaning a ditch using a DM ($7,836) is significantly more than the preliminary estimate/mile ($5,954), it is still almost 50% of the cost of cleaning the ditch using conventional ditch cleaning methods. In spite of the DM significant limitation discussed above, the benefits of the DM resulting from a better production rate, cheaper cost/mile and a more environmentally friendly ditch configuration can potentially make it a useful component of an integrated ditch maintenance system (IDMS).

The research also tested temporary erosion control products (TECPs) that are currently available in the market and evaluated their effectiveness in protecting seeded ditches and in

establishing vegetation. These products include different types of hydraulic mulch, erosion control blankets and straw mulch. Field tests of TECPs have revealed the potential benefits of using such products in controlling erosion of the slopes and bottoms of the ditches after cleaning. Such benefits can occur with the careful selection of the right TECP product and its correct installation. A "Temporary Erosion Control Products for Roadside Ditches" manual was developed to familiarize highway maintenance personnel with best practices for installation, recommended application rates and selection methods of TECPs.

An integrated ditch maintenance system (IDMS) is recommended to adequately maintain ODOT's roadside ditches network despite constrained finance and growing resource scarcity. An IDMS integrates various practices and equipment for maintaining ditches by selecting the best equipment/practice for a given project, reducing run-off entering the ditches, effectively using temporary erosion control products in ditches, reducing sediments entering the ditches, and improving scheduling of ditch maintenance operations.

For the integrated ditch maintenance systems to be effective, it is important to develop an inventory of the ditch network and assess the volume of water and sediment moving throughout the network. An inventory of roadside ditches can help prioritize and target management efforts, using criteria of soil type, slope, cost, and impacts to receiving water bodies.

Chapter 1- Introduction

An important consideration of road construction is the removal of water (drainage). Roads are designed to drain rain and snowmelt away from the road, toward the lower elevation of the roadside ditch. Once the water reaches the ditch, it can flow along the ditch and eventually away from the roadway, protecting the stability of the road subgrade (AASHTO 1996). Over a period of time roadside ditches might collect large amount of silt or debris and may become overgrown with heavy vegetation (ISU 2006, NYDOT 2009). This interferes with the proper flow of water in the ditches and in the culverts and drains that connect them. When the ditches 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. Furthermore, water that does not drain away properly will soak the base material of the road bed causing pavement breakup, potholes, cracking, shoulder disintegration, base saturation, and eventually total pavement failure. A well maintained ditch will prevent road failure and help keep roads in good conditions (Brady et al. 2014, Kitsap county 2012).

Ditch maintenance consumes a lot of time and requires substantial labor and equipment resources throughout the year. The Ohio Department of Transportation (ODOT) maintenance crews maintain approximately 43,000 lane miles of open roadside ditches creating significant constraints on ODOT budgets and labor. Money spent on ditch cleaning/maintenance directly affects the long-term cost of all roadway maintenance by slowing deterioration, reducing the scope for future repairs and protecting the investment made in roads against premature loss.

1.1. Goals and Objectives

The overall goal of this project was to evaluate ODOT's current roadside ditching process and provide best practice recommendations on how to increase efficiency, decrease labor hours, and improve safety, production and cost effectiveness. Since environmental issues are a major concern for ODOT, the project also aims to provide recommendations for BMP's dealing with erosion and sedimentation (E&S) control in roadside ditches. The objectives of the project were as follows:

1. Determine the state of current procedures and practices by Ohio DOT and other state DOTs for roadside ditch cleaning with a focus on production rates, costs, grade control, erosion and sedimentation controls, and best management practices.
2. Evaluate alternative ditch maintenance practices and available equipment for potential implementation in Ohio based on cost, environmental impact, applicability to different ditches' shapes and depths, and production rates.
3. Compare and contrast ditch maintenance solutions that are currently available and provide a recommendation on the most viable solution.
4. Compare and contrast ditch erosion and sedimentation control solutions that are currently available and provide a recommendation on the most viable solution.
5. Perform in-field testing/analysis of recommended E&S control products to evaluate their effectiveness in establishing healthy and dense vegetation in roadside ditches and improving stormwater quality.
6. Perform in-field testing/analysis of Ditchmaster Model 800 to determine its production rate under different project conditions.
7. Develop a manual for temporary erosion and sedimentation control methods to familiarize highway maintenance personnel with BMPs for erosion and sedimentation control measures in roadside ditches.
8. Perform a cost analysis of the Ditchmaster Model 800 to determine Return on Investment (ROI).
9. Develop two decision trees that help users (1) decide when to use Ditchmaster Model 800 and (2) select appropriate temporary erosion control measures.
10. Prepare a comprehensive final report documenting the findings and performance of in-field testing and true ROI.

1.2. Organization of this report

This report is divided into seven chapters. Chapter 1 introduces the research topic and includes a list of the research objectives. Chapter 2 presents background research on the current practice for roadside ditch cleaning, erosion and sedimentation control measures for ditches, as

well as field observations of current practices and survey information collected from ODOT, other transportation departments, and equipment manufacturers. A comparison of current practices and recommendations for field testing is presented in Chapter 3. Results of field tests conducted to evaluate temporary erosion control products (TECPs) are presented in Chapter 4. Chapter 5 presents results field tests conducted to evaluate the effectiveness of the DM 800 in cleaning roadside ditches. Based on earlier chapter analysis, as well as testing results, Chapter 6 presents cost analysis of recommended equipment and decision trees for selecting ditch cleaning methods and temporary erosion control products. Lastly, Chapter 7 summarizes the research conclusions and recommendations for ODOT continuing to move forward in their endeavor to cost-effectively maintain ditches.

Chapter 2- Current Roadside Ditch Cleaning and Erosion and Sedimentation Control Practices

Background research into the current state of practice for roadside ditch cleaning, erosion and sedimentation control measures for ditches are presented in this chapter. The research for this chapter was conducted in 2015 and formed a foundation for the later chapters. This chapter is divided into two sections:

1. Evaluation of the current ODOT processes for roadside ditch cleaning and erosion and sedimentation control measure for ditches
2. Evaluation of alternative ditch maintenance practices and available equipment for potential implementation in Ohio

2.1. Evaluation of the current ODOT processes for roadside ditch cleaning and erosion and sedimentation control measure for ditches

This section includes results from three activities: (1) Literature review, (2) ODOT phone interviews, and (3) On site assessment of ODOT ditch cleaning operations.

2.1.1. Literature Review

The literature review focused on ditch cleaning operations, erosion and sedimentation control measures for ditches and best practices for cleaning ditches.

2.1.1.1. Ditch cleaning

Roads are designed to drain rain and snowmelt away from the road, toward the lower elevation of the roadside ditch. Once the water reaches the ditch, it can flow along the ditch and eventually away from the roadway, protecting the stability of the road subgrade (AASHTO 1996). Over a period of time roadside ditches might collect large amounts of silt or debris and may become overgrown with heavy vegetation (ISU 2006, NYDOT 2009). This interferes with the proper flow of water in the ditches and in the culverts and drains that connect them. Water

that does not drain away properly will soak the base material of the road bed causing pavement breakup, potholes, cracking, shoulder disintegration, base saturation, and eventually total pavement failure. A well maintained ditch will help prevent road failure and help keep roads in good conditions (Brady et al. 2014, Kitsap county 2012).

Ditch cleaning/maintenance includes work such as removing sediment that has filled in the ditch, seeding a side slope, clearing brush, removing invasive species or noxious weeds, and mowing. Basic field measurements and site inspection often precede routine maintenance to determine the correct type of equipment needed and the proper cleaning procedures (Brady et al. 2014)

2.1.1.2. Erosion and sedimentation control measures for ditches

Sediment enters ditch systems from two main sources: gravel from the road, and soil that erodes from the banks or bottom of ditches. Proper road maintenance can reduce the amount of gravel and dirt entering the ditch system (Elfering and Biesboer, 2003). Sediment continues to be the primary pollutant by volume in Ohio's streams and rivers (CRWP 2012). Unvegetated roadside ditches erode and contribute tons of sediment annually to local receiving streams. Most erosion occurs during large storm events that produce high flows of stormwater within roadside ditches.

Pollutants attach themselves to sediments and are transported by the stormwater runoff throughout the watershed, degrading the water quality of receiving streams and rivers (CRWP 2012). Many of the pollutants in the ditches' runoff are attributed to motor vehicle operation and may contain oil, grease, and heavy metals such as lead, copper, and zinc (Elfering and Biesboer, 2003).

The effects of stormwater runoff on receiving waters are typically a function of the proximity of development site discharges to the receiving water body and the size of the receiving water body relative to discharge volumes and flow rates. The impacts of stormwater runoff from

ditches vary widely depending on surrounding land use, climate patterns, soil characteristics, receiving water characteristics, and the local traffic volume (Kitsap 2012).

Erosion and sedimentation control and storm water quality treatment in ditches typically relies on the vegetation in ditches. Vegetation filters sediment and pollutants attached to the sediment as the water flows through the plants. Vegetation also slows down the water, allowing a portion of it to infiltrate into the soil and allowing some of the debris and pollutants to settle out (Elfering and Biesboer, 2003).

Ditches that are stripped of the vegetative cover during ditch cleaning maintenance operations should be immediately seeded to control erosion and sedimentation and promote treatment of the storm runoff prior to discharge into the receiving waterbody. Vegetation is used to stabilize soil, reduce erosion, prevent sediment pollution, and reduce runoff by promoting infiltration. Vegetation controls erosion by reducing the velocity and the volume of stormwater flow and protects bare soil surface from raindrop impact. Healthy, dense vegetation promotes infiltration and reduces the amount of runoff. The establishment of quality vegetation requires selection of the right plant materials for the site, adequate soil amendments, careful seedbed preparation, and maintenance (ODNR 2006).

Soils within roadside ditches are often compacted, poorly drained and may be nutrient deficient. These characteristics along with seasonal fluctuations in weather patterns sometimes make it difficult to establish vegetative cover immediately following ditch maintenance operations (CRWP 2012). It is therefore important that after seeding, the soils and seed are temporary protected until vegetation is established. There are many options for protecting the seeding including mulching, hydroseeding, erosion control blankets, tackifiers, biostimulants, and polyacrylamide flocculent products. These options are further described below.

- Mulching: A protective layer of mulch, usually of straw, applied to bare soil is used to abate erosion by shielding it from raindrop impact. Bagged mulches, such as soil stabilization granules (made of recycled newsprint and wood shavings), are handy for small areas and are activated by water. Mulch also helps establish vegetation by

conserving moisture, holding fertilizer, seed, and topsoil in place, moderating soil temperatures and creating favorable conditions for seeds to germinate (ODNR 2006). When it comes to protecting ditch projects, mulch is not as effective as erosion control blankets. Straw mulch is inexpensive but is likely to be washed or blown away. Straw mulch must be anchored to be effective (Brady et al. 2014).

- Hydroseeding: Hydroseeding (or hydromulching) is a planting process that uses a slurry of seed and mulch. It is often used as an alternative to the traditional process of broadcasting or sowing dry seed. The hydroseeding slurry is transported in a tank, and sprayed over prepared ground. The slurry often has other ingredients including fertilizer, tackifying agents, bonded fiber matrix (BFM), and/or fiber mulch. Hydroseeding holds moisture and protect against soil loss from wind, rain, sun and pests and is very effective for hillsides and sloping lawns (Kitsap 2012). Hydroseeding will typically cost less than planting with sod, but more than broadcast seeding. Results are often quick with high germination rates producing grass growth in about a week. When fiber mulch is added to the hydroseed slurry, it accelerates the growing process by maintaining moisture around the seeds thereby increasing the rate of germination. If the seed mix is combined with a long term bonded fiber matrix (BFM), it will provide a quick erosion control measure until the seed emerges and grows into a healthy stand of groundcover.
- Erosion control blankets: Erosion control blankets are made of wood fiber, straw, jute, coir (coconut) or a combination of these, typically with either 1 or 2 layers of plastic or jute netting which holds the material together (Brady et al. 2014). Netting can be applied over mulch or straw and anchored with staples. Jute is a natural biodegradable fiber that can replace plastic netting. Jute netting over straw mulch is comparable in price to plastic netting, has been used successfully in ditches and lasts up to 2 years. Erosion control blankets should be used in critical ditch location where ditch side slopes are steeper than 3:1 and ditches that drain directly to a lake or river.
- Tackifiers: Tackifiers are used to enhance erosion control by binding soil particles, especially clays, in place, preventing detachment of soil particles by rain splash impact

and high flow velocities. In addition, several additives (Polyacrylamide flocculent products and biostimulants) can be added to tackifiers to further improve stormwater quality treatment. Polyacrylamide (PAM) flocculent products act as a flocculent to remove suspended particles from stormwater runoff, decreasing turbidity and improving water quality. PAM flocculants make the soil particles bind into larger clumps that are less likely to move. PAMs can be used with mulch to improve its effectiveness. PAMs can be broadcast in granular form with a fertilizer spreader, or they can be sprayed or blown along with seed. The granular form must be wetted to be activated (Brady et al. 2014). Biostimulants additives (such as guar gum or polysaccharide based tackifiers) when added to tackifiers stimulate growth of vegetation expediting stabilization. Biostimulant additives contain hormones, vitamins, amino acids and mineral nutrients that naturally stimulate germination and growth (CRWP 2012).

Sometimes there exist critical areas in ditches where erosion potential is high. These areas include steep slopes (up to 1:1); ditches subject to high velocities (> 3.5 fps); and areas subject to limited scour. In such instances, soil erosion can be reduced through the use of turf reinforcement matting. Turf reinforcement matting (TRM) is a permanent, non-degradable rolled erosion control product used to reinforce natural soil and vegetated growth with synthetic materials to prevent erosion and maintain the durability of vegetated areas. Turf reinforcement is generally an interwoven material applied to areas where natural vegetation alone is not sufficient to withstand expected flow conditions or to provide sufficient long-term erosion protection (ODNR 2006). Turf reinforcement matting is not appropriate for areas which will be constantly inundated with water and therefore unable to establish adequate vegetation.

In other cases, it is not possible to establish vegetation in ditches. Examples include cases in which there is rocky substrate, high velocity flow conditions, steep gradients, a culvert outlet that is close to the ditch bank, or heavy shade. In such instances, riprap can be used. Riprap may be needed at both ends of a culvert. It will prevent erosion around the pipes and scouring at the pipe outlet. For many driveway culverts, riprap is not needed if vegetation is holding the soil in place. Riprap is costlier than vegetation, but in an area prone to erosion that requires

more frequent repair, riprap can be cost-effective. Geotextile fabric or a layer of gravel placed under the riprap prevents soils from being scoured out beneath the riprap (Brady et al. 2014).

Storm water treatment in ditches also includes flow attenuation measures that dissipate the velocity of flowing water to prevent failure of the fore slope or road berm and promote sedimentation of larger particles of sediment. The most common flow attenuation measure used in ditches is the check dam. A check dam is a shaped rock dam constructed in swales, grassed waterways or diversions. It reduces the velocity of concentrated flows, thereby reducing erosion within the swale or waterway. While a rock check dam may trap sediment, its trapping efficiency is extremely poor, therefore it should not be used as the primary sediment-trapping practice. As an alternative to rock, high flow compost filter socks may be used as check dams. A filter sock is a sediment-trapping device that uses compost inserted into a flexible, permeable tube with a pneumatic blower device. While the primary use of compost filter socks as check dams is still to reduce flow velocity and subsequent channel erosion, these filter socks have improved sediment removal. Rock check dams and filter sock check dams are superior to straw bale dams based on their reduced maintenance and increased effectiveness. Check dams should be maintained by removing sediment from behind the check dam once it accumulates to one-half the original height of the check dam. (ODNR 2006). Another alternative to rock riprap check dams is the wattle.

Wattles are tube-shaped erosion control practices filled with straw, coconut fiber, or composted material. Each wattle is wrapped with ultra-violet degradable polypropylene netting or 100% biodegradable materials like burlap or jute. Wattle materials are lightweight, easily transportable and can be tailored to necessary lengths at the job site or preassembled at the service yard for later installation on any shaped ditch or swale. Wattles reduce the velocity of concentrated flows, thereby reducing erosion within the ditch or swale (CRWP 2012)

2.1.1.3. Best Practices for cleaning ditches

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

- Planning the job should be done well in advance the ditch cleaning operation to ensure that when equipment and men arrive at the job site the ditch 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).

- During planning, one should determine what to do with the waste material that will be cleaned out of the ditch (ISU 2006).

- 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).

- Ditches that do not currently have good vegetative cover, ditches with poor soils, or ditches that are stripped of the vegetative cover can be enhanced to promote treatment of the storm runoff prior to discharge into the receiving water body (Kitsap County 2012).

- Check dams can be provided in ditches with steep slopes. In addition to slowing the flow and spreading flows across the width of the ditch, the check dam will provide for an area to pool water and promote infiltration (Kitsap County 2012).

- When cleaning ditches, machinery should be operated adjacent to the ditch and no heavy equipment should be allowed in the bottom of the ditch to minimize disturbance and compaction of the undisturbed soil in the bottom of the ditch (Brady et al. 2014).

- Since erosion is one of the major problems with ditches, the growth of vegetation is encouraged. Areas of dense native vegetation with intact soil that appear to be a highly functioning water quality ditch should not be removed (IRF 2010).

- One of the major problems when vegetation is used to control erosion in ditches is the control of weeds which become a major problem once grass loses its vigor and density.

Weed encroachment is often the result and not the primary cause of poor turf. Weed eradication often will not result in permanent improvement unless conditions that weaken the turf are corrected (IRF 2010).

- Before reseeding a disturbed soil area, amend all soils with compost wherever topsoil has been removed.

- The best way to know if ditch systems are functioning properly is to observe and inspect them, especially during and immediately after rain or snowmelt events when higher flows put more stress on the ditches (ISU 2006).

2.1.2. ODOT Phone Interviews

A total of twenty county maintenance garages in Ohio were contacted and interviewed regarding ditching, equipment, erosion and sedimentation practices, and safety concerns. The interview was used to obtain an understanding of current ODOT processes for ditch cleaning as well as current ODOT erosion and sediment control practices. Table 2.1 lists the counties interviewed.

Table 2.1. List of ODOT Counties Interviewed

County	District	County	District	County	District	County	District
Allen	1	Sandusky	2	Stark	4	Vinton	10
Hancock	1	Seneca	2	Fayette	6	Belmont	11
Putnam	1	Ashland	3	Clark	7	Tuscarawas	11
Van Wert	1	Erie	3	Mercer	7	Geauga	12
Ottawa	2	Mahoning	4	Scioto	9	Lake	12

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

District _____ County _____ Phone Number _____

Name of contact _____ Lane miles maintained _____

1. What equipment is used for ditch maintenance?
2. What variables affect the equipment selected (availability, soil type, right-of-way size, size of ditch, grade, etc.)
3. What is the production rate of each method?
4. What factors most affect productivity (soil type, ditch depth, ditch length, etc.)?
5. Do you use GPS or laser to maintain grade?
6. Where is waste disposed of after each ditch cleanout?
7. What type of erosion and sedimentation measures do you use in ditches?
8. How do you decide what ditches need to be cleaned?
9. How many people are typically involved in a ditch cleanout?
10. What are your biggest safety concerns when cleaning ditches?
11. What type of maintenance activities do you perform on equipment?
12. Is maintenance performed in-house or are there specialized activities that need to be done by the manufacturer?
13. Is there any ditch cleaning equipment that you would like evaluated as part of this study?
14. Do you recommend other people in Ohio or in states near Ohio for the research team to talk to?

2.1.2.1. Interview Results

Equipment

As shown in Table 2.2. which summarizes responses to Question 1 of the interview, the predominant ditching equipment used in Ohio is a Mini-Excavator, or Trackhoe. The second most commonly used machine is the Gradall; however, there are a smaller number of these available throughout the state and counties report sharing Gradalls amongst themselves. In conversations

with Mahoning county workers, they expressed that the productivity of both machines; the Mini-Excavator and Gradall, is heavily dependent on operator expertise. Six counties mentioned that they use a Backhoe, though this appears to be an outdated method based on county feedback. When asked about productivity, Stark County acknowledged that the Trackhoe is twice as efficient as the Backhoe. Two counties currently use a Tiger Ditcher, and two other counties mentioned having previously used it.

Table 1.2. Survey Results for Equipment Usage

Machine	Trackhoe	Gradall	Backhoe	Tiger
Number of Counties	18	9	6	4
Percentage of Counties	90%	45%	30%	20%

Grade Control

The most common form of maintaining grade in the state is with the usage of laser equipment, with fourteen counties confirming its usage. Five counties expressed that they did not use either laser or GPS for maintaining grade. Instead, grade is maintained by following the road's grade. Only one county, Tuscarawas, confirmed using a GPS tripod, citing its predominantly flat terrain as the reason. In conversations with a Liebrecht Manufacturing employee, laser was recommended for areas with rolling terrain, and GPS was recommended for flat terrain as a more precise grade is needed to obtain flow.

Ditch Spoil Disposal

Seventeen counties reported that after ditch cleaning, spoil material was disposed of at ODOT outposts or approved dump sites. Seven counties reported giving it back to the landowners after their consent and their signing of a waiver. Five counties said they re-used the spoil material on the same project, particularly by spreading it on the berm or on the backside.

Deciding which ditches need to be cleaned

When asked for their reasoning regarding which ditches are to be cleaned, all counties cited a combination of both inspection and complaints. However, some counties expressed that complaints, at times, took priority. Inspections appear to take precedence in episodes of severe rain.

Crew Size

Counties in Ohio reported employing crews of as small as one person to a total of nine people when performing ditch cleanouts. Ottawa County reported using small crews of 1-2 people when hauling was not required and crews of 6-7 when hauling was required. Most counties stated they used crews of 5-6. This was further reinforced during site visits, where it was observed that ditch cleaning crews typically involve 5 workers, where 2 are flaggers, 1 is the equipment operator, 1 is the grounds man, and 1 serves as truck driver.

Safety concerns

Before any ditching operation, counties are required to contact the Ohio Utility Protection Service to identify and mark gas, water, and fiber optic lines. In addition to this, counties reported their primary concerns were moving equipment, traffic, flagging, overhead utilities, blind spots, and miscommunication among grounds-men and operators.

2.1.3. On site assessment of ODOT ditch cleaning operations

In order to complement the information obtained from the phone interviews, the research team conducted two site visits to observe ditch cleaning operations in Ohio. The visits served to observe current ODOT maintenance practices first hand, including crew composition, equipment usage and maintenance, and environmental measures taken. Table 2.3 provides more information about the date and location of the site visits. The first site visit took place in Mahoning County in District 4, and the second site visit took place in Putnam County in District 1. The locations of each were important as they encompassed contrasting terrain, machinery, and practices. Whereas Mahoning County in northeast Ohio has a rolling terrain, Putnam County in west Ohio has a much flatter terrain; and while Mahoning County has many ditches that lie on landscaped yards, Putnam County has many ditches that lie on the edge of farmlands.

Table 2.3. Summary of Site Visits and Demonstrations

Date	District	County	Description
8/11/2015	4	Mahoning	Ditch cleaning using Mini-Excavator Ditch cleaning using Gradall
8/12/2015	4	Mahoning	Ditch cleaning using Mini-Excavator Ditch cleaning using Gradall Tour of ODOT maintenance facilities
8/18/2015	1	Putnam	Ditch cleaning using Tiger Ditcher

The site visit in Mahoning County consisted of a tour of ODOT maintenance facilities, as well as a demonstration of various ditch cleaning operations, one with a Mini-Excavator, and the other using the Gradall. The first ditching operation as shown in Figure 2.1. was carried out in a small stretch of ditch in a suburban neighborhood. A crew of six workers, which consisted of one equipment operator, two flaggers, two grounds-men, and one truck driver, arrived approximately one hour before ditching began to setup the work zone. After unloading the Mini-Excavator from the flatbed used to transport it, work began on cleaning out the 57’ long ditch. The crew was able to perform this cleanout in 16 minutes, without taking into account site set-

up or truck downtime, as this project only required one truck. Although this seemed fast at first glance, when extrapolated, it amounted to 213.75 ft/hr or 0.04 mi/hr. In longer stretches of ditch, where a larger amount of dirt is required to be moved, and multiple trucks are needed, this production rate could possibly be even lower. The newly cleaned ditch was then left in its bare state, with no seeding or mulching put into effect. This is a concern, since as discussed in the literature review section, ditches that are stripped of the vegetative cover during ditch cleaning maintenance operations should be immediately seeded to control erosion and sedimentation and promote treatment of the storm runoff prior to discharge into the receiving waterbody. Vegetation is used to stabilize soil, reduce erosion, prevent sediment pollution, and reduce runoff by promoting infiltration.

Figure 2.1. Mini-Excavator in Mahoning County (August 11, 2015)

The second ditch cleaned by the ODOT crew as shown in Figure 2.2, was adjacent to a landscaped yard of a church. The ditch was wider and deeper than the first one seen. A crew of five workers consisting of one equipment operator, two flaggers, one grounds-man, and one truck driver used the Gradall to perform the ditch cleaning. The operation moved at a rate of

0.03 mph, slightly slower than that of the Mini-Excavator. Like the first ditch, it was left in its bare state. In conversations with Mahoning county workers, they expressed that the productivity of both bucket machines, the Mini-Excavator and Gradall, is heavily dependent on operator expertise. It was also observed that similar to the Mini-Excavator, the Gradall's bucket disturbed much of the ditch cross section which increases the size of the area that need to be reseeded to control erosion and sedimentation. On the other hand, rotary ditch cleaning equipment that disturb minimum surface areas of the ditch during ditch maintenance reduces the amount of re-seeding, and potentially reduces erosion and increases the time needed before the next cleaning.

