USES AND INSTALLATION OF HDPE LINER TO REDUCE SOIL EROSION AND PREVENT WATER LOSS

By

Christopher Ray Topliff

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ABSTRACT

This thesis seeks to make an accurate account of research conducted on HDPE regarding slope and one soil stabilization process as well as the lining procedure. Through observations made on several ponds a 2:1 slope was determined to be the most effective at eliminating animal loss within a lined pond. The scrape marks left by self-extracting animals let to the determination that 40 mil HDPE was adequate for keeping wildlife from stepping through the liner. Included are all methods and tools needed to accurately accomplish the task of lining a pond or capture point, including welders of three different variations and the tools needed to cut and move HDPE lining material. For private construction, that is simply a best management practice that should be adhered to as it ensures positive results. Professional and government contracted work often has a regulatory requirement stating that all seams be tested to prove a good seal. During the lining process, environmental factors such as wind, climate and precipitation also play a big role due to their effect on the planning and implementation phases. Personnel safety is a major factor on any construction or job site, however HDPE and indeed geosynthetic liner installation in general presents its own unique risks and challenges. Also discussed are the different types of HDPE lining materials and their uses. During the initial stages of any lining project, surveying is perhaps the most critical early process undertaken. It is crucial that a well surveyed line be established so that a trench can be cut accurately, avoiding any low spots that would at best reduce the holding capacity and at worse create a spillway and erosion problem.

Approved:

[Chairman, Thesis Committee] [Date]

[Member, Thesis Committee] [Date]

[Member, Thesis Committee] [Date]

[Department Head/Direct Supervisor] [Date]

[Dean, Academic College] [Date]

[Dean, Graduate School] [Date]

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CHAPTER 1

HDPE INTRODUCTION AND HISTORY

INTRODUCTION

The average annual precipitation is 20.36” for Amarillo (NOAA, 2014), however in recent years the amount of rainfall has been as low as 7.01” (NOAA, 2015) and water conservation has become a high priority, especially during the traditionally hottest months of the year. While this trend may recently have shown signs of correcting itself, the fact remains that in recent years the High Plains has seen a negative departure from traditional rainfall averages as shown in Figure I-1 from the National Oceanic and Atmospheric Administration.

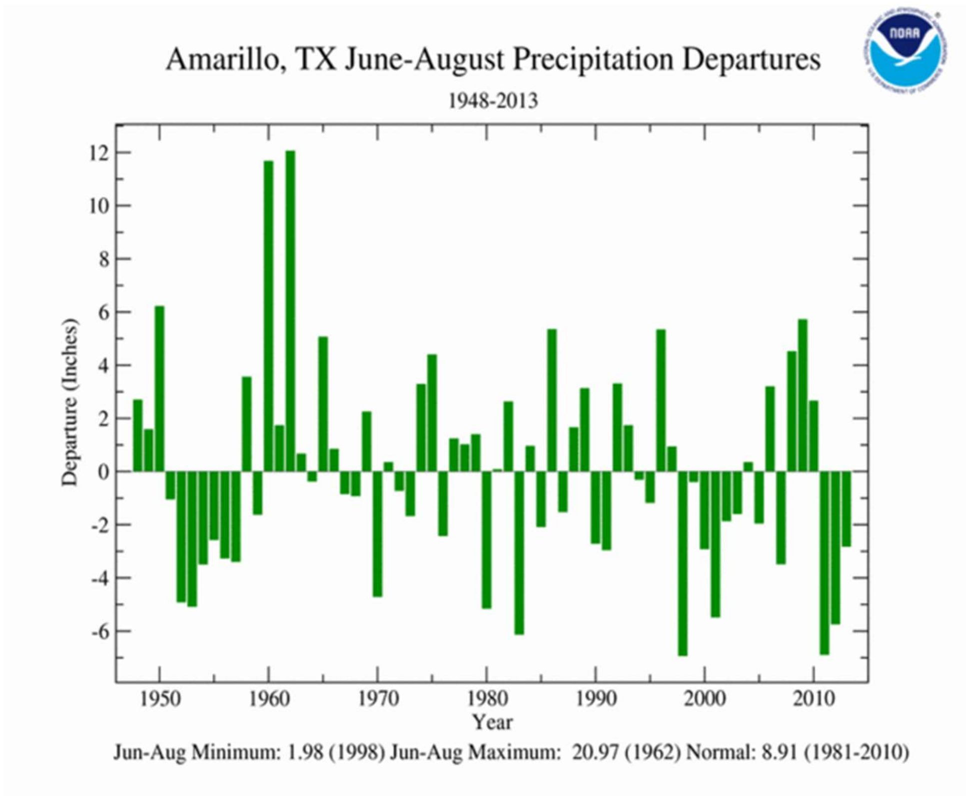

Figure I-1 Amarillo Summer Precipitation Record

(NOAA, 2013)

Many areas of the Texas panhandle that have historically had surface water have seen these reservoirs evaporate completely. In response to this trend the lining of the ponds and lakes with differing materials has become commonplace, not just for animal but also human consumption. Many of these areas have traditionally sandy soils. Through the use of geosynthetic liners water conservation practices can be put into effect even though the soils lack the necessary qualities to retain water. One such instance occurred on Bill Craft's farm located south of Clarendon, Texas and is documented in the "Case Studies" portion of this paper. These same technologies are also used within a multitude of industries including petroleum, agriculture, and construction. While many different technologies are used to line these ponds, including polyvinyl chloride (PVC), Ethylene Propylene Diene Monomer (EPDM), Low Density Polyethylene (LDPE), and numerous types of clay liners, the technology that stands out as the best for the rigors of usage and resistance to the elements is High Density Polyethylene also known as HDPE. The other liners listed have major flaws, PVC is highly susceptible to degradation by the UV radiation, EDPM can be chewed up by small mammals, and LDPE does not have the sheer strength of HDPE, which do not lend themselves well to exposure to the elements and wildlife. West Texas A&M has been installing and evaluating geosynthetic lining for 20 years. This previous experience in the impetus for the research conducted for this thesis. While HDPE has shown to be the most suited to the task out of the liners listed, it does have the drawback of requiring highly specialized equipment to install, namely the welders required to attach panels. Additionally, smooth HDPE liner on its own requires an incredibly lengthy period to reestablish vegetation due to the lack of soil retention common with this product. This can be remedied with the addition of a textured liner. One such textured liner was evaluated for this thesis. Furthermore, through the evaluation of the numerous ponds constructed during the research phase of this project, some of which can be found in the "Case Studies" portion of this paper, a slope of 2:1 was determined to be the most effective at allowing for wildlife to extract itself from a lined pond. This was accomplished by allowing a lined pond on Dr. Jim Roger's ranch to remain only partially filled for over a year. During this period animal tracks were studied for scraping of the liner and preference of slope for use. Local power company Excel Energy uses a 1:1 slope and has experienced numerous instances of animal drowning within its ponds. Through the slope evaluation it was also determined that 40 mil thickness HDPE was optimal for eliminating tearing of the liner by self-extricating wildlife. 20 and 30 mil both exhibited considerable breakthrough by animals while to employ a lining material thicker than 40 mil would be less cost efficient.

