LOCATING BURIED PIPELINES IN DREDGE AREAS: HAZARDS, CHALLENGES, AND SOLUTIONS

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ABSTRACT

Underwater pipelines cross every major and many minor navigable waterways in the United States. Dredging over these pipelines presents a range of hazards from damage to the pipeline and loss of use to environmental damage, the destruction of the dredging plant, and serious injury or death. As we deepen and widen ship channels, pipelines with adequate cover when installed may lie too close to the surface for safe dredging. In addition, there is evidence that pipelines move horizontally or vertically after construction. In existing channels, the large safety zones required around poorly located pipelines can make safe dredging difficult or impossible. While we generally know of the existence of pipelines crossing waterways, locating them precisely enough to safely dredge is difficult due to uncertainty about the original placement, the potential movement of those pipelines, and the limitations of existing pipeline detecting and positioning technology. In this paper we will discuss pipelines in dredging areas, the regulatory framework for pipelines crossing waterways, existing procedures for locating buried pipelines before dredging, procedures for dredging over buried pipelines, and examine the reasons that pipeline locations may not be known or correct. We will survey existing technologies to detect and locate pipelines, discussing the advantages and disadvantages of each approach. We will then present Revelation, a novel pipe detection technology that promises to find pipelines and provide accurate locations in all three dimensions, regardless of depth or depth of cover. Revelation is a technology measuring small variations in the earth's magnetic field created by the pipeline both offshore and on land. It is specific to pipelines and other long, cylindrical, conductive objects, eliminating false positives and allowing for the real-time detection of previously unknown pipelines. Lastly, we will discuss deployment options and present some examples comparing Revelation to other methods of locating pipelines.

Keywords: Dredging, pipeline, utility, safety

INTRODUCTION

Dredgers continually work over top of buried utilities and pipelines. Our focus here is oil and natural gas pipelines due to the risk should they be damaged. These risks include damage and loss of use of the pipeline, environmental impacts due to spills, equipment damage, injury, or death. A study by the Coastal and Marine Operators Pipeline Industry Initiative (CAMO) found that marine vessels report 6 pipeline strikes a year, leading to 25 fatalities over 20 years. Examples include:

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- In 2013 a tugboat pushing a loaded oil barge struck a natural gas pipeline in shallow water south of New Orleans, as they maneuvered around an obstacle. The fire resulted in total loss of the tug, 4 injuries, and one fatality (NTSB, 2013-03-12)
- In 2014 a hopper dredge hit a natural gas pipeline in the Delaware river. Fortunately there were no injuries or damage to the vessel, but the pipeline was taken out of service and the waterway closed for one hour while the gas bled off (Daily Local, 2014-08-07)
- In 2018 a dredge spud struck a natural gas pipeline in Matagorda Texas that ignited leading to total loss of the dredge, shutdown of the waterway for several days, but fortunately no loss of life (Waterways Journal, 2018-04-23)
- In 2020 a cutter suction dredge in Corpus Christi hit a propane pipeline resulting in total loss of the pipeline, 5 fatalities, 5 injuries, loss of the dredge, and damage to adjacent facilities (NTSB, 2020-08-21)
- In 2021 in an anchorage in San Pedro Bay, California, container ships dragging anchors hit an oil pipeline that later ruptured, releasing an estimated 588 barrels of oil and leading to $160 million in damages and cleanup costs

Figure 1a. A dredge burns after hitting a propane pipeline in Corpus Christi, TX, Courtesy of Corpus Christi Caller Times

