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Field Trip Guidebook

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ASSOCIATION OF MISSOURI GEOLOGISTS

55th Annual Meeting and Field Trips
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Columbia, Missouri

Guidebook and Field Trips
"*Frontiers in Geology*"

Subtera Underground Storage Space

University of Missouri Geotechnical Field Research Site - A World's First Installation in Trenchless Technology

The Geology of Wine in Missouri

Bioherms, Reefs, and Waulsortian Mounds

Introduction to Trenchless Installations Using HDD

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Introduction

The application of geologic information to the needs of the public is the most pressing challenge facing the geoscience community today. The traditional fields of mining, petroleum, and education for geoscience employment are now supplemented by environmental and engineering geoscience. As the need for geoscience information increases, job opportunities for geoscientists will also increase. Non-traditional fields of endeavor for geologists are opening up for geologists, who by the virtue of their appreciation of the art and science of 'doing' geology, can capitalize on these new opportunities.

The geologic information needed by the public influences the quality of our lives. Finding a deposit of oil or gas, finding a source of a mineral commodity, or characterizing the condition of the subsurface is only one part of the practitioner's job. Assembling and correlating the information obtained is where the test of a geologist's abilities begins. Attaining a finished product to the geologist's work and *optimizing* is an even greater challenge. When the finished product of a geologist's work is presented clearly to the public, and public authorities, citizens, or private concerns act on the information gained, then it directly impacts the quality of daily life in Missouri. The new field of geoinformatics is intended to obtain information from geologists, sort through the information to find the most useful information and concepts, and then pass that information on in a clearly understandable way to a user who acts upon the information obtained. This field guide is intended not only to introduce you to some of the geology of the Columbia, Missouri area, but it is hoped that it will introduce you to some frontier areas in geologic thought.

The first day's field trip will showcase and present some of the unique resources that occur in central Missouri. A stop at Boone Quarries' completed underground operation, Subtera, will illustrate a recent addition to the underground storage space reserve in Missouri. The second stop of the day will be at the University of Missouri's Geotechnical Research Site. Research that has been completed at this site in the past, is ongoing, and is planned for the future has and will have far-reaching impacts on our society. The final stop for the day will be to Les Bourgeois Vineyards and Winery, and includes an impressive vista of the Missouri River bottoms above Rocheport. The *geology of wine* in Missouri is a previously unexplored subject, which we hope to address for the first time here in Missouri.

The first field trip stop of the second day will examine the concepts of Waulsortian mounds in the Mississippian system of central Missouri, their formation, and how they fit into the overall scheme of Missouri's geologic history.

The second field trip stop on the second day will explore a subject that few geologists are aware of, *trenchless technology*. Trenchless technology is the collective term meant to denote the sum of the equipment, the supplies, and methods used for the installation, replacement, and/or renewal of subsurface utility product pipe without the primary use of a trench. Minimizing surface disturbance in urban areas is only one advantage to trenchless technology, which passes on both short-and long-term benefits to facility owners and the public. Most geologists are unfamiliar with these methods, and the need for geologic input that precedes new installations and may be required for upgrades and renewals. The importance of the right type of geologic information to the contractor and the facility owner cannot be understated.

Thank you for your readership and your participation. It is only through the participation of the membership of the Association of Missouri Geologists that we are able to continue our efforts successfully to educate geologic professionals to better serve the needs of all Missourians.

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Trenchless Technology from the Geologist's Viewpoint

What is trenchless technology? Trenchless technology, simply put, is the collection of methods, materials, and techniques that are required to install, upgrade, or renew utility product pipe without the primary use of a trench. Trenchless technology is pursued for two reasons.

The first is that it may be impossible or extremely costly to make an open-cut utility pipe installation. Railroads, state highways, airports, natural areas, historical areas, and many agencies do not allow or strongly discourage open-cut installation across land that they control. The example of a railroad is probably the most applicable. Millions of dollars of goods move over the railroad on a main line, including vehicles, coal, bulk chemicals, and agricultural commodities. To make a tunnel for a golf course is not something that the railroad will allow an open cut installation for, simply because the golf course's needs do not take precedence over the goods and services that the railroad provides. Railroads are usually very insistent about their precedence in any case, but movement of goods and services is more important to society at large than the need for easy access for golf carts for a recreational activity from one side of the tracks to the other.

The second reason that trenchless technology is used is to decrease the overall long-term social cost of utility product pipe installation. The public needs access to reliable and safe water, efficient sewer lines, and reliable electrical power. Water distribution pipes are buried under the frost line as are sewer pipes. Electrical distribution poles and telephone distribution poles are becoming less desirable as a matter of aesthetics in urban and suburban areas. So where do they go? Underground installation is the only logical choice. But there are other reasons as well. In the long term, trenchless installations cost less than traditional open-cut installation, PLUS there is the added attraction of having fewer personnel in an open trench. Open-trench accidents occur monthly in the U.S., causing death and injury to many construction workers who either fail to take the proper precautions working in an open trench, are rushed by the time constraints on a job, make an error in soil identification and don't install trench protection where it was needed, or simply FORGET. Trenchless installations prevent many if not most trench accidents by simply not digging a trench for utility product pipe installation in the first place.

The social costs of trenchless installation are substantially lower than those of open-cut installation. A short list of open-cut social costs is shown as Figure 1.

Table 1. Social Costs of Open-cut Construction

(After Najafi, 2004)

Potential Cost	Description of Problems
Vehicular and Traffic Disruption	General public pays for increased time spent in traffic delays, using detours. Costs include extra fuel, vehicle maintenance and repair.
Road and Pavement Damage	Increases the roughness of pavement structure, leading to pavement structural failures, poor restoration may lead to repeated repairs. Differential settlement, poor backfilling, patching, successive utility cuts aggravate overall problems.
Damage to Adjacent Utilities	Cost of repair is an added cost to the contractor. Some utility strikes are a potential safety hazard to the contractor as well as the public.
Damage to Adjacent Structures	Dewatering, excess excavation, improper techniques in shoring and underpinning may cause uneven settlements and distress as a result of open-cut underground utility construction.
Noise and Vibration	Vibrations and noise may lead to inconvenience and citizen complaints.
Air Pollution	Open-cut installations in dry periods may lead to excessive dust; heavy construction equipment uses more fuel and generates excess CO, hydrocarbon, and NO_x gases. All are of special concern in close proximity to schools and hospitals.
Pedestrian Safety	Diversion of traffic onto residential streets increases hazards to pedestrians; open-cuts are also safety hazards to pedestrians, especially children and the elderly.
Business and Trade Loss	Customers avoid open-cut areas causing business and trade losses. The loss of gross receipts taxes decreases governmental income – loss of parking in controlled areas even decreases meter revenue!
Damage to Detour Roads	Detours caused by open-cut construction increase loads on the detour road, which may not be designed to accept heavy motor vehicle traffic. This decreases road life span and may lead to damages.
Site and Public Safety	On-site accidents to construction workers and the general public increase in areas of open-cut construction.
Citizen Complaints	A disruption to the normal flow of life caused by open-cut construction increases the frequency and magnitude of citizen complaints.
Environmental Impacts	Open-cut construction may permanently alter or damage sensitive affected areas such as rivers, streams, natural habitats, public parks, protected natural areas, wetlands, historic districts and buildings, etc.

Why are these methods not used to their fullest potential? The emphasis on installations has been, in the past, on return on investment. It takes longer in some instances to recoup the investment made when trenchless installation is used. This is now changing, and is an exciting time to be involved in all sorts of trenchless installation. Horizontal directional drilling (HDD), for instance, has now been used for environmental remediation of both radiologically contaminated soils and petroleum-contaminated soils. HDD has also been used, quite economically, for the installation of shallow municipal water supply wells (ex. Des Moines, Iowa).

Another reason that these methods are not used is that they are looked upon as "different" or "new" by those persons who resist change in the upper levels of management of utility companies and regulatory agencies, who are usually conservative in their desire to apply proven technologies to systems so that little transition time is needed to train employees' thinking as well as their own. Trenchless methods are proven methods, some over 100 years old.

Trenchless methods offer attractive cost solutions as well as savings to the public and utilities. Where vertically drilled river bottom water wells are planned at substantial cost, ONE horizontal well can provide the yield of ten vertical wells. Instead of winding a sinuous path around obstacles in a river bottom, a sewer line can be installed straight to the treatment facility, sometimes at a substantial cost savings. Individuals as well as municipalities can benefit. In some cases, MULTIPLE installations can be made as one.

One large obstacle to the dissemination of the technology is a lack of training for those who need it. Largely through the efforts of the North American Society for Trenchless Technology (NASTT) and the International Society of Trenchless Technology (ISTT), this is changing. Manufacturers, vendors, consultant companies, utility providers, and others have banded together and promoted what was once thought of as a 'fringe' technology and brought it into the mainstream of utility installation and renewal.

One area where little progress has been made is the mating of engineering geologic method and information to the technology. It is repeatedly stated that geotechnical information must be made available to the contractor prior to commencement of a project. This information tends to be overlooked by some engineers who attempt to cut overall project costs by decreasing the amount of geotechnical information available, or omitting site investigation entirely from a project. At best, a geologic map is added that may have some useful information but does not characterize or quantify the level of risk for the contractor. At depths where utilities are installed, the geotechnical information may be in the form of a NRCS soils map that is misleading to a contractor who may not understand the limitations of the map and what it represents. What does this statement mean? Take the following case study as a pertinent example.

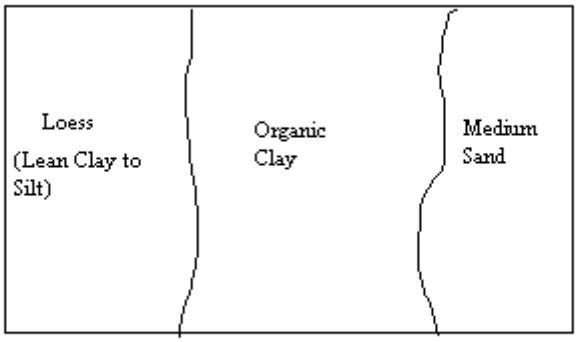
Sample case study:

A contractor is hired to install a natural gas distribution line by horizontal directional drilling across the Missouri River bottom. He is given a soil map that is intended to supply the geotechnical information that he needs. Additional information regarding the soils is provided by the project engineer in the form of engineering soils information and data test ranges copied from the agricultural soil survey for the county. He is starting in an area that is atop one of the Missouri River bluffs. He checks the map, and thinks the installation will be a simple one, as seen in the diagram on the following page, Figure 2. This is not so.