HDPE is an organic polymer derived from natural gas or crude oil. It is also a byproduct of gasoline production. It has many intrinsic resistances to both elemental and manmade degradants. UV radiation, chemical degradation, and puncture resistance make this geosynthetic lining material ideal for many different situations. Add to this the many different forms that HDPE is available in and it becomes the best choice for many different applications. These variations include both smooth and textured styles, different colors to match the needs of the project, as well as soil stabilizing varieties that allow for the collection and holding of bedding material for grasses or other native plants. Just as with any construction material, there are considerations that need to be made when working with HDPE. Weather plays a very large factor due to the extreme effects it can have on HDPE liner. Heat, cold, rain and wind all play very large parts when planning and implementing a lining project.

Construction of an HDPE liner takes quite a few skills and specialized tools. A correct survey of the site is of extreme importance. An incorrect survey will completely throw off a project in ways that may not become obvious until after a pond has been filled. After surveying and trenching is completed the specialized tools of the trade come into play. These include hand, wedge and extrusion welders, as well as many quality control and assurance tools. All of these require special maintenance and care in their use. Each has its own strengths and weaknesses and the right welder must be used for each unique situation. In addition to these welders there are additional tools that may not be required but are extremely helpful when cutting and moving HDPE. Placing and installing liner provides its own challenges and there are techniques specific to geosynthetic liners that allows for ease of installation. After installation trenching is necessary to complete the construction. Once installed liners must be then tested, often the standards to which they are tested are dictated by the project itself. If the liner must meet regulatory compliance there are additional testing steps that must be taken for these projects.

For examples of different construction types multiple case studies have been added to this document to show the challenges and techniques used for each situation encountered. Additionally a study was conducted to determine the efficacy of soil stabilizing liners at retaining sediment for plant growth and beautification of a site.

THE MANUFACTURE OF POLYETHYLENE

Polyethylene is produced through the modification of natural gas or the catalytic cracking of crude oil. This substance is then taken to a polymerization plant where under the correct conditions of temperature, pressure and catalysts the ethylene monomers link together to form chains. The difference in pressure produces either high density polyethylene (HDPE) or low density polyethylene (LDPE), with “low pressure” process producing the former and “high pressure” producing the latter.

The process for the production of LDPE was discovered by accident in the 1930’s while HDPE was likewise discovered accidentally in 1952. The major difference between the two processes was the inclusion of an aluminum catalyst created by German and Italian scientists, which allowed for the polymerization reaction to take place at much lower pressures as is shown in Figures 1-1 and 1-2. This new type of polyethylene was found to be much stiffer than its low density counterpart with much greater strength.

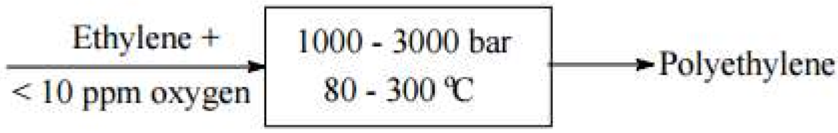

Figure 1-1 High Pressure Polymerization Process
(Lepoutre, n.d.)

Figure 1-2 Low Pressure Process with Aluminum Catalyst
(Lepoutre, n.d.)

Whatever type of polyethylene produced it usually is initially available in a pellet form which can then be further refined to a manufacturers specifications. These pellets are then molded into many different products. For the manufacture of geosynthetic liners the pellets are put through a process known as blown film extraction. The pellets are pushed through an Extruder Screw as seen in Figure 1-4, where the pellets are put under pressure and heat then extruded out into the Film Extruder (Figure 1-5) to complete the film blowing process. This film is then collected on rolls to be used at its destination.

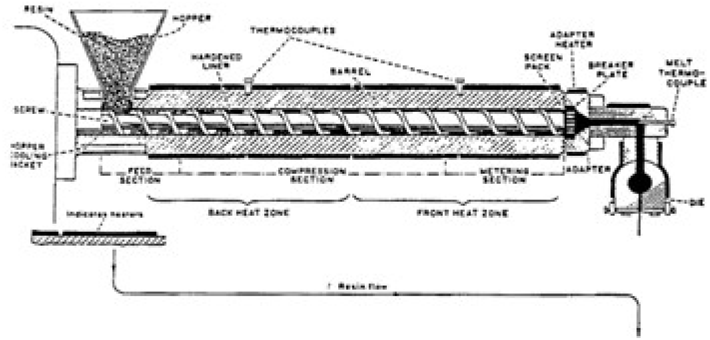

Figure 1-4 Cross Section of Extruder Screw

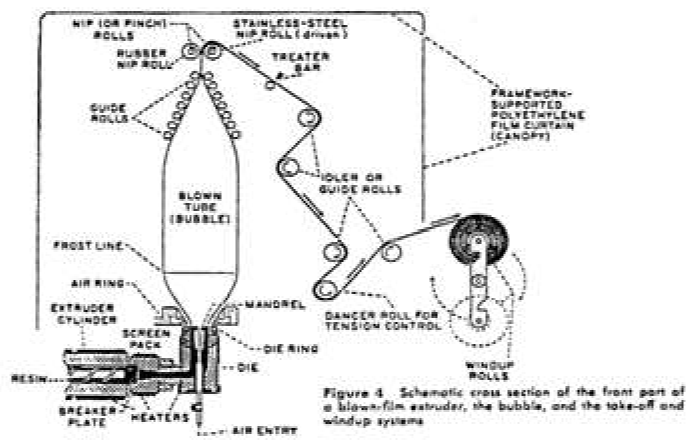

Figure 1-5 Cross Section of Film Extruder

Environmental and Economic Considerations

‘In the United States, approximately 13%’ (Environmental Protection Agency, 2016) by weight of the waste stream is due to plastics. Polyethylene, of course, is only one of the many plastics contributing to this figure. HDPE is one of the most recycled plastics as it can be reheated and turned back into pellets by the manufacturer. However, this process can be time consuming and costly as all the plastics must be moved to a manufacturing facility and any contaminants that remain within the plastic can weaken the final product. Reclaimed plastics cannot, under Food and Drug Administration regulations, come into contact with food which somewhat limits the use of recycled materials.