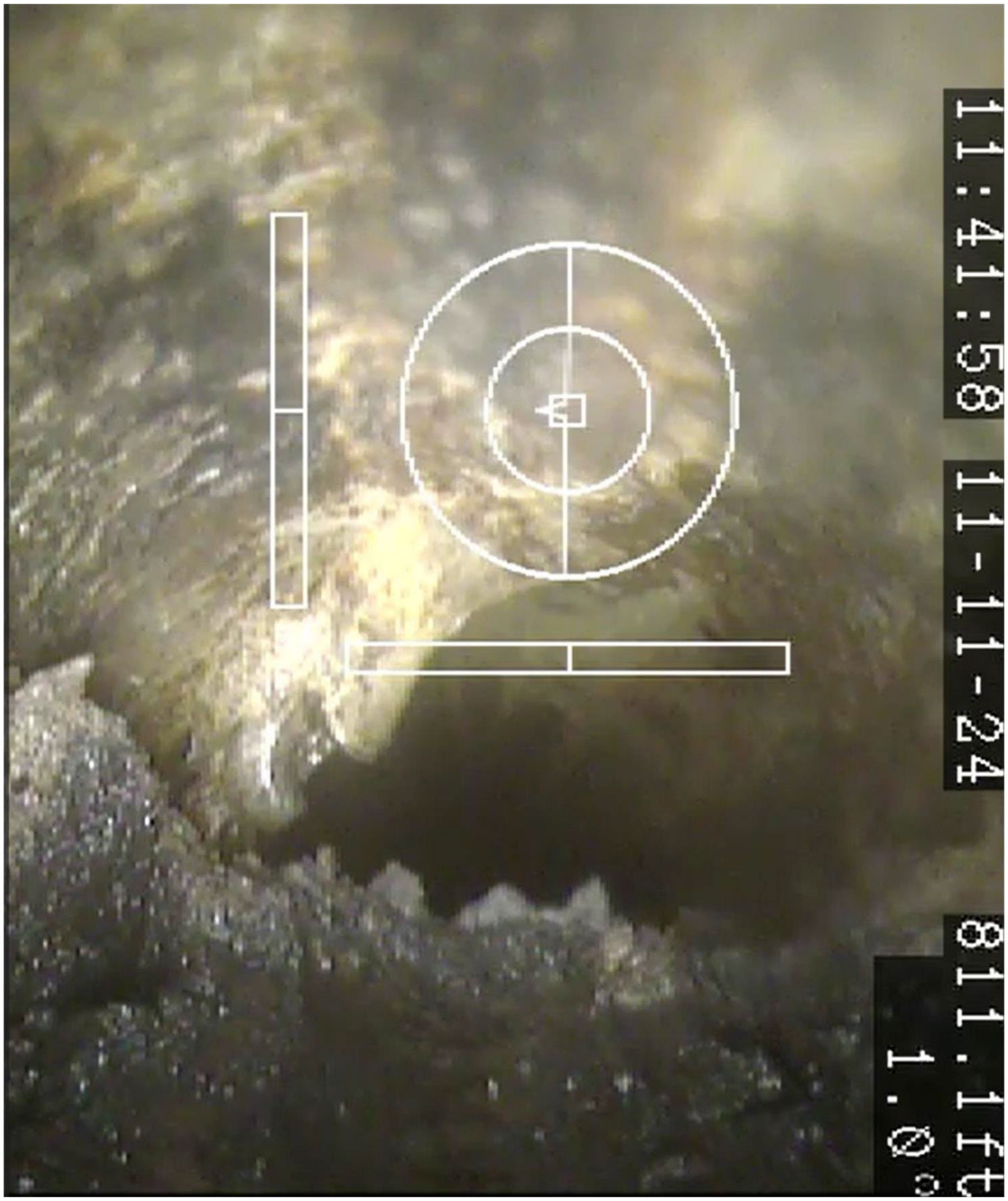
Figure 1b. The aftermath of a natural gas strike, courtesy of Waterways Journal

As these examples show, it is not just the digging head of the dredge that risks hitting pipelines, in fact there are many points of contact between dredging equipment and the bottom. All of the areas listed below must be verified clear of pipelines or utilities before any equipment touches the bottom.

Cutter Suction Dredges

Cutter Suction Dredges (CSDs) are the most complex dredging operations. The rotating cutterhead disturbs the soil several feet below the desired digging depth. Dredge operators often calibrate the digging depth to the Bottom of Suction (BOS), which is located at the bottom inside the cutter backring. However, the Tip of Cutter (TOC) is in front of and lower than the BOS. Which point on the cutter arms or cutter tooth is deepest varies with dig depth, making calibrating to TOC difficult. The CSD rotates on a spud at the stern of the dredge that can penetrate 10 or more feet into the bottom, depending on the soil. The CSD has swing anchors at the front of the dredge that it uses to dig side-to-side. These anchors are generally kept some distance behind the cutterhead and must be raised and repositioned throughout the day.

Figure 2. A frame from an inspection video inside a natural gas pipeline showing a dent created by a spud or other object hitting the pipe, courtesy of Callan Marine



These anchors can drag during digging, pulling them across and into the seafloor. The floating pipe behind the dredge is usually anchored as well, and submerged pipe is placed directly on the seabed, and may be pulled into shallow areas. Tugs attending the dredge often touch bottom in shallow areas alongside channels.

Shore Equipment

Dredges building new land or placing material in onshore disposal areas have support equipment that is at risk. This includes excavators and bulldozers that shape newly pumped soil, along with the equipment used to manage the shore pipe. Often dredging operations are preceded by digging existing soil to build or repair dikes in disposal areas.

Clamshell Dredges

Clamshell buckets are not positioned as precisely as a cutterhead, as they are suspended from wires, making depth control difficult. In addition, buckets used for soft to stiff soils dig a scallop shape while closing, digging in several feet below the nominal dig depth. These dredges use spuds or anchors to stay in place while digging and to step ahead.

Hopper Dredges

Hopper dredges only touch bottom with the digging heads, and generally do not disturb far below the desired dig depth. In addition they are continuously moving so do not stay in the zone where natural gas is accumulating. However, as the example above shows, they can still hit pipelines in or near the work zone.

Laydown Areas and Anchorages

In addition to active work areas, there are the laydown areas on shore and anchorages in the water for storage of dredging equipment. On shore the laydown yard has to accommodate the large equipment used to move heavy dredge parts. In the water, the dredging company has to find areas to keep unused equipment, which might be secured with anchors or spuds. This includes the location designated as safe harbor in the event of severe weather.

THE HAZARDS ASSOCIATED WITH DREDGING OVER PIPELINES

Any time a dredge digs over a pipeline there is the risk of damaging it, leading to loss of the use of the pipeline and costly repairs. Depending on the length of the pipeline, distance to the nearest valves, and the pipeline pressure, it can take hours or days to purge the contents of the pipeline before repairs can be safely undertaken.