Figure 2.2. Gradall in Mahoning County (August 11, 2015)

The second site visit was in Putnam County Ohio. As shown in Figure 2.3, the research team observed the usage of a Tiger ditcher attachment on a tractor on a stretch of ditch which was approximately 1200 feet in length. A crew of three workers participated in this ditch cleanout, where one served as the equipment operator, and two served as grounds-men. The grounds-

men travel on foot along the tractor to communicate to the operator about any interruptions along the ditch line, as well as to use the laser to confirm that the desired grade is being created. As this attachment tossed the dirt on the ditch backside, no trucks, nor truck operators, were required. Once the ditch was cleaned, the dirt on the backside was pulverized, flattened, and seeded. Although the tiger ditcher moved significantly faster than the mini excavator or the Gradall, it had a small cutting head and required several passes to shape the ditch. Also, there are concerns that the ditch spoil that was tossed by the tiger ditcher on the backside of the ditch, would be quickly eroded back to the ditch in case it rains before vegetation is established.

Figure 2.3. Tiger Ditcher in Putnam County (August 18, 2015)

2.2. Evaluation of alternative ditch maintenance practices and available equipment for potential implementation in Ohio

2.2.1. Phone Interviews of manufacturers of Ditching Equipment

The research team assembled a list of ten manufacturers that design and produce ditching equipment. Each manufacturer was phone-interviewed regarding their various models. The interview addressed horsepower requirements of tractor if needed, cost, production rate, and

GPS capabilities, among others. Summary of the results of the phone interviews are included in Table 2.4.

Table 2.4. Summary of results of manufacturers' phone interviews

Manufacturer	Roadside ditches?	Farming ditches?	Models	Requires tractor?	HP req.	Cost	Auto-load waste?	Provide training	Production Rate	Dirt shoot?	GPS/Laser compatible?
DitchMaster	Yes		800 400	No	N/A	355k - 310 K	Yes	2 days	0.5 to 1.5 miles/day	No	No
US Rotary Ditcher	Yes	Yes	RD200/TC200	Yes	70 - 180	60k - 150k	No	Yes	2 hrs/mi - 45 min/mi	Yes	Yes
Maddock	Yes	Yes	RD90/RD160	Yes	60 (minimum)	140k/160k	No	Yes (full day)	3-5 mi/day (re-establishing) or 7-10 mi/day (cleaning)	Yes	No
Liebrecht	Yes	Yes	Waterway Ditcher	Yes	200 (minimum)	56k	Yes		.75 mi/hr	Yes	Yes
Dynamic Ditchers Inc.		Yes	Wolverine Ditcher	Yes	220-350	56k-58k	No	Yes	750 yd/hr	Yes	Yes
Sheyenne Tooling & Mfg	Can be	Yes	Cyclone Ditcher	Yes	200 - 350	46k +	No	Yes (At facility)	1.5-2 mi/hr	Yes	Yes
Hurricane Ditcher	Yes	Yes	Baby Side-Arm Original Side Arm Ditch Angel	Yes	90-150 150-250	25-30k 56k 33-37k	No	Yes (one hour)	1 mi/hr	Yes	Yes
Erickson Mfg	Yes	Yes	Eagle Ditcher	Yes	150 - 225	28k	No	No (provide book)	2-4 mi/hr	Yes	Yes
Amco Mfg	Yes	Yes	Vertical Rotary Offset Rotary (preferable for roads)	Yes	50-120	5-6k	No		3-4 mi/hr	Yes	Yes
Diamond Mowers	Yes	Yes	Ditcher attachment	Yes	70 PTO	8.9k	No	Yes	Not available (depends on conditions)	Yes	No

After the phone interviews, the research team excluded 5 out of the 10 manufacturers from further analysis. The ditchers of the 5 excluded manufacturers were either deemed more appropriate for farming or were too small and could only remove woody vegetation as opposed to effectively cleaning the ditches and removing accumulated sediments. The remaining 5 manufacturers (US Ditcher, Ditchmaster, Maddock, Liebrecht and Hurricane ditcher) were further contacted (by phone, through emails or in person) to get more information about their products. A summary of the information obtained from those manufacturers is included in the sections below.

Ditchmaster

A Ditchmaster uses a 27" horizontal rotating auger to remove spoil material from ditch bottoms. Ditchmaster comes in 3 models. Models 400 (left-arm) and 700 (right-arm) are truck

mounted and self-loading. The truck - mounted Ditchmaster uses a horizontal rotating auger to remove spoil material from ditch bottoms. Solid materials then travel through a three stage conveyor mechanism and drop into an 8-10 cubic yard open dump body as illustrated in Figure 2.4. Cutting and conveying mechanisms are powered by hydraulic drive units.

Figure 2.4. Ditchmaster Model 400- Left arm truck mounted

Model 800 (left arm) as illustrated in Figure 2.5, pulls an attached dump truck and loads the ditch' s waste to the dump truck. Once the attached dump truck is completely full with the ditch's waste, it is unattached from the Ditchmaster then travels to the dump site while another dump truck is attached to the Ditchmaster to receive the ditch's waste. Model 800 is more suited for larger ditch cleaning jobs where the large quantity of ditch waste cannot fit in the 8-10 cy bed of models 400/700. Having a constant supply of dump trucks to receive the waste increases the production rate but at the same time increases the crew size.

Figure 2.5. Ditchmaster Model 800- Left arm truck mounted

All Ditchmaster models use hydraulic controls that enable the operator to extend, retract, lower or raise the Ditchmaster to accommodate any roadside ditch sections up to 3 feet in depth. When extended, the cleaning arm reaches out 8 1/2 feet. By retracting the arm, Ditchmaster can clean on a very narrow road. For highway travel the arm folds and locks to a vertical "tuck in" position for a legal width of eight feet and height of twelve feet eight inches.

The Ditchmaster is extremely mobile and does not need a tractor and moves from one ditching project to another at highway speeds. It can clean right up to most obstacles, such as mailboxes, culverts or across pipes. Ditch cleaning operations can be staffed with one operator, one ground man and whatever personnel are required to handle traffic. Ditchmaster is equipped to remove rocks up to 5 inches in diameter, sod, grass, small brush, and other similar debris.

Ditchmaster is ideal for residential subdivision work. The rounded ditch is more appealing to the resident who mows to the edge of the pavement. The rounded ditch bottom created by Ditchmaster gives more area for drainage and faster water flow.

Ditches created or cleaned by Ditchmaster are environmentally friendly. Only the actual ditch space is disturbed during ditch renovation. Conventional ditch cleaning methods typically remove or disturb up slope vegetation and this creates additional future erosion back into the ditch and thus reducing the time needed before the next cleaning.

US Ditcher, Inc.

US Ditcher, Inc, manufactures two models of sidearm ditchers. Model RD15, as shown in Figure 2.6, is typically used for shallow ditch cleaning. It can clean roadside ditch sections up to 5 feet in depth. When extended, its cleaning arm reaches out 16 1/2 feet. Model RD20 is typically used for deep ditch cleaning. It can clean roadside ditch sections up to 8 feet in depth. When extended, its cleaning arm reaches out 20 feet. Both models are pulled by a tractor and come in mechanical or hydraulic drives option.

Figure 2.6. Side arm US Ditcher in operation (Source: http://usditcher.com)

The side arm US Ditchers are designed to discharge the ditch's waste either to the left or right. It can be set up to throw the ditched material to the right of the ditch's bank 30 to 100 plus feet and in a 50 to 130 degree broadcast to prevent accumulation (as shown in Figure 2.6), or windrow the material to the right on the ditch bank at about 3ft away. It can also be set up to windrow the material to the left side of the ditch (on the shoulder) where it can be later picked up with a belt loader or a backhoe and carried away to a dumping site or leveled with a motor grader to cover eroded shoulders.

The side arm US ditchers are most productive when the ditch's waste can be spread out away from the road as shown in Figure 2.6. If spreading the waste out away from the road is allowed,

the side arm US Ditchers can outperform conventional ditching methods by a ratio of 10:1 (i.e. 10 times cheaper). If the ditch's waste needs to be carried away to a dumping site, additional equipment (e.g. loading equipment, backhoe and motor graders, belt loaders, dump trucks) and supporting crews are needed which will significantly increase the cost of ditching.

Maddock

Maddock Corporation manufactures two models of sidearm rotary ditchers; Model RD 90 and Model RD160. Both models are Power Takeoff (PTO) driven, use hydraulic drives and are pulled behind a tractor. The ditcher controls are electric-hydraulic so the only required connection to the tractor besides the drawbar hitch is a conduit and operator's control station.

Model RD 90 as shown in Figure 2.7, is designed to be pulled behind a 100 hp tractor. Its conical-shaped rotating steel drum is equipped with carbide tipped, replaceable cutter bits, producing a V-shaped ditch with a 12- inch wide flat-bottom, 53 degree sides, 19 inch depth of cut. It can clean roadside ditch sections up to 4.5 feet in depth. When extended, its cleaning arm reaches out 7 feet.

Model RD 160 is designed to be pulled behind a 200 hp tractor. Its conical-shaped rotating steel drum as shown in Figure 2.8, is equipped with carbide tipped, replaceable cutter bits, producing a V-shaped ditch with a 12- inch wide flat-bottom, 38 degree sides, 27" inch depth of cut. It can clean roadside ditch sections up to 5 feet in depth. When extended, its cleaning arm reaches out 7 feet. The cutter head hydraulic circuit has a built-in pressure relief valve that will stall the cutter head at a predetermined pressure. This aids in protecting the cutter head in case of contact with underground obstructions. An "Emergency Stop" button is located in the operator's station to serve as a kill switch for the engine and cutter drive.

The Maddock side arm rotary ditchers have a right discharge cutter head so the machines move with traffic, on the right side of road. They are designed to throw the ditched material to the right of the ditch's bank 30 to 50 feet as shown in Figure 2.7). If throwing the waste out away from the road is not allowed, the Maddock side arm rotary ditchers are not recommended.

Figure 2.7. Maddock model RD90 ditcher in operation (Source: http://www.maddockcorp.com)

Figure 2.8. RD160 cutting head (Source: http://www.maddockcorp.com)

Hurricane Ditcher

Hurricane Ditcher manufactures two models of sidearm ditchers; the Baby Sidearm and the Original Sidearm. Both models are pulled by a tractor and use a mechanical (chain) drive. Both models use round digging wheels which allow the operator to remove soil from the bottom of the ditch without disturbing the sides. This procedure reduces erosion by leaving the banks of the ditch sodded.

The Baby Side arm as shown in Figure 2.9, is typically used for shallow ditch cleaning. It contains a 26" digging wheel with 5 hardened replaceable paddles. Paddles can be resurfaced as needed. It can reach out 10 feet from the center and 5 feet down in a ditch. When pulled by a 100 HP tractor, the Baby Sidearm can clean 1 mile of ditch every hour, removing 7-8 inches of soil from the bottom. The Baby Sidearm can be equipped with laser or GPS control for precise grade control.

The Original Sidearm is typically used for deep ditch cleaning. It contains a 42" digging wheel with 9 hardened replaceable paddles. Paddles can be resurfaced as needed. It can be operated at a distance of 5 feet to 14 feet from the center of the tractor and at a depth of 9 feet to 3 feet respectively. When pulled by a 200 HP tractor, the Original Sidearm can clean 1 mile of ditch every hour, removing 10-12 inches of soil from the bottom.

Figure 2.9. Hurricane Baby Sidearm Ditcher in operation (blowing dirt mode)

(Source: http://www.hurricane-ditcher.com)

Liebrecht

Liebrecht Manufacturing sells several models of sidearm rotary ditchers and waterway ditchers. The side arm ditchers as shown in Figure 2.10, spreads the ditch's waste up to 100 ft and come in different models with different cylindrical head sizes (36", 42" and 48"). They can clean out

existing ditches up to 6 feet deep. Liebrecht can customize the side arm ditchers to clean deeper ditches (up to 10 feet). Liebrecht side arm ditchers are designed to be pulled behind a 200-250 hp tractor.

Figure 2.10. Liebrecht Side Arm Ditcher (Source: http://www.farmdrainage.com/)

The Liebrecht waterway ditchers as shown in Figure 2.11, also come in different models with different cutting wheel sizes (5', 6', 7' and 8'). The 6', 7', and 8' waterway ditchers have multidirectional dirt shoots, (Up/Down and Forward/Rear). The 5' waterway ditcher only has an up/down dirt shoot. Multidirectional dirt shoots allow the operator to spread the dirt out to max distance or pile it up next to the ditch. All of the waterway ditchers have side blades to cut side slopes of the ditch. The waterway ditchers can be used in mud, rocks, brush and other heavy debris. The 8' waterway ditcher can clean out existing ditches up to 4 feet in depth and has an optional truck loading hood that enables the operator to dump the ditch's waste directly to a truck. Liebrecht waterway ditchers are designed to be pulled behind a 200-250 hp tractor.

Figure 2.11. Liebrecht 8’ Waterway ditcher loading a dump truck

2.2.2. Field observations of rotary ditching equipment

The research team conducted three site visits to observe rotary ditching equipment not currently used by ODOT. Table 2.5 provides more information about the manufacturer of equipment observed, date and location of the site visits.

Table 2.5. Site Visits to observe rotary ditching equipment

Date	Manufacturer	Location	Equipment observed
8/18/2015	Liebrecht	Kalida Village, Putnam County	8’ Waterway Ditcher
10/28/2015	Hurricane ditcher	Highland	Hurricane Ditcher Company Demo
11/6/2015	Ditchmaster	Knoxville, Tennessee	Ditchmaster model 400 field observation

The first site visit took place in Kalida village in Putnam County. During this site visit, a 2’ deep ditch of approximately 1200 feet was cleaned out using Liebrecht’s 8’ Waterway Ditcher. The Waterway ditcher is a pull type ditcher that straddles the ditch directly. The machine was equipped with a GPS system and a hood attachment that allowed for truck loading as shown in Figure 2.11. The crew was made of five workers, where two served as flaggers, one as the equipment operator, one as a truck driver, and one as a grounds-man. The operation began with a “first pass” over the stretch of ditch. This allowed the GPS to calibrate and register the terrain. After this run, the machine was brought back to the start, and the operator set the desired grade on the computer. The operation took approximately 20 minutes. The observed

speed was calculated to be 0.68 miles per hour. Although the observed speed of the Liebrecht waterway ditcher is much faster than using either the mini excavator or gradall for ditch cleaning, the major limitation of the Liebrecht 8' water way ditcher is its large size and the fact that it travels on top of the ditch which make its use not feasible when the ditch is interrupted frequently by drain pipes and culverts and if the right of way is narrow and is interrupted by telephone poles, mailboxes as show in Figure 2.12. Another limitation of the Liebrecht 8' water way ditcher, as shown in Figure 2.13, is the large size of the ditch it produces and the large area of vegetation that it removes; vegetated areas should be preserved as much as possible because they control erosion and provide a significant amount of water quality treatment.

Figure 2.12. Liebrecht 8' waterway ditcher barely avoiding obstacle during site visit

Figure 2.13. Ditch produced by Liebrecht 8' water way ditcher

The second site visit took place in Lynchburg village in Highland county. Hurricane Ditcher Company demonstrated their Original Side-Arm ditcher and their Baby Side-Arm ditcher as

shown in Figure 2.14. Both machines are PTO driven pull type ditchers. They were both used on a 2' deep ditch in wet conditions. The Hurricane side arm rotary ditchers have a left discharge cutter head so the machines move against traffic, on the left side of road. The Hurricanes side arm ditchers are designed to throw the ditched material to the left of the ditch's bank 30 to 50 feet depending on the position of the deflector (as shown in Figure 2.15). A cylinder to control the deflector is standard on each side arm ditcher. This allows the throw of the soil to be controlled from the tractor cab instead of a manual adjustment. A deflector extension is available that would allow the operator to pile the extracted soil, instead of throwing it as shown in Figure 2.15.

The Hurricane side arm ditchers are most productive when the ditch's waste can be spread out away from the road (as shown in Figure 2.9). If spreading the waste out away from the road is allowed, the Hurricane side arm ditchers can outperform conventional ditching methods by a ratio of 10:1 (i.e. 10 times cheaper). If the ditch's waste needs to be carried away to a dumping site, additional equipment (e.g. loading equipment, backhoe and motor graders, belt loaders, dump trucks) and supporting crews are needed which will significantly increase the cost of ditching.

Figure 2.14. Hurricane's Original Side Arm (left) and Baby Side Arm (right)

Figure 2.15. Hurricane Baby Sidearm Ditcher in operation (Piling dirt mode)

The third site visit took place in Knoxville, Tennessee. During this site visit, the research team observed the cleaning of two separate ditches using the Ditchmaster model 400. Ditchmaster model 400 is a left arm truck mounted and self-loading dither that uses a 27” horizontal rotating auger to remove spoil material from ditch bottoms. It uses a horizontal rotating auger to remove spoil material from ditch bottoms. Solid materials then travel through a three-stage conveyor mechanism and drop into an 8-10 cubic yard open dump body as illustrated in Figure 2.4.

The first ditch was a 2’ deep ditch of approximately 180 feet. The crew was made of 2 workers, where one was the equipment operator, and the other was the grounds-man. The operation took approximately 33 minutes. The observed speed was calculated to be 0.062 miles per hour. The City of Knoxville crew stated that the observed speed is a little less than the typical average speed because the ditch contained some rocks which seemed to have been used as riprap in the past.

The second ditch was 3’ deep and approximately 45 feet. The ditch was cleaned in 7.5 minutes. The speed was calculated to be 0.068 miles per hour. A before and after pictures of the ditch is shown in Figure 2.16. As shown in the Figure, the Ditchmaster produce a rounded ditch that provides more area for drainage and faster water flow while limiting the area of the vegetation that is disturbed.

Figure 2.16. Before and after pictures of the ditch cleaned by the Ditchmaster

2.2.3. Phone Interviews of Other DOTs

The research team contacted various state DOTs and municipalities with similar geographic conditions to Ohio. Each DOT was asked about their ditching process, and information was gathered about equipment used, grade control, and erosion and sedimentation control. In addition to phone interviews, the research team acquired documentation and guides pertaining to other states that highlighted information on their erosion and sedimentation control techniques, as well as ditch maintenance procedures. The sections below highlights information obtained from other DOTs.

Indiana

- Gradall and backhoe are predominant machines used
- Tiger ditcher is not used because it throws its material to the side
- Newer technology has not been used
- Tri-pod levels are used for grade control in any major ditch line (over 200 feet in length)
- Average daily production is 1000-1200 ft/day
- Avoid creating V-shaped ditches

Pennsylvania

- Uses Gradalls and grader
- No GPS or laser are used
- Use silt fence and/or straw bales if ditch drains into creek
- Maintenance is done during most of construction season
- Approximately 400,000 feet (75 miles) of ditch line are cleaned every year

Michigan

- Recommended crew size of 5
- Average daily production of excavator is 400-800 lineal feet
- Average daily production of grader is 400-800 lineal feet
- Average daily production of tractor/backhoe is 300-500 feet

- Avoid creating V-shaped ditches
- If spoils are left on site, debris is removed, and soil is graded and prepared for seeding

Virginia

- Uses Ditchmaster model 800 for ditches up to 3 feet deep. Uses gradall for deeper ditches
- Ditchmaster requires periodic maintenance such as greasing and changing the blades
- Ditchmaster production rate is twice as fast as gradall
- Maintain 2064 miles of ditches in 2 counties.
- Have developed a maintenance plan with a seven year rotation.
- Ditchmaster is used 75% of the time and gradall 25% of the time.
- Ditchmaster crew is composed of 2 flaggers, operator of Ditchmaster, and 3 truck drivers.
- Gradall crew is composed of 2 flaggers, operator, spotter, and ground man and 2 truck drivers
- Ditchmaster works great on small ditches. Gradall does a poor job on small ditches as it usually disturbs shoulders significantly
- One key advantage of the Ditchmaster is that the operator doesn't have to be as skilled.
- Spoil from ditch is used for landfill cover and if clean, it is used on future road projects.
- Ditchmaster is fastest in dry sandy soil.
- When VDOT purchased the Ditchmaster, they looked at other rotary ditchers and the main reason they bought the Ditchmaster is environmental benefits. Ditchers that scatters the ditch waste on the side of the ditch may result in unsightly scene from ditch waste landing on trees and may increase liability of VDOT if there are damages to nearby farmland.

Chapter 3 – Comparison of Current Practices and Recommendations for Field Testing

A comparison of current practices for cleaning ditches and for controlling erosion and sedimentation in recently cleaned ditches are presented in the form of two matrices of alternatives. Based on this comparison, a ditcher was selected and recommended for field testing. A preliminary cost analysis of the proposed ditcher is presented in this Chapter as well as a preliminary plan for the field tests.

3.1. Ditching Equipment Matrix of Alternatives

As shown in Figures 3.1 and 3.2 the ditching equipment matrix of alternatives helps the user identify the best ditch cleaning option. The matrix also provides information on, manufacturers, model numbers, applicability, placement of equipment relevant to ditch, cost, tractor horsepower requirements, maximum depth of ditch, maximum reach, cutting head size, ditch waste disposal, grade control (GPS or laser), impact on traffic, and production rate.

	Type	Description	Manufacturers	Model	Applicability	Placement	Cost	Tractor HP requirement	Maximum depth of ditch
Traditional Methods	Mini excavator	A hydraulic powered shovel mounted on a rubber track.	Kobelco	SK85CS	Track allows it to navigate off road terrain. Used for deeper ditches.	Road; shoulder; adjacent to ditch	80K	N/A	12'8"
	Rubber tired excavator	A telescoping boom mounted on a highway speed carrier.	Gradall	XL3100	Cannot be placed on grass/dirt since it will slide or sink. Used for wider ditches.	Road or Shoulder	110K	N/A	16'6"
Researched Methods	Self loading auger ditcher	Uses a horizontal rotating auger to remove spoil material from ditch bottoms. Solid materials then travel through a three-stage conveyor mechanism and drop into a 8-10 cubic yard open dump body.	Ditchmaster	400/700 (Left arm/ right arm)	Better for small jobs where truck change is not required.Used for shallow ditches. Suited for properties where spoils cannot be tossed.	Road or Shoulder	310K/317K	N/A - Truck Mounted	3'
	Truck loading auger ditcher	Uses a horizontal rotating auger to remove spoil material from ditch bottoms. Can have a truck attached for loading of spoil.	Ditchmaster	800	Used for shallow ditches. Suited for properties where spoils cannot be tossed.	Road or Shoulder	355K	N/A - Truck Mounted	3'
	Truck loading waterway ditcher	Pull type ditcher that uses an 8' diameter circular spinning wheel and two conveyor belts to remove dirt. Dirt can either be tossed or loaded into a truck using a chute attachment.	Liebrecht	8' Waterway Ditcher	Also shapes banks to create a flow into the ditch. Not very effective if the ditch is interrupted frequently by drain pipes and culverts and if the right of way is narrow and is interrupted by telephone poles, mailboxes, etc.	Directly above ditch line	58K	200	4'
	Side arm ditcher	Pull type ditcher that uses an extended arm with cutting head to cut bottom of ditch and toss spoil.	Maddock	RD 90	Best usage is near farmlands where dirt can be spread onto field.	Adjacent to ditch	135K	100	4.5'
				RD 160	Best usage is near farmlands where dirt can be spread onto field.	Adjacent to ditch	165K	140-160	5'
			US Ditcher	RD15	Deflector allows for dirt to be piled near ditch for flattening and seeding or for collection.	Adjacent to ditch	60K	80-100	5'
				RD 20	Deflector allows for dirt to be piled near ditch for flattening and seeding or for collection.	Adjacent to ditch	80K	120-150	8'
			Hurricane	Baby Side Arm	Deflector allows for dirt to be piled near ditch for flattening and seeding or for collection.	Adjacent to ditch	30K	90-150	5'
				Original Side Arm	Deflector allows for dirt to be piled near ditch for flattening and seeding or for collection.	Adjacent to ditch	56K	150-250	9'

Figure 3.1. Ditching Equipment Matrix of Alternatives

	Type	Description	Manufacturers	Model	Maximum reach	Cutting head size	Waste	GPS or Laser	Impact of Traffic	Production rate
Traditional Methods	Mini excavator	A hydraulic powered shovel mounted on a rubber track.	Kobelco	SK85CS	24'7"	Interchangeable ditching bucket	Loaded	Laser	Requires closing of lane	.04 mph (from observations)
	Rubber tired excavator	A telescoping boom mounted on a highway speed carrier.	Gradall	XL3100	22'3"	Interchangeable ditching bucket	Loaded	Laser	Requires closing of lane; Operation has to be stopped for incoming traffic because of boom.	.03 mph (from observations)
Researched Methods	Self loading auger ditcher	Uses a horizontal rotating auger to remove spoil material from ditch bottoms. Solid materials then travel through a three-stage conveyor mechanism and drop into a 8-10 cubic yard open dump body.	Ditchmaster	400/700 (Left arm/ right arm)	8.5'	27"	Loaded	Laser	Requires closing of lane	0.06 - 0.13 mph
	Truck loading auger ditcher	Uses a horizontal rotating auger to remove spoil material from ditch bottoms. Can have a truck attached for loading of spoil.	Ditchmaster	800	8.5'	27"	Loaded	Laser	Requires closing of lane	0.08 - 0.15 mph
	Truck loading waterway ditcher	Pull type ditcher that uses an 8' diameter circular spinning wheel and two conveyor belts to remove dirt. Dirt can either be tossed or loaded into a truck using a chute attachment.	Liebrecht	8' Waterway Ditcher	N/A - Directly above the ditch	8' diameter wheel	Loaded or Tossed	GPS or Laser	Requires closing of lane	.68 mph when loading truck (observed)
	Side arm ditcher	Pull type ditcher that uses an extended arm with cutting head to cut bottom of ditch and toss spoil.	Maddock	RD 90	7'	Conical 19" depth of cut	Tossed	Laser	Requires of closing lane	.3125 mph
				RD 160	7'. Optional extended boom 10'	Conical 27" depth of cut	Tossed	Laser	Requires closing of lane	.3125 mph
			US Ditcher	RD15	16.5'	Conical 24" depth of cut	Tossed or Piled	GPS or Laser	Requires closing of lane	.5 - 1 mph
				RD 20	20'	Conical 30" depth of cut	Tossed or Piled	GPS or Laser	Requires closing of lane	.5 - 1 mph
			Hurricane	Baby Side Arm	10'	26"	Tossed or Piled	GPS or Laser	Requires closing of lane	1 mph
				Original Side Arm	14'	42"	Tossed or Piled	GPS or Laser	Requires closing of lane	1 mph

Figure 3.2. Ditching Equipment Matrix of Alternatives (Continued)

3.2. Recommendation for ditching equipment

Based on the matrix of alternatives, the site visits and the phone interviews, the research team recommended the Ditchmaster (Model 800) for field testing. The truck mounted Ditchmaster is an economical solution for cleaning ditches that are:

- Less than or equal to 3 feet deep
- Do not contain rocks
- Not offset by more than 8.5 feet from the edge of the road

The Ditchmaster and the Liebrecht waterway 8' ditchers are the only available ditchers that can load the ditch's waste directly to a dump truck. Other ditchers blow the waste to the adjacent land which:

- May expose ODOT to liabilities in case the ditch's waste is contaminated
- May not be acceptable to property owners
- May damage crops in farms
- May tarnish highway wall barriers, trees, and other structures near the ditch

Some of the other ditchers pile the ditch's waste which can be later picked up by a loader. However, this requires additional loading equipment and the cost savings resulting from the increased production rate of those ditchers is offset by the cost of the additional loading equipment and their operators.