CHAPTER 2

CHARACTERISTICS OF HDPE

UV Resistance

"[HDPE comes] in a wide variety of colors or pigments. The choice of which color to use will generally depend on one, or a combination of, the following; cosmetics, customer requirements, and application or stored medium. One color that has been continuously specified for higher end applications, such as outside storage of sodium hypochlorite, is black. This color is usually achieved by dry blending carbon black with the primary powder resin prior to molding.

Carbon black (CB) is a form of nearly pure, elemental carbon. It differs in molecular structure from the more common forms of elemental carbon – graphite and diamond – and therefore also differs in physical properties. Carbon black is softer than either graphite or diamond and is intensely black in color, although the color does vary slightly depending on the manner in which it is made, the contaminants that are present, and the particle size. Carbon black is manufactured by burning hydrocarbon fuels in a controlled manner with insufficient oxygen for complete combustion. It is like the soot that forms around the top of a glass chimney of a kerosene lantern. In fact, kerosene is the most common hydrocarbon used in the manufacture of carbon black.

Carbon black has many applications in plastics. It is used as a pigment, conductive filler material, particulate reinforcement, and ultraviolet light (UV) absorber. In rotomolded tanks CB is used both as a pigment and as an ultraviolet light absorber. Carbon black has proven to be the standard against which all other pigments, such as forest green and white, and other UV absorbers are compared.

2- Weathering of Plastics: All materials absorb sunlight radiation – it's what makes them heat up in the sunshine. While the effect of sunlight is minimal beyond just simple heating in many materials, some other materials are actually degraded by sunlight. Most plastics are in this latter group. Studies of the degradation of plastics by sunlight have shown that sunlight is a spectrum of frequencies and that the most destructive frequencies for plastics are those at the higher energy end of sunlight – in the ultraviolet range of the spectrum. The absorbed UV light breaks, or cleaves, the weak chemical bonds or molecular chains of the polymer material. This leads to shorter chains, which in turn causes the plastic material to become more brittle. This process is called, photodegradation, and it leads to loss of mechanical properties and/or discoloration, cracking, fading, and chalking. In other words photodegradation leads to weathering of plastics [as shown in Figure 2-1].

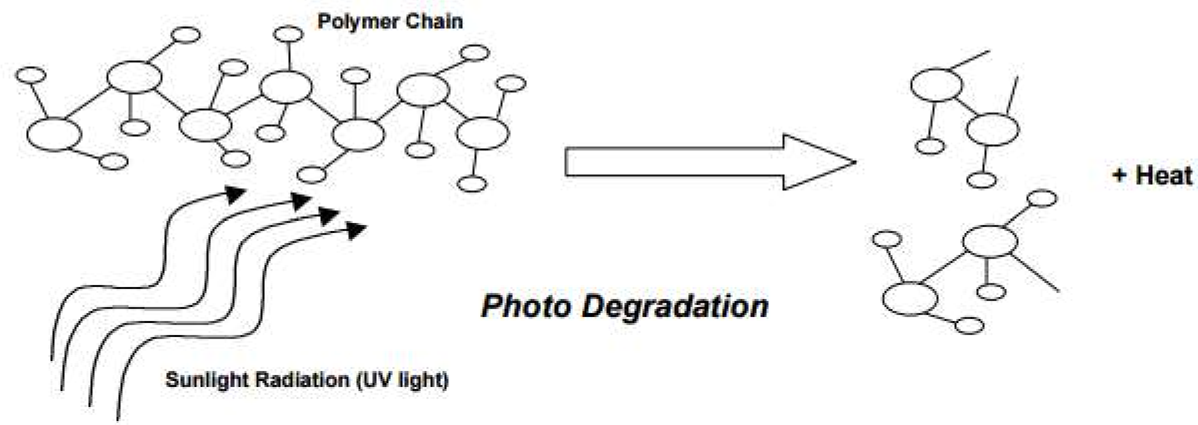

Figure 2-1 Photodegradation of Polymer Chains

3- UV Stabilizers: In order to protect outdoor plastic products from the damaging UV light, the plastic needs to be shielded from these harmful rays. Of course shielding from sunlight using some umbrella-like shading system is often impractical and could be very expensive. Therefore, a simple, inexpensive method is desirable and that system has been found with internal stabilizers. These stabilizers, an example of which is carbon black, are added to the plastic before molding. The stabilizers absorb or screen out the damaging UV light and transform the energy of the rays, the UV light, into heat, which is dissipated harmlessly throughout the product.

The typical failure point for general purpose is when the property of interest, in this case tensile strength, falls below 50% retention. Research and experimental data has shown that the natural material (no color added) falls below 50% in less than 6 months exposure. This can be compared to carbon black which shows that even after 30 months exposure, the product is still well above the 90% retention value, see figure 1. This clearly illustrates the effectiveness of carbon black as an excellent UV stabilizer.

Most of these colorants would also have a UV screening agent added to assist in protecting the plastic material. While these UV screening agents are quite effective, they can be costly and are usually less effective than carbon black by itself.

Even though black tanks tend to have a higher overall temperature than light or white tanks, the UV protection from carbon black, [as shown in Figure 2-2] outweighs any temperature effects, as demonstrated by the superior retention of properties upon exposure. The benefits gained in extending the life of the tank and reducing the possibility of catastrophic failure due to the degradation of the plastic, make carbon black the preferred pigment, especially for higher-end applications, such as the storage of harsh chemicals like sodium hypochlorite.