Any time a pipeline is damaged there is a risk that the contents of the pipeline will leak into the surrounding water. For oil this leads to spills that befoul plant and wildlife, along with exposure to any toxins in the oil. In addition the cleanup can cost up to $10,000 per barrel (160 liters) of oil spilled. Natural gas leaks add carbon into the atmosphere, contributing to climate change.

While oil spills and pipeline damage may shut down a dredge while the cleanup is underway, fire presents a severe and imminent risk to crews and equipment. The engines and electrical equipment on board dredges and marine equipment present ignition sources. It is not uncommon for the gas from a damaged pipe to enter the engine room via ventilation systems, where it is ignited by the engines themselves. In this scenario crew members in bunks or working in the engine room may not even be aware of the fire hazard in time to evacuate.

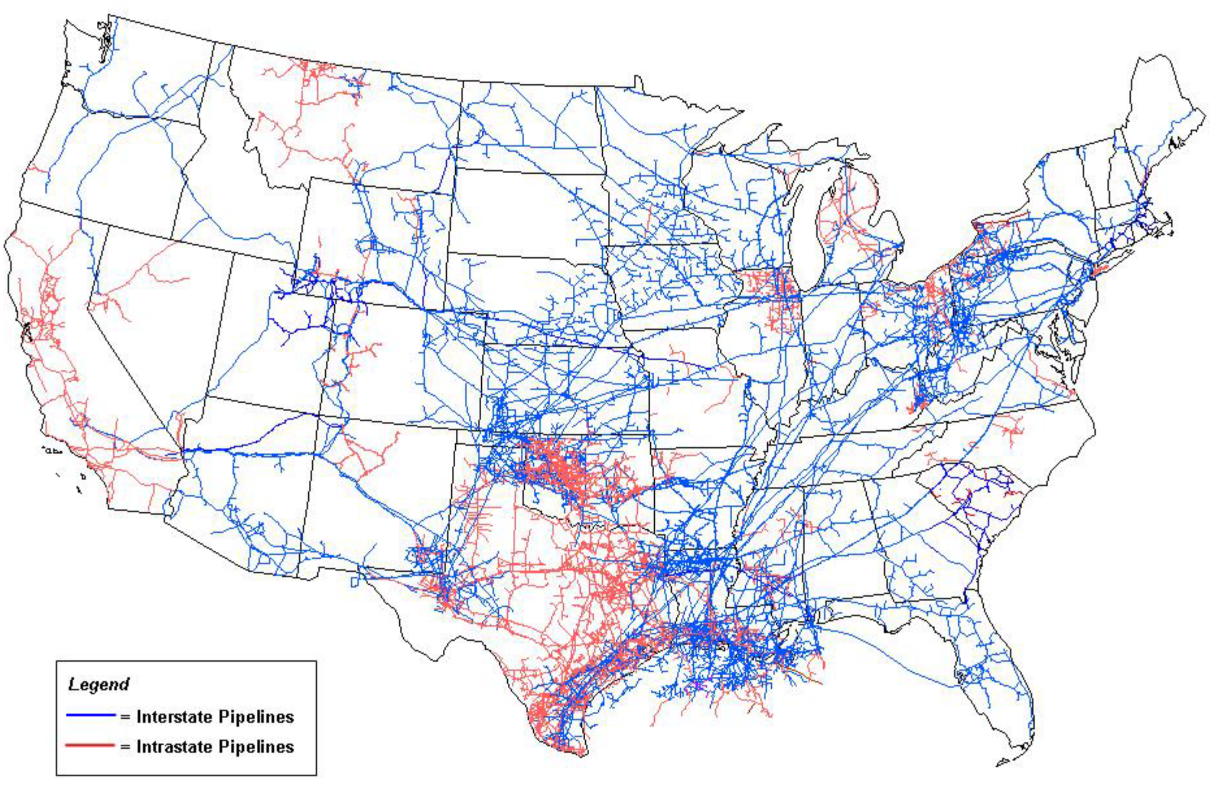
PIPELINE CROSSINGS IN THE UNITED STATES

According to the U.S. Energy Information Administration (USEIA), in 2008 there were over 306,000 miles (492,000 km) of natural gas transmission pipelines in the United States (Figure 3), along with many thousands more miles of distribution lines. This includes 9,500 miles (15,000 km) on transmission lines in the Gulf of Mexico. In addition, there are 190,000 miles (305,000 km) of liquid petroleum product pipelines

(American Petroleum Institute). In preparation for the Houston Ship Channel Expansion project, project designers identified over 100 pipelines crossing the work areas, of which 8 required removal and 14 required relocation (McCollum et al 2022). For dredge operators, the question is not if there are pipelines crossing a waterway, but where.