As indicated in the 'reality check' in Figure 3, a cross-section across the soils map, we see that a limestone underlies the loess unit that he first must penetrate, and that cobbles and boulders are present at the base of the limestone bluff. In addition, the clay extends farther out under the sand than is indicated by the lines drawn on the map. There are three, if not four misrepresentations that the engineer has made to the contractor in this instance. The first misrepresentation is one of scale. The scale of the soils map does not indicate the cobbles and boulders at the base of the bluff. These cobbles and boulders in the case of horizontal directional drilling could prove to be disastrous, as any percentage of gravel, cobbles, or boulders greater than 50% of the total by weight would make horizontal directionally drilled installation a NO GO scenario.

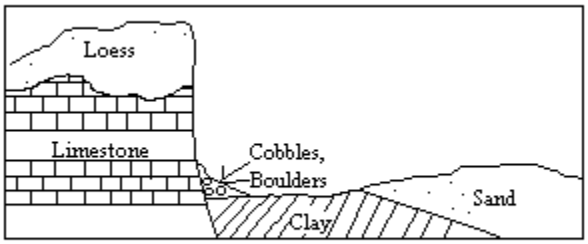
The overall setting of this particular boring can be complicated even further if we also consider that the pH of the contractor's drilling fluid will change across the bore, that the alluvial deposits may contain large tree stumps or wood at shallow depth which can complicate the progress of the overall project, or that permits may be necessary to cross land which is owned by the Missouri Conservation Department, under levees administered by the US Army Corps of Engineers, or under right-of-way owned by the Missouri Department of Transportation.

The first problem that the contractor encounters is that the map does not adequately represent the conditions that are present. The limestone may be pinnacled – he doesn't know what the rock-soil contact is like, the degree of weathering present on the rock contact, nor the hardness of the rock that he may encounter. Mixed-face and variable-rock change in condition claims are tow of the most common claims against owners that attorneys encounter in the world of construction litigation, and there are other equally valid problems with this scenario also.



Soil Map, Showing Three Soil Types

Figure 2. The soils map presented to the contractor in the case study. Note that the contractor will be drilling through three soil types that he thinks are relatively easy to drill through.



Topographic Profile, Cross-section

Figure 3. Depiction of the REALITY of the situation. The loess has limestone under it, before the contractor even reaches the clay in the next map unit, and the clay extends under the sand of the next map unit. Cobbles and boulders are not even shown on the soils map depicted in Figure 2.

The second problem is the presence of limestone under the loess atop the bluff. This limestone prevents installation by horizontal directional drilling without the use of a down hole mud motor and rock tooling. If the contractor doesn't have the correct tooling when he arrives on site, this could result in a costly trip back to the shop to get the right tooling and drilling fluids.

The third problem in this planned installation is the elevation change from the top of the bluff to the bottom of the bluff…if this elevation change is not recognized; again, the wrong type of locating technology might be used to locate the drill head. The final problem is the subsurface boundary of the soil , which is different from that depicted upon the map. In changing from clay to sand, installation requires possible drilling fluid changes. This may mean a delay for the contractor in the installation, and again, a loss of money.

The upgrade, repair, and installation of utilities is absolutely necessary for the smooth functioning modern society. In the following sections of this guidebook, some of the issues regarding utility installation and its relation to geology will be examined in more depth and detail.

The PROBLEM that faces us is that there is insufficient knowledge and expertise in the geologic community to address trenchless installation issues and questions. This lack of understanding is both at the Federal and State regulatory and survey levels. One example from a typical publication of the Natural Resources Conservation Service is the tables that are published in a county survey. These extremely useful publications can be used in community land use planning, containing a very broad range of information about the soil types in a county. Besides their original intended use for agricultural land use planning, these documents contain tables which indicate soil suitability for other uses including building site development, recreational areas, sanitary facilities (sewage treatment lagoons and septic tank absorption fields), and construction materials. Under the table “Building Site Development” (Table 11 in most NRCS County Soil Survey Documents) map units are rated for shallow excavations, but do not even include trenchless installation.

With the dissemination of some of the materials presented here, hopefully in the future trenchless installation will become more prevalent as a method of utility installation to reduce overall long-term and social costs to the public and to utility companies who perform such installations.

Limitations on Installation Technology Determined By Soil Type

"Showstoppers" in a geologic sense are physical conditions that make a bore physically impossible or require the input of so much equipment, material, and manpower to make overcoming them uneconomical. Certain types of equipment are not intended for certain types of soil/rock conditions. One classic example repeatedly occurs in auger boring, simply because owner and contractor don't work out the geotechnical details in advance. Augers will not transport boulders out of steel casing if the boulder is greater than 1/3 the size of the auger diameter. If a 24-inch diameter auger encounters 10-inch boulders, the entire string of augers must be withdrawn, and a worker must go inside the pipe to the excavation face to remove the obstruction. This is dangerous work due to the possibility that the hole may collapse towards the worker, and that confined-space entry procedures must be used to prevent asphyxiation at the end of his crawl through the pipe. Such conditions drive the cost of completion upwards, and may result in a change-of-conditions claim. Man-made objects may be equally cost-prohibitive. It has been common practice in some areas to use old steel-reinforced concrete rubble as fill material. If a horizontal bore should encounter such rubble with reinforcing bars or a steel pin, the bore is usually terminated to avoid costly delays.

Once the various types of soil and rock materials in the planned bore path are known, this information may be used when the bore type is chosen. Bores that have substantial amounts of gravel may prove difficult for horizontal directional drilling (HDD). If greater than 50% gravel is encountered in the soils investigation, this is a strong indication that horizontal directional drilling may be impossible without the addition of substantial amounts of drilling fluids, up to 1.5 times the amount of the gravel to be removed from the bore path. Cobbles and boulders may make pipe jacking or auger boring impossible. There are other geologic conditions as well that may have influence on the type of pipe chosen or the type of drilling fluids used during the boring process.

What geologic conditions should be considered?

After determining the type of soil or rock present, groundwater is an important factor to consider. It may affect borehole stability or the properties of drilling fluids. If water is present which flows naturally upward under pressure at a particular point, also known as artesian conditions, an unsupported bore may collapse under the pressure of the water. Though not as common in Missouri as in coastal plain areas of the United States, saltwater can be a problem during a bore, both for flocculation of the soil and for drilling fluid pH, which should be kept as close to the 6.8 – 7.2 range as possible to prevent mud from reacting chemically with the surrounding soil. Knowing the depth of the permanent groundwater level is also critical.

To really become aware of the potential problems that may be in a proposed bore path, the designer needs to be aware that the primary function of the geologist in the process is to determine the soil and rock classification, both by origin of the soil and by the grain-size distribution of the soil. When this information is obtained, accurate predictions about the variability of materials in the bore path can be made. Classification shoul made by grain-size distribution and by a material's origin.

A geologic investigation may be simple for a small project. If you're linking a traffic light to a controller box fifty feet away, simply looking in two or three utility "potholes" that were completed to verify the location of underground utilities may be sufficient. You stick your arm down the hole, grab some soil, verify its consistency, and you're done. For larger projects, a substantial number of borings may be necessary to determine the underlying bedrock configuration, water table elevation in comparison to the surface, the uniformity or variability of the soil, and relationships between individual boring locations to determine variability, along with laboratory testing of soil parameters.

Repeatedly, geologists and are asked, "How many borings are enough?" The answer to that question depends upon the geologic setting involved, the length of the crossing, the depth of the crossing, and the types of materials present. One bore is NEVER enough, and two bores is the MINIMUM necessary to characterize a crossing. Soil conditions can change drastically from one side of the crossing to the other. For projects that cross road fill, construction records to determine types of road fill used should also be consulted.

The kind of information required to complete a horizontal boring successfully depends on the depth and length of the installation, the possible methods to choose from, and the variability of the soil and rock between the entry and exit points of the bore. Overemphasis is impossible on a single statement: *The soils and geology information necessary to complete a boring should be obtained IN ADVANCE, and its scope should be limited only by the degree of VARIABILITY between the exit and entry points for a crossing.*

Obtaining soil and rock information is the most critical part of bore planning. Professionals in horizontal boring information often quote the phrase, "BORE THE PLAN, BUT PLAN THE BORE." If you don't get the information in advance, serious problems can and often do result. A pertinent example of this is presented in the case study on the following pages.

CASE STUDY

MoDOT Job No. J6I0651D, Route I-270, St. Louis County

One element of a planned interchange reconstruction at Interstate 270 and Route 100 was a horizontal boring. The purpose of the approximately 300-foot crossing, a planned 54 inches in diameter, was to allow drainage from the east side of I-270 to the west side, south of Route 100 (Manchester Road). The contractor had recruited the help of a subcontractor on this job who had claimed to have completed a bore using the same method with some success at the St. Louis-Lambert airport.

An eight-inch pilot bore on the planned bore path was completed successfully. The contractor planned to pull back a 54-inch steel pipe, directly behind a backreaming tool homemade for this purpose. According to accounts obtained afterwards, no drilling fluids were used to begin the backreaming process from west to east. Three different soil and rock materials were in the path of the planned bore, according to District Geologist Rob Lauer: a cobble, gravel and clay fill material on the west, cobbles, gravel and boulders in the middle of the bore, and solid rock of the St. Louis Limestone formation on the east (See Figure 6).

The bore was never completed. A fill failure occurred on the west side of the southbound I-270 onramp (See Figure 4), and the backreaming process was stopped less than ten feet from the edge of the pavement for that onramp. Analysis of the causes of this failure after it occurred revealed distinct problems that should have been evident to the contractor and subcontractor. First, there was a lack of accurate and reliable soils information about the path of the bore. This information would have saved the contractor and his subcontractor needless embarrassment as well as monetary loss. If there had been adequate advance information about the geology and soils, the bore method chosen might not have been selected. Additionally, if the presence of predominant coarse grain sizes was known (boulders, cobbles, and gravel), an adequate drilling fluid could have been chosen. Also, it might have been realized that the geology and soils of the St. Louis Lambert airport area, though somewhat similar in isolated locations, are entirely different in composition and strength to the soils and rock that were encountered at this location.