The research team recommended the truck mounted Ditchmaster over the Liebrecht because it is more mobile and can clean right up to most obstacles, such as mailboxes, culverts or poles. The Liebrecht 8' waterway ditcher, because of its large size, would not be a feasible solution if the right of way is narrow and is interrupted frequently by mailboxes and telephone poles.

Another advantage of the Ditchmaster over the Liebrecht 8' waterway ditcher is that its 27'' round digging wheel allows the operator to remove soil from the bottom of the ditch without disturbing the sides. This procedure reduces erosion by leaving the banks of the ditch vegetated.

The research team recommended Model 800 over Models (400/700) because as previously discussed, Model 800 pulls an attached dump truck and loads the ditch's waste to the dump truck. Once the attached dump truck is completely full with the ditch's waste, it is unattached from the Ditchmaster then travels to the dump site while another dump truck is attached to the Ditchmaster to receive the ditch's waste. Having a constant supply of dump trucks to receive the waste increases the daily production rate.

3.3. Preliminary Cost Benefit Analysis

To be able to perform a cost analysis for the proposed Ditchmaster, it is important to first estimate the hourly ownership cost. Ownership costs are those costs which accrue whether or not the equipment is used. For ODOT, the ownership cost is the purchase price as follows:

- Ditchmaster model 700: $317,000
- Ditchmaster model 800: $361,200

The hourly ownership cost can then be calculated by dividing the ownership cost 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 after getting input from VDOT and the City of Knoxville has decided to use conservative values of 300 hours for the expected use rate per year and 10 years for the useful life of the equipment. Thus the hourly ownership cost is:

- Ditchmaster model 700: $317,000/(300*10)= $105.67/hr
- Ditchmaster model 800: $361,200/(300*10)= $120.4 /hr

Maintenance and repair costs for the Ditchmaster varies from $3,000 to $5,000/year according to VDOT and the city of Knoxville. To be conservative, the research team used $5,000/year for the maintenance and repair costs and calculated the total hourly costs as follows:

	Ditchmaster 400 or 700	**Ditchmaster 800**
Expected use rate per year (hrs/year)	300	300
Useful life (years)	10	10
Purchase Price ($)	317000	361200
Hourly ownership cost ($/hr)	105.67	120.40
Yearly maintenance costs ($)	5000	5000
Hourly maintenance/repair costs ($/hr)	16.67	16.67
Total hourly costs	122.33	137.07

Once the hourly cost of the proposed Ditchmaster is calculated, a cost analysis comparing the proposed Ditchmaster and the traditional process for cleaning ditches using a mini excavator 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 hourly rates of equipment used and crew wages were obtained from ODOT as follows:

- Mini Excavator: $40.85/hr
- Dump truck: $53.54/hr
- Highway Tech (with overhead): $28.69/hr
- Flagger (with overhead): $21.6/hr

The production rates of the various processes were determined as follows:

- Mini Excavator: 0.04 miles per hour, observed
- Ditchmaster model 700: 0.068 miles per hour, observed
- Ditchmaster model 800: 0.09 miles per hour (based on interviews and literature review)

To perform the cost analysis, it is also important to determine the effective ditching hours when the ditcher and/or excavator will actually be performing ditching. Because of the mobility of the Ditchmaster model 800, its ability to move between jobs and the constant supply of trucks that haul the waste to dumping sites, the effective ditching hours/day for the model 800 is assumed to be 6 hours/day based on input from other DOTs and cities using the Ditchmaster.

On the other hand, if a mini is used for ditching, a semi is needed to move the mini from one job to another which significantly reduces the hours of actual ditching per day. The effective ditching hours for the mini will depend on the size of the ditching project (longer ditches will require less set up time/linear feet and will increase the effective ditching hours/day). The effective ditching hours for the mini was assumed to be 4 hours. For the Ditchmaster model 400/700, the effective ditching hours/day was assumed to be 5 hours since it does not have a constant supply of dump trucks to receive the waste and has to haul the waste itself to dumping sites.

Knowing the effective ditching hours/day and the production rates, the daily ditching output in miles /day can be calculated by multiplying the effective ditching hours/day by the production rate.

Ditching Process	**Speed (mph)**	**Effective Ditching hours**	**Miles/day**
Ditchmaster 400 or 700	0.068	5	0.34
Ditchmaster 800	0.09	6	0.54
Mini	0.04	4	0.16

Finally, the daily ditching output in miles per day and the daily equipment and crew costs are used to calculate the average cost/mile of cleaning a ditch using the various processes.

Mini Excavator			
	$/hr	Number	Total ($/hr)
Mini Excavator	40.85	1	40.85
Dump Truck	53.54	2	107.08
Flaggers	21.6	2	43.2
Highway Tech.	28.64	4	114.56
Total Hourly Cost			$ 305.69
Total Daily Cost			$ 2,445.52
Average Production (miles/day)			0.16
Average Cost per Mile			**$ 15,285**

DM800			
	$/hr	Number	Total ($/hr)
DM800	137.07	1	137.07
Dump Truck	53.54	2	107.08
Flaggers	21.6	2	43.2
Highway Tech.	28.64	4	114.56
Total Hourly Cost			$ 401.91
Total Daily Cost			$ 3,215.25
Average Production (miles/day)			0.54
Average Cost per Mile			**$ 5,954**

DM400 or DM700			
	$/hr	Number	Total ($/hr)
DM400/700	122.33	1	122.33
Flaggers	21.6	2	43.2
Highway Tech.	28.64	2	57.28
Total Hourly Cost			$ 222.81
Total Daily Cost			$ 1,782.51
Average Production (miles/day)			0.34
Average Cost per Mile			**$ 5,243**

Although the average cost per mile for Ditchmaster Models 400/700 is less than that of Model 800, the research team in consultation with ODOT technical liaison team is recommending Model 800 because it has a higher daily ditch cleaning rate which would allow for more miles of ditch cleaning per year. This is important if a ditch maintenance plan is adopted by ODOT.

An analysis of the cost comparisons will reveal that the cost savings of the Ditchmaster Model 800 result from the following:

- Increased production rates: The production rate of the Ditchmaster is 0.09 miles per hour. The observed production rates of conventional methods vary between 0.03 and 0.04 miles per hour.
- More hours of actual ditching per day: Because of the mobility of the Ditchmaster Model 800, and its ability to move between jobs and the constant supply of trucks that haul the waste to dumping sites, the actual ditching hours/day is 6 hours/day. On the

other hand, if a mini is used for ditching, a semi is needed to move the mini from one job to another which significantly reduces the hours of actual ditching per day.

It is important to note that the Ditchmaster, in addition to providing cost savings for each mile of ditch cleaned, allows for more miles of ditch cleaning per year. This is important if a ditch maintenance plan is adopted by ODOT. When the ditches are not maintained, they can obstruct the necessary and designed flow of storm water from the roadway which can lead to safety concerns of water and/or ice on the roadway as well as premature roadway failure from saturated subsurface. A key attribute of any ditch maintenance plan is the number of years between cleaning a given ditch in the county's inventory. Feedback from other DOTs that have a ditch maintenance plan indicated that typically they use a 6-7 years cycle.

Phone interviews of ODOT county managers indicated that the number of miles of ditches that are maintained by each county varies from 300 to 500 miles. If an average of 400 miles is used, and assuming that ODOT maintenance crews will be spending 60 days on ditching operations per year, one can calculate the number of crews required for a ditch maintenance plan with a 7 years cycle as shown below.

Number of ditch miles to be maintained by county	400
Ditch maintenance plan cycle in years	7
Number of ditch miles to be maintained by county per year	57
Number of days ODOT crews will be ditching (days)	60

	Ditchmaster 400 or 700	Ditchmaster 800	Mini
Speed (mph)	0.068	0.09	0.04
Effective Ditching hours	5	6	4
Miles/day	0.34	0.54	0.16
Miles/year	20.4	32.4	9.6
Number of crews required	**3**	**2**	**6**

3.4. Erosion and Sedimentation Control Products Matrix of Alternatives

Figure 3.3. shows the “Erosion and Sedimentation Control Products Matrix of Alternatives”. The matrix lists the applicability of the various products, costs and application rate.

3.5. Recommended solutions for in-field testing and analysis

3.5.1. Evaluate the proposed Ditchmaster

The research team recommended that an ODOT crew be trained on using the Ditchmaster model 800. The research team recommended conducting several productivity studies to determine the production rate of the proposed Ditchmaster model 800 under different project conditions.

3.5.2. Evaluate erosion and sedimentation control measures

The research team recommended conducting several studies to evaluate the effectiveness of different types of hydraulic mulch, and erosion control blankets in controlling erosion and sedimentation in ditches. Before conducting these studies the research team recommended that ODOT personnel receive training on how to properly apply these products.

	Description	Product	Manufacturer	Applicability	Unit Cost		Application Rate (lb/acre)
					Cost	Unit	
Mulch	Stabilization product held in place by netting	Paper	X	Traditional erosion control technique	$ 30.00	Bag	2500
Netting	Used in conjuction with regular applied mulch	Netting	Conwed	Used in conjuction with regular applied mulch	$ 0.16	SY	X
Erosion Control Blankets	Stabilization fabric bound by single or double layers of netting.	Straw	Rhino	Traditional erosion control technique	$ 0.60	SY	X
		Coconut	Western Excelsior	Does not allow much vegetation growth. Used for areas with faster flows.	$ 1.08	SY	X
		Excelsior	Western Excelsior	For slopes of 2:1 or less. For low to moderate rainfall and flows.	$ 0.75	SY	X
		Jute	Belton	Adds organic matter to soil upon decomposition.	$ 0.80	SY	X
Hydraulic Mulches	Slurry of seed, mulch, and additives that is sprayed and forms a protective layer over terrain.	Flexterra	Profile	Can be used on slopes steeper than 2.5:1. Reduces soil loss when compared to blankets.	$ 42.50	Bag	3000
		Hydromulch	Conwed Fibers	Useful for moderate slopes of 2:1 and rough graded slopes.	$ 14.20	Bag	2000
		Enviroblend	Conwed Fibers	Covers 20% more ground per pound when compared to paper mulch.	$ 14.15	Bag	2000
		Cellulose Mulch	Conwed Fibers	Useful for mild slopes of 4:1 and rough graded slopes.	$ 12.30	Bag	2000
		Jet Spray	Profile	Improves performance of jet spraying machines.	$ 13.00	Bag	2000
		Seed Aide	Profile	Combination of hydromulch and tackifier.	$ 16.85	Bag	4356
Tackifier	Additive used to bind soil particles and prevent detachment as a result of high velocity flows or raindrops.	Slicky Sticky	Turfmaker	Combined with hydroseeding products to improve performance.	$ 215.00	Case	20
		Fiber Bond Ultra	ProPlus	Combined with hydroseeding products to improve performance.	$ 27.50	Bag	90
		Contack	Conwed Fibers	Combined with hydroseeding products to improve performance.	$ 135.00	Case	40
		TackDown	Profile	Combined with hydroseeding products to improve performance.	$ 65.00	Case	50
Barriers	Allows the flow of water while trapping sediment and debris.	Rock Dams	X	Traditional erosion control technique	X	X	X
		Straw Wattles	X	Cheaper and less labor intensive than rock dams.	$ 0.95	LF	X
		Terra Tubes	Profile	Offers superior sediment retention. Can be used as slope interruption device, flow check, and as a stormwater treatment element.	$ 2.53	LF	X

Figure 3.3. Erosion and Sedimentation Control Products Matrix of Alternatives

Chapter 4 – Erosion Control Products Field Tests

When ditches are stripped of the vegetative cover during ditch cleaning maintenance operations, the risk of erosion is high. Once particulate is worn and dislodged, it is transported and carried to another location where it becomes deposited via the process of sedimentation. Sedimentation not only necessitates the need for dredging of large waterways, but at a smaller level, increases the frequency of roadside ditch cleaning.

A well-established vegetative cover is one of the most effective methods of reducing erosion in recently cleaned ditches. Vegetation is used to stabilize soil, reduce erosion, prevent sediment pollution, and reduce runoff by promoting infiltration. Vegetation controls erosion by reducing the velocity and the volume of overland flow and protects bare soil surface from raindrop impact. Healthy, dense vegetation promotes infiltration and reduces the amount of runoff.

Vegetation is established in ditches through permanent seeding. Permanent seeding includes seedbed preparation, planting seed and protecting the seeds with temporary erosion control products. Several erosion control products exist in the market and the objective of the temporary erosion control products (TECPs) field tests was to evaluate their effectiveness in quickly establishing healthy and dense vegetation in roadside ditches. Three field tests were conducted to evaluate the following temporary erosion control product categories:

1. Hydraulic mulch products
2. Temporary erosion control blankets
3. Straw mulch

Table 4.1 provides more information about the dates and locations of the field tests.

Table 4.1. Summary of TECPs field tests

Date	District	County
7/11-7/14/2016	4	Mahoning
11/16/2016	4	Van Wert
6/1/2017	1	Putnam

In addition to the field tests listed in Table 4.1, the researchers completed an erosion control testing plan for a site in Putnam County. The researchers visited the site on September 14 and September 19, 2016 but there were some problems with the ditch cleaning and the ditch was full of water so testing the installation of the erosion control products have been canceled. Roadside ditches should be dry before Erosion control products can be successfully applied.

4.1. Planning for the TECPs field tests

As stated earlier, the objective of the field tests were to compare the performance of hydraulic mulch products, straw mulch and temporary erosion control blankets (TECBs) in protecting seeds applied in ditches to establish permanent vegetation. There is an abundance of hydraulic mulch products and TECB products available that vary significantly in performance and cost.

TECBs can be made of wood fiber, straw, jute, coconut or a combination of these, typically with either 1 or 2 layers of plastic or jute netting which holds the material together. The performance of these blankets vary significantly. For example, a wood excelcior blanket is 55% heavier than a straw blanket, allowing it to resist high velocities and has faster seed germination.

Hydraulic mulch products are typically classified in the following broad categories depending on their ability to bind to the soil which is partly affected by the amount of tackifiers they contain:

1. Stabilized Mulch Matrix (SMM) products which contain about 5% tackifiers. They are made of thermally refined wood fibers, tackifiers, and activators that anchor mixture to

the soil surface. They can offer erosion control on flat surfaces to grades of 4H:1V. The SMM is phytosanitized, free from plastic netting, and when cured forms an intimate bond with the soil surface to create a continuous, porous, absorbent and flexible erosion resistant blanket that allows for rapid germination and accelerated plant growth.

2. Bonded Fiber Matrix (BFM) products which contain about 10% tackifiers. They consist of a matrix of defibrated fibers and cross-linked insoluble hydro-colloidal tackifiers that allow up to 1350 % water holding capacity. They dry to form a breathable, built-in-place blanket which contours with the surface to maintain intimate soil contact and offers erosion control on moderate to steep hills.
3. Flexible Growth Medium (FGM) products which combines both chemical and mechanical bonding techniques to lock the engineered medium in place and promote accelerated germination with minimal soil loss. FGM products are more expensive but are immediately effective upon application because they bond directly to soil. They are made of a matrix of thermally refined wood fibers, cross-linked biopolymers, and water absorbents that allow up to 1500% water holding capacity. They can immediately bond to the soil surface. Their flexible yet stable matrices retain > 99% of soil, vastly reducing turbidity of runoff for up to 18 months.

The above hydraulic mulch product categories vary greatly in longevity, strength, heaviness and the rate of water flow they can handle. As illustrated in Figure 4.1, the product categories are separated into tiers based on the recommended steepness of slope, flow velocities and shear stress that they can sustain.

Figure 4.1. Hierarchy of Hydraulic Mulch Categories

Table 4.2 includes representative values of the properties of the various hydraulic mulch products including:

- Maximum ditch's side slope that can be protected by the TECP
- Curing time: length of time that a product needs to dry out and gain its designed strength
- Functional longevity: is a term describing how long an erosion control material/BMP is predicted to provide desired performance attributes. The higher the functional longevity, the more storms the BMP can withstand; since paper mulch for example has a low functional longevity, it won't last very long (it will be gone after 1 or 2 rain events).
- Cost

Knowing the values of these properties is important to the proper selection of the TECPs as is discussed in Chapter 6.

Table 4.2. Typical attributes of hydraulic mulch categories

Hydraulic mulch Type	SMM	BFM	FGM
Maximum Ditch Side Slope	4H: 1V	3H:1V	1H:1V
Curing Time	24 hours	24 hours	2 hours
Functional Longevity	3 months	6 months	18 months
% tackifier	5%	10%	10% and other polymers
Example of available products	Terramatrix	Promatrix	Flexterra
Cost (product only, without installation) $/acre	$ 1,200.00	$ 1,520.00	$ 2,160.00

4.1.1 Review of other DOTs' approved list of Hydraulic mulch

Before selecting Hydraulic mulch products for field testing, the research team conducted a literature review to determine other state DOTs' experience in utilizing/specifying Hydraulic mulches. The following describes the results of the literature review.

In 2010, Texas evaluated the performance of Flexterra FGM for 3H: 1V slope protection applications in both clay and sandy soils. Results were compared to standards of sedimentation and vegetation density. The allowable sediment loss per 100 sq feet was 7.89 and 631.8 respectively for clay and sandy soils. Results of Flexterra show only 0.72 and 53.78 pounds of sediment lost per 100 sq feet. In terms of vegetation density, the standard for both types of soil was 50%. Flexterra showed vegetation cover of 309.66% and 84.97% in sandy and clay soils respectively. Based on these positive test results, TxDOT moved to add Flexterra to its Approved Product List for slope protection (Texas DOT 2014).

In California, Bonded Fiber Matrix was applied to exposed soil after huge wildfires at rate of 2,000 pounds per acre. The applied product stayed intact and did its job during Southern California's rainy season. It withstood five rain events, including one in early March that saw more than four inches fall in a 24-hour period. There was only clear-water runoff, nearly no washouts and no loss of soil after the rain event.

South Carolina DOT used Terra Tubes and Flexterra for 2H:1V slope protection on Highway 290 project. Flexterra was hydraulically applied at rate of 3,500 pounds per acre over the 200 foot long slope. Terra Tubes were used as slope interruption devices at parallel intervals of 25 to 50 feet to disperse water runoff. The slopes demonstrated dramatic growth establishment when springtime arrived. The soil stabilization was so successful that South Carolina DOT wrote Flexterra into its constructions specifications as an equal to double side blankets for slopes up to 2H: 1V (Profile 2012).

4.1.2 Selected TECP for testing

Based on the review of other DOTs experiences with TECPs and consultation with manufacturers, the following 7 products were selected for the field tests:

1. **Terra Tubes** are engineered composites of wood fibers, man-made fibers and performance-enhancing polymers—all encased in heavy-duty cylindrical tubes to decrease the speed of water flow.
2. **Proganics BSM** is a combination of recycled Thermally Refined® bark and wood fibers with a proprietary blend of biopolymers, biochar, seaweed extract, humic acid, endomycorrhizae and other beneficial constituents. It has been designed as a topsoil alternative that accelerates the development of depleted soils/substrates with low organic matter, low nutrient levels and limited biological activity.
3. **Flexterra FGM** is combination of 100% recycled wood fibers, 100% biodegradable man-made fibers and other naturally derived biopolymers.
4. **Promatrix EFM** is composed of 100 recycled Thermall Refined wood fibers, 100% biodegradeable interlocking man-made crimped fibers and advanced micro-particles.
5. **Wood with tackifier mulching** is more advanced wood fiber mulching which contains 100% recylced wood fiber and tackifier.
6. **Coconut erosion control blanket** is a natural, stitched coconut blanket that provide a temporary organic cover to reduce erosions, protect seeds, enhance germination, and hasten re-vegetation.

7. **Curlex II erosion control blanket** consists of softly barbed, interlocking, curled, Aspen excelsior fibers. The top and bottom of each blanket are covered with photodegradable or biodegradable netting.

It should be noted that some of the products above have much higher erosion control performance but are more expensive. One objective of the field tests was to identify proper TECPs that will affordably achieve and maintain environmental compliance for different ditch conditions.

4.1.3. Application rates

The application rates shown in Table 4.3. were used based on manufacturers' recommendation.

Table 4.3. TECPs' application rates

Hydraulic Mulch	Application Rate (lbs./acre)	Gallons of water required for each 50lb bale
Flexterra	3000	125
Promatrix	3000	85
Wood with Tack	2500	100
ProGanics	3500	67

ODOT Roadside Mix seeds were used at a rate 400 lbs/acre and fertilizer 15/30/15 was used at a rate of 50lbs/7,500 ft^2.

Table 4.4. shows the unit costs of the various products purchased

Table 4.4. Unit costs of TECPs used

Product	Description	Unit Cost
Flexterra	50 lb bag	$ 35.25
Promatrix	50 lb bag	$ 23.00
Wood with Tack	50 lb bag	$ 14.50
Terra Tube	32' tube	$ 81.25
Curlex® II	8' x 112.5' roll	$ 48.00
AEC Premier Coconut™:	8' x 112.5' roll	$ 67.07
6" Steel Wire Staples:	Box 1,000	$ 32.00

To simplify the process of determining the quantities of the hydraulic mulch mix required for the field tests, a spreadsheet "TECP-quantity" was developed as shown in Figure 4.2. In the spreadsheet, the user enters the size of the ditch, the size of the hydroseeder and both the mulch application rate and water mixing rate. The spreadsheet calculates the required number of hydraulic mulch bales, the amounts of seeds and fertilizers and the volume of water in gallons needed for the mix.

In case of large ditches that need more water than the size of the available hydroseeder, the spreadsheet will divide the application into different "trips" and will provide the # of bales, the amount of seeds and fertilizers and the volume of water required for each "trip". The spreadsheet has already been populated with information corresponding to several mulching products that were tested during the research project. Information on additional mulching products can be easily added.

Furthermore, in ditches where it is recommended to use wattle products such as terra tubes, the spreadsheet will calculate the number of wattles needed based on the ditch's slope and length.