Pipelines installed in US waters are permitted by the Army Corps of Engineers (USACE). Interstate pipelines on shore are permitted by the US Department of Transportation (USDOT). Intrastate pipelines, are generally permitted by the respective states. Per the US Code of Federal Regulations (CFR), Title 49, Subtitle B, Chapter I, Subchapter D, Part 192, Section 192.327, Natural Gas Main and Transmission lines placed in the water must have 30" (762mm) of cover in soil, and 18" (457mm) of cover in rock. However, "all pipe installed in a navigable river, stream, or harbor must be installed with a minimum cover of 48 inches (1,219 millimeters) in soil or 24 inches (610 millimeters) in consolidated rock between the top of the pipe and the underwater natural bottom (as determined by recognized and generally accepted practices)." (Section 192.327, Paragraph e). Offshore pipe at less than 12 feet (3.7 meters) deep, must have 36 inches (914 millimeters) of cover in soil or 18 inches (457 millimeters) in consolidated rock.

Figure 3. Natural Gas Pipelines in the United States (Courtesy of the U. S. Energy Information Administration)



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Pipelines deeper than 12', but less that 200', must be installed so that the top of the pipe is below the natural bottom. Section 192.612 requires that pipelines in in the Gulf of Mexico and inlets in less than 15 Ft (4.6m) of water be periodically inspected and reburied if they are exposed or pose a hazard to navigation.

Difficulties Locating Pipelines

Despite permitting and regulatory requirements, finding the location of existing pipelines is very difficult. Most, if not all, pipelines can be identified using one-call systems, permit applications, and state or federal databases. However, there is a "lack of dependable and up-to-date information regarding most of the pipelines, particularly pipelines that were abandoned." (McCollum et al 2022). Dredgers require sub-meter accuracy in pipeline locations in order to make plans for safely dredging over such pipelines.

Pipelines are difficult to locate for a number of different reasons. First is that the original location of the pipeline may have been incorrect or unavailable. Ownership transfers can make it difficult or impossible to find that information. In addition, the various databases may have information on pipelines that were proposed but never installed. Pipeline shown on older drawings may not be transferred to later iterations of the same project. Records on older and abandoned pipelines are easily lost during changes of ownership or recordkeeping. Pipelines placed years or decades ago may not have good locations due to the technology available during installation, particularly if the owner or installer did not follow proper procedures.

Another reason pipelines are difficult to locate is that they may move in three directions once placed: Axially, horizontally, and vertically. Forces on the pipe caused by laying, pipeline operation, or soil movement can cause pipes to walk (movement along the axis), or buckle (lateral or vertical movement). Axial movement is caused by forces on the pipe during installation and operation. During installation, axial forces include the weight of the pipe, pull force of the laybarge, and pressure differences between the pipe and surrounding water. During operation the relevant forces include cyclic changes in pressure and temperature, the resistance to the flowing fluid, and transient pressure pulses due to startup, shutdown and valve changes. This axial movement causes walking or buckling of the pipe. Movement of the soil or changes in pore pressures due to wave or current can cause horizontal or vertical movement of the pipe (Duan et al., 2023). Large storm events promote such movement by inducing soil movement, extreme waves and currents.