The recipe for failure included:

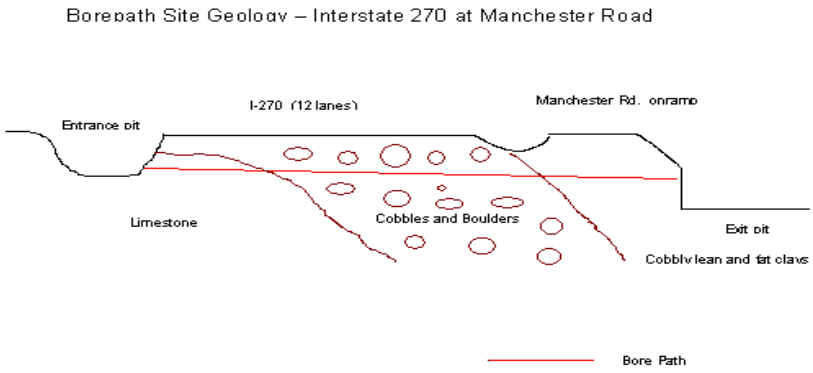
a. One inexperienced subcontractor,

b. Three soil and rock materials were incompatible with the type of boring chosen,
c. No advance geotechnical information about the bore path was obtained,
d. One incompatible boring method (HDD backreaming) was paired with another (the use of an auger boring/pipe jacking frame), and
e. The addition of drilling fluids was only used during the pilot bore but not the backream, where it was probably needed the most.

Thus, failure was assured.

Figure 4. Photo of aborted horizontal boring at I-270 southbound onramp from Route 100 (Manchester Road), St. Louis County, looking east. Photograph by District 6 geologist Rob Lauer.

Figure 5. Diagram of Crossing.



Could this bore have succeeded? After analysis, it was found that it could, but the expense might have outweighed the benefit of the crossing. Pipe would have to be rammed through the cobbles, boulders, and gravel (See Figure 5). Then, 54-inch augers or man-entry methods would have to be used to clear the pipe, so that a microtunneling machine could be inserted to complete the final rock portion of the bore. All in all, an EXTREMELY expensive undertaking would have been required.

Figure 6. Photograph of entry pit, pipe jacking/auger boring frame, east side of pilot bore at Interstate 270 and Route 100 (Manchester Rd.). Photo by District 6 Geologist Rob Lauer.

This case study leads us to question, “how are soil and rock characterized?”

Both are characterized on the basis of textural characteristics and particle size. Rock is characterized on the basis of composition. Soil CAN be characterized on the basis of composition, but normally the finer particle sizes use laboratory testing methods that exceed the intent of this field guide. Soil strata on a boring log, as well as rock strata, should be described and recorded in accordance with a specific standard or protocol. Soil should be described in terms of texture, color, consistency, and any modifiers regarding color and secondary texture, and moisture content. Rock should be described according to type, degree of weathering present, and an estimate should be made of its overall strength. Descriptors and modifiers for soils may apply only to cohesive soils (clays and silts) or non-cohesive soils (sands, gravels, etc.). All of these characteristics (with the exception of color) pertain directly to the progress to be expected during, or the difficulty of completing, a horizontal boring. Pipe is jacked much more efficiently through medium stiff clay than very hard clay. Wetness

characteristics may influence the choice of equipment and the ease of excavating an entrance or exit pit for the pipe. Gravelly clays are much less conducive to HDD than pure, relatively gravel-free clays. It's a whole lot easier to bore through weathered rock than it is to bore through unweathered rock. These are but a FEW examples of the comparisons that can be made from geotechnical data in completing a site-specific boring plan.

When all the assembled data has been accumulated, including laboratory data that may prove to be necessary, the geologist plots it on a profile view. This is why accurate topographical information along and adjacent to the alignment of a planned bore is crucial to project success, since it allows comparisons to be made, equipment or method to be chosen, and alignment of the bore to be 'firmed up' to decrease risk for the contractor and for the owner. To insure complete soils information for a horizontal boring, information should be site specific for a project, either by locating by northing/easting or by station and offset. All previous studies or boring logs should also be referenced to the same system.

Horizontal bores have been used for installation of utility product pipe for over a hundred years, though the number of horizontal bore equipment types available for the contractor to use has only risen drastically in the last 20 years. The earliest installations were accomplished by hand tunneling, with precautions and methods similar to those used in the mining industry for ore recovery. This was exhausting, dangerous work, only used in extreme cases where horizontal pipeline installations were absolutely necessary to make additions to a utility system.

There are seven major types of horizontal bore installations that are possible today. Experienced crews and equipment operators should carry all out. The type of horizontal bore chosen is usually based on three criteria:

1) The length of the crossing to be made,
2) The depth of the crossing to be made, and
3) The type of utility product pipe to be installed.

The type of soil and rock to be encountered in the planned bore path is a major influence on the selection of equipment to be used, as has been previously stated. Availability of equipment and trained operators is an additional necessity when selecting a type of horizontal boring for use. Project budget requirements are also a major consideration. It is not unusual for a major oil company to airlift a pipe ramming crew and their equipment to a remote jungle pipeline crossing for installation of horizontal directional drilling casing or for the rescue of product pipe which is stuck during backreaming. However, the budgetary requirements of most highway construction projects do not justify this type of mobilization.

The basic boring types presented here are not all-inclusive in their scope; these boring types are those that may be encountered by inspectors, engineers, and designers within the state of Missouri. It is the responsibility of the geologist, engineers, and inspectors to become familiar with the types of boring equipment used, their capabilities, their limitations, and above all, to ASK QUESTIONS about safe efficient operation. All equipment manufacturers are more than willing to answer these questions. Vendors, contractors, and project management staff often also supply unique insights that might not otherwise be gained.

Ground conditions that are conducive to the suitability of various trenchless methods are shown in Table 2. Technological advance and innovations in tooling and method may change the possibilities presented in the table, but for the most part, you can consider the information correct.

Auger Boring

Auger boring is a technique that is used extensively in road crossings. The method utilizes a process of simultaneously jacking steel casing while removing spoil inside the casing by means of rotating continuous flight augers. Spoils are transported back to the entry point or bore pit where they are removed. This technique has several distinct advantages for use in right-of-way. The use of steel casing is the first advantage. Steel is permitted by utility policy under all types of right-of-way, including high-type roads and interstate highway. A second advantage to this method is that this is a common enough method so that many contractors are available statewide which can perform this type of boring. This enables the utility owner to get competitive bids for the service. A final advantage that should be mentioned is that the method provides continuous support for the roadway while boring.

Two types of auger boring are used: cradle auger boring (this method requires the auger boring machine to be supported by a crane and is thus not used extensively) and track auger boring. This method allows the installation of pipe from 4 to 60 inches in diameter, with drive lengths usually in the neighborhood of 100 to 600 feet, though longer bores are possible under ideal conditions. Larger diameter bores are also possible, but unusual. Steel casing is required since it can best support vertical soil loads as well as jacking thrust and torque from the auger boring machine. It is possible to use horizontal auger boring to create an unsupported borehole by using only the cutting head and auger. This practice is not allowable in MoDOT right-of-way due to the inherent danger of overexcavation.

Table 2. Suitability of Ground Conditions for Various Horizontal Boring Methods

Ground Conditions	Auger Boring	Micro-Tunneling	Pipe Ramming	Impact Moling	Pipe Jacking	Horizontal Directional Drilling (HDD)	Utility Tunneling	Pilot Tube Micro-Tunneling
Soft to very soft clays, Silts and organic Deposits	Y	Y to M	Y	N	M	Y	Y	M
Medium to very stiff Clays and silts	Y	Y	Y	Y	Y	Y	Y	Y
Hard clays and Highly weathered Shales; Coal	Y	Y	M	M	Y	Y	Y	Y
Very loose to loose Sands; Above the water table	M	Y	Y	M	M	Y	Y	M
Medium to dense sands Below the water table	N	Y	N	N	N	Y	N	M
Medium to dense sands Above the water table	Y	Y	Y	M	Y	Y	Y	Y
Gravels and cobbles 50-100mm (2-4") diameter	Y	Y	Y	M	Y	M	Y	Y
Soils with significant Cobbles, boulders, and Obstructions larger than 100-150mm diameter (4-6")	M	M	Y	M	M	M to N	M	M
Weathered rocks, weathered shales, and well consolidated soils such as glacial till.	Y	Y	M	M	M	Y	Y	N
Slightly weathered And unweathered rock	Y	Y	M	N	N	M	Y	N

Y =Yes – Method is generally suitable when performed by experienced contractor with suitable equipment.

M = Marginal – Difficulties may occur for contractor, some modifications of equipment or procedure may be required to successfully complete the bore.

N = No – This method is not generally possible under these conditions. Substantial problems will occur, and the method is generally unsuitable for and the equipment is unintended for the conditions present.

(Table adapted for MoDOT use from Najafi, Mohammed et al., Trenchless Construction Methods and Soil Compatibility Manual, 3rd ed.)

The basic steps involved in a horizontal auger boring project are as follows:

a. Jobsite preparation – The jobsite should be accurately surveyed, borings should be completed to characterize the soil and rock materials that may be encountered, conflicts with other utilities should be resolved, and job access and working space should be assured. Usually, an area of about 75 feet by 150 feet is required for the bore pit and all equipment, including additional auger flights, pipe, support equipment, and vehicles.

b. Bore pit excavation and preparation – The bore pit on the entry side of the bore should be excavated when all utilities have been located using Missouri One-Call. All applicable state and Federal safety regulations must be followed for sloping the pit, or the pit must be shored adequately to prevent collapse. If wet conditions prevail at the jobsite, a gravel base should be added at the bottom of the boring pit, or a concrete pad may be poured. The end of the pit away from the roadway should have adequate provision for a thrust block to be installed, or a concrete thrust plate should be poured so that the machine thrust can push pipe through the bore path. Figure 7 illustrates a typical bore pit excavation with stone base.

Figure 7. Horizontal Auger Boring Site Set-up With Gravel Base in Pit. Note that no thrust block is needed to push casing, as rock is exposed on the equipment end of the bore pit. Photo courtesy of American Augers, Inc.

c. Equipment set-up – When the site has been prepared, the auger boring equipment is set up in the pit. The most critical part of this
d. process is aligning and setting the track for the boring machine so that line and grade are established from the beginning of the bore, and can be maintained. Figure 8 illustrates a typical equipment set-up.