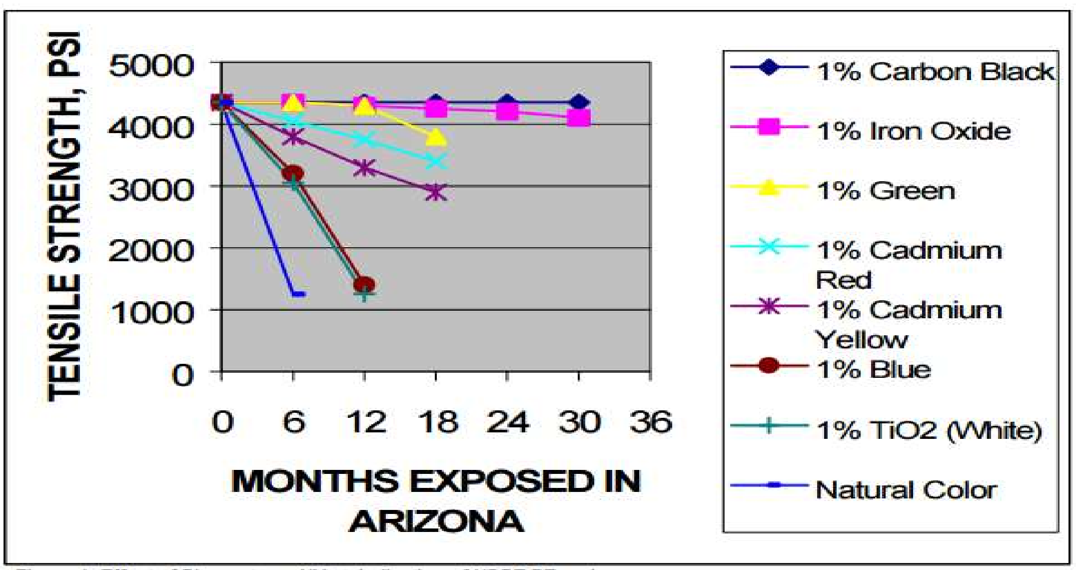

Figure 2-2 Effect of Pigments on UV Stabilization of HDPE PE Resins
(Team Innovation, 2003)

4- UV Index: One method to gauge or quantify a UV stabilizer's ability to prohibit UV degradation is to give it an UV-X index value or rating. The larger the X value, the better the UV protection is and the longer the plastic material can be exposed to UV light without significant loss in its mechanical properties. To determine the UV index, the plastic product/material is exposed to simulated environmental conditions in a Weather-OMeter. When the chosen mechanical property for evaluating the performance, elongation at break or tensile strength, reaches 50%, the X value is established and is usually expressed as a multiple of 1000 hours of exposure. For example, a material having an X value of 8, UV-8, means that it withstood 8000 hours of exposure to UV light before the elongation at break was reduced to 50% of the original value." (Team Innovation, Why Some Rotomolded Tanks are Black in Color) Figure 2-3 shows the outstanding UV resistance of HDPE. In the Figure it can be seen that even after 28 years in direct sunlight researchers have seen no real degradation of the material.

Type	Specification	Predicted Lifetime in Texas, USA
HDPE-1	GRI-GM13	>28 years (Incubation ongoing)
LLDPEE-1	GRI-GM17	>28 years (Incubation ongoing)
EPDM-1	GRI-GM21	>20 years (Incubation ongoing)
PE-R-1	GRI-GM22	≈17 years (reached halflife)
fPP-2	GRI-GM18 (temp. susp.)	>27 years (Incubation ongoing)
fPP-3	GRI-GM18 (temp. susp.)	>17 years (Incubation ongoing)

Figure 2-3 Predicted Lifetime of Material Exposed to Texas Sun

(Peggs, 2008)

Chemical Resistance

Due to the nature of HDPE and its chemical resistant properties it has become very popular for industrial and waste disposal applications. The chemical resistance of HDPE is such that it is considered chemically inert. When exposed to solvents it neither swells nor dissolves. (Palanna, 2009) This makes it an excellent lining material in chemical and hazardous waste sites. A list of chemicals and their reactions with HDPE can be found in the appendix (Table A-1)

HDPE's inertness also means that it does not take up any chemicals in the manufacturing process. Because of this, the material also does not emit any chemicals during its lifespan. Due to this inertness the FDA has even approved HDPE for food packaging and is used to package many everyday food products perhaps the most obvious of which is milk cartons. This property also makes HDPE a viable lining material for what could be considered delicate eco- systems such as man-made wetlands. Projects meant for fish, birds and other aquatic organisms that are highly susceptible to chemical toxicities can be accomplished with HDPE due to this chemically inert property. This is best shown by the ability of single celled aquatic organisms to thrive in ponds that have been constructed using these materials. As algae are often the primary producer in these biomes this allows other consumers farther up the food chain to exist and thrive. Without these primary producers, self-sustaining ecosystems could not develop in these constructed wetlands.

Puncture Resistance

Chemical resistance is of great importance, but of equal importance is puncture resistance. Many of the soils being lined with this material are highly porous thus any large puncture can easily drain an otherwise sound pond. While the particular degree of puncture resistance of a selected material differs depending upon the thickness; basic 40 mil HDPE will resist puncture from deer hooves and, depending upon how compacted the base soil beneath the liner, cattle will find it difficult to puncture as well. This resistance allows livestock and wildlife to utilize a lined structure without the need to further reinforce the material closest to the shoreline. The chances of an animal damaging the liner while trying to extract themselves is highly unlikely due to how resistant the material is to puncture.

Water Conservation

An HDPE lined pond does not have a higher evaporation rate than any other lined pond. The evaporation rate seen is around one quarter to on half inch per day. This number can fluctuate with temperature and wave action. Wave action will slightly increase the evaporation rate to closer to one half inch due to the increased surface area of the water.

CHAPTER 3

TYPES OF HDPE LINER

HDPE liner comes in many different varieties so as to best suit any project. There are variations in thickness, color, texture as well as many types of specialized liners for soil erosion control.