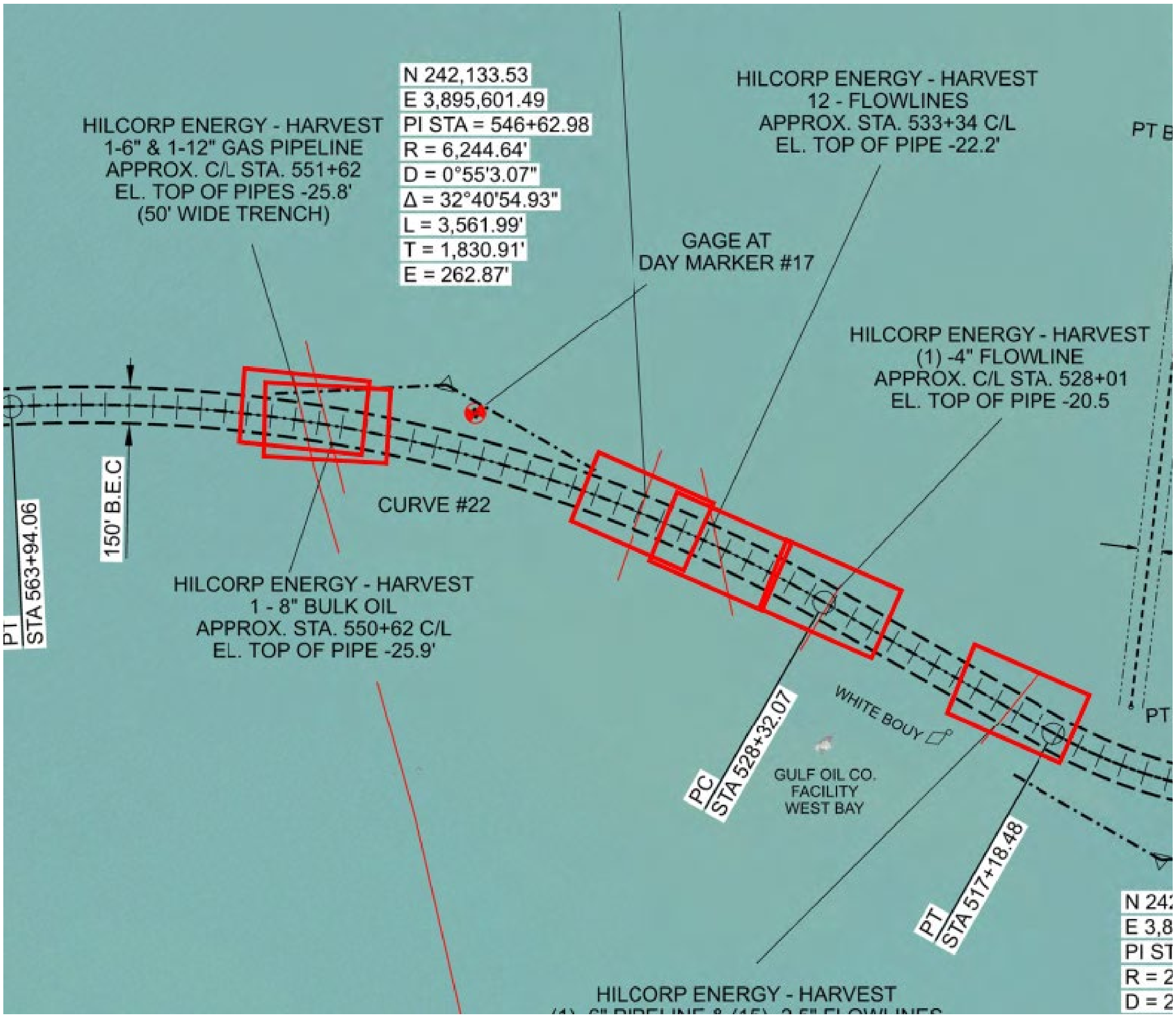
Dredging over pipelines

Any time a dredging contractor digs over a pipeline or other buried utility, they should prepare a detailed work plan for the operation, which is shared and reviewed by the dredging client and pipeline owner. The plan should include at a minimum:

- A communication plan for relaying project information to all stakeholders, including the dredge crew
- The location of the pipeline and associated safety zone(s)
- Work procedures for the dredging, including equipment restrictions or modifications, monitoring procedures, and an accountability process in case the plan is not followed
- Emergency procedures, including crew duties and instructions, spill response, and notification lists

Dredging over a known pipeline involve establishing a safety zone within which typical dredging methods are either prohibited or controlled. These zones are typically 200 – 300' (45 – 90m) wide (Figure 4). Anchoring and spudding inside the zones is prohibited. A long enough dredge can typically dig over these areas, keeping the anchors and spuds out. If the area is too wide, the dredge can dig from one side, turn around, then dig from the other.

Figure 4. Pipeline crossings in Tiger Pass, LA, with 250' safety zones in red



Depth control is critically important when dredging over pipeline or utilities. The contractor will set a maximum disturbance depth that leaves the cutter or bucket well clear of the expected depth of the pipeline. Ideally this is at least a cutter diameter (up to 9' or 2.7m), but worst case should be 5' (1.5m) to account for inaccuracy in positioning and digging. On CSDs the cutterhead positioning should be checked and calibrated every day, while bucket positioning should be checked multiple times per day. The cutter should be calibrated to the lowest tooth (TOC). Dig tracks should be checked every shift to ensure that the operator is following the dig plan. Sometimes the cutter is turned off and chained to ensure that it does not turn. This provides two benefits. It reduces the damage should the cutter hit the pipeline, and reduces the risk that the cutter will dig down below the maximum depth while swinging. The downside of these measures is that it increases the chance of leaving shoals, which then requires dredging over the area a second time.

FINDING AND LOCATING PIPELINES

Pre-dredge procedures for expected pipelines & utilities

Locating pipelines starts well before the dredge arrives, preferably at the design stage. For a contractor, the first step is to look at the projects plans and specs, which should give the locations of known pipelines and utilities. Designers should look at drawings from past projects in the vicinity and records from previous projects. The next step is to call or check online with the state-wide 811 system, for example in Texas at https://texas811.org/, or in Illinois, call Julie (https://www.illinois1call.com/). This is a legal and often contractual requirement. The user should also check state and national level GIS databases of pipelines such as the National Pipeline mappings System maintained by the PHMSA (https://www.npms.phmsa.dot.gov/), or that of the Texas Railroad Commission (https://gis.rrc.texas.gov/GISViewer/). However, care should be taken with databases and GIS tools as they may contain false positives in the form of abandoned or permitted but never built pipelines.

Designers and dredging contractors should always contact the owners of pipelines directly to obtain the best available information and agree on work plans. Pipeline owners will often want a representative on site during dredging. Project designers should get a Clearance Letter or Letter of No Objection indicating that the owner is aware of the project and either agrees that the pipeline is safe to dredge over, or has been moved or removed.

Locating Pipelines

Once expected pipelines have ben identified at the design stage, the location of the pipeline must be verified to at least sub-meter accuracy. The most reliable and accurate way to do this is to physically locate the pipeline and make visual identification. However, in the marine environment this is very difficult. Accessing a buried pipeline is a dredging project in its own right, with attendant time, expense, and hazards. Making visual contact requires diving operations, and may not work in turbid water or at depth.

There are a number of sensing technologies that are currently used to locate buried pipelines. They all share the flaw that you need to know that a pipeline exists in a general location before looking. In addition, they may not be able to penetrate the seabed, may generate false positives, or provide imprecise vertical elevations. The Revelation technology, described below, is a new technology that addresses many of these downsides.