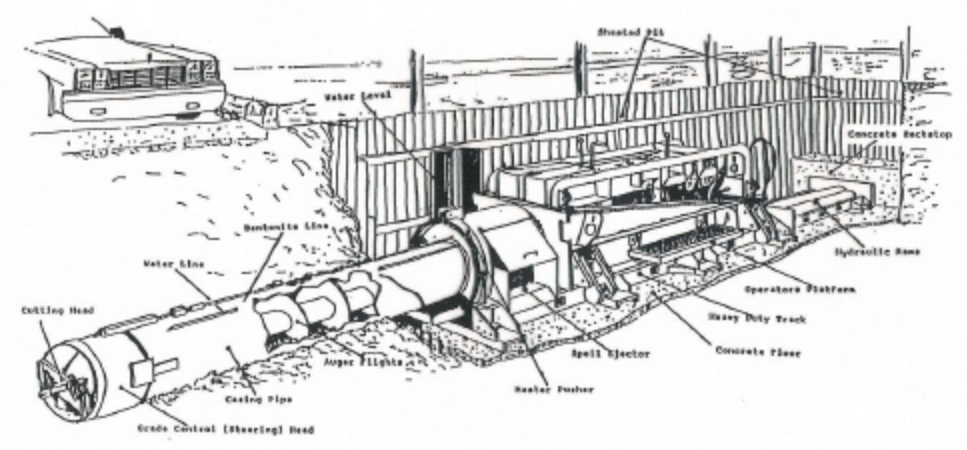


Figure 8. Typical Auger Boring Set-up. Note in this drawing that OSHA guidelines are upheld by use of sheeted pit, and that a concrete backstop has been poured to provide a thrust plate. This auger boring system has a grade-control, or steering head to allow minor corrections to line and grade control by the use of two-axis hinges.

e. Preparation of casing – Casing used in auger boring should be new, of good quality, and of sufficient thickness to support the design load for the highway, which includes live load (traffic loading), dead load, and overlying soil load. Precision machine-cut bevels on ends of casing will speed the process of welding. According to MoDOT policy, a certified welder must make the welds. Alternatively, a mechanical connection may be made using screw-fit pipe or a Permalok$_{TM}$-type connection between pipes. Finally, an adequate leading-edge band should be welded on the leading pipe segment to prevent damage to the casing pipe during the auger boring thrust process. This is referred to as “banding the casing”, and protects the pipe from damage. Not only does this band decrease skin friction on the surface of the pipe while it is being thrust, it strengthens the leading edge of the casing should rock or boulders be encountered, and provides for bentonite lubricant to be added during boring. This band is shown as Figure 9.

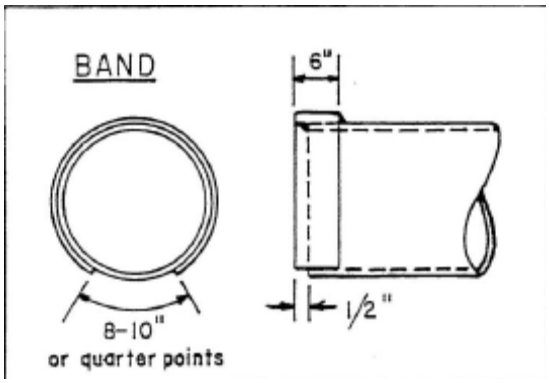


Figure 9. Leading-edge casing band used in auger-boring to protect casing and prevent pipe skin friction. This band is installed on the leading edge of the pipe string being thrust.

f. Installation of casing – The casing is installed, with particular attention to the lead segment at the start of the bore, during a process known as "collaring". This starts the cutting head into the ground, without lifting the following lead casing out of the auger track. The auger boring machine is rotated at low RPMs and with minimal thrust. When the lead casing is seated, the machine is shut down and line and grade are checked versus the line and grade desired. This important process insures the overall success of the auger bore on attaining line and grade on critical installations.

g. Removal of augers at the completion of the bore – When the final segment of pipe has been installed, the machine is shut down and the auger cutterhead is removed. The machine is restarted and the augers are cleaned by rotating them in a clockwise direction in the lowest gear, removing individual flights with their torque plates one at a time until the casing is clear.

h. Installation of carrier pipe if required – Carrier pipe is now installed inside the casing, using blocks, pre-manufactured casing spacers (also known as "spiders", or sliplined in the casing. Grout or sand backfill is installed at this point.

i. Site restoration – After the carrier pipe is installed, the boring machine, tracks, tools, and augers are removed from the pit. The pit is then re-filled and the area is restored to prior conditions.

Figure 10. Auger boring set-up showing simultaneous thrust and casing advancement. Photo courtesy of Barbco, Inc.

A fine recent publication is available from the ASCE entitled “Horizontal Auger Boring Projects”, which is part of the ASCE Manuals and Reports on Engineering Practice series, number 106 in that series.

Pipe Ramming

Pipe ramming is the most robust method of horizontal boring. It can drive pipe over 145 inches in diameter over 200 feet, and the upper limits to diameter and drive length have not yet been approached. Due to the nature of the percussion used to drive the pipe with either a hydraulically-powered or pneumatically-powered pipe ram, steel pipe must be used for this type of boring. Set-up for this type of bore is similar to that for auger boring, but unlike auger boring, pipe ramming is not stopped by the presence of cobbles or boulders in the bore path. A reinforced steel band at the leading edge of the first pipe usually moves the cobble/boulder aside or breaks it, swallowing the pieces if the pipe ram is bored open-ended. The basic procedure is simple, and is suitable for all types of ground conditions except solid rock, and is the safest to use in road crossings, since ground under the roadway is never left unsupported. The versatility of the pipe ramming method even allows its use to install guide casing

in gravelly or cobbly soils in what has come to be known as the “conductor barrel” method.

There are two types of pipe ramming, closed-ended and open-ended. Closed-end pipe ramming is limited to pipes eight inches in diameter and smaller. When a pipe is rammed closed-ended, the surrounding soil is compacted or driven away from the pipe as the force of the percussive energy is transmitted to the surrounding soil. This can lead to soil heave over the pipe, which is not suitable for a very shallow installation. One foot of soil cover for every inch diameter of pipe is usually sufficient to prevent soil heave over a closed-ended installation.

Open-ended or open-faced pipe ramming allows a pipe to be rammed through soil with the front of the leading edge of the conduit or casing open, so that a borehole of the same size as the casing is created. This allows most of the in-line soil to stay in place, except for that small amount of soil compaction that occurs during the ramming process and the small amount of soil displaced by the thickness of the pipe. After the ramming process is complete and the casing is in place, soil is removed from the pipe either mechanically or by the use of compressed air.

Bentonite (drilling mud) lubrication is used in stiff clays and some other soils on both the outside and the inside of the pipe, carried by a feed line welded to the pipe that allows it to drip on the outside of the pipe and also on the inside, where it lubricates the soil as the pipe passes. An added benefit of this lubrication is that it also acts as a lubricant when compressed air is used to clean the pipe.

Routinely, pipe of 12 to 36 inches diameter is rammed as conduit or casing underneath roadways. From 36 inches to around 80 inches in diameter, an experienced and knowledgeable pipe installation contractor should be consulted. From 80 inches to over 140 inches, special equipment and pipe ramming manufacturer assistance is usually required.

The pipe ramming procedure is as follows:

1) An adequate shaft or pit is constructed.
2) A cone (if closed-ended) or adequate leading-edge band is installed or welded onto the leading edge of the conduit or casing.
3) Place casing in the drive pit area and adjust for the desired line and grade.
4) Attach the percussion hammer and connect to its power source.
5) Initiate the drive and continue until installation is complete.
6) Remove the cone if used, or clean out the casing as required.
7) Restore the area to its intended function.

Figure 11. Preparing pit for 147-inch pipe ram near Altoona, Iowa. Photo courtesy of TT Technologies. Note concrete pad for preparation of pit area.

Figure 12. Pipe ramming set-up for pipe ram at Altoona, Iowa. Note pipe ram atop frame that will allow it to move forward as pipe is advanced. Photo courtesy of TT Technologies.

Figure 13. Pipe being rammed through railroad embankment at Altoona, IA. Note hydraulic hoses attached to back of pipe ram. Photo courtesy of TT

Figure 14. Completed pipe ram at Altoona, IA. Photo courtesy of TT Technologies.

Figure 15. Completed job at Altoona, IA. Though the distance was short (less than 100 feet), the railroad stayed open throughout the process. The diameter of pipe rammed made it a world-record installation. Photo courtesy of TT Technologies.

Impact Moling/ Methods of Soil Compaction

Compaction methods are the simplest of all horizontal boring methods, but are limited to small pipe sizes and are probably the most inaccurate of all horizontal boring methods. Minimal soil information is required. There are three predominant methods that are used. These are:

1) The Push Rod Method
2) The Rotary Rod Method
3) The Percussion Method.

A rod pusher is a machine that pushes or pulls a solid rod or pipe through the earth simply by displacing soil in the path of the rod/pipe without rotation or

impact. The resultant hole is the diameter of the rod or pipe that was thrust through the soil. The power source for this method ranges from the power take-off of a backhoe or tractor to a small hydraulic machine that is put into a small (usually less than two or three feet depth)
bore pit. Push rods are usually four feet in length, and are thrust through the ground without rotation. The accuracy of this method is largely dependent upon the initial set-up of the machine and the soil conditions.The rotary rod method, or rotary method uses the same power source and the same size of launch pit, but instead of pushing through the soil, has a rotary cutting action that allows it to bore through possible rock conditions in the path of the bore. This bore type, like the rod pushing method, is useful only where accuracy is not critical, and the method's accuracy again is largely dependent upon the initial set-up of the machine and the soil conditions.

The percussion method is possibly the most useful of the three. In this method, a pneumatically or hydraulically powered piercing tool goes underground trailing a power source line that is either electrical or hydraulic that powers the reciprocating action of the tool. The soil around the tool provides friction for the rearward stroke of the tool, thus a soil with frictional characteristics is necessary for the proper operation of the tool.
The tool will vibrate but not move in unstable, saturated soils. Due to the impact of the tool and the shape of the tool, this method is also known as "impact moling" or "missile moling". The tools range in size from about 1.75 inches in diameter to 7 inches in diameter. In one of the few rules of thumb that are applicable to trenchless installation, it is usually recommended that there are between ten inches and one foot of cover for every inch of tool diameter to avoid heaving above the tool. This general rule could also apply to the rotary rod and push rod methods.