There are many different thicknesses of HDPE liner ranging in from 20 to 120 mil. One mil is equal to .001 inches. Table 3-1 extrapolates this. The proper mil thickness should be selected during the planning stage of any project and is dependent upon the stresses that will be experienced upon the liner. 40 mil thickness liner is the most commonly used for unregulated projects as it offers the greatest overall balance between strength and ease of manipulation while still providing the same UV protection as thicker liners. This determination was made by evaluation of Dr. Jim Roger's pond (Case Study No. 3) and ponds lined previously with thicknesses of liner less than 40 mil. After completion, the pond was left only partially filled and a study was made of the scuff and scrape marks left on the liner by animals escaping. While on the ponds with thinner liner punctures would often occur during the extrication process, no such punctures were noted on Dr. Roger's pond. While thicker liners do exist, thicknesses greater than 40 mil are more expensive and have puncture resistances unnecessary to the task. However, if the project is regulated by a governmental entity such as the EPA, TCEQ, or the Railroad Commission these entities often have regulations stating the thickness of the liner to be used for different purposes. An example of this is found in the EPA guidance for non-hazardous waste landfills which states, "... HDPE liners...should have a minimum thickness of 60 mil. These recommended minimum thicknesses ensure that the liner material will withstand the stress of construction and the weight load of the waste, and allow adequate seaming to bind separate geomembrane panels. Reducing the potential for tearing or puncture, through proper construction and quality control, is essential for a geomembrane to perform effectively". (Environmental Protection Agency, 1999)

Mil(s)	**Inches**	**Millimeters**
10	0.01	0.254
20	0.02	0.508
30	0.03	0.762
40	0.04	1.016
60	0.06	1.524
80	0.08	2.032
100	0.1	2.54
120	0.12	3.048

Table 3-1 Mil Thickness Table

Specialty Liners

Manufacturers also produce specialty types of liner that are designed for use in certain instances. These specialty liners can be many different colors as well as textures. The use of colored liners can be a purely aesthetic choice or a functional one. Textured liner will increase friction in projects where the slickness of traditional HDPE would be a detriment. Soil stabilizers are another common type of specialty liner that are used when retention of soil that would otherwise erode away is of concern.

Colored Liner

While black is by far the most common color for any HDPE liner it does come in various colors. While many different colors of HDPE are used in numerous household products, for geosynthetics green and white are the most common. The use of green liner is usually an aesthetic choice allowing for any exposed liner to blend in more easily with the landscape as shown in the canal lining project in Figure 3-2. White HDPE reflects more UV radiation than black liner but it also increases the ability to detect any damage to the lining. This is particularly useful in projects such as the dam shown in Figure 3-3 where cuts in the liner could prove very damaging.

Figure 3-2 Green HDPE Liner
(Comanco Environmental Services, 2013)

Figure 3-3 White HDPE Liner
(Solmax, 2013)

Textured Liner

Smooth HDPE is an excellent choice for gently sloping ponds and catches; however it does create a problem if the angle of the embankment is too steep. In these situations textured liners are the industry standard. Not only do they allow for any wildlife to extract themselves from a manmade wetland, in industrial applications where steep sides are common they are a must. If the sides of an embankment have a ratio of 6:1 (Six horizontal units to one vertical) textured lining material is used to increase friction between the liner and the embankment making slippage less likely. Textured liners also come mainly in black, green and white, and can be had is single and double sided texturing. Figure 3-4 shows the aggressiveness of this texturing.

Figure 3-4 Textured HDPE Liner
(Huatao Group, 2011)

Soil Stabilizer Liner

Soil stabilizing liners are called upon to reduce soil erosion. Usually these liners have a cell type pattern that allows for soil to remain trapped within these cells promoting the growth of plants on top of them. They are used often on steep slopes and along the edges of water bodies. Some of these liners even have mats of unwoven HDPE fibers attached to the cell bodies to promote additional holding capabilities as with the example in Figure 3-5. This type of soil stabilizing liner is of the type used for the research conducted in this paper. These cells can vary greatly and can be simple grid patterns less than a centimeter thick to large pockets to hold more soil. These large pockets can vary greatly in size and depth however Figure 3-6 gives a common example.

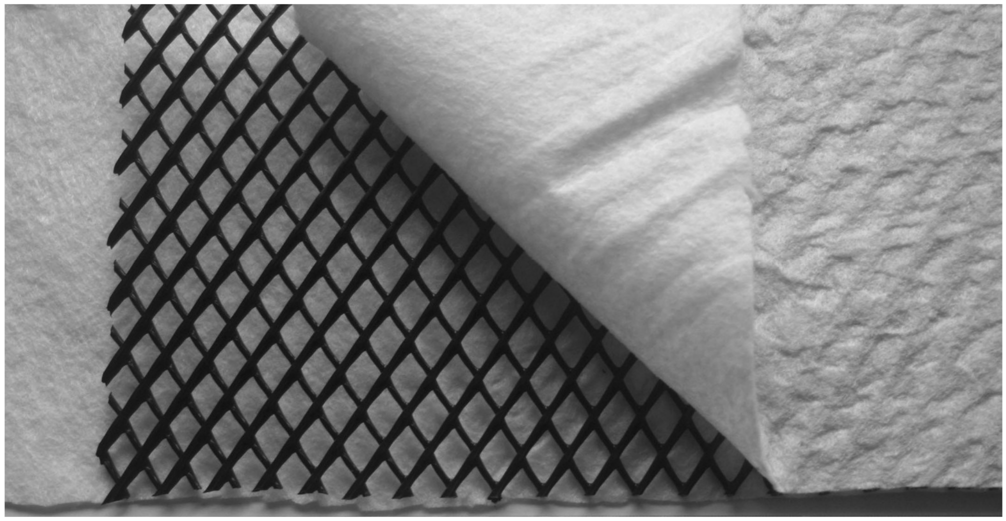

Figure 3-5 Soil Stabilizer HDPE Liner with Unwoven HDPE Fabric Layers
(Müller, Saathoff, 2015)

Figure 3-6 Soil Stabilizer HDPE Liner
(Contech, n.d.)

CHAPTER 4

LINING CONDITIONS AND CONSIDERATIONS

As with any construction project weather and construction type play a very crucial role in the planning and implementation phases.

Cold

As the temperature drops HDPE liner will shrink. Liner that has been trenched on both sides will actually be lifted off of the ground as much as one to one and a half feet. HDPE is also less malleable when it is cold so it has a tendency to roll back up after coming off of the roll. Welding may take longer and the heating elements of the hand welder and track welder may need to be heated to a higher degree.

Heat

During hot weather and exposure to direct sunlight HDPE is effected in a number of different ways. It will become more malleable, however with this the heat needed to create a weld is much less. This can lead to burn throughs much easier and greater care must be taken during the welding process. Due to the carbon black imbedded within the HDPE it is very resistant to UV degradation however this also means that it absorbs heat much more readily. This be as much as 40 degrees higher that the ambient temperature. Knee pads and gloves are recommended for any workers that will be kneeling on and handling the liner for extended periods as it can cause first degree burns resulting in blistering of the skin.