Magnetometer surveys are the most common, they are widely available and offered by many survey companies. They work by detecting the magnetic signature of conductive (usually ferrous) objects on or below the seabed. However, they are not very precise, telling the user only that there is a conductive object reasonably close to the sensor, but not how far or deep. They also only penetrate 5 – 10’ (1.5 – 3m) below the mudline and give no indication of penetration depth or elevation. Magnetometers detect any conductive object, so are prone to false positives (for our purposes that is, objects they find might be relevant for other reasons). There is no indication of the size of shape of the object, and cannot distinguish between e.g. a crab trap, an anchor, or a pipeline, or between a shallow small object and a deep large object.

Sub-bottom profilers are an acoustic technology that uses sound energy to illuminate and map the subsurface. They are under active development and continue to improve for this purpose. A sound pulse is generated that travels through the seabed, reflecting off of discontinuities and objects in the soil. The strength and timing of these reflections gives an indication of the type of discontinuity and depth. Different types of profilers can be restricted to fairly shallow depths (less than 100’ 30m), or reach depths well beyond any navigation dredging. There is a tradeoff between depth and resolution in both the horizontal and vertical directions, although manufacturers advertise centimeter accuracy in typical dredging depth ranges. The main flaw of these is in interpretation of the results, as the ‘signature’ of a pipeline is similar to other embedded objects (false positives), or may be obscured by other reflective layers.

Physical probes are another option for pipelines in relatively shallow, soft sediments. While these have the advantage of providing accurate positions in all three dimensions, they require good knowledge of the general horizontal location of the pipe. It can be time consuming to find a pipe with a relatively small probe, particularly for small-diameter pipelines. The force that can be applied to the probe is of necessity limited to prevent damaging the pipe, so they do not penetrate well in stiff or dense sediments, and have limited depth range. They are subject to false positives, as the probe cannot distinguish between a pipeline of other object that blocks its path.

More exotic technologies are available to pipeline owners, including installed sensors on the pipeline and smart pigs, both of which require physical access to the pipeline or interrupting service. Electromagnetic line locators are used on shore, but are not suitable for a marine environment, and do not provide elevations.