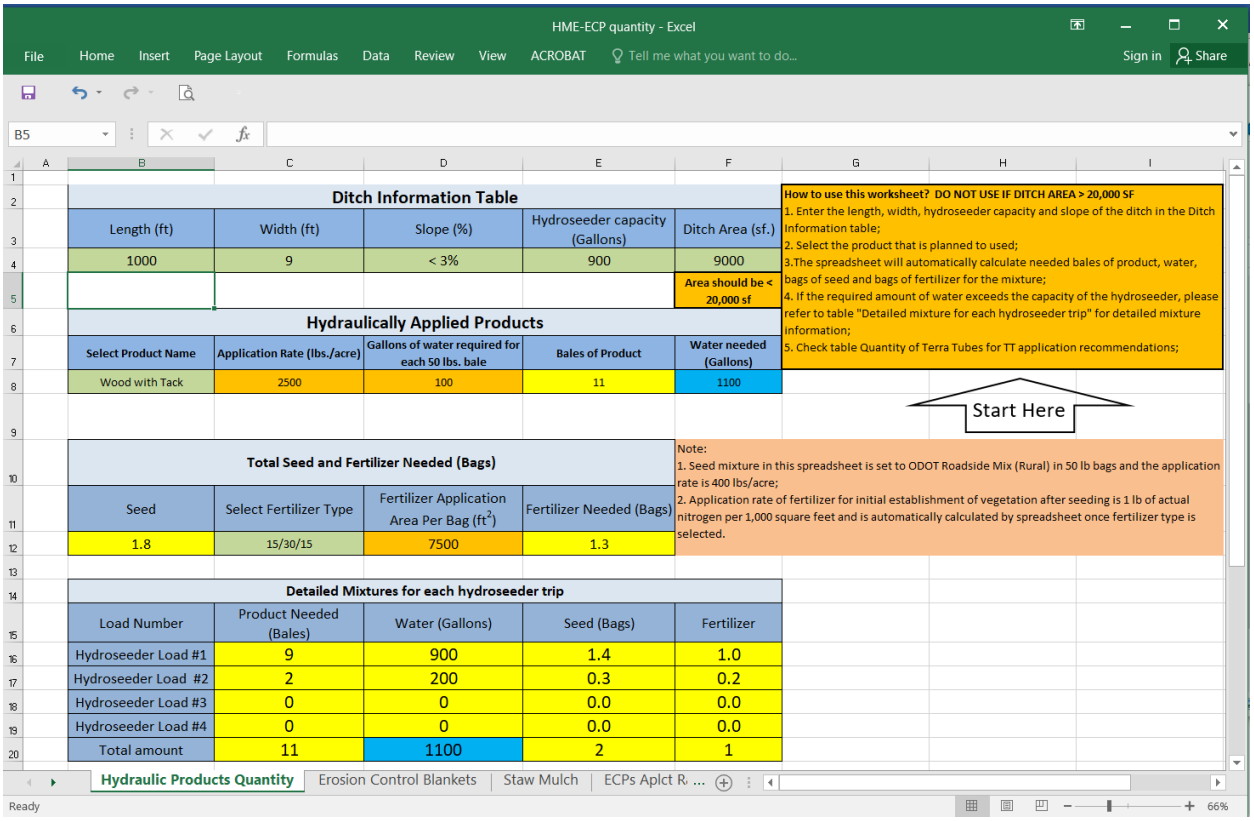

Figure 4.2. Spreadsheet "TECP-quantity" to calculate quantities for the hydraulic mulch mix

4.1.4. Hydroseeder

Proper equipment and accessories are crucial for successful application of hydraulic mulches. Typically, a hydroseeder and a fan nozzle are required. A hydroseeder is made up of several components including the tank, the agitation system, and the pumping system. Each of these components has few different options. The tank size of hydroseeders can vary from 300 gallons to 4,000 gallons. For ditch applications, considering the total application area is normally small, a tank with 700 – 1,000 gallons' capacity should be enough.

Hydroseeders typically have two kinds of agitation systems: jet agitation and mechanical agitation. It is recommended that the hydroseeder be mechanically agitated and not jet agitated so that it has enough power to mix the viscous hydraulic mulch mix aggressively. Mechanically agitated hydroseeders use either a centrifugal pump or a gear pump. A centrifugal pump allows spraying the hydroseed mix further which may not be important for

ditches since they are typically close to the road. The gear pump allows pumping thick viscous slurries. The specifications for the Bowie hydroseeder used for the research is shown in Figure 4.3.

BOWIE INDUSTRIES, INC

BUILT STRONG...BUILT TO LAST™ MADE IN THE USA

Hydro-Mulchers®
- Bowie 300
- Lancer 500
- Lancer 600
- Victor 800
- Victor 1100
- Imperial 1500
- Imperial 3000

Alternative Daily Cover Mulchers
- ADCM 800
- ADCM 1100

Aero-Mulchers®
- Model MG-30
- Model SG-50
- Crimp-Disc

Parts & Service

Bowie Dealers

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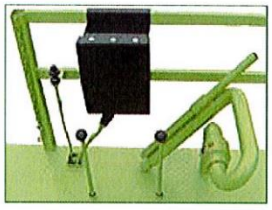
Bowie Hydro-Mulcher Victor 1100

Bowie's Victor 1100 is available as a trailer, gooseneck or skid model. The Bowie Victor 1100 is the choice for intermediate hydro-mulching jobs. The gooseneck makes hauling and maneuvering much easier and provides additional area for hauling the product to be sprayed. The skid model can be mounted on your own equipment, and the trailer model can be towed with a standard hitch.

For more production and less time loading, this size unit is head and shoulders above other similar machines. With the Bowie Victor 1100, you can go up to 600 lbs. of mulch per tank load and spray with a hose or from the deck using the ergonomic discharge cannon. The large access opening to the tank allows for easy and quick cleaning. The Bowie Victor 1100 also features controls on the deck which can be used for ground level operation.

Bowie Hydro-Mulcher 1100 Gallery

Click on any photo to view an enlarged version.



Specifications

Engine:
John Deere 49 hp Diesel Engine

Length:
GN 21'-6" (655 cm)
Trailer 19'-8" (599 cm)
Skid 13'-6" (411 cm)

Width:
GN 7'-4" (224 cm)
Trailer 7'-4" (224 cm)
Skid 6'-9" (203 cm)

Height:
GN 8'-7" (262 cm)
Trailer 8'-7" (262 cm)
Skid 7'-8" (234 cm)

Empty Weight:
GN 6250 lbs (2835 kg)
Trailer 5980 lbs (2712 kg)
Skid 4880 lbs (2213 kg)

Pump Options:
3" Bowie Gear Pump
4" x 2" Centrifugal Pump

Liquid Capacity:
1134 US Gallons (4292 Liters)

Optional Equipment:
Clear Water Flush System

Standard Included Parts and Equipment:

4-Nozzles

4-Part F Quick Couplers

1-Part D 1 1/2"

1-2 5/16" Ball (Trailer Mounted Only)

Spanner Wrench

Parts Manual

Engine Manual

Warranty

All specifications subject to change without notice.

Figure 4.3. Hydroseeder Spec

There are various types of nozzles available for hydroseeding operations. The degrees of spray patterns can vary from 0° to 65° while the flow can vary from 35gpm to 200 gpm. According to literatures reviewed, recommendations from TECP manufacturers and field tests, a nozzle with 50° degree fan pattern and a flow of 30 – 45 gpm will work best.

4.2. Field test results and analysis

Observations from the field tests are detailed in the following subsections.

4.2.1. Mahoning County Test on 7/11-7/14/2016

The researchers conducted the first test of temporary erosion control products (TECPs) in Mahoning County during the period of July 10 -14, 2016. The research team purchased the products required for the tests in Mahoning County and coordinated with Manufacturers Representatives to be present during the products' installation to provide training and directions to ODOT personnel.

A total of 11 ditch sections were chosen for installing erosion control products. All 11 sections were cleaned using a Gradall one week prior to the field test. The 11 sections were designated a letter from A-J as shown in Figure 4.4.

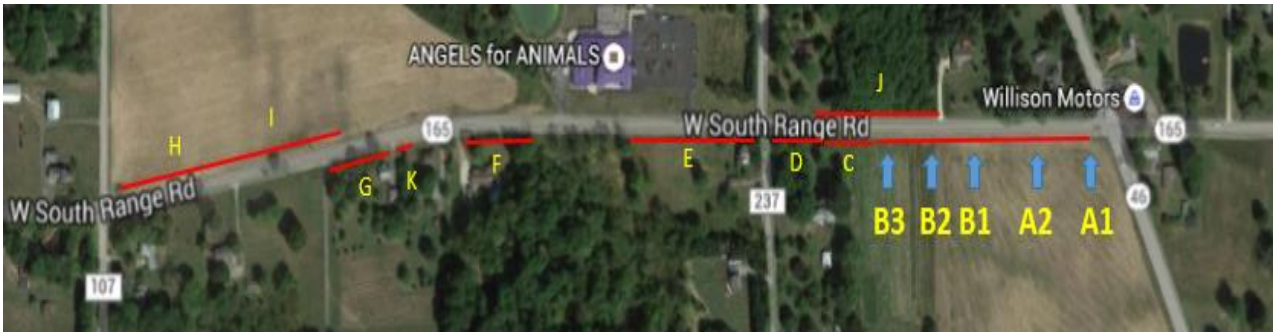


Figure 4.4. Ditch segments tested in Mahoning County

Different TECPs were applied to the various ditch sections as shown in Table 4.5. The length of all ditch sections and their longitudinal grades were measured and are shown in Table 4.5.

Table 4.5. Properties of Mahoning County's ditch sections and TECPs used

Road Section NO.	Product Applied	Longtitudinal grade	Length (ft.)
A	Proganic and TT + Flexterra	1.67%	330
B	Flexterra	1.67%	330
C	Wood with Tack	1.67%	159
D	Wood with Tack	1.67%	119
E	Wood with Tack	2.78%	372
F	Straw Seeding	2.44%	189
G	Curlex Double Netting Blanket	0.52%	190
H	Promatrix	1.50%	343
I	Proganic and Promatrix	1.50%	343
J	Coconut Blanket	1.67%	349

In order to keep track of the performance of erosion control products with time, the research team marked on the side of the pavement several locations were pictures are to be taken. Each picture-location's mark includes the ditch section's designation (A –J) and picture number. For example, A1 in Figure 4.4. indicates the first picture's location in ditch section 1.

After the products' installation, ODOT District 4 provided the researchers with weekly pictures showing the vegetation establishment in the tested ditches. The researchers developed a spreadsheet showing the progress of vegetation establishment and documented their observations on the effectiveness of the various erosion control products in establishing vegetation. Figures 4.5- 4.9 show the progress of vegetation establishment in the various ditch sections.

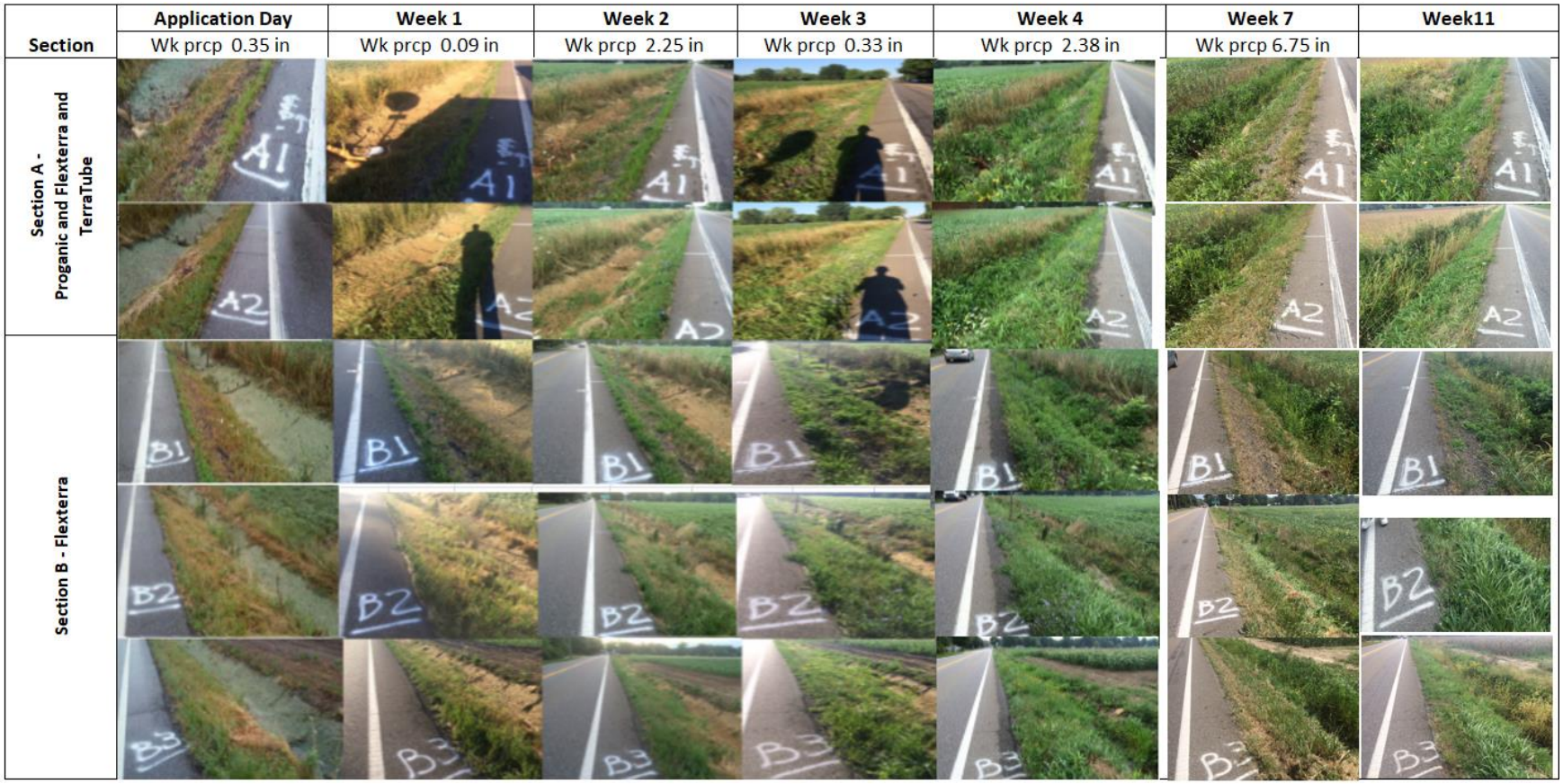


Figure 4.5. Progress of vegetation establishment in Mahoning county ditch sections

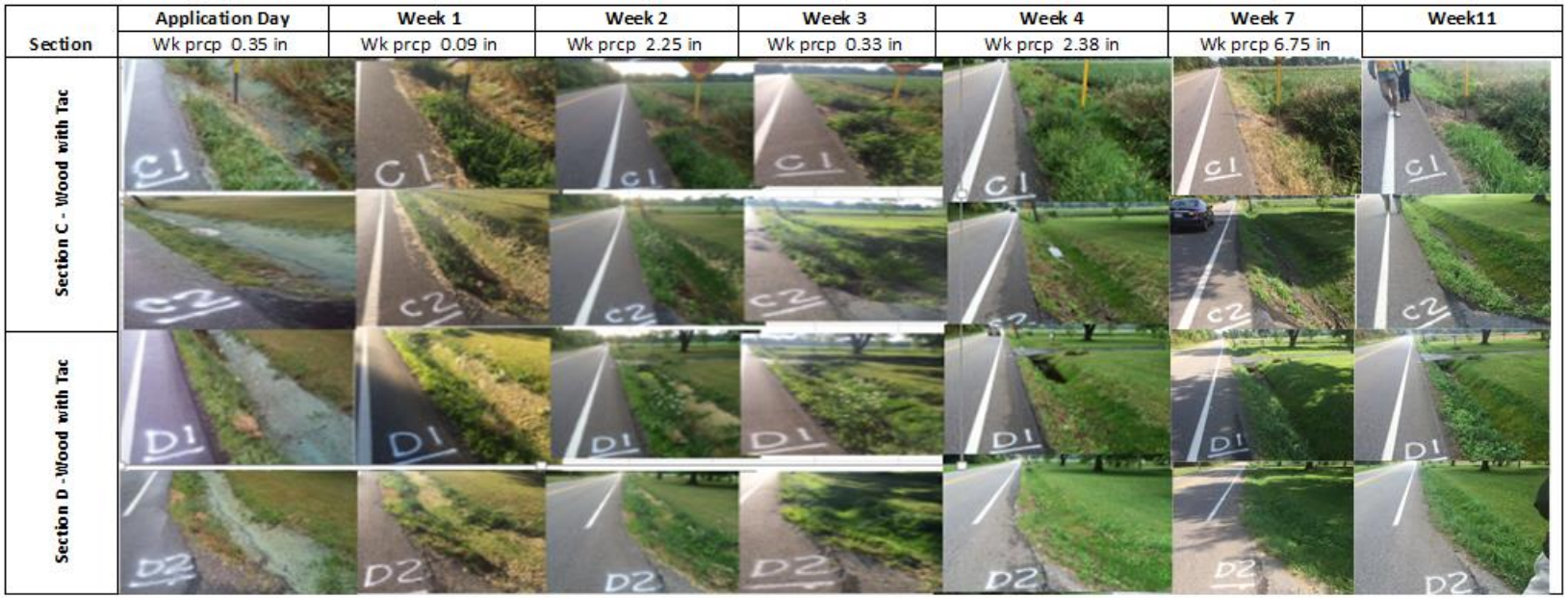


Figure 4.6. Progress of vegetation establishment in Mahoning county ditch sections

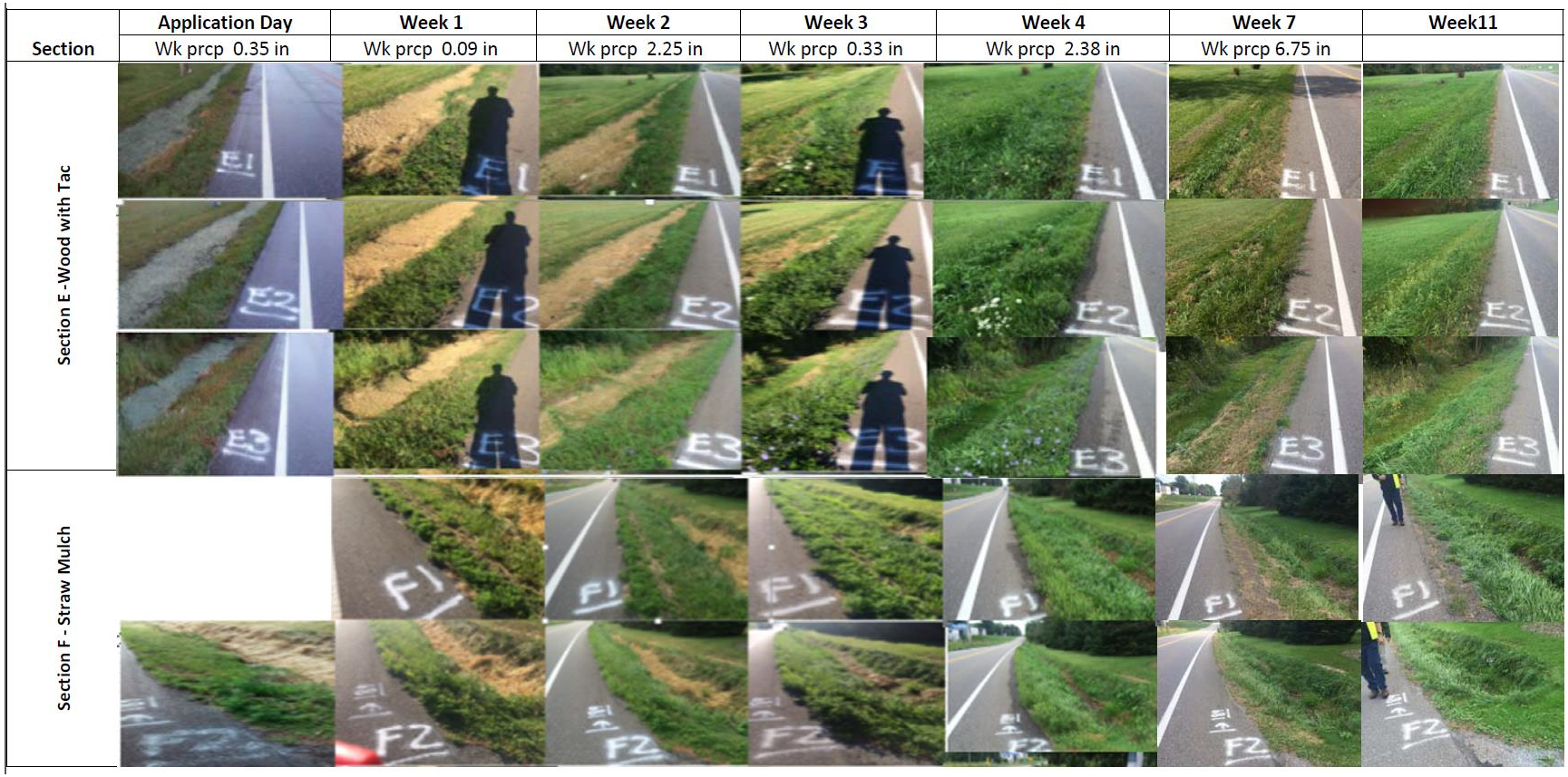


Figure 4.7. Progress of vegetation establishment in Mahoning county ditch sections

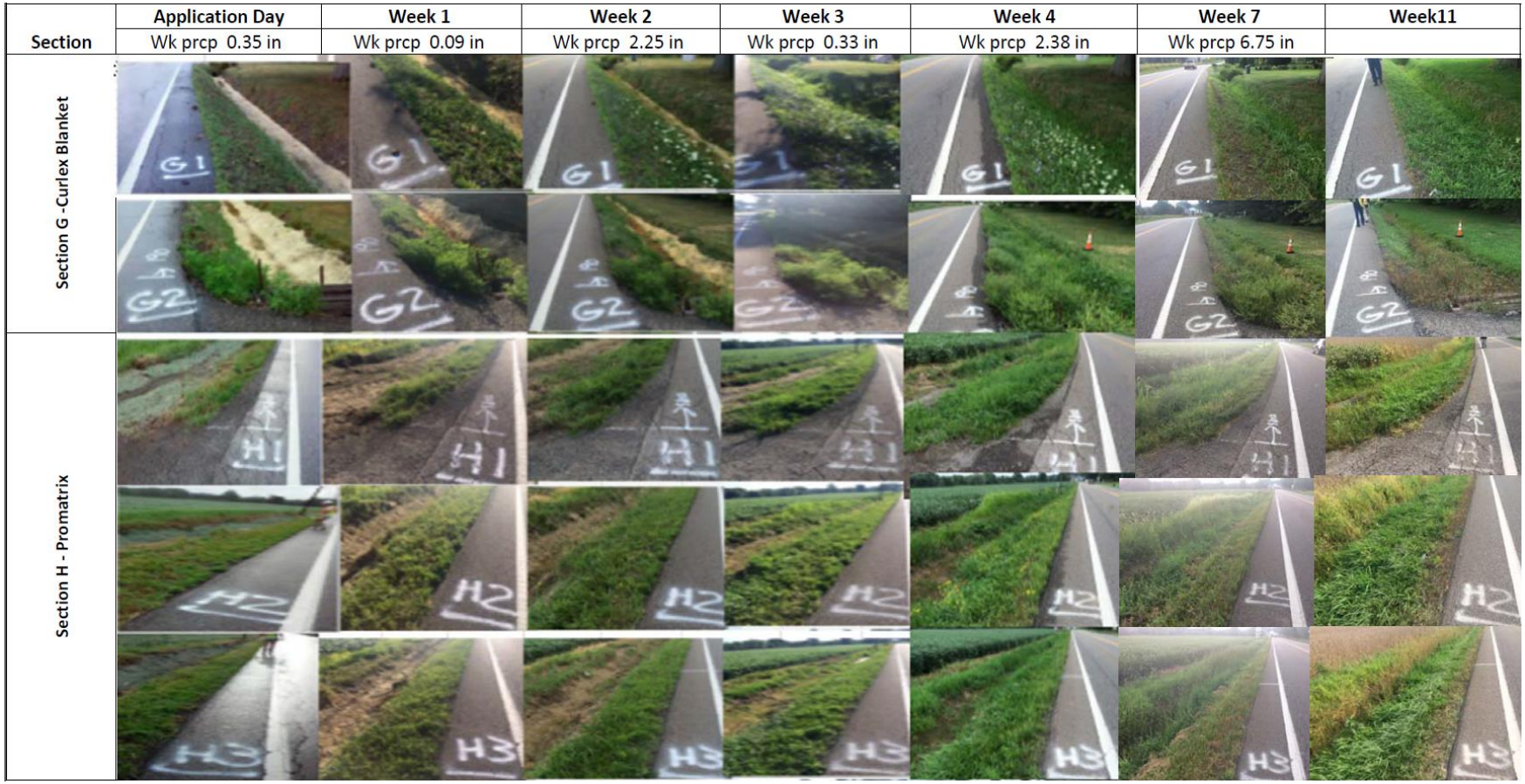


Figure 4.8. Progress of vegetation establishment in Mahoning county ditch sections

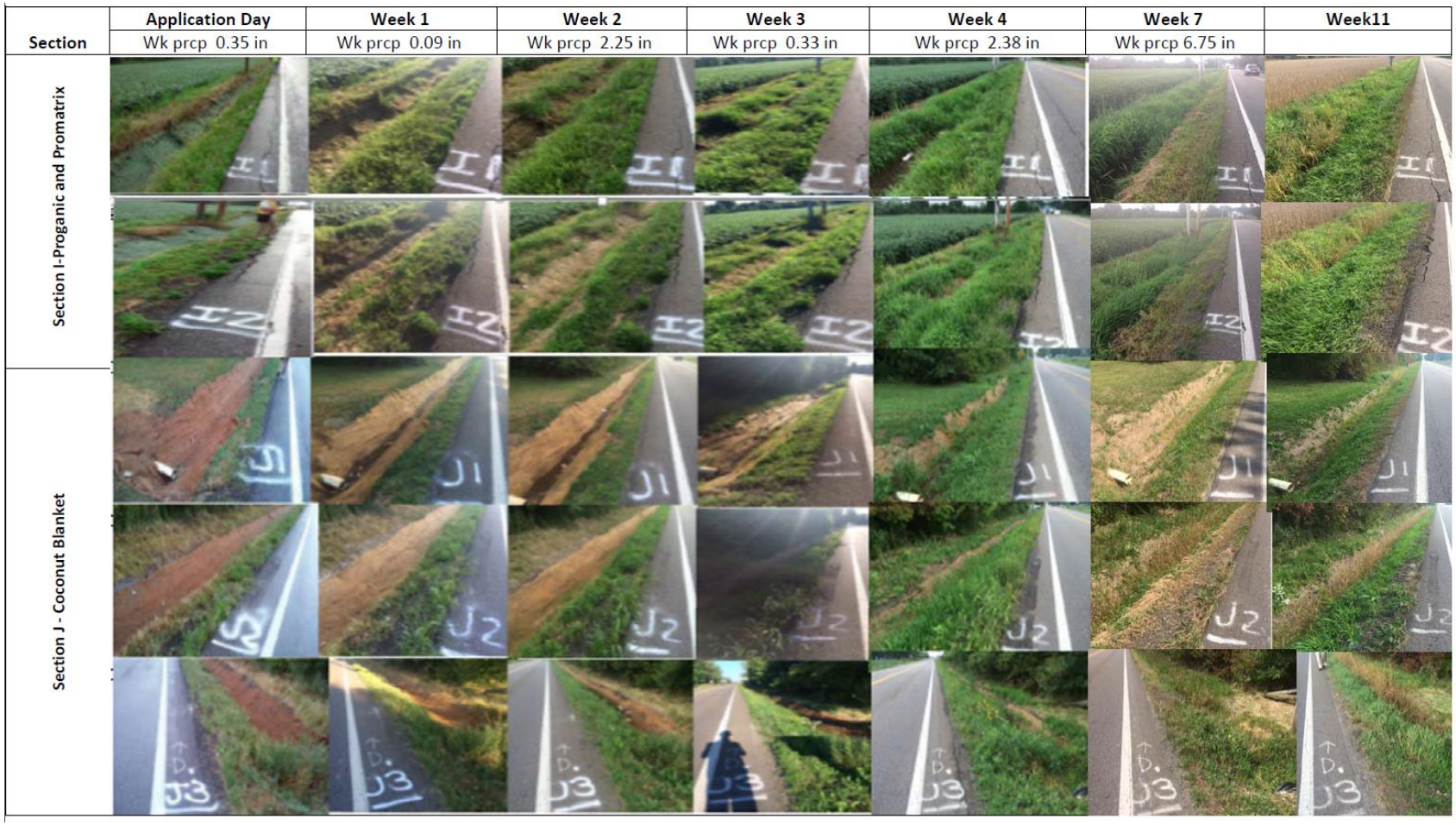


Figure 4.9. Progress of vegetation establishment in Mahoning county ditch sections

Table 4.6 summarizes observations on the effectiveness of the various temporary erosion control products in establishing vegetation.