Thus, to prevent soil heave with a soil compaction tool,

[Required Depth of Cover (in.)] = [Tool Diameter (in.)] X 12 .0

is a useful relationship to remember.

These methods are limited by their accuracy. Their use is largely motivated by the fact that they are rapid and economical. Whether they are truly cost effective remains to be seen.

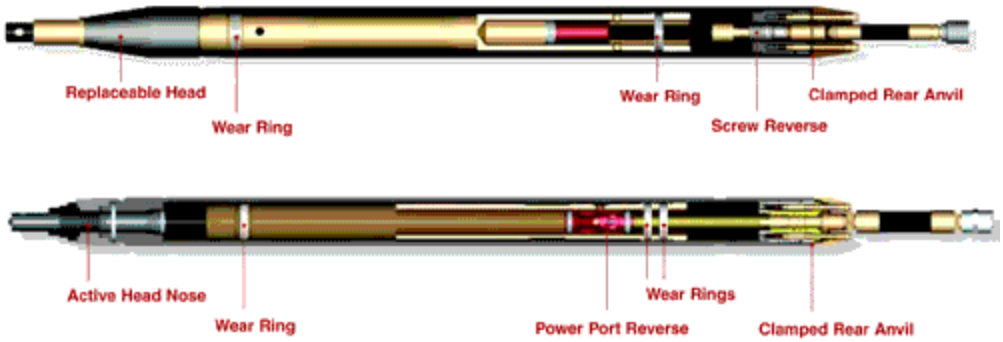


Figure 16. Examples of Hydraulically (air compressor attachment to right) Powered "Impact Mole" Compaction Tools. Photo courtesy of Earth Tool, Inc.

Pipe Jacking

The term "pipe jacking" can be applied to a specific type of horizontal boring technique, or it can be applied equally as well to the process of advancing pipe forward by thrust during auger boring, microtunneling, or utility tunneling. This distinction should be made to avoid confusion. During pipe jacking, the pipe is advanced by means of hydraulic thrust, similar to using an auger-boring frame or another type of hydraulic thrust frame. The jacking force is transmitted down the pipe segments during the tunneling process. Workers must be inside the pipe during jacking and spoil removal. Because of the large jacking forces involved in pushing large diameter pipe through the ground (normally vitrified clay or concrete) the design floor and construction of the jacking arrangement are critical to the overall success of the drive. The shaft floor and thrust reaction structure must be designed to withstand the jacking forces that will be initiated, as well as designed to uphold the weight of the heavy pipe segments that are being placed upon them repeatedly for the length of the drive. One of five different soil removal systems is used to extract spoil from the inside of the pipe being driven: wheeled carts or skips which roll out of the pipe, belt or chain-driven conveyors, slurry (drilling mud) systems, vacuum extraction, or continuous-flight augers.

The key difference between pipejacking and microtunneling is that pipe jacking involves man-entry during spoil removal, where microtunneling does not.

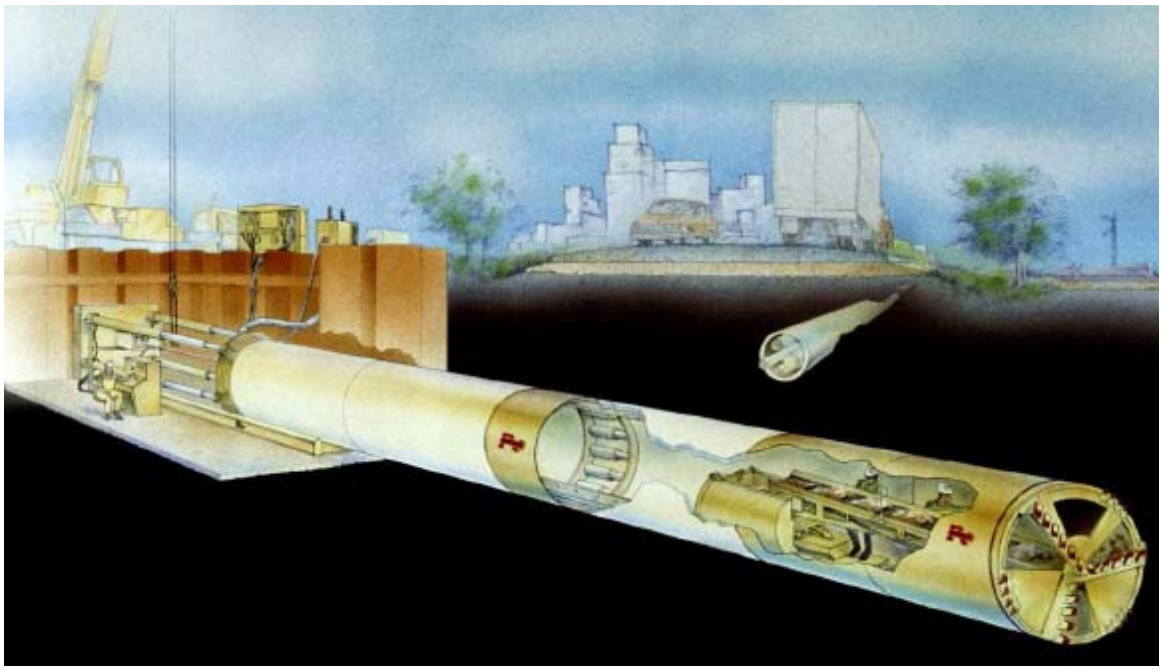


Figure 17. Generalized view of a pipejacking system. Photo courtesy of Akkerman, Inc.

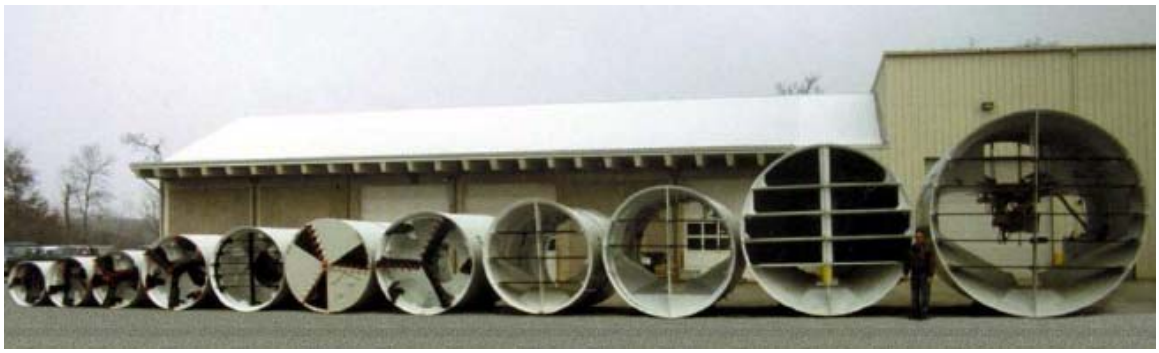


Figure 18. A variety of sizes and configurations are available for pipe jacking as this lineup of cutterheads illustrates. The four largest heads on the right are cutter boom heads, which allow a scoop backhoe arrangement to go through the slats and remove material in the path of the pipe jack. The remaining heads on the right are rotating TBM (tunnel boring machine) – type cutterheads. Photo courtesy of Akkerman, Inc.

Figure 19. Backhoe soil removal attachments. These go inside the pipejack, extend through the face of the backhoe cutterhead, and cut soil material to be moved in advance of the pipe thrust. Photo courtesy of Akkerman, Inc.

Figure 20. Pipejack skip haul system prior to reentry into pipe. Additional materials will be removed from the soil face, the pipe will be thrust forward as the materials are removed, and pipe advance will continue. Photo courtesy of Akkerman, Inc.

Microtunneling

Microtunneling, as previously stated, is basically pipejacking without man-entry. Where pipejacking may or may not give continuous support to the tunnel face (which directly affects the roadway above), microtunneling does provide continuous support to the tunnel face. Microtunneling also works in a wide range of soil conditions, and it maintains close tolerances to line and grade because the head is usually laser-guided. It is normally used well below MoDOT roadways and is not normally a problem, but should be mentioned here because it may affect roads in extreme cases. One major disadvantage to microtunneling is cost, which is far above that of pipejacking.

Horizontal Directional Drilling (HDD)

Of the range of horizontal boring systems that may be seen in Missouri, Horizontal Directional Drilling, or HDD, is probably the most common. It may also be used at the shallowest depths. Since it is used at the shallowest depths and is most common, the potential for damage to MoDOT right-of-way is the greatest. Unfortunately, among permit inspectors, engineers, designers, construction inspectors, and many others within the organization HDD is the least well-understood of ALL horizontal boring technologies. Horizontal directional drilling (HDD) was originally conceived as a concept in the 1970's by an innovative road boring contractor by the name of Martin Cherrington. The first rigs were huge, intended to cross rivers and place utility product pipe. The first crossing was a mere 600 feet, with no steering capability. Locating the cutter head was not accomplished, and the entire boring was done blind.

In 2007, year 7,400–foot crossing was made by a drilling rig with over a million pounds of pullback capability. Though this is unusual, it illustrates the capabilities that have been reached. The majority of rigs that will be seen in Missouri are in the 7,000 to 50,000- pound range. To understand this better, let's look at how HDD is done today.

HDD is basically a two-stage process where a pilot bore is drilled along a specified or intended installation path, and then is enlarged the hole to accommodate the installation of a utility product pipe. HDD is a *fluid-assisted, mechanical cutting* method of bore creation. It is NOT water jetting, which is a *mechanically assisted, fluid cutting* method of bore creation. HDD is permitted in MoDOT right-of-way, while water jetting is not.

It is generally agreed that there are three classes of horizontal directional drilling systems, which can install pipe up to 48 inches in diameter. HDD systems can install pipe at depths of 200 feet. This makes it suitable to cross underneath rivers, highway interchanges, and large obstacles. Since HDD can be steered while drilling, it can go over, under, or around most obstacles in its path. The

three classes of HDD that are available are shown in Table 3.