Wind

Wind can be the most challenging environmental condition that exists when working with geosynthetic liners in general. Large surface areas and the light weight of the material make them very easily lifted by gusts of wind. WARNING: If a gust of wind does begin to take a piece of lining material the safest practice is just to let it go. There are two reasons for this: First with no structure to pull against the material will likely fold in on itself and will not go very far. Second and most important a significantly large piece of liner can pull a 150 lb man into the air and carry him for 5 to 10 yards. If this is off of the raised edge of a pond the fall could result in serious injury or death. Large numbers of sandbags or equally heavy weights of at least 30 lbs each should be on hand to weigh down liner that has not been anchored into a trench yet.

Rain

Due to the fact that the bottom of a pond or containment area must be dry prior to being lined a significant rain event will put a project on hold. An exception to this rule is if the liner has been prefabricated. In that event driving on the bottom of the pond or on the liner after it has been placed is highly advised against as this can create ruts in the pond bottom which can cause stress points on the liner if the ruts remain after the pond has been filled.

Electrical Safety

Depending on the type of welder that is needed for the task, any jobsite can have live 120v and 240v lines stretched across it. Extreme caution must be taken to avoid electrical shock or electrocution when working with electricity within close proximity to water. It is a best management practice during any welding task to designate someone to keep watch over any cords in use. This will also help the welder accomplish his task with greater ease as he is not adding to his work load by keeping watch on the cables or dragging them with him.

CHAPTER 5

SURVEYING

Surveying

While surveying is its own occupation, and a surveying firm could certainly be hired to complete marking the edges of a proposed pond this can easily be accomplished by the lining crew provided they have acquired the right equipment for the task. Surveying, though not a prohibitively hard task, is a crucial step in mapping out the line that the anchor trench will follow. If not completed correctly the trench can dip below its optimal position and either restrict what would have otherwise been greater capacity and cause liner to show around the rest of the bank, or cause a point where water can spill over where it was not intended. The severity of which the surveying team performs their job is also dependent upon the client and task. If a pond is meant for beautification of a property then showing liner could be considered an eyesore and the build rejected by the client. If the properties of the soil that make up the base of the pond are such that spillage over a low point could compromise the structural integrity of the pond then correct measurements are a must. However, if the pond is simply a catch or secondary containment that is not a permanent structure then the surveying may not need to be as precise as the pond will more than likely be built larger than needed and less care is taken in the appearance of the finished product. If this is the case the pond needs to be oversized. Whatever the construction type, care must be taken in this stage to assure proper placement of the anchor trench. While patching liner or adding more is possible, raising the shoreline to correct improper surveying requires a great deal of effort especially after the pond has been filled. Taking extra time during the surveying and final grading process is encouraged as it will save a great deal of time as the project progresses. Incorrect surveying in the initial stages of a project could translate to variations of up to a few feet in the location of the anchor trench. There are four basic tools a crew will need to complete the surveying of a pond correctly.

Surveying Tools

Transit

There are many companies that make these devices and prices can range from a couple of hundred dollars to a couple of thousand depending upon the model. For the purposes of lining a pond, however, these more expensive transits are not required as they are equipped with features that are of little use is this type of surveying. A simple transit will suffice for surveying in an anchor trench. While the transit you have purchased may not look identical to the one pictured in Figure 5-1 the basic controls will be the same or similar.

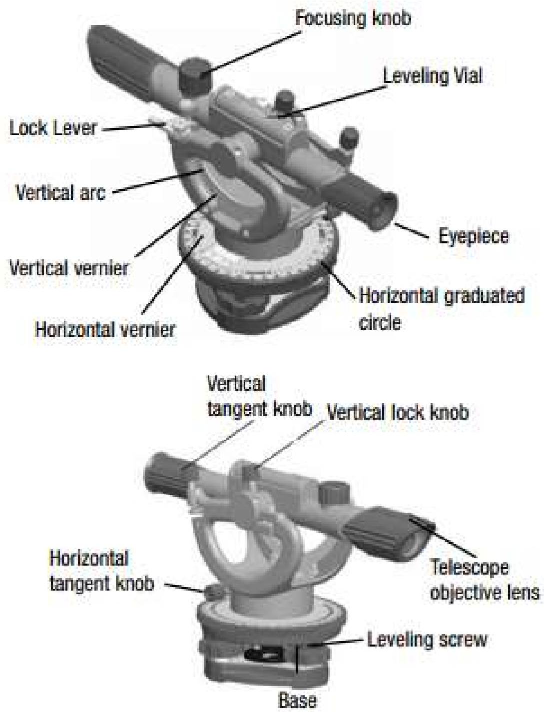

Figure 5-1 Diagram of Surveying Transit
(Johnson Level, 2010)

Surveying Tripod

This is the stand that the transit will be attached to and provide a platform from which to operate it. The most common process for attaching a transit to a tripod is to screw the transit onto the tripod. When erected it is paramount to the operation that the tripod be set up correctly and remain level throughout the process. The three most common materials that are used to construct surveying tripods are wood, aluminum, and fiberglass. The material selected makes little difference to the end result during this process due to the short duration of surveying for these projects. However, there are slight differences in the materials. According to engineersupply.com: "Wood Tripods - Of all materials, wood is the most stable and less susceptible to expansion when exposed to the warming effects of the sun. Wooden tripods also have excellent vibration damping characteristics. Aluminum Tripods - Aluminum is completely resistant to conditions of high humidity. Aluminum tripods are also light-weight, providing convenience when setups are often changed. Being a metal, aluminum can expand and contract through temperature changes. To maintain accuracy aluminum tripods should only be used for setups of short duration such as no longer than one to two hours. Fiberglass Tripods - Fiberglass is resistant to the elements and provides a long lasting tripod. As a tripod, fiberglass material remains flexible and can deform over a very long setup time." (Engineering Supply, n.d.)