Table 4.6. Mahoning County field tests' weekly observations of vegetation growth

		# weeks after installment		Week 1 07-20-16	Week 2 07-27-16	Week 3 08 -05-16	Week 4 08 -17-16	Week 7 09-07-16
			Weekly Precipitation	0.09 in	2.25 in	0.33 in	2.38 in	6.75 in
Road Section NO.	Product Applied	Longtitudinal grade	Length (ft.)	Vegetation Establishment	Vegetation Establishment	Vegetation Establishment	Vegetation Establishment	Vegetation Establishment
A	Proganic and TT + Flexterra	1.67%	330	None	Started growing	Established	Well established	Well established
B	Flexterra	1.67%	330	None	Started growing	Good growth	Good growth	Well established
C	Wood with Tack	1.67%	159	Started growing	Good growth	Established	Established	Well established
D	Wood with Tack	1.67%	119	Started growing	Good growth	Established	Established	Well established
E	Wood with Tack	2.78%	372	None	None	Good growth	Well established	Well established
F	Straw Seeding	2.44%	189	None	None	Started growing	Good growth	Good growth
G	Curlex Double Netting Blanket	0.52%	190	None	Started growing	Good growth	Good growth	Well established
H	Promatrix	1.50%	343	None	Started growing	Good growth	Good growth	Well established
I	Proganic and Promatrix	1.50%	343	None	Started growing	Good growth	Good growth	Well established
J	Coconut Blanket	1.67%	349	None	None	None	Started growing	Good growth

Based on Table 4.6 and Figures 4.5 – 4.9, the following observations were made:

- In general, the TECP's effectiveness in vegetation establishment from fastest to slowest is: hydraulic mulch, erosion control blankets, and straw mulch. This can be attributed in part to the hydraulic mulch's water holding capacity that is higher than the erosion control blankets and the straw. In some ditch sections, the "Wood with Tack" hydraulic mulch produced grass growth in about a week.
- The "Wood with Tack" performance varied with the ditch's grade. For section E where the ditch's grade was steeper (2.78%), vegetation growth was slower than in sections C&D where the ditch's grade was only 1.67%.
- Although the "Wood with Tack" mulch is cheaper than Promatrix and Flexterra, it showed better results in some ditch sections (C and D). As shown in Table 4.6, all ditches were gently sloping with a longitudinal grade less than 3% so all hydraulic mulch products were appropriate for stabilizing the sides of the ditch and there was no need for a more expensive high performing product. In fact, as shown in Table 4.6, high performing mulch products such as Flexterra and Promatrix actually were slower in establishing vegetation. This can be explained by the fact that these products form a

thicker blanket on top of the soil which is good for better erosion control when steep slopes call for it but may delay seed germination. This observation points out the importance of properly selecting the right TECP based on specific project conditions and avoiding over-engineering as it can lead not only to higher costs but in some cases lower performance. A detailed process for selecting hydraulic mulch products was developed as part of this research and is presented in Chapter 6.

- The Curlex II wood excelsior blanket performed better than the Coconut blanket. Again this can be explained by the fact that the Coconut is a thicker blanket which is good for better erosion control when steep slopes call for it but may delay seed germination. A detailed process for selecting temporary erosion control blankets was developed as part of this research and is presented in Chapter 6.
- For ditch sections A and I, the Proganics Biotic Soil Medium (BSM) which is a recommended alternative to top soil did not have a marked impact on vegetation growth. This can be explained in part by the fact that the top soil in ditches that supports vegetation has a thickness of up to 8 inches and that typically ditch cleaning operations does not remove the entire depth of top soil. Based on this observation the research team concluded that the use of Proganics is not justified in ditches.

In addition to the above conclusions obtained from the analysis of the pictures, feedback from ODOT crews installing the various TECPs concluded:

- Straw mulch is typically blown away because of moving trucks on the road.
- Installation of temporary erosion control blankets is much more labor intensive compared to the use of hydraulic mulch.
- If temporary erosion control blankets are not fully decomposed at the time of the following mowing and/or cleaning, they get tangled up in cleaning equipment and mowers.

4.2.2. Van Wert County Test on 11/16/2016

A total of 7 ditch sections were chosen for installing erosion control products. All 7 sections were cleaned using a mini-excavator one week prior to the field test. The 7 sections were designated a letter from A-G as shown in Figure 4.10.

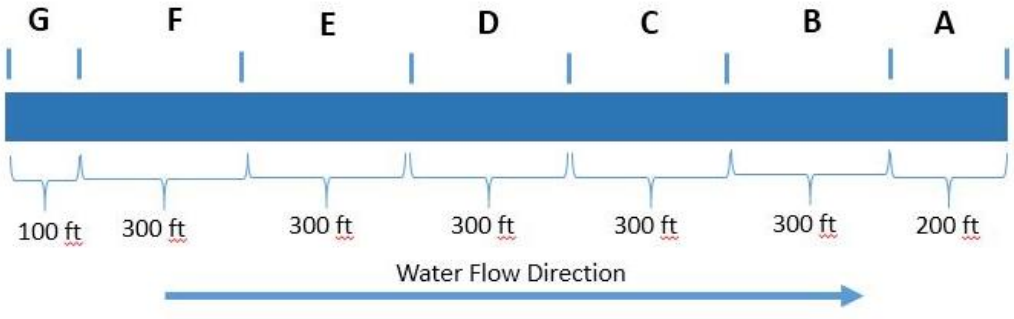


Figure 4.10. Ditch segments tested in Van Wert County

Different TECPs were applied to the various ditch sections as shown in Table 4.7. The length of all ditch sections were measured and are shown in Table 4.7.

Table 4.7. Properties of Van Wert County's ditch sections and TECP used

Ditch Section NO.	Product Applied	Length (ft.)
A	Curlex Double Netting Blanket	200
B	Flexterra	300
C	Flexterra + Proganics	300
D	Promatrix + Proganics	300
E	Promatrix	300
F	Wood with tack	300
G	Seed and Fertilizer	100

In order to keep track of the performance of erosion control products with time, the research team marked on the side of the pavement several locations were pictures are to be taken. Each picture-location's mark included the ditch section's designation (A –G) and picture number.

After the products' installation, ODOT District 1 provided the researchers with pictures showing the vegetation establishment in the tested ditches. The researchers developed a spreadsheet showing the progress of vegetation establishment and documented their observations on the effectiveness of the various erosion control products. Figure 4.11 shows the progress of vegetation establishment in the various ditch sections.

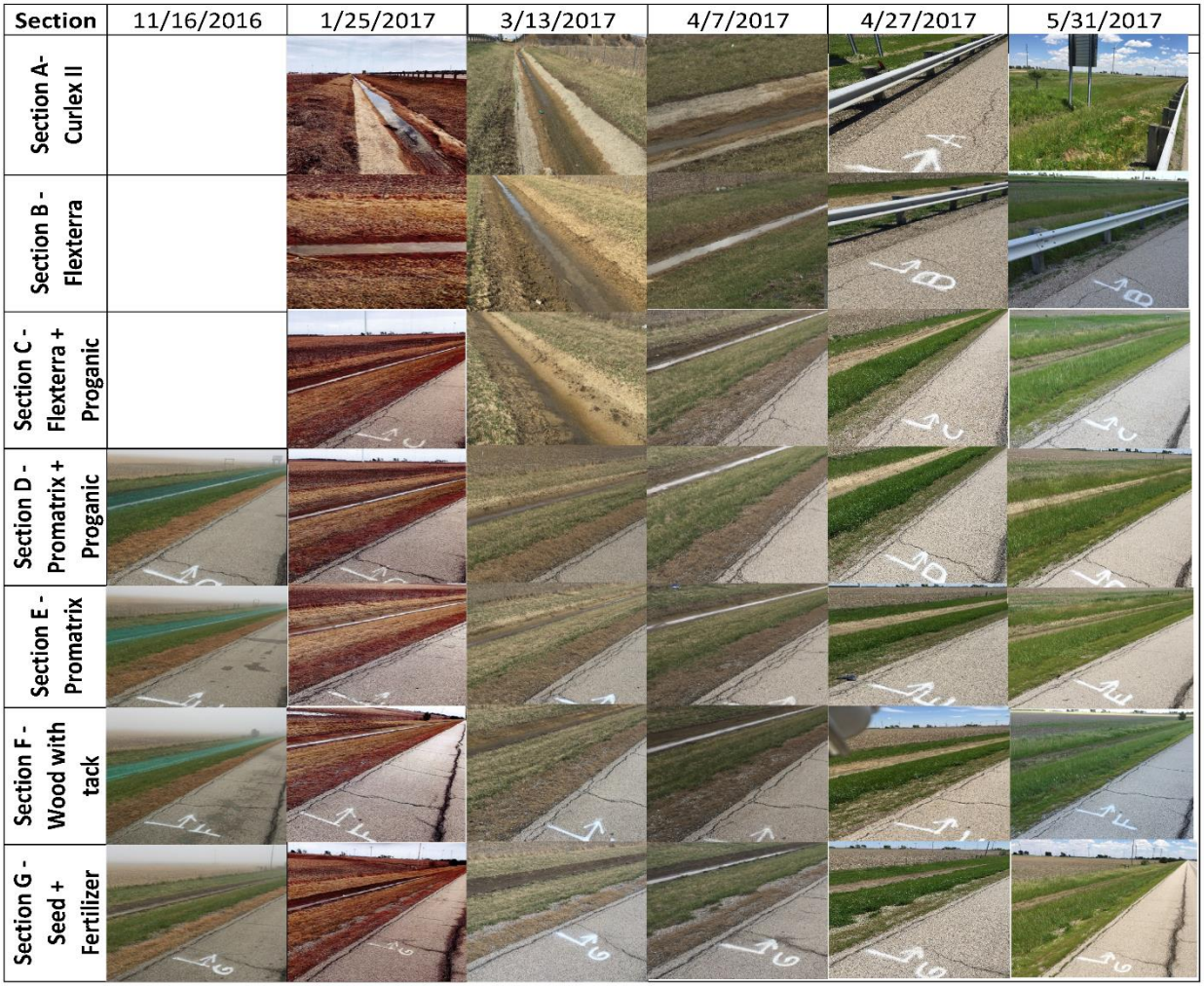


Figure 4.11. Progress of vegetation establishment in Van Wert county ditch sections

The Van Wert test was purposefully performed in November to test the ability of the temporary erosion control products to protect the seeds over the winter cold months. As shown in Figure 4.11, none of the product performed well. It was thus concluded that cold weather has a huge

impact on grass germination. Although it was previously believed that erosion control blankets and hydraulic mulch can promote germination in Winter times because they increase the surface temperature when applied, results from the Van Wert test didn't confirm that. Thus it is recommended to seed and provide temporary erosion control protection only during ODOT seeding season from April 15 to October 15. When ditch cleaning occurs after October 15, outside of the growing season, ditch substrates remain exposed throughout spring snowmelt, thereby sustaining high risks for erosion and elevated suspended sediment loads.

4.2.3. Putnam County Test on 6/1/2017

In this test, temporary erosion control products were installed in two separate ditches. As shown in Figure 4.12, the first ditch located on US 224 was divided into four sections (A to D) and the second ditch located at the intersection of US224 and US 190 was divided into two sections (E and F).

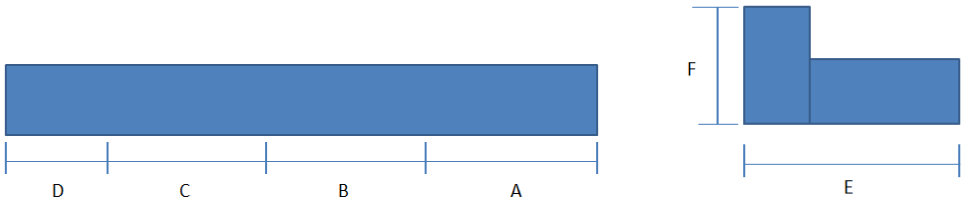


Figure 4.12. Ditch segments tested in Putnam County

Different TECPs were applied to the various ditch sections as shown in Table 4.8. The length of all ditch sections were measured and are shown in Table 4.8.

Table 4.8. Properties of Putnam County's ditch sections and TECP used

Ditch Section NO.	Product Applied	Length (ft.)
A	Curlex Double Netting Blanket	400
B	Promatrix	400
C	Wood with tack	400
D	Straw Mulch	200
E	Flexterra	400
F	Seed and Fertilizer	224

In order to keep track of the performance of erosion control products with time, the research team marked on the side of the pavement several locations were pictures are to be taken. Each picture-location's mark includes the ditch section's designation (A –F) and picture number.

After the products' installation, ODOT District 1 provided the researchers with pictures showing the vegetation establishment in the tested ditches. The researchers developed a spreadsheet showing the progress of vegetation establishment and documented their observations on the effectiveness of the various erosion control products. Figure 4.13 shows the progress of vegetation establishment in the various ditch sections.

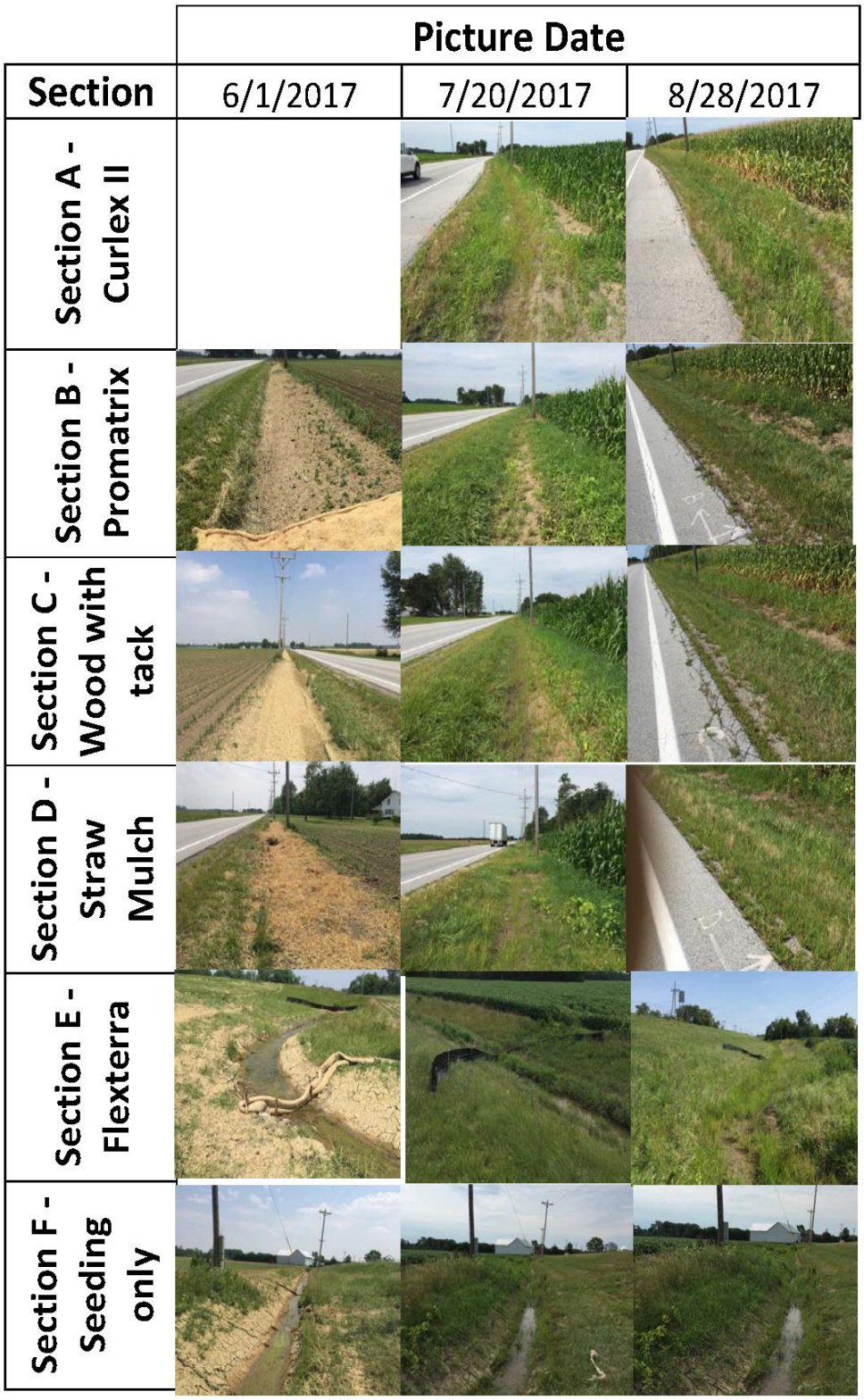


Figure 4.13. Progress of vegetation establishment in Putnam county ditch sections

In the Putnam County test, lessons learned from previous tests were used to properly select what temporary erosion control products should be installed in each ditch section. For example, the high performance hydraulic mulch Flexterra was applied at the most critical ditch section E that was close to a stream and had steep and long slopes. Flexterra was able to quickly establish vegetation to protect the ditch's slope. As shown in Figure 4.13, all TECPs performed as expected. Section F that was only seeded and fertilized didn't experience adequate vegetation growth.

4.3. Manual of Temporary Erosion Control Products for Roadside Ditches

Based on lessons learned from the field tests, a "Temporary Erosion Control Products for Roadside Ditches" manual was developed. The objective of the Manual is to familiarize highway maintenance personnel with best practices for installation, recommended application rates and selection methods of TECPs.

Chapter 5 – Ditchmaster Field Tests

5.1. Procurement of Ditchmaster and training

In phase 1 of the project as described in Chapters 2 and 3, the research team evaluated the current ODOT process for roadside ditch cleaning, and developed a matrix of alternatives for cleaning ditches that compares and contrasts available solutions and recommended testing the Ditchmaster Model 800 shown in Figure 5.1 for potential use in Ohio. The cost analysis performed has estimated the average cost/mile of cleaning a ditch with a Ditchmaster model 800 to be less than half the cost of conventional methods currently used by ODOT for ditch cleaning.

Figure 5.1. Ditchmaster model 800

The research team contacted Ford Manufacturing Inc., the manufacturer of "Ditchmaster" and obtained specifications of Model 800. The specifications specified both the Chassis and ditching unit. The research team shared the specifications with ODOT and got feedback from the technical liaison team on some modifications to the chassis specifications as provided by Ford Manufacturing. Ford manufacturing quoted a new price based on ODOT requested modifications. The technical liaison team also suggested that the research team look into the possibility of ODOT directly purchasing the chassis from Freightliner to take advantage of ODOT discounts as long as it doesn't affect the warranties on the Ditchmaster. The research team

worked closely with ODOT to order the Ditchmaster as a complete unit while still getting the ODOT discount on the chassis from Freightliner. The purchase price was $348,765.

5.1.1. Features that make the Ditchmaster Model 800 unique

Shaping the ditch while removing spoil material

The Ditchmaster model 800 uses a horizontal rotating auger to remove spoil material from a ditch, and shape the ditch in the process.

Loading the spoil material to dump trucks

As shown in Figure 5.2, the Ditchmaster model 800 pulls an attached dump truck and uses a conveyor to load the ditches spoil material into the dump truck. Once the attached dump truck is completely full with the ditch's waste, it is unattached from the Ditchmaster then travels to the dump site while another dump truck is attached to the Ditchmaster to receive the ditch's waste. The dump truck then hauls the spoil material to a dumping site where it can be disposed of in a manner that meets current environmental regulations.

Figure 5.2. Ditchmaster model 800 pulling a dump truck

Truck mounted side-arm ditcher

The Ditchmaster model 800 is a truck mounted, side-arm ditcher that moves from one ditching project to another at highway speeds.

Those features (listed above) were deemed important to the research because of the following:

Shaping the ditch while removing spoil material

The Ditchmaster model 800 shapes the ditch in an environmentally friendly way: only the actual ditch space is disturbed during ditch maintenance/cleaning. Other methods typically remove or disturb up slope vegetation and this creates additional future erosion back into the ditch and thus reduces the time needed before the next cleaning.

Loading the spoil material to dump trucks

This feature allows the spoil material to be hauled to a dumping site where it can be disposed of in a manner that meets current environmental regulations. Other ditchers blow the ditches spoil to adjacent land which:

- May expose ODOT to liabilities in case the ditch's spoil is contaminated
- May not be acceptable to property owners
- May damage crops in farms
- May tarnish highway wall barriers, trees, and other structures near the ditch

Truck mounted

The Ditchmaster model 800 is truck mounted and moves from one ditching project to another at highway speeds. Other ditchers are pulled by a tractor and can only move from one project to another at an average speed of 25 mph. The Ditchmaster model 800 can clean right up to most obstacles, such as mailboxes, culverts or across pipes which is important to ODOT because the right of way that ODOT can use while cleaning ditches is typically narrow and is interrupted frequently by mailboxes and telephone poles.

5.1.2. Training

Training on Ditchmaster model 800 (DM 800) operation was completed in both Districts 1 and 4 during the period of October 5-7, 2016. The training included a short demonstration on how to dig a ditch with the machine in an old abandoned ODOT rest area in Mahoning County. Several ODOT technicians operated the machine and feedback was generally positive for most of the demonstration. The DM800 was able to dig a nice rounded swale as shown in Figure 5.2.

However, towards the end of the demonstration, the soil was wet and sticky and jammed the conveyor system that carried the soil waste from the ditch to the dump truck. It was apparent from Day 1 that the soil's type and water content have a major impact on the performance of the Ditchmaster.