Table 3. Comparison of Main Capabilities of Horizontal Directional Drilling (HDD) Systems (Isley and Ghokale, 1997 with new data)

System Description	Product Pipe Diam.	Depth Range	Bore Lengths	Torque	Thrust/Typical Uses Pullback	
Maxi – HDD	24 – 60 in. *	≤ 200 ft.	≤ 7500 ft.'*	≤150,000 ft.-lbs.*	≤1.3 million ft.-lbs.*	Major highway, River crossings
Midi - HDD	10 – 24 in.	≤ 75 ft.	≤ 900 ft.	900 – 7000 ft.-lbs	20,000 to 100,000 ft.- lbs.	Smaller rivers, Roadways, Obstacles
Mini -HDD	2 – 10 in.	≤ 25 ft.*	≤ 600 ft.	< 950 ft. – lbs.	<20,000 ft.-lbs.	Telecom cables, Gas and power

* Represents data that has been updated, based upon manufacturer's rating of equipment, and reported and verified world-record's crossing in *Trenchless Technology* magazine by Michels Pipeline Co.

There is no significant operational difference in the three types of systems. Different size applications do require different system modifications to allow pump volume for spoil removal, deeper locating capabilities, and different types of directional control to achieve these ratings.

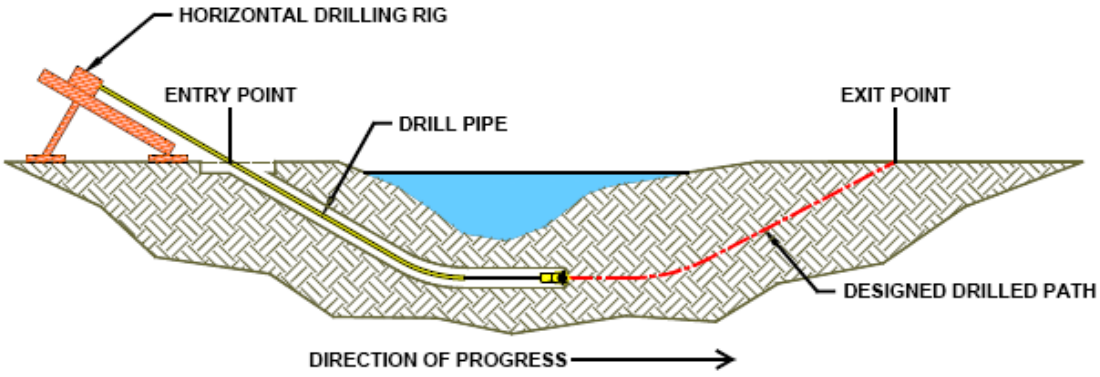


Figure 21. Diagram of Horizontal Directional Drilling Process Pilot Bore. Obstacle in this case to be overcome is a stream or small river.

Figure 21 illustrates the first step of the two-stage HDD process. In this process, a pilot hole is completed underneath an obstacle. This pilot bore will serve as a guide hole during the backreaming process. It should also be noted that this is not in actuality a hole but a bentonite slurry pathway that is created by the pilot bore. Tracking of the pilot bore is accomplished by a radio sonde in the drill bit. Normally, the pilot bore's slurry path is 4 to 8 inches in diameter, depending on the soils or rock the bit will be cutting through, the size of the rig, and a number of other factors.

Locating the bit is critical to success. Too shallow, and the drill string can emerge prematurely, possibly strike utilities, or encounter other difficult conditions that can conclude the bore before backream even begins. Locating the drill bit is done by one of two means:

1) A walk-over locator which picks up the radio from the transmitter in the drill bit, or
2) Gyroscopic means, which are usually used over long distances and require specialized equipment and training/interpretation.

Figure 22. Components of a walkover locator system for HDD. From top left proceeding counterclockwise - driller's locator box and recording unit, 3 different transmitters, spare batteries, and walkover locator unit. Photo courtesy of Digi-Trak, Inc.

Figure 22 illustrates the typical components of a walkover tracking system…a transmitter (sonde) which transmits important information about drill head attitude (pitch, roll), drill head temperature, the battery life of the batteries in the transmitter, and the depth and direction of the drill head. Gyroscopic tracking systems are used on larger rigs which track the drill head from the operator's console.

Once the pilot bore is completed and has emerged from the target point, the pilot boring process is complete. The drilling rig is turned off while tools are changed at the other end of the drill string. A backreamer is added at the end of the drill string that will enlarge the slurry pathway. Attached to the backreamer is the utility product pipe. The pipe may be ductile iron, steel (if it has appropriate flexible joints of sufficient strength for the pullback), PVC (either fusible or with restrained joints) or high-density polyethylene (HDPE). Various methods are used for different types of pipe, dependent upon whether the pipe is flexible or rigid, and the overall length of the installation. If installation takes place below the water table, the pipe may be filled with water to prevent the buoyancy of the pipe from increasing the friction between the top of the pipe and the wall of the bore.

Care MUST be taken during the backreaming process to allow the appropriate amount of mud to be removed from the slurry pathway as the pipe advances. If it does not, sufficient forces may develop to hump soil material above the pipe, to force drilling fluids from the slurry pathway to the surface, or both. Flattening of the bore pathway can also result, which may cut adjacent underground utilities as the backreamer passes them. The importance of maintaining flow at proper levels during the backream cannot be overstated.Figure 23 illustrates the backreaming process. There are housings available from many manufacturers now that allow the tracking of the backreamer so that proper depth may be maintained, to avoid cutting utilities when flattening of the bore path occurs.

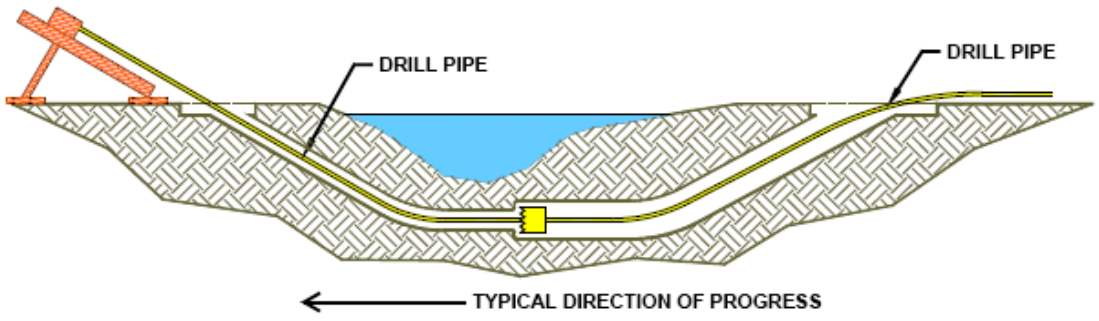


Figure 23. Illustration of the backream process.

Various types of drill bits and backreamers are available from a variety of source vendors. Different types of drill bits are used in different conditions, and different types of backreamers are used in different conditions as well. One type of reamer should not be used underneath the roadway. This specific type is known as the compaction reamer. It is actually not a reamer, as it does not cut soil out of the slurry pathway. Instead, it packs the soil up against the sides of the hole, and displaces it so that the product pipe can be installed. Figure 24 ,Figure 25, and Figure 26 illustrate various types of HDD bits and reamers. Figure 27 illustrates a specialized type of rock-cutting bit.

Figure 24. Sample types of HDD backreamer attachments. Photo courtesy of Frank Canon of Baroid IDP.

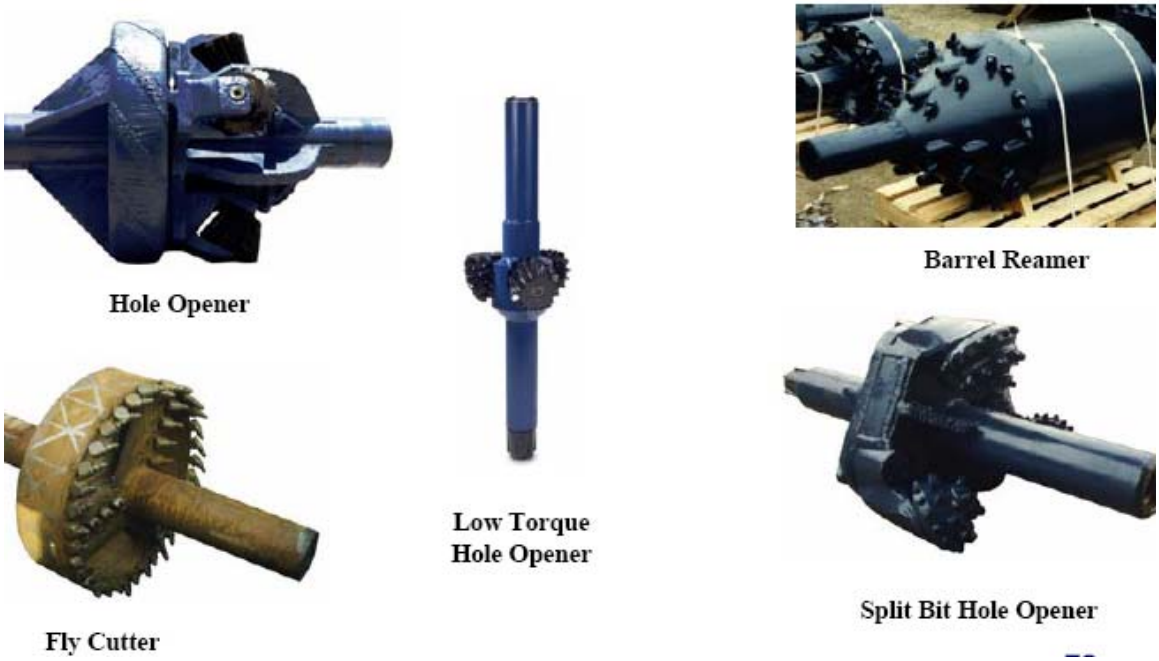


Figure 25. Other types of backreamer attachments for HDD. Photo courtesy of Frank Canon of Baroid IDP.

Figure 26. Hardfaced cutting blade bit for horizontal directional drilling. Photo courtesy of Frank Canon of Baroid IDP.

Figure 27. Specialized Vermeer Trihawk$_{TM}$ rock cutting bit. Note slot in center of tool, which may be opened with Allen wrenches to insert the locating transmitter. Photo Courtesy of Vermeer, Inc.