Surveying/Stadia Rod

The surveying rod is the instrument traditionally ran by the Chainman. The name for the position comes from the fact that this individual originally would carry a 66 foot long chain. The surveying rod has stadia lines that mark off in feet the different elevations. These stadia are measured in tenths of feet NOT inches. The rod is viewed through the site of the transit to determine the elevation. These rods are generally made from fiberglass, and while not particularly fragile great care must be taken when handling these rods. If sand or dirt find their way between the sliding portions of the rod they can abrade the paint off of the rod obscuring the numbers. For the purposes of determining the location of the trench the Chainman will use the surveying rod to determine the points along the shore that are the same elevation as the original point.

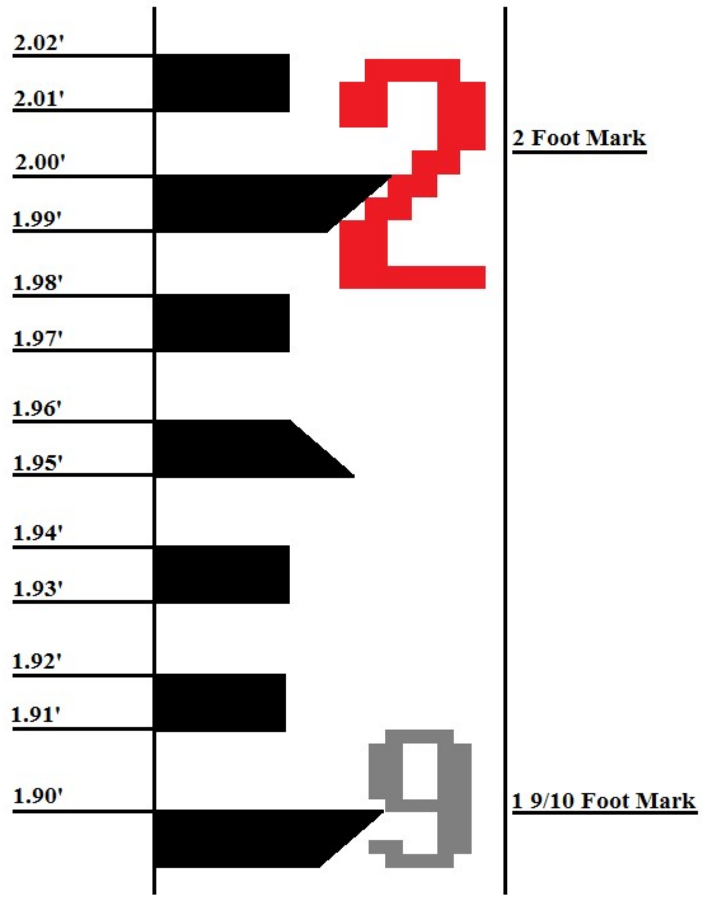

Figure 5-2 Stadia Rod Diagram
Created in Microsoft Paint 2009

Paint Lines and Flags

To indicate to the operator of the trencher the location of the anchor trench a paint line on the ground works best. The paint line allows the operator to see at a glance if he is on target or not. In lieu of paint ordinary marker flags can be used to determine the line that the trench will take around the pond. These can be obtained at most hardware stores. These flags are inserted into the ground right at the base or the surveying rod. They are used as markers for the man cutting the trench to follow. Ordinary marker flags are used instead of more substantial marking devices, like rebar for instance, due to cost savings and the fact that they may be caught up by the trenching machine if such a device is in use. While flags can work it has been my experience that operators have a hard time seeing them as they trench backwards. Additionally there is no reference between flags. This issue can cause major problems with trench location and an erroneously dug trench can lead to a great deal of corrective dirt work after completion of lining as was the case with Dr. Jim Rogers pond, which was off by a foot due to incorrect trenching.

Procedure

The first step is to find an area along the shore line of the pond that is relatively flat. This is the area on which the tripod and transit will be erected. Most transits have a set of bubble levels on their bases indicating the plumbness of both the X and Z axis. Get these levels as close to plumb as possible by adjusting the length of the legs of the tripod. To fine tune the level of the transit atop the tripod most transits are equipped with knobs on their bases. These knobs are spun to get the bubble levels to read plumb as shown in Figure 5-3.

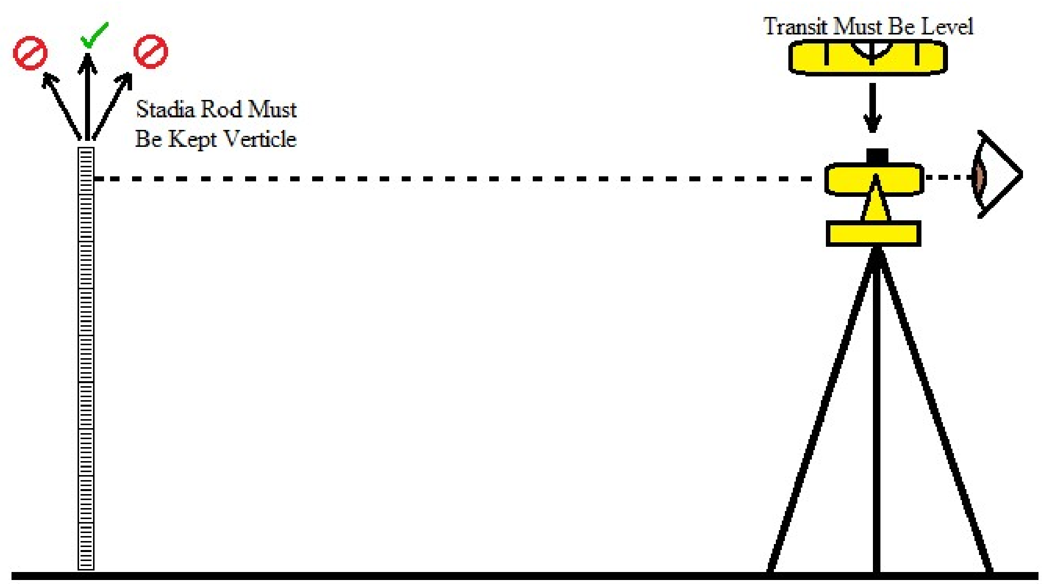

Figure 5-3 Correct Positioning and Usage of Transit and Stadia Rod
Created in Microsoft Paint 2009

1. Once the transit and tripod are level and secure the crew should decide where they believe is the highest point that needs to be lined. The highest point that needs to be lined in a pond is the lowest point (That is NOT the spillway if one is included in the construction design) that will be considered shoreline as lining the rest of the shoreline above this point serves no purpose. This can also be referred to as the high-water mark as water cannot theoretically go above this point, however water will go where it wants. Figures 5-4 and 5-5 provide a demonstration of this with a cross sectional and topographical view.