On Day 2 of the training on October 6th, the Ditchmaster was used to clean a roadside ditch in a residential neighborhood in Mahoning County. There was significant rainfall in that area before the test and the soil was wet and sticky which again jammed the conveyor system as shown in Figure 5.3.

Figure 5.3. Jamming of the conveyor system

5.2. Field tests results and analysis

In order to determine the production rate of the Ditchmaster under different project conditions, the research team conducted several field tests. Table 5.1 provides more information about the date and location of the field tests.

Table 5.1. Ditchmaster field tests

Date	District	County
10/6/2016	4	Mahoning
10/7/2016	1	Hardin
10/24/2016	1	Defiance
11/8/2016	4	Mahoning
6/20/2017	1	Putnam
7/19/2017	4	Mahoning
7/20/2017	4	Mahoning

A productivity data collection sheet, shown in Figure 5.4, was developed by the research team to record data from the tests. Data collected included:

- Test location
- Weather conditions: Temperature and precipitation
- Ditch configuration: Length, width, distance from pavement edge, grade
- Vegetation in ditch;
- Crew size
- Time log including stop, resume and end time of operation.
- Reasons for stopping the operation.

The production rate for each test was calculated as

Production rate = Length of ditch cleaned (miles)/((start time – end time) in hours)

The research team also took pictures and videos of the cleaning operations and recorded feedback from ODOT highway technicians regarding their experiences with the ditching machine.

DitchMaster Productivity Data Collection Sheet

Put a sample of soil (16 ounces or 2lbs) in a ziploc bag, seal the bag and clearly mark project date/location

Place bag inside another ziploc bag and mail to: **Hazem Elzarka, 2850 Campus Way Dr. ML 0071, Cincinnati, OH 45221-0071**

Please take pictures of ditch before and after cleaning. If possible take short videos of operation

Please email this sheet, pictures and video to: **hazem.elzarka@uc.edu**

Project Date:	
Ditch Location:	

Using ODOT location finder, please enter latitude and longitude of ditch

Latitude:		Longitude:	

Ditch Depth (ft):		Ditch offset from edge of road (ft):	

Ditch slope:

Gradient (%) =		Direction (from high to low) (ex: N-S):	

Amount of cleaning: depth of sedimentation in inches to be cleaned:	

Vegetation

Has the vegetation in ditch been mowed before cleaning operation (Y/N):

Describe type, height and density of vegetation in ditch, if any) (ex: dense 2ft weeds)

Weather				Soil condition in ditch			
Temperature		Rain (Y/N)		□	Sticky	□	Dry

Crew: Please list crew and function

#1	DitchMaster operator		#2	Truck driver	
#3	Ground person		#4		
#5			#6		
#7			#8		

Time and production rate data

	Time		Length of ditch completed (ft)	Reasons for stopping
	Hours	Min		
Time project **started**:				
1st Stop time				
Resume time				
2nd Stop time				
Resume time				
3rd Stop time				
Resume time				
4th Stop time				
Resume time				
Time project **finished**				

Total length of ditch cleaned (ft)	

Issues/concerns: Please describe any issues, or concerns cleaning the ditch

Figure 5.4. Ditchmaster productivity collection data

5.2.1 Field Test Results

Table 5.2. summarizes productivity results and feedback from the field tests.

Table 5.2. Results from Ditchmaster field tests

Date	County	Seg.	Dist. (ft)	Time (Min.)	Speed (MPH)	Notes
10/6/2016	Mahoning					Soil in the ditch was wet and sticky. Conveyor was jammed. Had to cancel cleaning operations. No data was collected.
10/7/2016	Hardin					Dense vegetation in dense slowed down operation. When vegetaion was mowed, Ditchmaster performed much better. No productivity data was collected since operator was not experienced.
10/24/2016	Defiance					Soil in the ditch was wet and sticky. Conveyor was jammed. Had to cancel cleaning operations. No data was collected.
11/8/2016	Mahoning		450	120	0.04	The frist 250' dry topsoil, machine worked great: filled single axle dump truck in about 35 minutes. The last 200' of ditch: wet top soil (not standing water wet), the machine was only conveying about 1/3 of soil. Auger and paddles were packed with muddy top soil.
6/20/2017	Putnam	1	750	105	0.08	It rained the day before so there were two wet spots that have significant water ponding in ditch which caused some trouble to the machine. Onsite cleaning was performed with no water.
		2	340	40	0.10	Offsite cleaning of machine too about 20 minutes. One wet spot in ditch.
		3	310	40	0.09	One wet spot in ditch slowed down operation.
7/19/2017	Mahoning	1	350	59	0.07	The Operator needed some time to get familiar with the machine
		2	622	53	0.13	
		3	738	66	0.13	
7/20/2017	Mahoning	1	509	45	0.13	Too hard to go around manhole covers in ditch line. Ditch very damp. Didn't pick up well, mostly pushed dirt to side
		2	1200	90	0.15	First 650 ft. Ditch was damp, didn't pick up dirt well. Last 550 ft. Dirt was dry and cleaned up well

5.2.2 Analysis of field tests

The field tests have concluded that the Ditchmaster model 800 has some limitations and some advantages.

5.2.2.1 Limitations of the Ditchmaster 800

One of the main conclusions from the field tests was that the amount of water in the soil has a very strong impact on the performance of the DM. Visual inspection of the soil in the ditch can provide a very good idea on whether the DM is going to work or not. If you use a shovel and the dirt stick to the shovel, the soil is too wet for the Ditchmaster.

Figure 5.5 shows two soil samples from the Putnam field test conducted on 6/20/2017; the soil sample on the left was too wet and caused the Ditchmaster to jam. The soil sample on the right was collected from the boundary of the wet area and the dry area where the DM performed well. Field tests have shown that if the ditch's soil is as dry as the right soil sample in Figure 5.5, the DM will work well even if there is 1 – 2 ft. tall weeds in the ditch.

Figure 5.5. Soil samples from Putnam field test conducted on 6/20/2017

5.2.2.2 Advantages of the Ditchmaster 800

Production rate

As shown in Table 5.2, the production rate of the DM has gradually increased as the ODOT technicians got more experienced in operating the machines. In addition to the field tests shown in Table 5.2, Mahoning County has used the DM on one of their ditch cleaning projects in September 2017 and was able to clean 3000 ft. of ditches in one day. This is a significant increase over the current production rate of 800-1000 ft. per day using the mini-excavator or Gradall as discussed in Chapter 2.

Shape of ditch bottom

As shown in Figure 5.6., the DM produces a shallow and relatively smooth round ditch bottom. This facilitates establishment of grasses which filter out contaminants and can be maintained by routine mowing. A well-maintained, smooth-flowing ditch will be free of heavy vegetation (tall grass, trees, cattails, etc.) and standing water, with enough grade to ensure self-cleaning and continuous flow. A smooth bottom is also good because sharp edges sometimes left after cleaning the ditch with a mini excavator or a Gradall are prone to erosion and the large clods of soil left behind will make it difficult to install erosion control blankets tightly against the soil surface. Furthermore, traditional V-shaped ditches created by conventional cleaning methods are problematic because they concentrate surface flow and lead to incision and erosion (Chesapeake 2016).

Figure 5.6. Ditch cleaned by the Ditchmaster

Does not "over ditch"

As shown in Figure 5.6, the DM does not disturb too much soil and thus minimizes the amount of soil exposed after cleaning. On the other hand, conventional ditch cleaning methods as shown in Figure 5.7. remove or disturb up slope vegetation which creates additional future erosion back into the ditch and reduces the time needed before the next cleaning. Furthermore, as shown in Figure 5.7, conventional ditch cleaning methods over time results in "over-ditching" and deepened roadside ditches can capture greater amounts of groundwater, further destabilizing the ditch. In addition, deep, incised ditches also present dangerous hazards to pedestrians and cars (Chesapeake 2016).

Figure 5.7. Ditch cleaned by a Gradall

5.2.3. Recommendations

The inability of the DM to effectively clean ditches having wet sticky soil is a significant limitation as it limits its use for "emergency" ditching to relieve flooding during seasonal rain storms or spring thaw runoff. In spite of this limitation, the benefits of the DM resulting from a better production rate and a more environmentally friendly ditch configuration can potentially make it a useful component of an integrated ditch management system (IDMS) as described in more detail in Chapter 7. An IDMS integrates various practices and equipment for ditch maintenance by selecting the best equipment/practice for a given project.

For the DM to be a useful component of an IDMS, it should only be used when the ditch is dry. In Ohio, the chances of ditches being dry are typically higher from May 15th to October 15th. During these 5 months, even if it rains, the ditches will dry faster because of the relatively warm weather. Another advantage of conducting the ditch cleaning during those months, is that seeding and establishment of permanent vegetation will likely be more successful.

Chapter 6 – Cost Benefit Analysis and Decisions Trees

6.1. Ditchmaster Cost Benefit Analysis

The preliminary cost benefit analysis of the DM800 conducted in Phase 1 of the project as detailed in Chapter 3 was revised to reflect actual cost of the machine, production rate, days the machine will be used per year and effective ditching hours per day. Table 6.1. compares the values assumed during the preliminary cost analysis and the value used in the final cost analysis together with an explanation of why the values have changed.

Table 6.1. Changes to cost analysis input

Variable	Preliminary Cost Analysis	Actual Cost Analysis	Reasons for Chage
Production rate	0.09	0.11	Actual measurements when soil in ditch is dry
Effective Ditching hours/day	6	4	Reduced because of need to get the machine ready in the morning and clean it at the end of day
Purchase cost of	$ 361,200.00	$ 348,765.00	Reduced because ODOT Freightliner discout
Days machine will be used per year	38	30	Reduced because field tests indicated that machine can only be used when ditches are dry

The new values were used to perform the final cost analysis using the same procedure as described in Chapter 3.

First the hourly ownership cost of the DM 800 was calculated as follows assuming maintenance and repair cost = $5,000/year.

	Ditchmaster 800
Expected use rate per year (hrs/year)	240
Useful life (years)	10
Purchase Price ($)	348,765
Hourly ownership cost ($/hr)	145.31875
Yearly maintenance costs ($)	5000
Hourly maintenance/repair costs ($/hr)	20.83333333
Total hourly costs	166.1520833

Once the hourly cost of the DM800 is calculated and using the following rates for auxiliary equipment and resources:

- Dump truck: $53.54/hr
- Highway Tech (with overhead): $28.69/hr
- Flagger (with overhead): $21.6/hr

and using the following production rate and effective ditching hours as previously discussed:

	Ditchmaster 800
Speed (mph)	0.11
Effective Ditching hours	4
Miles/day	0.44

The revised average cost/mile of cleaning a ditch using the DM 800 is calculated to be $7,836.

DM800			
	$/hr	#	Total ($/hr)
DM800	166.152	1	166.15
Dump Truck	53.54	2	107.08
Flaggers	21.6	2	43.2
Highway Tech.	28.64	4	114.56
Total Hourly Cost			$ 430.99
Total Daily Cost			$ 3,447.94
Average Production (miles/day)			0.44
Average Cost per Mile			$ 7,836.22

Although the revised cost/mile for cleaning a ditch using a DM ($7,836) is significantly more than the preliminary estimate/mile ($5,954), it is still almost 50% of the cost of cleaning the ditch using the conventional ditch cleaning methods. As discussed in Chapter 5, this cost saving can potentially make the DM800 a viable alternate to conventional ditch cleaning methods provided that the soil in the ditch is not wet nor sticky.

6.2 Ditching Equipment Decision Tree

There are limitations to the field tested Ditchmaster model 800. The model 800 is a viable solution for cleaning ditches that:

- Do not contain wet/sickly soil
- Are less than or equal to 3 feet deep
- Do not contain rocks
- Are not offset by more than 8.5 feet from the edge of the road

If the above conditions are not met, traditional methods of cleaning ditches using a mini excavator or a Gradall should be used as shown in the decision tree of Figure 6.1.

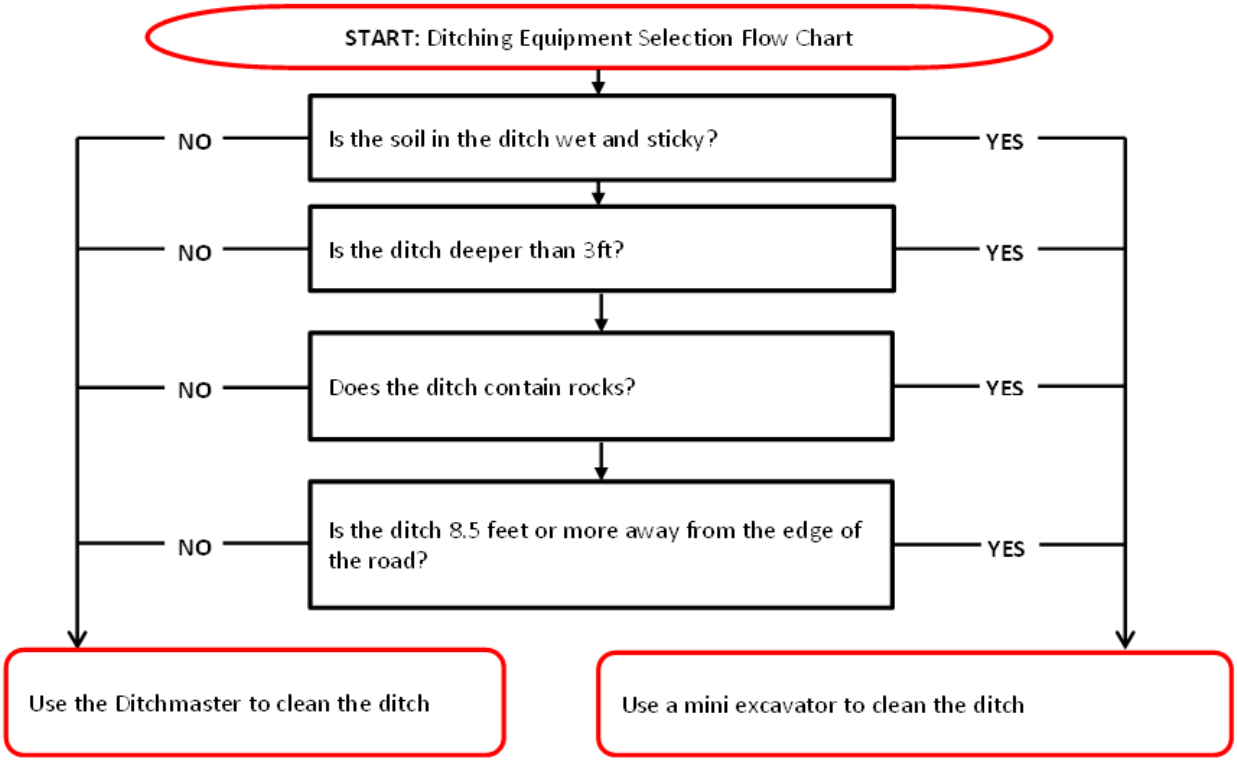


Figure 6.1. Ditching equipment selection decision tree

6.3 Temporary Erosion Control Products Decision Tree

A series of flowcharts were developed to assist Highway Maintenance Managers with selecting appropriate temporary erosion control products for a ditch that has been cleaned and that need to be seeded and protected.

6.3.1. Required Information

Before using the flow charts the following information should be obtained:

Is a hydroseeder available?

Ditch longitudinal grade:

The ditch's longitudinal grade is measured as a % and can be determined as shown in Figure 6.2. Note that Figure 6.2. includes 3 ditches with various grades.

Ditch length in feet

The ditch's length is measured in feet as shown in Figure 6.2.

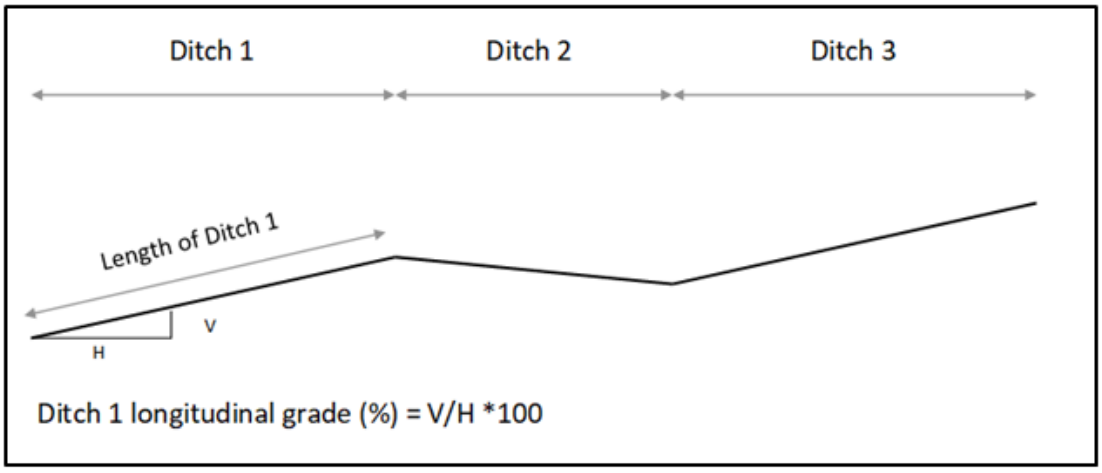


Figure 6.2. Determining ditch grade and length

Ditch side slope (H:V):

The ditch side slope is represented as an H:V ratio and can be determined as shown in Figure 6.3.

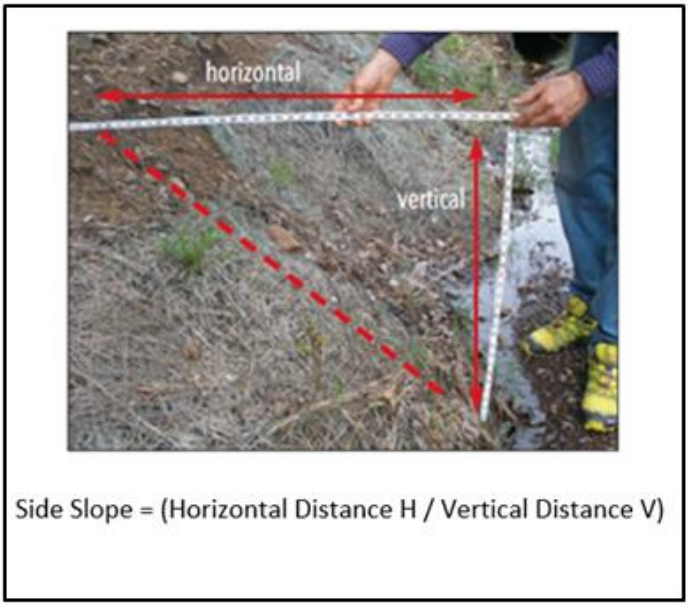


Figure 6.3. Determining ditch side slope (Brady et al. 2014)

Once you have measured the Horizontal Distance H and the Vertical Distance V as shown in Figure 6.3, convert your H and V measurements to the simplest ratio possible; for example, 45:15 reduces to 3:1.

% Wet Perimeter:

The estimated % of the ditch perimeter that will be subjected to water flow during the period of vegetation establishment (≈1 month if seeding takes place during the growing season from April 15 to October 15). The % wet perimeter can be determined as shown in Figure 6.4.

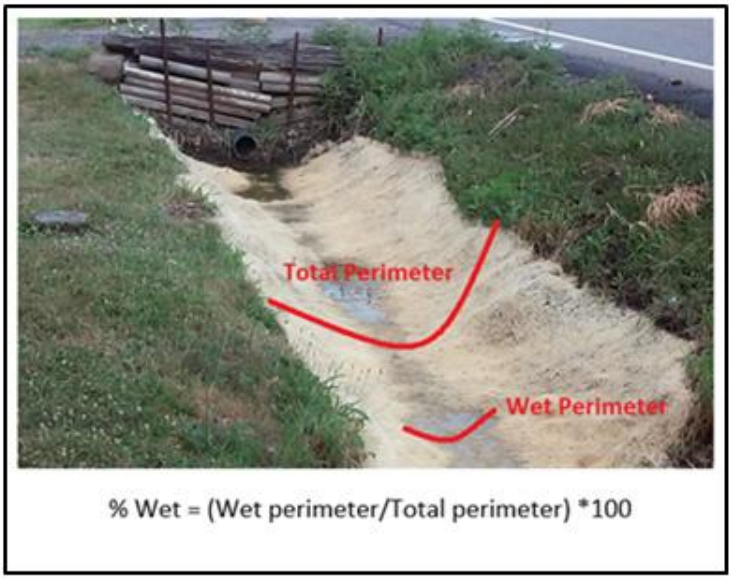


Figure 6.4. Determining ditch side slope (Brady et al. 2014)

Time before next rain storm

Time when ditch is cleaned

6.3.2. Importance of required information

This section discusses how the required information impact the selection process.

Is a hydroseeder available?

As discussed in the introduction section, several recent research studies have concluded that advanced hydraulic mulch products can be an effective method to grow vegetation in ditches. (CRWP 2012, Chesapeake 2016, *IRVM 2013*). However, these products can only be used if a hydroseeder is available.

Giving the importance of temporarily protecting a seeded ditch in order to control erosion and sedimentation as discussed above, the unavailability of a hydroseeder should not be a deterrent to seed a recently cleaned ditch and in this case, products that do not require a hydroseeder should be utilized.

Ditch longitudinal grade:

The ditch longitudinal grade has a significant impact on the flow velocity in the ditch and the value of the shear stress on the ditch's boundary. The steeper the ditch longitudinal grade, the larger the shear stress and the larger the flow velocity.

The selection of temporary erosion control products (ECP)s should *ideally* be performed based on expected shear strength. Shear strength is a term describing the amount of shear stress and concentrated flow velocity that the BMP can withstand. Natural vegetation, for example, can withstand a concentrated flow velocity of 5-6 feet/sec and a sheer stress of 2 lbs/sf. Typically, hydraulically applied erosion control products (HECP)s initially have low shear strength and can only withstand concentrated flow velocities of up to 2 ft/sec. HECPs can be used in combination of Jute netting to increase their shear strength until vegetation is established. Another alternative is to use flow attenuation devices such as rock check dams or wattles with HECPs to reduce concentrated flow velocities and shear stress. Figure 6.5 shows acceptable shear stress for different erosion control solutions.

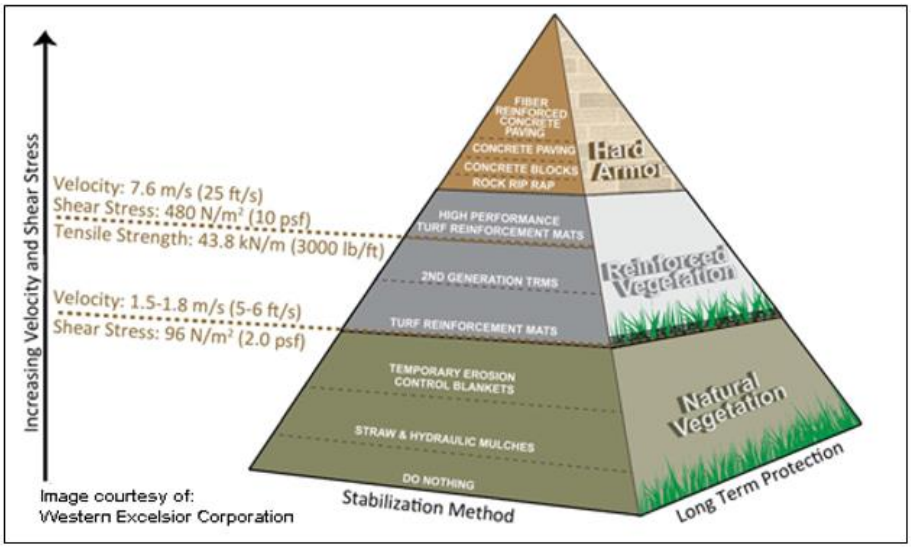


Figure 6.5. Selection of ECP based on shear stress (Western Excelsior Corporation)

It can be concluded from Figure 6.5. that if the expected shear stress on the ditch's boundary is greater than 2 psf. (lbs. per square foot), then temporary erosion control blankets are no longer feasible and a permanent turf reinforcement map is needed. Figure 6.5. also shows that once

established, natural vegetation can withstand shear stresses up to 2 psf. Thus the main function of temporary erosion control products is to ensure that vegetation is established and they are no longer needed after that.

Appendix A includes a methodology developed by the authors for calculating shear stresses using readily available data. However, since the methodology may be time consuming, the authors have developed the selection flow charts based on nationally acceptable rule of thumbs. The brief discussion of Figure 6.5. and the introduction to Appendix A were meant to alert the user that the ditch's longitudinal grade has a significant impact on the shear stress on the ditch's boundary and thus has a considerable effect on the selection of temporary erosion control products.

Ditches with gently sloping bottoms (less than 5%) can be stabilized with temporary erosion control products that protect seeds until vegetation is established. These temporary measures include various types of hydraulic mulches and erosion control blankets which will be later discussed in detail. If the ditch's longitudinal slope is between 3% and 5%, the temporary measures can be combined with check dams to improve results. The installation of check dams can help slow the flow of storm water and help protect the plants. It will also provide areas for the short-term ponding of storm water to facilitate infiltration.