The ArrowBore$_{TM}$ Process – a special subtype of HDD

One special method that needs to be considered under the heading of Horizontal Directional Drilling is the ArrowBore$_{TM}$ method. This is a patented method of using HDD to place utility product pipe on line and grade. With an experienced operator, the method has been used to install sewer lines to tolerances of less than 0.5% grade consistently. Many bores have been installed to less than 0.2% of desired grade. What is appealing about this method is that it can install reinforced concrete pipe to these tolerances easily. MoDOT in Districts 2 and 5 has used this method to retrofit drainage and/or install new drainage underneath existing pavement or fill with no adverse effect.

This method relies on the installation of “sight relief holes” at predetermined points on the bore path. These relief holes are used to physically verify the depth at which the pilot bore is made, and then are used again during the backream to verify the depth at which the utility product pipe is installed. Several key parameters that should be used in all other types of HDD are strictly adhered to. The first parameter is locator calibration. The locator unit is given fresh batteries prior to the start of the bore. Then, the transmitter is set at a measured distance from the locator, and the exact distance from transmitter to the locater receiver is

measured. This insures utmost accuracy for the bore from the start. The second parameter that is adhered to is careful mudflow calculation, and adequate time spent to allow mud to flow to replace the soil being cut out of the way of both the pilot bore and the backream. Formulation of the drilling mud meets manufacturer recommendations and specifications. Such tolerances are especially desired in applications such as gravity sewer installations.

One completed ArrowBore$_{TM}$ installation was during the construction of a bridge and interchange over the Burlington-Northern Santa Fe Railroad near Centralia, Missouri on Route 22, Boone County. The fill for the bridge approach could not be open cut, and drainage was required from one side of the approach embankment to the other side. This installation was completed WITHOUT a sight relief hole, and still maintained grade tolerance to less than 0.5%. The pipe installed was reinforced concrete pipe, and it was pulled in using specialized tooling. Figure 28 illustrates this boring.

Figure 28. ArrowBore$_{TM}$ installation on Route 22, Boone County, Missouri. Note inadequate and partially collapsed galvanized metal culvert to left of photo. ArrowBore$_{TM}$ used in this manner may be a highly valuable tool to MoDOT for the retrofitting of drainage within the right-of-way. Photo courtesy of Ted Dimitroff and Trenchless Flowline, Inc.

Pilot –tube Microtunneling

Pilot tube microtunneling is a relatively new, highly accurate method of installation of utility product pipe. This method, originally developed by Richard Vedder of St. Louis' Sverdrup Engineering (now part of Jacobs Civil Group) was used in the mid 1990's in Cape Girardeau, Missouri, for the installation of multiple sewer laterals from single manholes, rather than dig in city street right-of-way for the servicing of existing product pipe. The method has rapidly evolved since that time, leading to other improvements in boring technology.

The method should NOT be confused with other methods such as horizontal directional drilling or guided auger boring. The American Society of Civil Engineers Standard Construction Guidelines for Microtunneling 36-01 defines pilot tube microtunneling as a "multistage method of accurately installing a product pipe to line and grade by use of a guided pilot tube followed by upsizing to install the product pipe." Thus, pilot tube microtunneling can be considered to be a hybrid form of conventional microtunneling. It combines the laser-guided accuracy of microtunneling, the steering mechanism of horizontal directional drilling, and the spoil removal system of a conventional auger-boring machine. Augers are employed to transport spoil, and a guidance system is used that involves a laser and a camera-mounted theodolite. Typically, pilot tube microtunneling is used for installation of small-diameter pipes of sewer or water lines, and for house connections directly from the main line sewers. Typically, this method is used at shallow depths and in soft soils. Vitrified clay pipe or reinforced concrete pipe is installed by this method. Figure 29 and Figure 30 illustrate installation by this method.

Figure 29. First phase of pilot-tube microtunneling installation. The directional steering head is jacked into the soil by the thrust frame. The entire line and grade installation is controlled with tolerances measured in less than 1/10 inch. A theodolite guides the pilot tube placement.

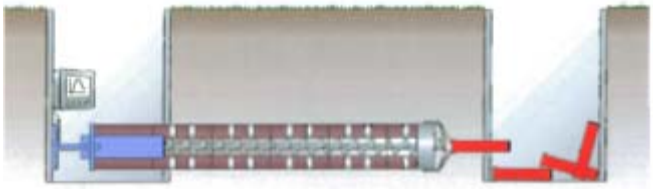


Figure 30. Second phase of pilot-tube microtunneling installation. In this phase, a cutterhead followed by augers advances the product pipe to the exit shaft, where the pilot tube sections are simultaneously removed.

Utility Tunneling

Utility tunneling is different from other types of horizontal boring or tunneling by the virtue of the tunnel's size and application though its construction techniques are similar to pipejacking. The primary difference between utility tunneling and microtunneling, for that matter, is the tunnel lining. Special liner plates or combination rib/lagging systems are used in utility tunneling to provide general ground support. Currently, all utility tunneling processes require personnel entry inside the tunnel during the tunneling process.

Excluding the preparatory work of constructing pits/shafts and field setup, a typical cycle of utility tunneling procedure comprises four major steps:

1) Soil excavation;
2) Soil removal;
3) Segmental liner installation; and
4) Directional steering and tunnel advancing.

Utility tunneling has been used since the early 1800s, when the first tunneling shield, a shield to protect workers from the cave-in of soils at the tunnel face, was invented. Since that time, utility tunneling has seen improvement in the addition of soft-ground tunneling techniques, pressure balance shields, and permanent linings.

Shifting the Paradigm From Open-Cut Towards Trenchless in Missouri

Trenchless installation of underground utilities is not a panacea for utility owners. In some cases it is much more costly to use trenchless methods than to use open-cut methods of installation. Missouri State Law does not preclude and may actually even promote the use of trenchless methods of installation:

> "…corporations shall have the power to lay conductors for conveying gas, electricity, or water through the streets, alleys, and squares of any city, town or village with the consent of the municipal authorities thereof under such reasonable regulations as such authorities may prescribe, and

such *companies are authorized to set their poles, piers, abutments, wires and other fixtures* along, across, or ***under any of the public roads, streets, and waters of this state in such manner as not to incommode the public in the use of such roads, streets, and waters***." (emphasis added – ghd; RSMo 393.010)

Where utility poles or transmission towers can be used effectively, electrical companies normally prefer them since they cost far less than trench or trenchless installations. But in the cases of water and sewer utilities, trenchless methods of installation are superior to open-cut methods of installation. Missouri State Law does not mention any trenchless method of installation, though by implication it is allowable, and in fact preferred if a utility is being installed under a road, street or water since it will not inconvenience the public.

Unfortunately, there are few individuals with training and experience in the use of trenchless methods from a regulatory or engineering standpoint. This must change for trenchless installation to be accepted readily as open-cut installations are. It is even more important to have trained individuals when processes and ideas of proprietary nature can be present as they might be in the field of trenchless installation. If an engineer, geologist, or regulatory agency does not know what particular method is being approved for an installation or crossing, courts have held that an approving individual or organization can be held liable for partial damages in cases involving patent infringement. For the period of the years 1980 through 2005, British Gas and its patent licensing agency, Advantica, LLC, successfully litigated a number of claims involving the trenchless method of pipe bursting where royalty license fees were not paid. The contractors who did not pay the licensure fees (measured on a per-foot length of installation, per inch size of burst pipe) were found to be liable for the amount of licensure for the burst pipe plus attorney's fees, and in most cases an unspecified damage figure.

Recognizing the overall utility of trenchless methods of installation and educating users is but only part of the task that needs to be accomplished. It's worth mentioning that some of the methods and equipment used is useful in other fields of endeavor as well. Pipe rams that have been used for ramming pipe underneath roadways can also be used as pile drivers for pile foundations. In fact, TT Technologies even makes a special attachment for its pipe rams that fits the end of an H-pile or I-beam so that it can be used as a pile driver. The City of Des Moines, Iowa saved several million dollars when it used horizontal directional drilling to install a municipal water well. The water well's yield was approximately 12 times that of a normal vertical well.

Fuel costs can decrease drastically with the use of the appropriate trenchless method, simply from less equipment being involved in the installation. Ted

Dimitroff of Trenchless Flowline, Inc and inventor of Arrowbore$_{TM}$ recently completed a comparison of installing a sewer or water pipe to a depth of 15 feet, *not including the costs of restoration,* and assuming the price of fuel to be $4.50/gallon. The results of this comparison are shown in Table 4.

Table 4. Comparison of Fuel Costs
Open Trench Cut 15 Feet Deep Versus Arrowbore Installation
(from Dimitroff, 2008)

OpenTrench Cut		Arrowbore Installation	
Fuel Used gal/day	Equipment	Fuel Used gal/day	Equipment
125	Excavator	15	Vertical drilling rig
100	Excavator	10	Horizontal drilling rig
75	Front-end Loader	10	Mini-excavator
20	Uni-loader	2	Fluid mixing system
50	Two dump trucks	25	Vacuum truck ½ day
15	Misc. pumps, generators, etc.	20	Pickup trucks
TOTAL 405 gallons/day		92 gallons/day	
Times 5 days/week		Times 5 days/week	
Times 36 weeks/year		Times 36 weeks/year	
= 72,900 gallons		= 16,60 gallons	

YEARLY FUEL COSTS

OpenTrench Cut	Arrowbore Installation
@$4.50/gal = $328,050.00	@$4.50/gal = $74,520.00
@$4.00/gal = $291,600.00	@$4.00/ga = $66,240.00
@$3.50/gal = $255,150.00	@ $3.50/gal = $57,960.00

Fuel Savings per year Per Crew

@ $4.50/gal - $253.530.00
@ $4.00/gal - $225,360.00
@ $3.50/gal - $197,190.00

Fuel savings also translate into carbon emissions savings. The British Columbia Chapter of the North American Society for Trenchless Technology asserts, based

upon actual measurements, that trenchless methods for pipe replacement projects reduce carbon emissions from 75 to 90 percent compared to open-cut construction (Griffin, 2008).

Trenchless technology offers a wide range of societal benefits in both the short and long term. It is an environmentally-friendly, cost-effective group of methods and means that requires geologic input in all new installations and for some forms of renewal and upgrade. It has too long been marginalized or ignored in many professions. Many geologists and engineers are unaware of the possibilities that may be open to its use. Education and training are necessary in both of these professions to overcome these obstacles.