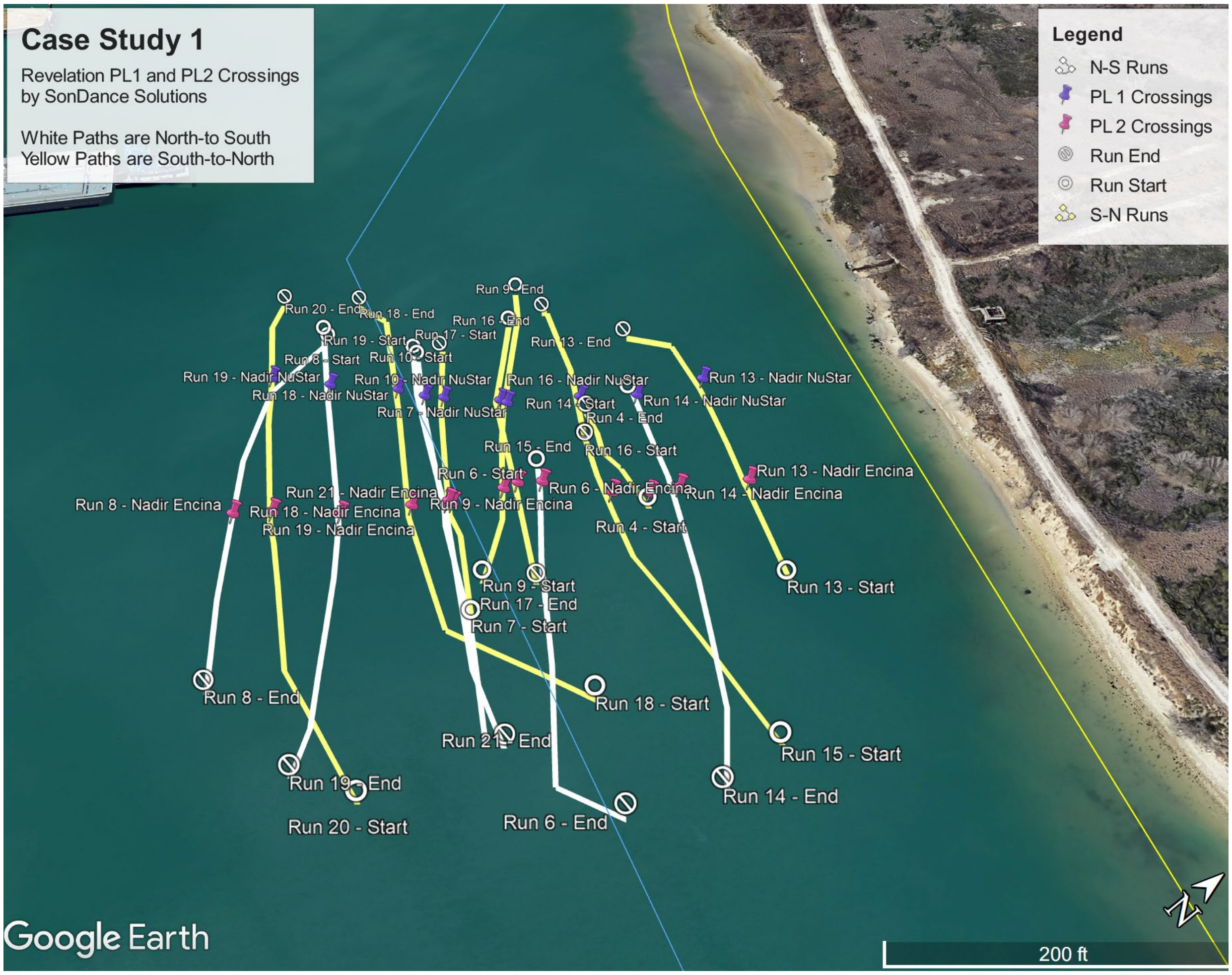
THE REVELATION TECHNOLOGY

The Revelation technology is a new method for locating buried subsurface pipelines for onshore and offshore. This innovation, developed by SonDance Solutions LLC, is patent-pending and currently utilized by dredgers, pipeline owners, marine survey companies, and infrastructure quality control companies. Revelation works by detecting the magneto-electric signature of a buried pipeline, against the backdrop of the Earth's ambient electro-magnetic field. In contrast to other methods, Revelation is specific to long conductive objects (so no false positives), and can detect pipelines in real time during the mapping survey (so can find and locate unknown pipelines). Post-processing after the survey utilizes proprietary algorithms to determine the target pipeline's distance from Revelation's custom manufactured sensors to ultimately yield the target's elevation**,** regardless of depth of cover. Pipeline diameters as small as 2" (50mm) have been verified via mechanical probing. Distances from the sensors to the target pipeline have been determined to 92' below the surface waterline under 40' of cover. Pipeline locations are determined in post-processing, and in theory provide the same 3-dimensional precision as the survey positioning system.

The Revelation sensor array is pulled behind a boat during the mapping survey, similar to many sub-bottom profilers. Typically a mapping survey starts with 2 - 3 initial profile lines to roughly locate any pipelines, followed by multiple passes over the pipeline to gather detailed data. Mapping runs generate a large amount of data that must be post-processed to develop precise locations, including elevations. The main disadvantage of this technology is ultra-sensitive sensors that can detect disturbances from nearby sources such as electrical equipment or rotating machinery.

Figure 5 shows a mapping survey conducted in a Gulf Coast port FOR a major dredging company that wanted verification of elevations of two buried pipelines in the dredge path. Revelation confirmed a 6" (150 mm) pipeline's elevation at 90' (27 M) would be clear (blue pins), and a second abandoned 10" (250 mm) pipeline near the 45' (14 m) project depth (red pins) would indeed be in the way of the dredging. The Revelation technology also detected an unknown strike-hazard located outside of the mapping runs in the southeast quadrant of the port. The dredger was notified and confirmed that this hazard was an abandoned sub-line.

Figure 5. Case Study 1



A second case study was conducted by a major pipeline operator in the Sabine River where a 30" (760mm) pipeline was exposed on the bank over 50' from the original placement, where deconstruction and reboring was required. The operator needed the exact positioning of this buried pipeline under the river and utilized three methods: (1) divers with mechanical probes, (2) PIG ILI data, (3) Revelation technology. Comparing all three methods' results, the operator accepted and chose the PIG ILI results with the Revelation technology's results for the deconstruction process.

A third case study occurred in Fresh Water Bayou, Louisiana (Figures 6 and 7). Two pipelines and an electric utility line were the targets for location confirmation. In this project's mapping process, the Revelation technology was tested with success on near-shore sites having previously determined mechanically probed pipeline elevations. The mapping process continued to complete the pipelines' entire navigable waterway profiles. Figure 7 shows the electric utility line, which was not verified by probing. The Revelation technology verified that the target utility line had been deconstructed and rebored 42' to the north of the original location, and provided a complete 3-D profile of the power line.