Moderately sloping ditches (5%–10% slopes) will likely require turf reinforcement mats which are considered permanent erosion control installations. Steeply sloping ditches (greater than 10%) need permanent armoring with concrete, rock lining, gabion baskets, riprap, geogrid, retaining walls, or other approved products. Permanent erosion control product installation should be properly designed by an engineer and are outside the scope of this Manual.

Ditch length in feet

The ditch's length also has an impact on flow velocity and shear stresses. Water flowing in long ditches picks up kinetic energy as it flows downstream uninterrupted for long distances thereby

increasing shear stresses on the ditch's boundary. It is therefore recommended to used check dams in combinations with Hydraulic mulches or temporary erosion control blankets for ditches longer than 600 ft.

Ditch side slope (H:V):

Steep side slopes of ditches can experience sheet erosion when it rains and therefore need a resilient temporary erosion control product. In cases where a ditch's side slope is steeper than 2H:1V, a double net temporary erosion control blanket or a Flexible Growth Medium (FGM) hydraulic mulch product such as Flexterra should be used for adequate protection of seeding. South Carolina DOT has conducted some field tests on Flexterra and based on those tests has written Flexterra into its standard construction specifications as an equal to double-sided blankets for applications on slopes up to 2H:1V (Profile 2012).

% Wet Perimeter:

When developing the selection process, the authors considered new trends of using hydraulic mulch in special ditch configurations since they are easier to apply and since new hydraulic mulch products that can be used for steeper ditch side slopes currently exist. At the same time, the authors also considered the main limitation of hydraulic mulch which is its inability to resist concentrated flows before vegetation is established. For this reason, the authors suggest not using hydraulic mulches in cases where a relatively large percentage of the ditch's perimeter (>30%) would be subjected to concentrated flow during the period of vegetation establishment; in such cases temporary erosion control blankets are a better choice.

Time before next rain storm

The curing time of the temporary erosion control product should be less than the time when the next rain storm is expected. The curing time is the length of time that a product needs to dry out and gain its designed strength. If a major rainfall takes places within the curing time of an applied hydraulic mulch product, there will be significant product loss due to water flush. A

temporary erosion control blanket has zero curing time whereas the curing time of hydraulic mulch products vary from 2 hours to 48 hours.

Time when ditch is cleaned

It is important to know when the ditch is cleaned because it will determine whether hydraulic mulches can be used or not. Per ODOT CMS 659.15, hydraulic mulch should be applied from March 1 to October 30.

6.3.3. Additional information considered in developing the selection flow charts

In addition to the information provided by the user, the flow charts consider other information that impact the selection process that was identified by the research team. These include:

Ease of installation

Erosion control blankets are more challenging to use compared to hydraulic mulch and it is recommended to use them in cases where hydraulic mulch won't work. In cases where terrain is rocky, rolled blankets might not be able to adapt to the contour of the land and hydraulically applied products become the better choice.

Schedule and resource requirements

Using hydraulic mulch is faster and requires less resources compared to blankets, as no fine grading is required to smooth the slopes before application.

Cost

In general, the purchase cost from least expensive to most expensive is: straw mulch, hydraulic mulch, erosion control blankets, and turf reinforcement mat. It should be noted that the purchase cost is only a part of the selection process since picking the product that will provide the best results is the most cost-effective solution as it will reduce future sedimentation and the need to re-clean the ditch.

Maintainability of the ditch

Using hydraulic mulches is more maintenance friendly compared to erosion control blankets. If the blanket is not fully decomposed at the time of the following cleaning, it may get tangled up in cleaning equipment and mowers.

Impact on wild life

The netting within most erosion control blankets can entrap wildlife and pause a danger to wildlife particularly if it takes several years to degrade. A net-free blanket, which is stitched together with a biodegradable thread, or hydraulic mulch is a better option for flatter areas that will be mowed or to prevent potential wildlife entrapment (Brady et al. 2014).

6.3.4. TECP Selection Flow charts

Four flow charts have been developed to assist Highway Maintenance Managers with selecting an appropriate temporary erosion control product based on the information discussed in the previous sections. These flowcharts are shown in Figures 6.6 to 6.9 and are as follows:

1. FC1- Flowchart to be used if a hydroseeder is available. Based on the outcome of this flow chart, the user should continue the selection process using FC3 (in case a hydraulic mulch is recommended initially) or FC4 (in case an erosion control blanket is recommended initially)
2. FC2- Flowchart to be used if a hydroseeder is not available. Based on the outcome of this flow chart, the user should continue the selection process using FC4 (in case an erosion control blanket is recommended initially)
3. FC3- Flowchart to select adequate category of hydraulic mulch.
4. FC4- Flowchart to select adequate type of temporary erosion control blanket.

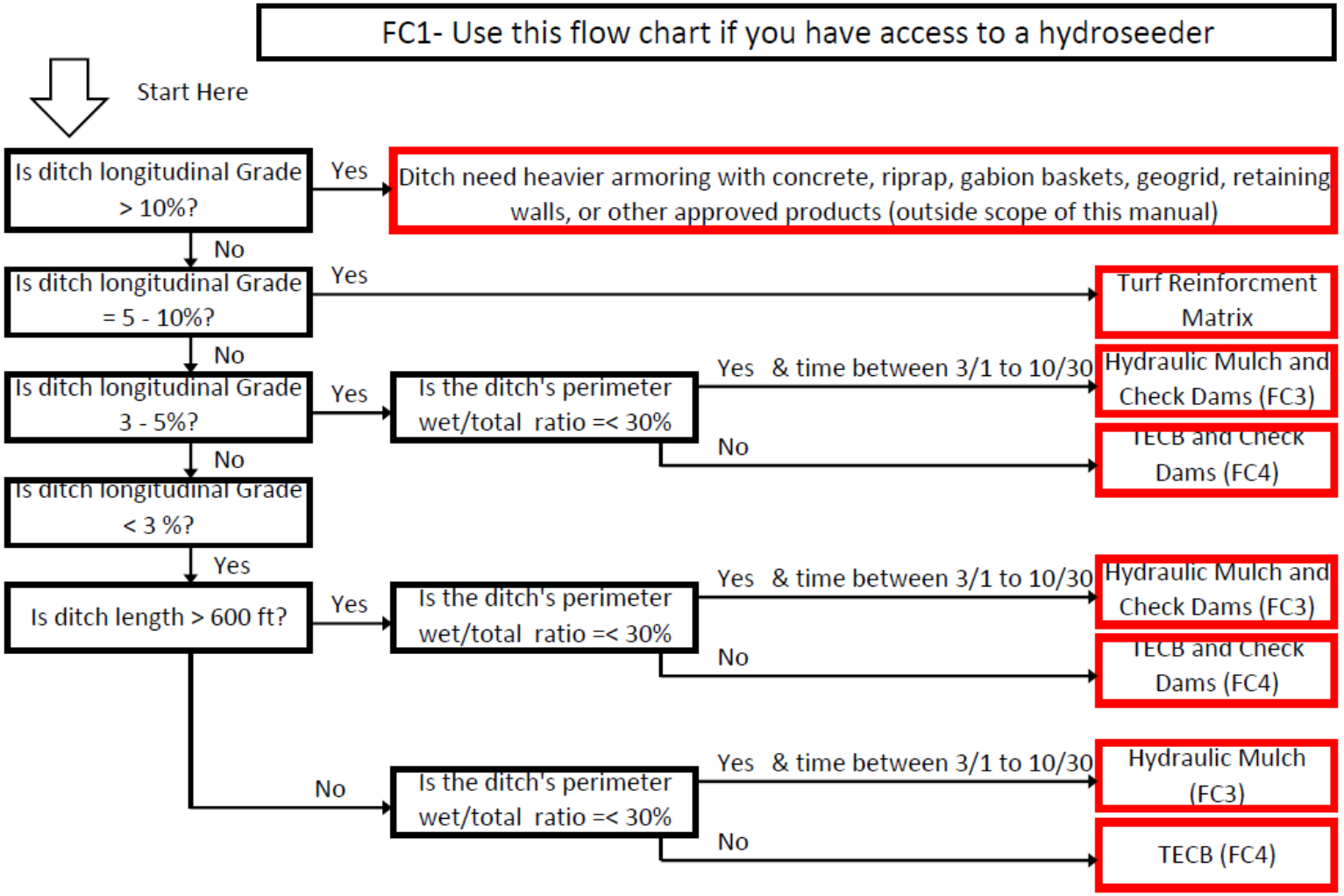


Figure 6.6. FC1- Flowchart to be used if a hydroseeder is available

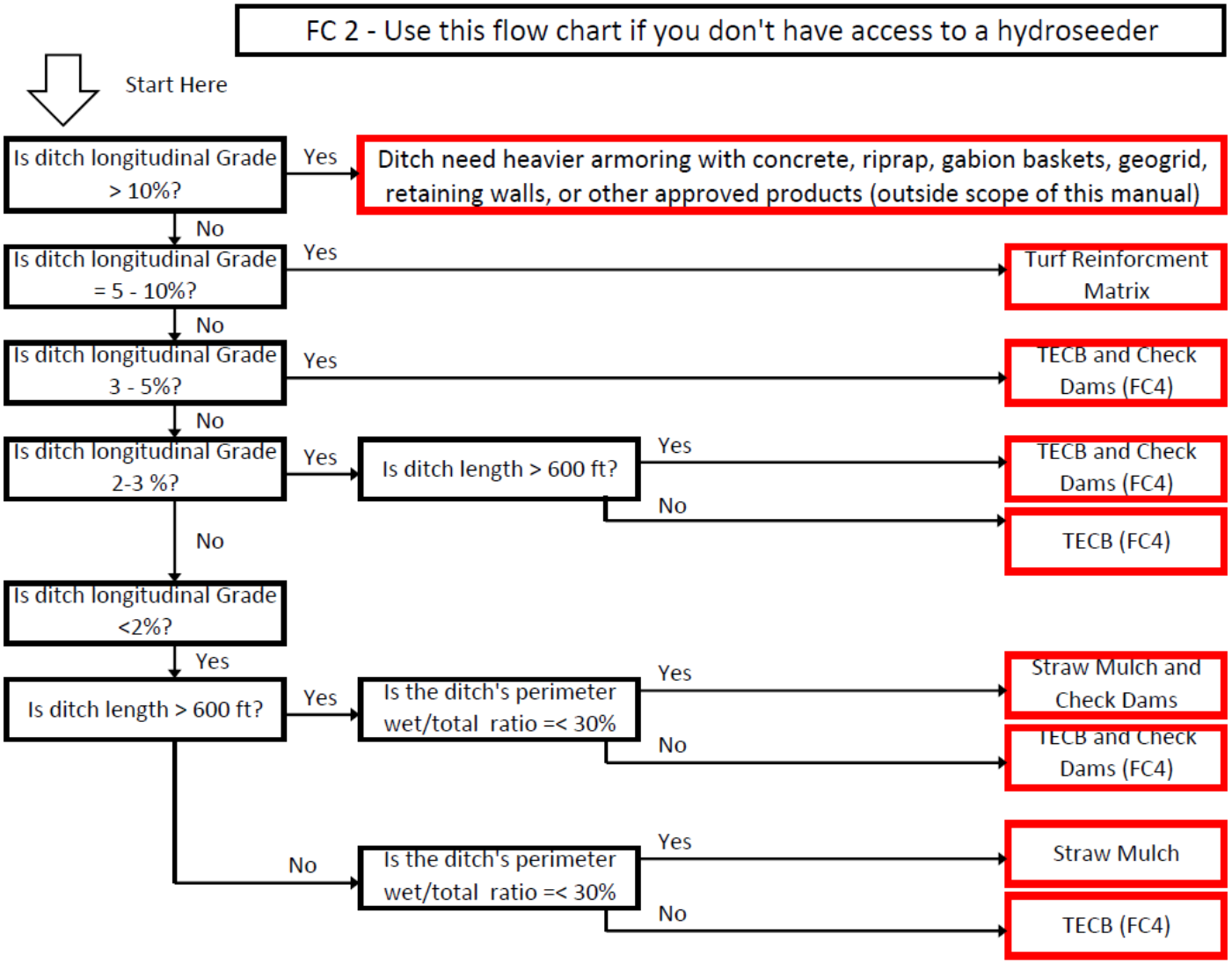


Figure 6.7. Flowchart to be used if a hydroseeder is not available

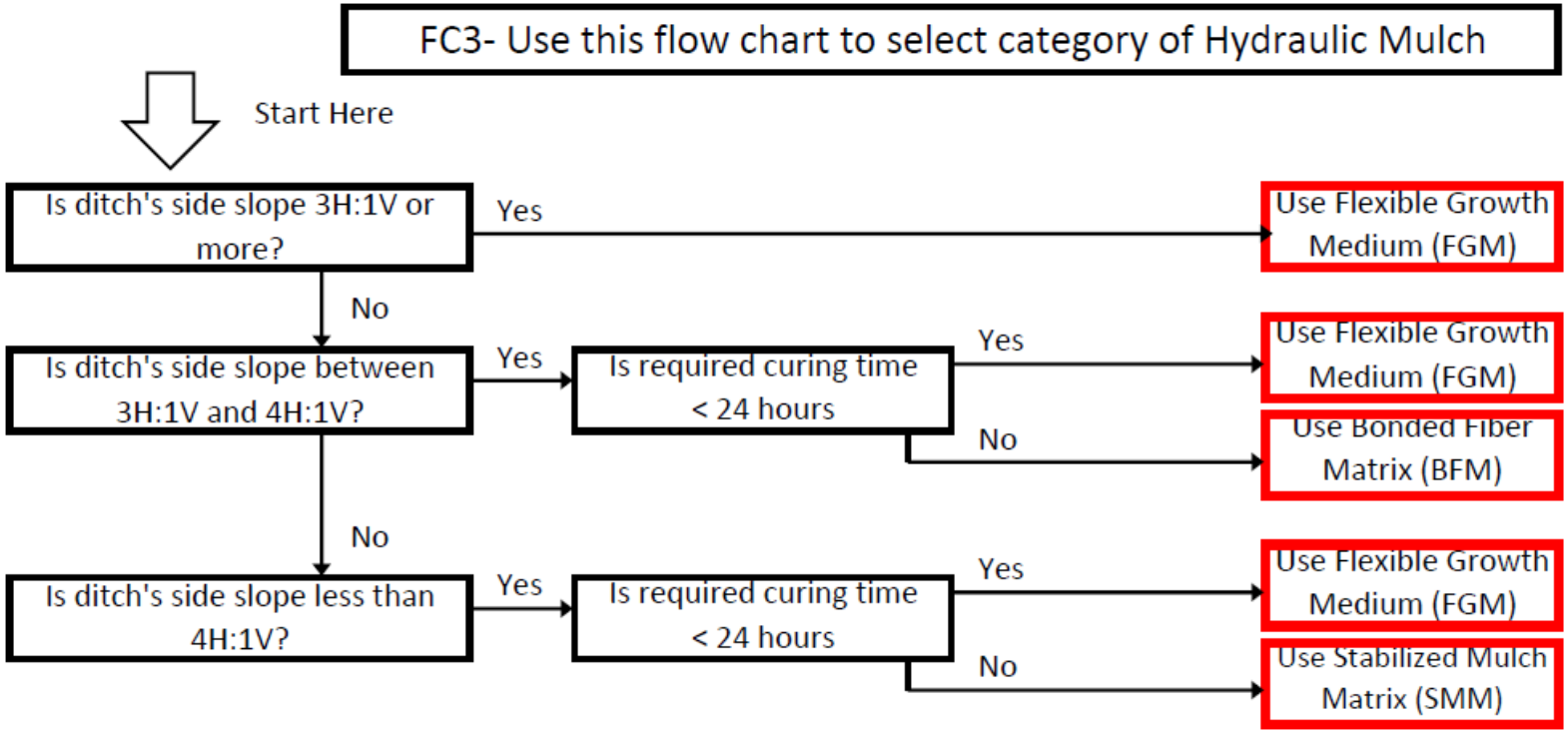


Figure 6.8. FC3- Flowchart to select adequate category of hydraulic mulch

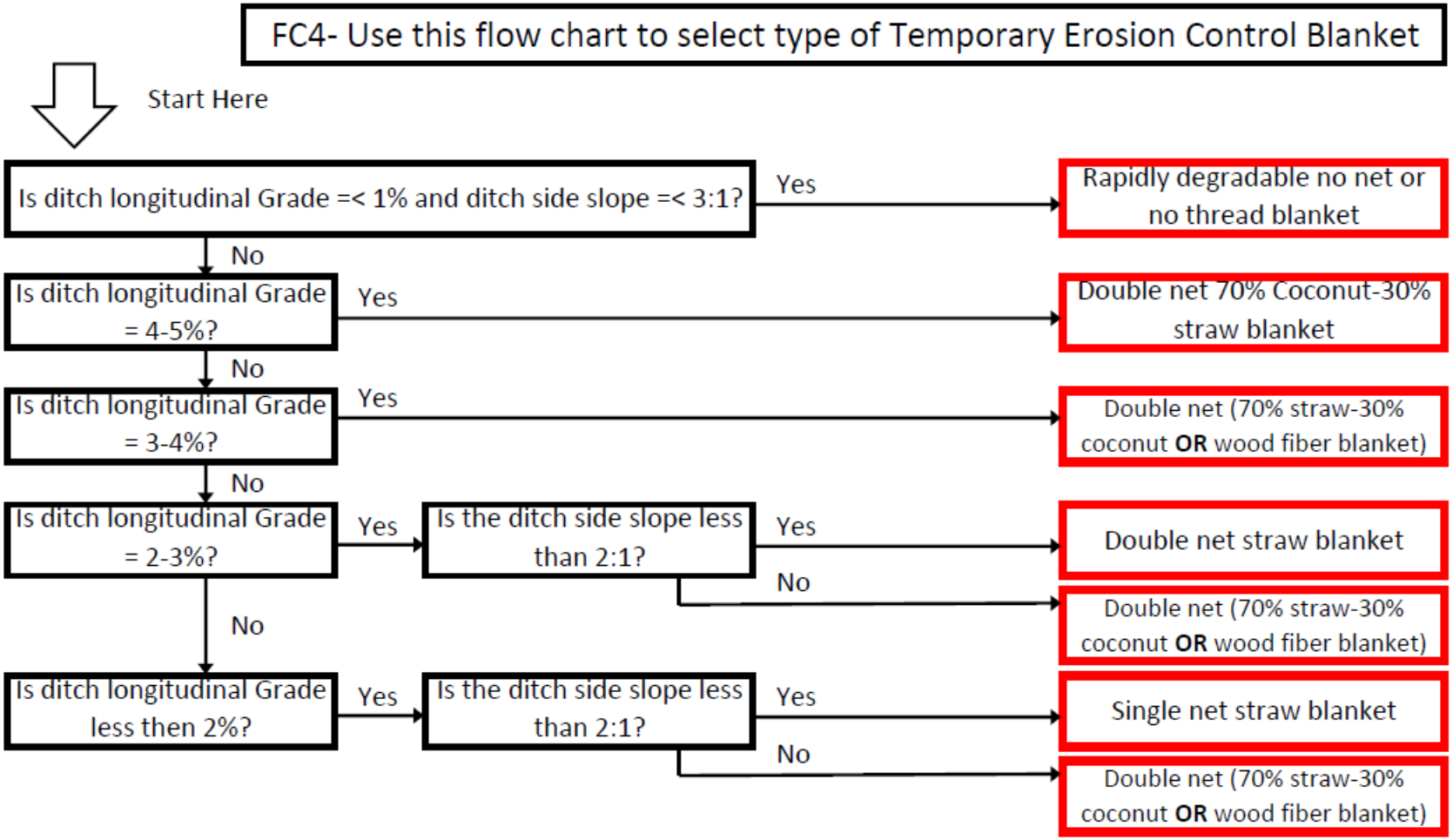


Figure 6.9. FC4- Flowchart to select adequate type of temporary erosion control blanket

To further assist Highway Maintenance Manager with selecting an appropriate temporary erosion control product, the research team developed an Excel spreadsheet "ODOT-FC" that incorporates all 4 flow charts. The user is asked a few questions and based on his/her answers, a recommended TECP is provided as shown in Figure 6.10.

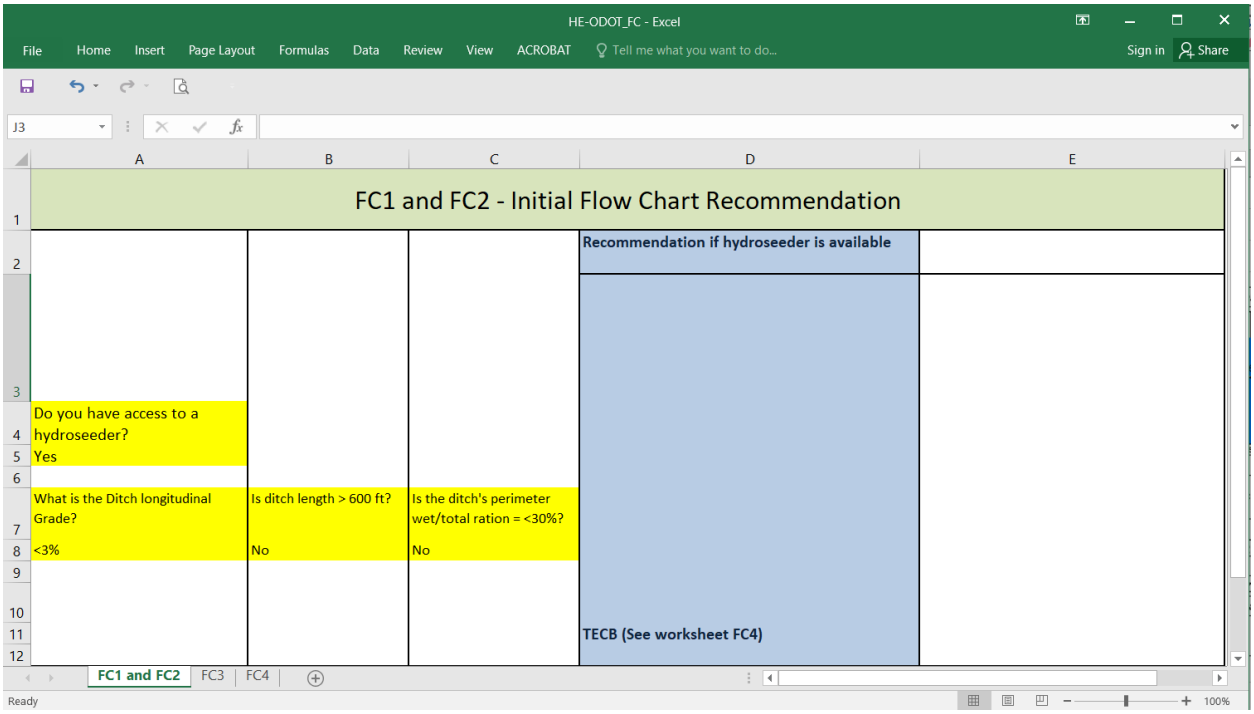


Figure 6.10. TECP Selection Spreadsheet "ODOT-FC".

The "Manual of Temporary Erosion Control Products for Roadside Ditches" includes sections that describe, in more detail, the various procedures that may be used for providing temporary erosion control for ditches.

Chapter 7 – Conclusions, Recommendations and Future Research

7.1. Conclusions

ODOT maintains approximately 43,000 lane miles of roadside ditches creating significant constraints on budgets and labor. The goal of this research is to improve ODOT's current process of maintaining ditches. To achieve this goal, the research team first evaluated the conventional methods that ODOT currently utilizes for roadside ditch cleaning. Such conventional methods which utilize a mini-excavator or a Gradall were found to have the following difficulties:

1. High cost: The cost analysis estimated the average cost/mile of cleaning a ditch with conventional methods currently used by ODOT to be $15,285 per mile.
2. V-shaped ditches: V-shaped ditches created by conventional methods cause more erosion and sedimentation as they concentrate surface flow.
3. Deep ditches: Over time, conventional methods lead to over-ditching and create deep ditches. Deep ditches are hazardous to pedestrian and cars and capture greater amounts of groundwater which destabilize the ditch's slopes.
4. Stripping of the vegetative cover: Ditches that are stripped of the vegetative cover during ditch cleaning are prone to significant erosion. These ditches should be immediately seeded to control erosion and sedimentation and promote treatment of the storm runoff prior to discharge into the receiving waterbody. The problem with current ODOT procedures is that in some cases, ditches that are cleaned are not seeded and in other cases, seeded ditches fail to establish vegetation.

To reduce the difficulties associated with current ODOT ditch maintenance procedures discussed above, the research team developed a matrix of alternatives that compared and contrasted solutions that are available today and provided the following recommendations for field testing:

1. Testing the Ditchmaster Model 800 effectiveness in cleaning ditches: The DM800 uses a horizontal rotating auger to remove spoil material from ditch bottoms. Solid materials then travel through a three stage conveyor mechanism and is dropped into an attached dump truck that is pulled by the DM. The DM produces a shallow and relatively smooth round ditch bottom. This facilitates establishment of grasses which filter out contaminants and can be maintained by routine mowing. The preliminary cost analysis estimated that the DM800 will cut the cost/mile of cleaning a ditch to $5,954/mile.
2. Testing temporary erosion control products that are currently available in the market and evaluate their effectiveness in protecting seeded ditches and in establishing vegetation. These products include different types of hydraulic mulch, erosion control blankets and straw mulch.