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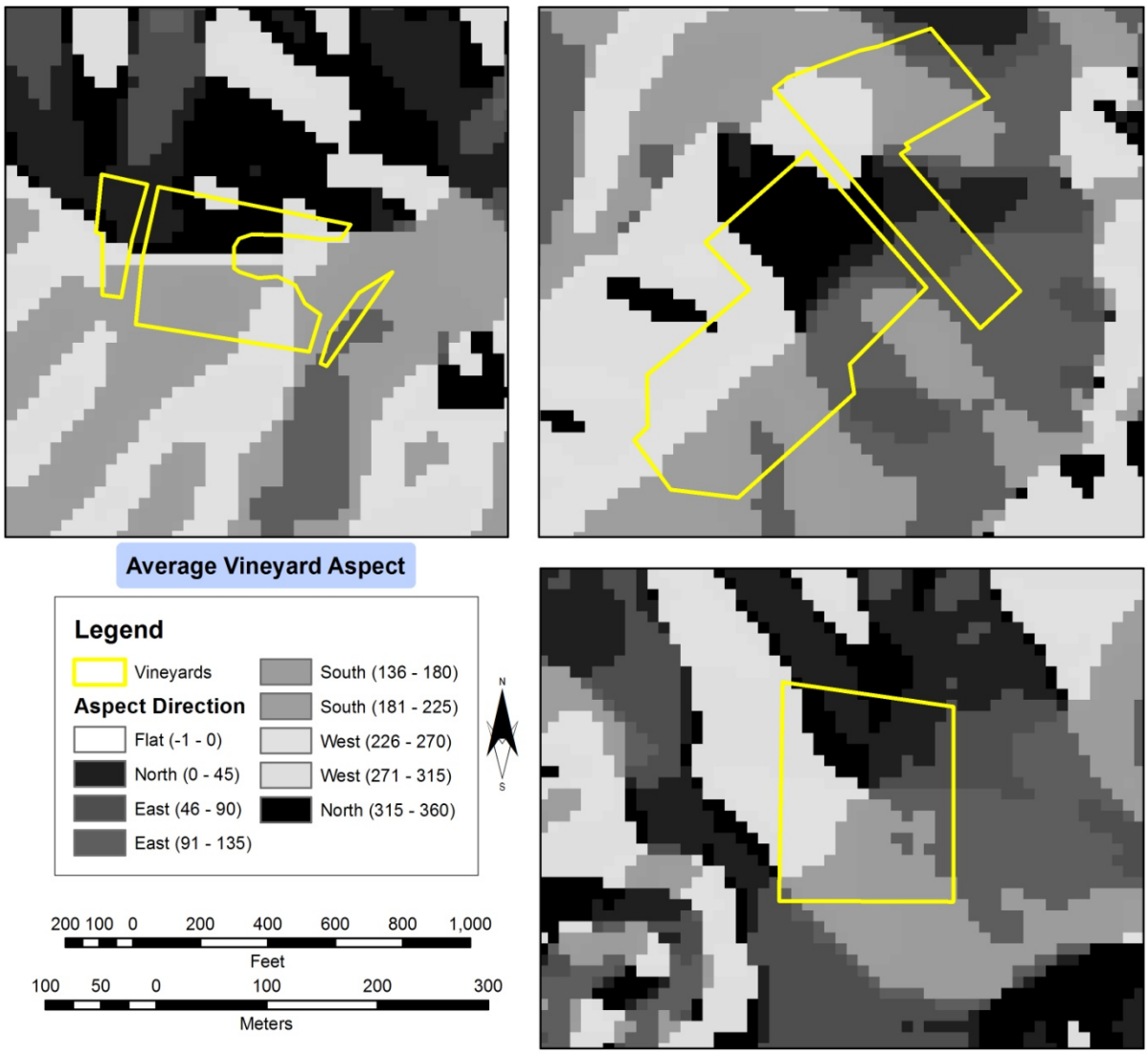

Figure 9. The aspect surface, created from the USGS DEM, with vineyard aspect obtained from visual assessment of the image.

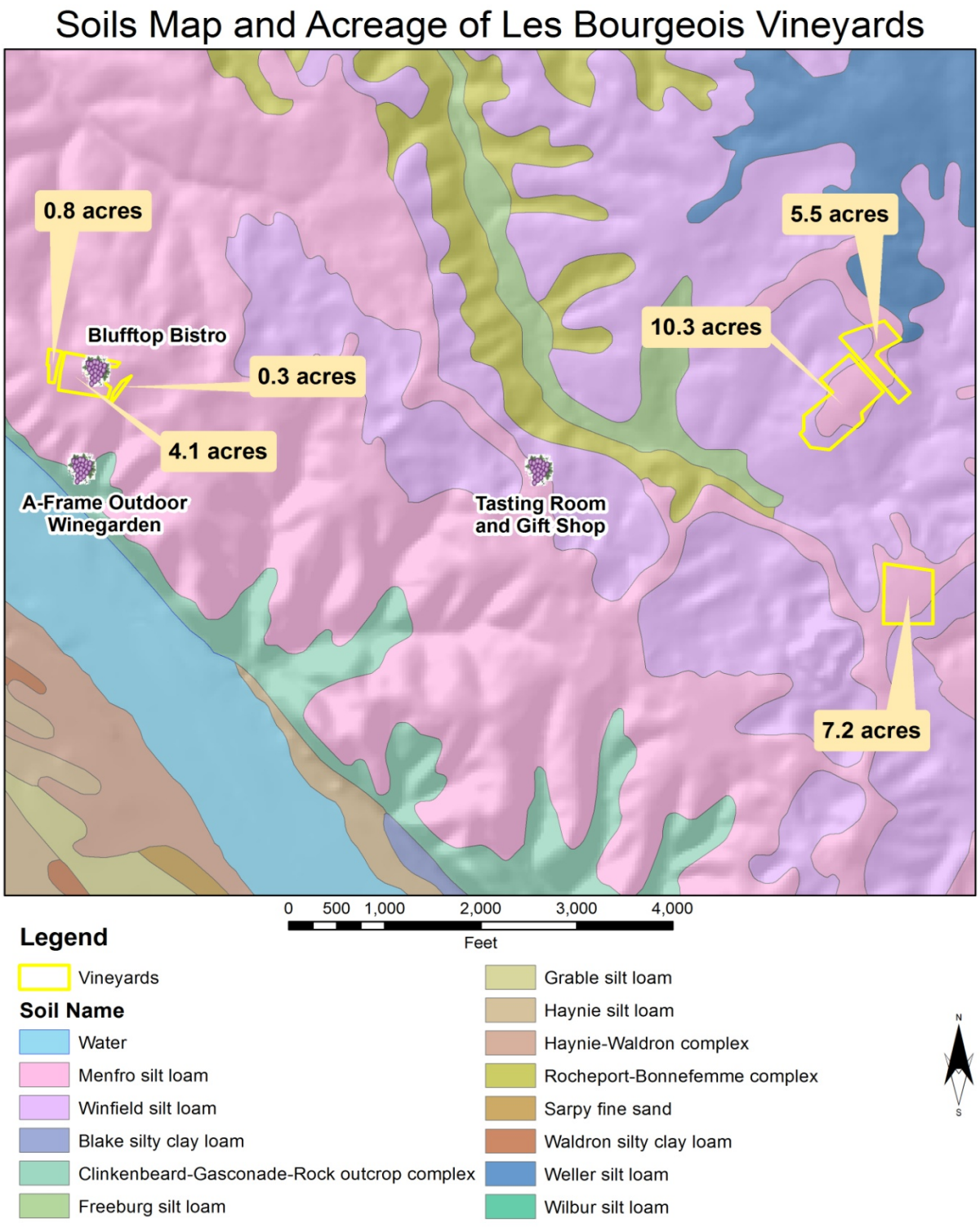

Figure 10. Les Bourgeois Vineyards plotted on a soils map made available on the CARES website and created by the NRCS. Soils map was modified to exclude soil types differentiated by slope.

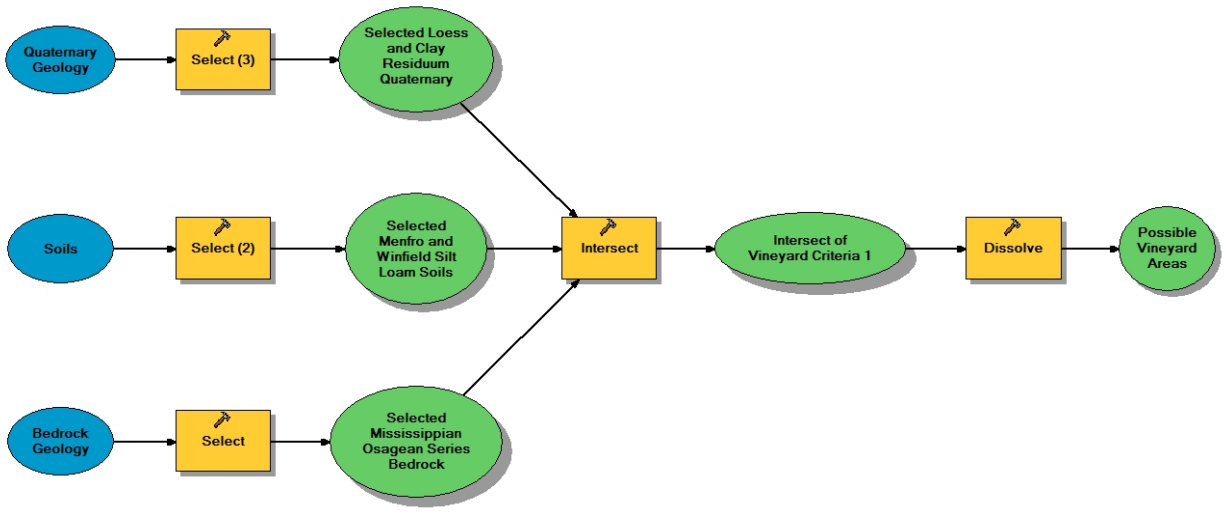

Figure 11. Flow chart showing the basic multi-criteria analysis that uses geology and soils to find possible vineyard establishment locations. This model is a work in progress but the results of this model are shown in Figure 4.

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