Figure 6. Pipeline profile after Verifying Mechanical Probe Elevations

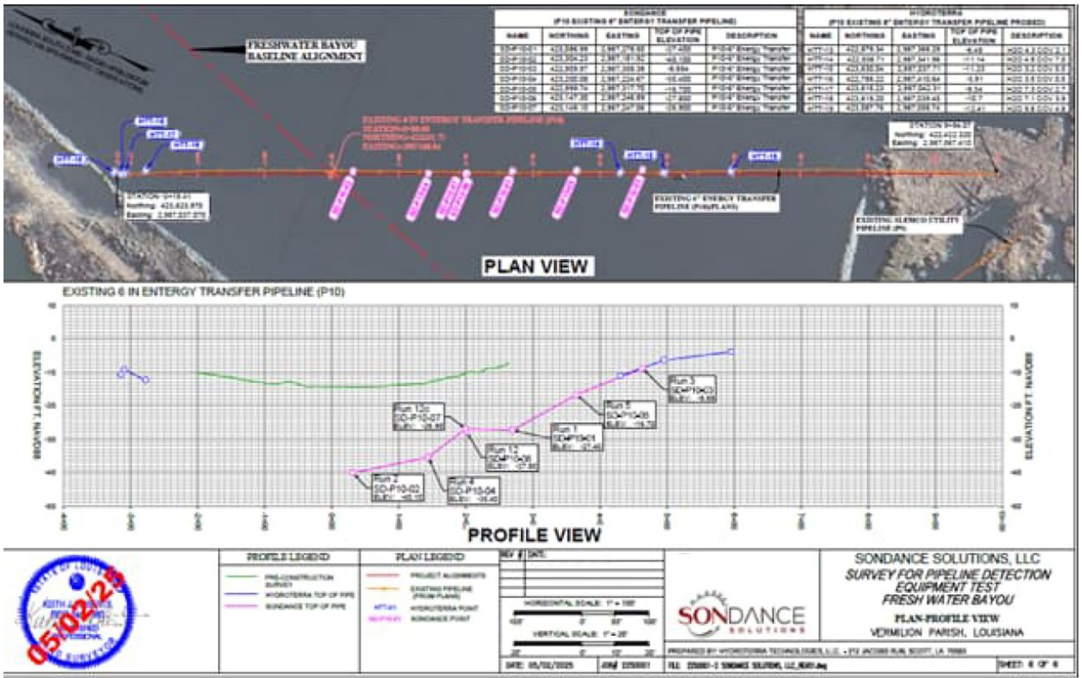
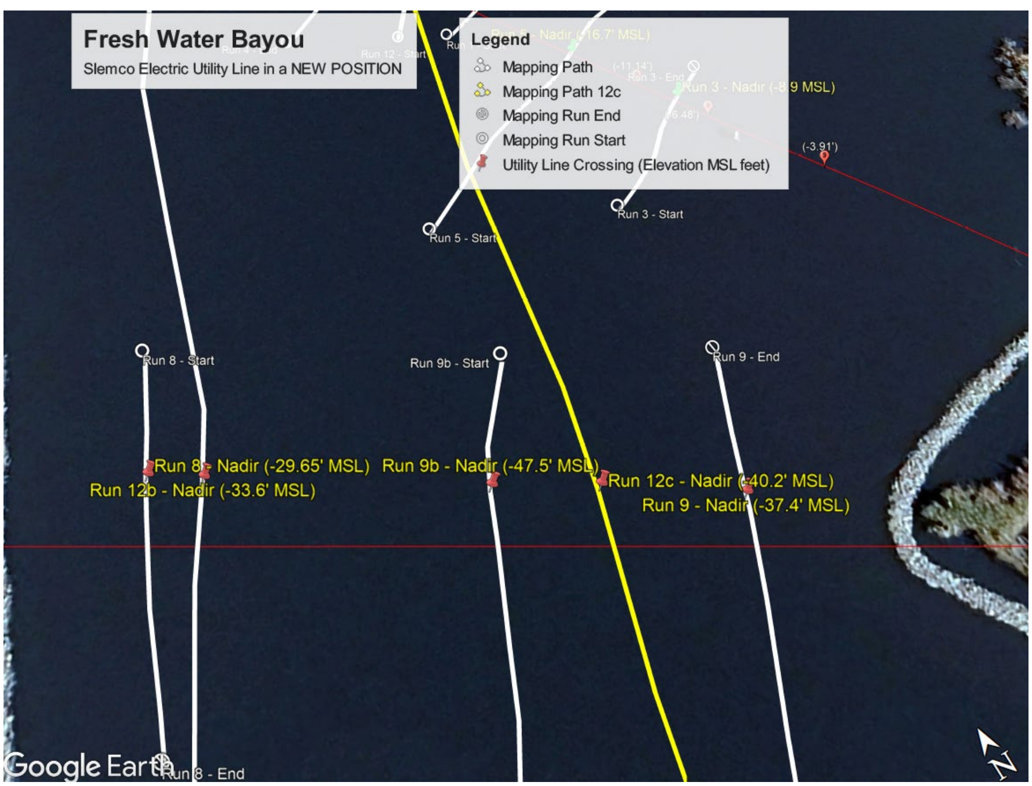


Figure 7. Utility line is Red Pins located 42' to north of original location (red line)



CONCLUSION

Natural Gas and oil pipelines in dredging areas pose an extreme hazard to Dredgers and other mariners, with pipeline strikes, associated injuries, and fatalities happening every year. The tools for finding existing pipelines are limited, particularly for decades-old pipelines. Once a pipeline in known, the precise location of the pipeline must be determined as documentation of the pipeline installation may be based on design rather than as-built information, and the pipeline may have moved in the meantime. Dredgers require at a minimum sub-meter locations of pipelines to write work plans and safely dredge over pipelines. However, precise locations are difficult to determine with existing technology. The patent-pending Revelation technology is an important new entrant in the detection field, finding known and unknown pipelines and locating them with high accuracy in all three dimensions.

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DATA AVAILABILITY

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We wish to thank our families for supporting us during this work and the development of Revelation.

NOMENCLATURE

All symbols should be defined in the text where the symbol is first mentioned. The author(s) may choose to also include a nomenclature table. If necessary, insert a two-column table and list symbol and units in one column and the definition in the second column.

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