Field tests of the DM have revealed its inability of cleaning ditches that have wet and sticky soil. This is considered a major limitation as it limits its use for "emergency" ditching to relieve flooding during seasonal rain storms or spring thaw runoff. Although the revised cost/mile for cleaning a ditch using a DM ($7,836) is significantly more than the preliminary estimate/mile ($5,954), it is still almost 50% of the cost of cleaning the ditch using conventional ditch cleaning methods. In spite of the DM significant limitation discussed above, the benefits of the DM resulting from a better production rate, cheaper cost/mile and a more environmentally friendly ditch configuration can potentially make it a useful component of an integrated ditch maintenance system (IDMS) as described in more detail in the next section. For the DM to be a useful component of an IDMS, it should only be used when the ditch is dry. In Ohio, the chances of ditches being dry are typically higher from May 15th to October 15th. During these 5 months, even if it rains, the ditches will dry faster because of the relatively warm weather. Another advantage of conducting the ditch cleaning during those months, is that seeding and establishment of permanent vegetation will likely be more successful.

Field tests of temporary erosion control products (TECPs) have revealed the potential benefits of using such products in controlling erosion of the slopes and bottoms of the ditches after

cleaning. Such benefits can occur with the careful selection of the right TECP product and its correct installation. A "Temporary Erosion Control Products for Roadside Ditches" manual was developed to familiarize highway maintenance personnel with best practices for installation, recommended application rates and selection methods of TECPs.

7.2. Recommendations

An integrated ditch maintenance system (IDMS) is recommended to adequately maintain ODOT's roadside ditches network despite constrained finance and growing resource scarcity. An IDMS integrates various practices and equipment for maintaining ditches by selecting the best equipment/practice for a given project. The attributes of the proposed IDMS are listed below:

- Reducing run-off entering the ditches
- Effective use of temporary erosion control products in ditches
- Reducing sediments entering the ditches
- Improved scheduling of ditch maintenance operations
- Selecting appropriate equipment for maintaining ditches

These proposed attributes are further discussed below.

7.2.1. Reducing run-off entering the ditches

Whereas traditional ditch maintenance focuses on scraping ditches to collect and rapidly transport water downstream, an IDMS focuses on diffusing runoff to enhance sheet flow, reduce flow velocities, and increase infiltration. Ideas that can be used to reduce run-off include:

- Diffusing runoff to other BMPs constructed along the roadway including bioswales, grass filter strips and sediment basins.
- Decreasing adjacent properties' routing of stormwater to roadside ditches. Some property owners discharge their stormwater into ODOT ditches as shown in Figure 7.1.

This practice increases erosion and the frequency of cleaning and is potentially expensive to ODOT. ODOT should encourage property owners to implement Low Impact Development (LID) and Green Infrastructure (GI) techniques to collect and treat stormwater on their properties. These techniques include rain gardens, pervious pavements and replacing mowed lawns with mulched gardens and trees.

Figure 7.1. Property owner discharging stormwater in ODOT roadside ditch

7.2.2. Effective use of temporary erosion control products in ditches

Ditch soils exposed during cleaning are a significant source of sediment and if not adequately protected will increase the frequency of roadside ditch cleaning. Ditches that are cleaned should be seeded immediately and before the next storm. Hydraulic mulch and/or erosion control blankets should be used to protect the seeds.

7.2.3. Reducing sediments entering the ditches

Sediment enters ditch systems from several sources including gravel from the road's shoulders, soil that erodes from the ditches and soil that erodes from bare non-vegetated slopes adjacent to the ditch. The amount of sediment entering the ditch can be reduced by compacting gravel shoulders and protecting slopes.

7.2.4. Improved scheduling of ditch maintenance operations

When practicable, ditch cleaning should be limited to seasonal periods of low erosion potential when the ditch is dry and preferably early in the growing season to ensure quick vegetation establishment after cleaning. When cleaning occurs late in the fall, ditch substrates remain exposed throughout the spring snowmelt, thereby sustaining high risks for erosion and elevated suspended sediment loads.

7.2.5. Selecting appropriate equipment for maintaining ditches

As concluded from this research, there is no universal best equipment for cleaning ditches. Different types of equipment have advantages and disadvantages and should be used when appropriate. The Ditchmaster tested in this research is good example of this; it was concluded that it is not for every project and that it can only be used when the soil in the ditch is not wet and sticky. There are other ditchers that were demonstrated during Phase 1 of the research that may have potential when the ditch cleaning waste is allowed to be thrown away to the right of the ditch's bank. It is important that the Highway Maintenance Manager carefully inspect the ditch prior to committing to a particular maintenance procedure. This would reduce the likelihood of the unnecessary disruption of work if an inadequate procedure is used.

7.3. Future Research

For the recommended integrated ditch maintenance systems to be effective, it is important to develop an inventory of the ditch network and assess the volume of water and sediment moving throughout the network. Recent advances in drones, GPS, GIS, remote sensing, including high-resolution light detection and ranging (LiDAR) derived topography data, show promise of improving our ability to map ditches, detect stream connectivity, and determine flow direction (Chesapeake 2016). An inventory of roadside ditches can help prioritize and target management efforts, using criteria of soil type, slope, cost, and impacts to receiving water bodies.

It is also important to evaluate current ODOT practices for controlling erosion and sedimentation from slopes and landscapes adjacent to the ditch and develop a manual of best practices similar to the manual developed as part of this research project for controlling erosion in ditches.

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Appendix A- TECP selection using shear stress calculations.

A.1. Erosion Control Product Selection

Due to the fact that maintenance personnel are not tasked with the design of roadside channels, they lack the parameters necessary to properly select erosion control products for the ditches that they are tasked with maintaining. A framework was developed for usage by ODOT maintenance personnel in order to select proper erosion control products after having performed ditch maintenance. This framework proposes the use of already available tools, such as ADOT's Rational Method Tool (ADOT, 2013) and the NRCS' Web Soil Survey (http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm), as well as the use of a spreadsheet for shear stress calculations, developed specifically for this project. By combining the outcome of these calculations with permissible shear stress values provided by manufacturers, maintenance personnel should be able to properly select a channel lining that resists the erosive forces of the flow of water in their ditch. This framework is summarized in Figure A.1.

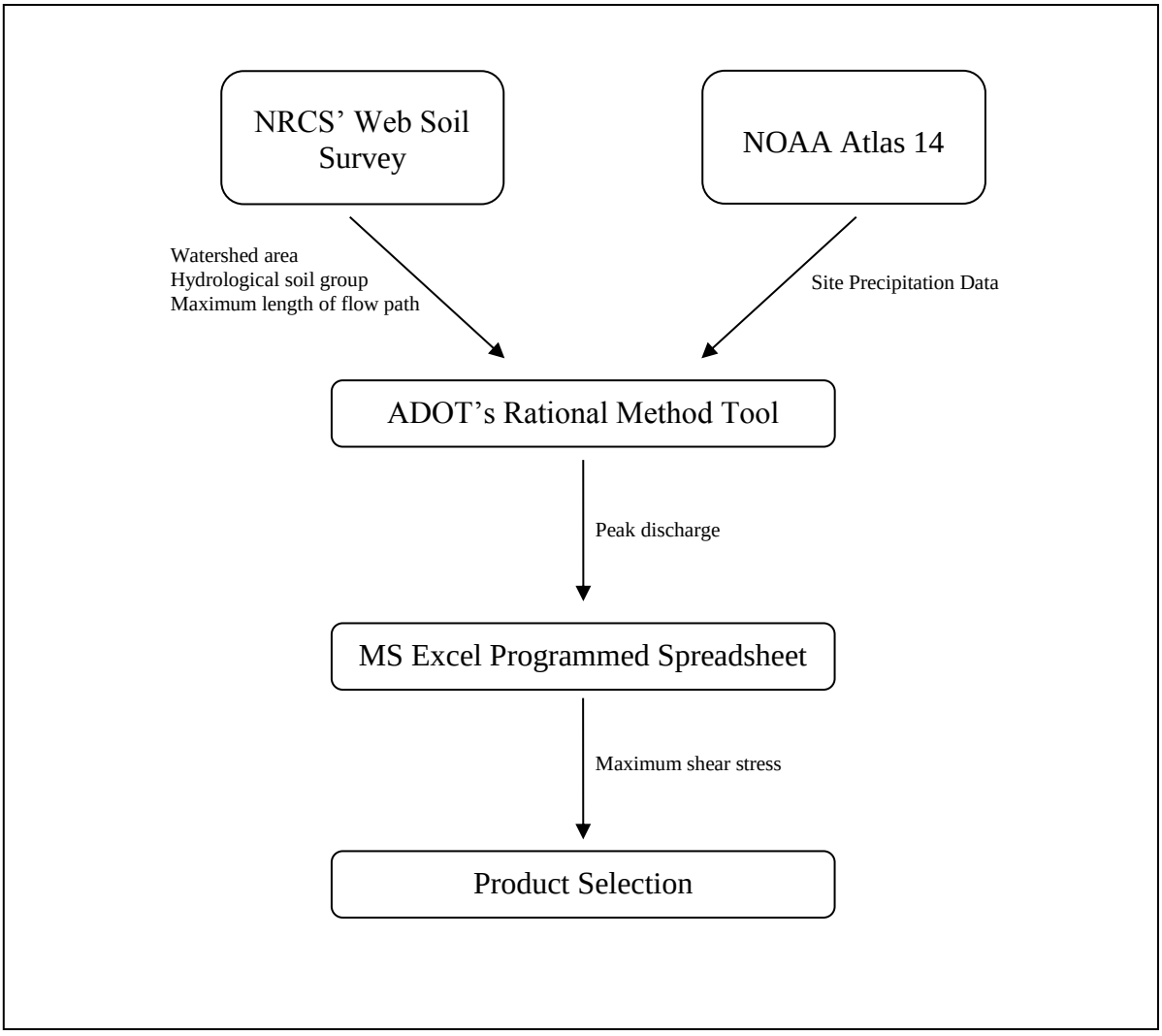

Figure A.1. Flowchart for channel lining selection procedure

A.1.1. Estimating Peak Runoff

In order to estimate peak runoff, this proposed framework makes use of the ADOT's Rational Method Tool. This tool allows for the input of sub basin information and rainfall information for calculations of peak discharges. Calculations performed are for watersheds of a maximum area of 160 acres (ADOT, 2014). The first data entered is related to the runoff coefficient, C. Input includes:

- Drainage areas in acres
- Hydrologic soil group classification
- Estimates of imperviousness and vegetation cover

The second data to be entered is related to the watershed slope. Input includes:

- Length of the longest flow path inside the watershed, in miles
- Total change in elevation along the abovementioned path

The third data to be entered is related to the resistance coefficient of overland flow. Input only includes:

- Selection of predominant landform type

Final data to be entered is rainfall data. Input includes:

- Rainfall depth acquired from NOAA Atlas 14: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

After entering all required input data, the program generates a table for the user that displays the peak discharge, in cfs, for 2, 5, 10, 25, 50, and 100 year storm events.

A.1.2. Calculating Shear Stresses

Using the peak discharge calculated in the previous step, the HEC-15's procedure for channel lining design is used to select a proper TECP. This procedure is summarized in Figure . In the case of Ohio, a 5 year storm and 2 year storm are used for flow depth and shear stress computations, respectively (ODOT, 2016).

A spreadsheet has been designed specifically for this task. The spreadsheet requires inputs of channel dimensions, depth of flow, longitudinal slope of the channel, Manning's roughness coefficient, and design discharge. The spreadsheets provide suggested values for Manning's roughness coefficient in accordance to ODOT's drainage manual. Some of these suggested values have been listed in Table 21.

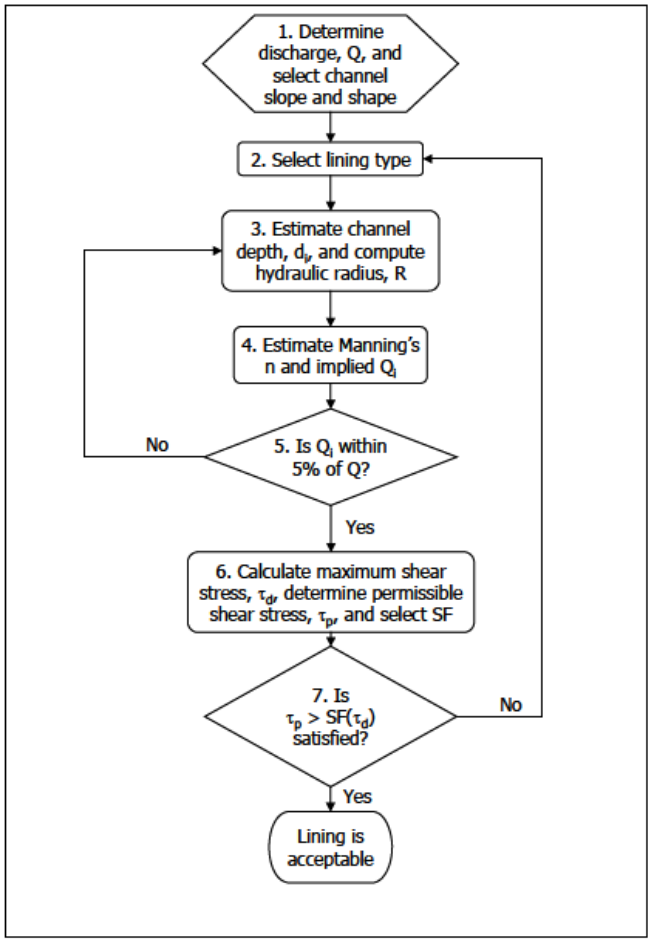

Figure A.2. Flowchart of HEC-15 design procedure (Kilgore & Cotton, 2005)

Table 2. ODOT's suggested Manning's roughness coefficient (ODOT, 2016)

Type of Lining	**n**
Bare Earth	0.02
Seeded	0.03
Sod	0.04
Item 670 (Erosion Control)	0.04

With these values, the spreadsheet then calculates wetted perimeter, area of flow, hydraulic radius, and discharge. The discharge value obtained is then compared to the design discharge and the user is notified if it is within 5% of this value. In cases where the values are not within 5% of each other, the user changes the initial depth of flow estimate, essentially performing the

iterations specified by HEC-15. Once the design discharge and calculated discharge are within 5% of each other, the depth of flow is used to calculate maximum shear stress at the bottom of the channel. The spreadsheet can be used to calculate maximum shear stress for ditches that are semi-circular, V-shaped, and trapezoidal in shape. Maximum shear stress values can then be compared to permissible shear stress values for proper TECP selection. Permissible shear stress values for various linings, as provided by ODOT, are shown in Table A.2.

Table A.2. ODOT's allowable shear stresses for channel linings (ODOT, 2016)

Protective Lining	**Allowable Shear Stress (lb/ft^2)**
Seed	0.40
Sod	1.00
ECB Type A	1.25
ECB Type B	1.50
ECB Type C	2.00
ECB Type E	2.25
ECB Type F	0.45
ECB Type G	1.75
TRM Type 1	2.00
TRM Type 2	3.00
TRM Type 3	5.00

According to ODOT specifications (ODOT, 2013):

- ECB Type A refers to single net straw blankets
- ECB Type B refers to double net straw blankets
- ECB Type C refers to double net straw/coconut blankets
- ECB Type E refers to double net coconut blankets
- ECB Type F refers to jute netting
- ECB Type G refers to single net excelsior blankets

A.2. Case Study: Mahoning County, OH

A roadside ditch in Mahoning County was selected for maintenance and erosion control protection by Mahoning County transportation officials. As seen in Figure , the area identified was a stretch of SR 165 that is located between intersections with R 95 and R 107. The stretch of road between these intersections was estimated at approximately 5,111'.

Figure A.3. Satellite imagery of site acquired from Google; ditch highlighted in yellow

As the road contained ditches on both sides, two watersheds were delineated for the northern and southern ditches respectively. Their respective delineations using NRCS' Web Soil Survey can be seen in Figure A.4. The northern watershed was calculated to be 158.1 acres in area, containing soils belonging to the hydrological groups C and D. From visual observations, impervious area was estimated to be 1% of the total area. This resulted in vegetated areas of 156.52 acres and impervious areas of 1.581 acres. The longest traveling path of water in this watershed was measured to be 4,640', or 0.8787 mi. The change of elevation along this path was determined to be 50'. The southern watershed was calculated to be 114 acres in area, containing soils primarily belonging to the hydrological groups C and D. Similarly to the northern area, impervious areas were estimated at 1% of the total area, resulting in 1.14 acres. Vegetated surfaces then resulted in 112.86 acres. The longest traveling path of water in this watershed was measured to be 3,827', or 0.7248 mi. The change in elevation along this path was measured to

be 20’. Precipitation data from NOAA Atlas 14 was acquired from the weather station located in Canfield, Ohio at coordinates 41.0167°, -80.7667°. The predominant landform type for time of concentration calculation was determined to be tilled agricultural fields for both watersheds.

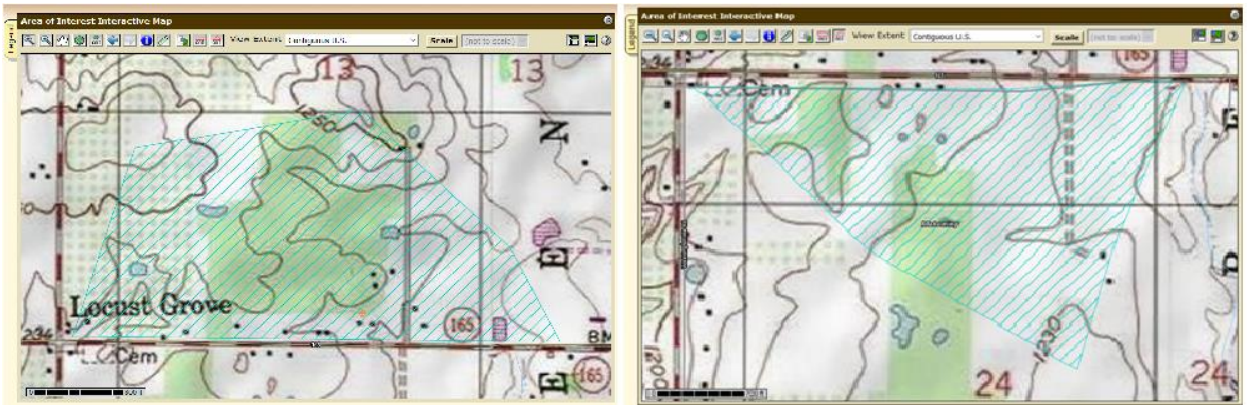

Figure A.4. Watershed delineations using NRCA's Web Soil Survey

Input of this information into ADOT’s Rational Method Tool yielded discharge values of 54.6 cfs and 34.7 cfs, for the 2 year storm in the northern and southern ditches respectively. Design discharge values were then input into the programmed spreadsheet along with values for longitudinal channel slope and Manning’s roughness coefficient. In this case, longitudinal channel slope was determined to be 0.01 and Manning’s roughness coefficient was 0.4, in accordance to ODOT’s provided value for ECBs. The worksheets with the input data for all three channel shapes can be found in the Excel Spreadsheet. However, as the machinery used to clean out the ditches produces a nearly semi-circular shape, only the values obtained from this shape will be presented in this section. Calculations for the northern ditch along this road resulted in a maximum shear stress of 1.622 lb/ft^2. On the other hand, calculations for the southern ditch along the same road resulted in a maximum shear stress of 1.273 lb/ft^2. Consulting the table provided with ODOT’s allowable shear stresses, ECBs of type B, C, and G would be suitable for the channel bottom. According to ODOT specifications, these would be equivalent to double net straw blankets, double net straw/coconut blankets, and single net excelsior blankets.

Appendix B- Ditchmaster specifications

SPECIFICATIONS
March 7, 2016

General

It is the intent and purpose of this specification to describe the minimum requirements for a self-contained ditching machine complete and ready for service. The single-axle truck mounted ditching machine shall use a horizontal rotating auger to remove spoil material from a ditch, shape the ditch in the process, and convey the solid material into another open dump truck body. Note: The unit shall be a Ditch Master® Model 800 or equivalent.

Chassis and Cab specifications

As prepared by Greg Simonic of Cleveland Freightliner, Inc. on February 23, 2016 (attached). Vendor certifies that chassis and cab as specified are suited for the application listed above.

Ditching Unit:

Unit shall have a chain driven, horizontal rotating auger cutting bit mounted on an extendible arm. Reversible auger shall be 27" in diameter with replaceable cutting ring. Shall have a 3-stage conveying system for debris; first stage shall be the arm assembly, second stage shall be the bucket elevator, and the third stage shall be an extendable belt conveyor. Cutting and conveying mechanism shall be hydraulically powered. Horizontal and vertical positioning of the auger and vertical, side to side swing, and extending of the belt conveyor shall all be controlled from the truck operator's position.

The unit shall be furnished with a double pump oil cooler hydraulic pump system, oil capacity 94 gallons. The auger cleaning motor, bucket elevator motor, and belt conveyor motors shall be variable speed electric over hydraulic.

Truck shall have a hydraulically operated tow bar truck to truck connection at the rear of the truck so that when latched a control lever will be moved to a float position to prevent damage to the hydraulic cylinder.

Power for the hydraulic circuits shall be supplied by a diesel auxiliary motor mounted on top of the truck frame rails. Controls and gauges for the motor shall be located in the truck cab.

All hydraulic circuits and auxiliary power unit controls shall be controlled by one person from inside of the cab. The hydraulic controls shall include electric over hydraulic and air over hydraulic controllers. The electric over hydraulic controls are used to control the motor RPM.

The extendable arm rotating auger shall have approximately 3' lateral travel, 8.5' lateral reach from truck wheel, 8' travel width, and 13'3" travel height. Maximum cleaning depth shall be 36" below grade. Approximate weight of ditching unit shall be 7,250 lbs.

Auxiliary Power Unit (APU):

APU shall be a new four cylinder fully enclosed turbocharged Cummins four cylinder diesel motor #QSB3.3P, 99 HP @ 2600 RPM, Emission Level = Tier 3 TPEM, Peak Torque = 306 ft-lbs @ 1600 RPM, at least 199 cubic inch displacement. Motor shall have a keyed switch (off/on/start), an adjustable RPM switch for electronic speed control, a diagnostic port, oil pressure and water temperature gauges, volt meter, tachometer, and top mounted muffler. The motor radiator shall include a guard to keep objects away from moving parts.

Conveyor System:

The retracted conveyor shall extend no more than 4'6" beyond the rear of the frame for transport and shall extend up to 13'6" past the rear of the frame when working. Conveyor swing shall be approximately 36" side to side and 12" up and down. Conveyor belt length shall be approximately 49 feet to load a single or tandem axle dump truck.

Warranty

In addition to the manufacturer's chassis warranty, the Ditchmaster and associated components and installation shall be warranted for one year, or the manufacturer's standard period, whichever is longer (less wear and normal maintenance items). Ditchmaster shall identify authorized repair facilities in Ohio, or may at their option send their technicians to perform warranty work. ODOT will not be responsible for transportation expenses for technician travel, parts, and labor associated with warranty work.
A copy of this warranty should be furnished with the quotation/proposal.

Insurance

Until ODOT accepts delivery, the vendor is responsible for all insurance against loss.

Delivery

Completed unit to include truck/body/auger/conveyor must be delivered from the Ford Manufacturing plant located at 714 NW Vine Street, Chehalis, WA 98532. Price must include freight from the above address to ODOT District 4 office, 2088 South Arlington Road, Akron, OH 44306.

Please call John De Bon at 330-786-3144 at least 48 hours in advance of delivery. Delivery shall be between 8:00 am and 3:00 pm.

The ditching machine must be complete, fully installed, and ready to go into service upon arrival.

Operation and preventive maintenance instruction

A manufacturer representative shall inspect the equipment after delivery and provide technical instructions on the operation and preventive maintenance requirements for the unit to ODOT personnel. This instruction must be scheduled with the University of Cincinnati and ODOT. The

manufacturer furnishing the equipment agrees to allow these instructional sessions to be videotaped by ODOT to be used for future instructions for ODOT personnel.

Technician Training:

The vendor agrees to conduct a training session (eight hours minimum – (1) one day) developed specifically for ODOT's equipment repair technicians. The training shall be scheduled through the University of Cincinnati. **Vendor shall provide the name and telephone number of the equipment manufacturer's training representative**.

Training shall commence, as determined by ODOT, approximately six to twelve months after the unit is placed in service by ODOT.

Training topics shall be determined by ODOT and communicated to the manufacturer's training representative. A list shall be sent to the manufacturer's training representative detailing any problems ODOT has encountered with the equipment. Training shall include complete diagnosis and repair of the listed problems as well as detailed preventive maintenance procedures (A, B, C, & D levels) and discussion of any problems or updates known by the manufacturer. The University of Cincinnati will send the list to the manufacturer two months prior to the scheduled training date.

Manuals

The vendor shall provide two copies of an operator's manual, parts manual, and service manual. At least one copy of the operator's manual shall be in hard copy form. Electronic format is acceptable for other copies.

The vendor shall provide two copies of manufacturer's production list of materials (line setting sheet) containing OEM part numbers. Electronic format is acceptable.