2. The Chainman will touch the base of the rod to determined high point while pointing the numbers on the rod at the Chief and holding it perfectly vertical. The Chief will site through the transit and determine the number that lines up in the cross-hair of the site. This number and corresponding line on the rod will be the point of reference that the rest of the trench line is measured from.

3. After this number is recorded by the Chief a flag is placed at the base of the rod and the Chainman will move a few paces left or right. The number of paces is largely dictated by the shape of the pond. A straight section of trench can have greater spacing between flag points than a section that includes curves. The more flags placed the greater the accuracy of the trench when it is cut.

4. When the Chainman gets to the next flag position he will again point the numbers on the rod at the Chief. When he sites through the transit this time the number that lines up with the crosshair of the transit will most likely be different. If the number in the crosshair is lower the Chainman needs to move downslope until the number in the crosshair matches the original. The opposite is true if the number is higher. The Chainman will move upslope

in the instance until the original number is met. When the desired number is showing in the crosshair place another flag at the base of the rod.

5. Repeat until the entire trench line has been marked with flags. After flagging is completed connect each flag with a paint line if paint is available. NOTE: If a lower high-water mark is found in the process of flagging the trench line this will be the new reference point and any flag placed up to that point will need to be remeasured.

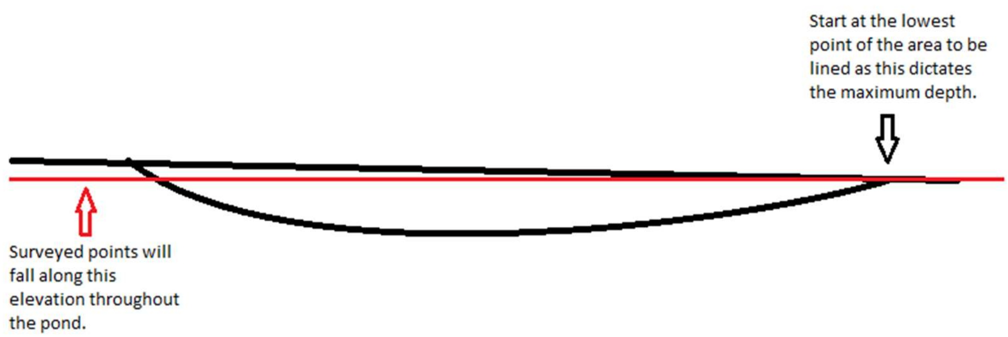

Figure 5-4 Cross Sectional View of High Water Mark
Created in Microsoft Paint 2009

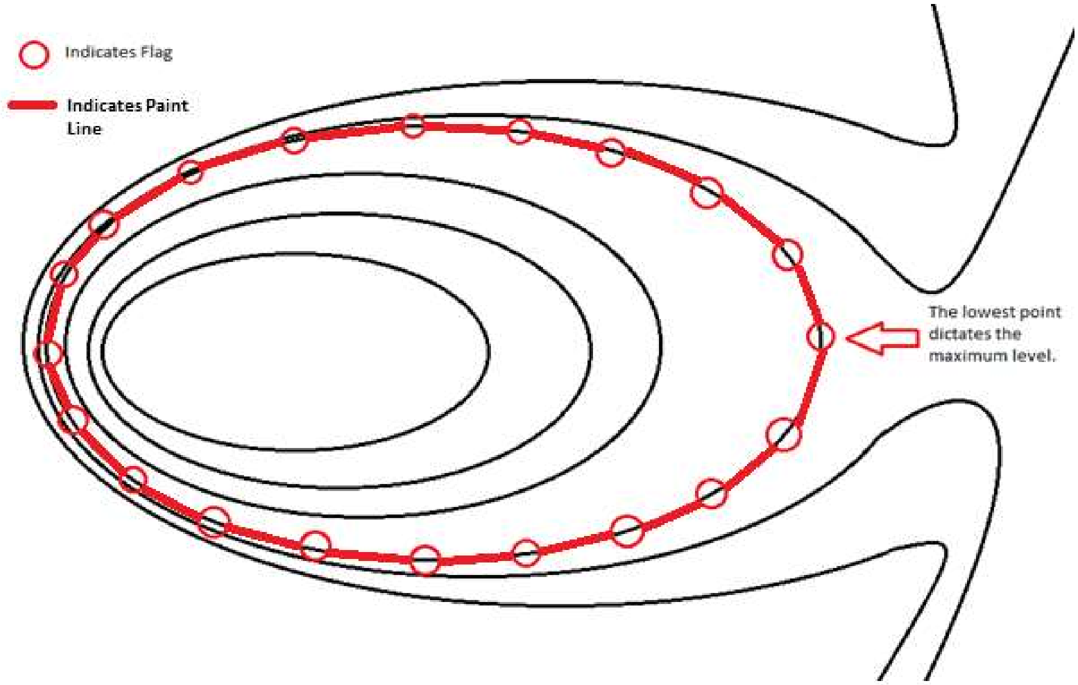

Figure 5-5 Proper Flag Placement Topographical View
Created in Microsoft Paint 2009

CHAPTER 6

TOOLS AND METHODS FOR HDPE LINING

There are a number of different methods for installing liner as well as a number of different and slightly specialized tools that, while not necessary, increase the efficiency and ease with which it can be accomplished. This section will go over these methods and tools and provide instruction on how to best employ them.

Tools

During the lining process three tools will be of great use. A pair of locking pliers designed to hold sheet metal, a disposable razor knife with hook blades, and a measuring device.

The sheet metal pliers allow for individuals to maintain a good purchase on the material as most HDPE lining is completely untextured. A pair should be supplied to every member of the crew as the material is extremely heavy and will require quite a few people if it being placed by hand. The large flat gripping surface, easily seen in Figure 6-1, of the pliers allows for a positive grip on the material. It should be mentioned that proper tension should be set on the screw. HDPE provides so little friction that even a slight lack of pressure from the pliers almost guarantees the pliers will slip off. The amount of force required to move large pieces of liner means that this can quickly become a personnel safety issue. If the pliers slip while the liner is being moved it can send a workman tumbling.

Figure 6-1 Sheet Metal Pliers
(RONA Home and Garden, n.d.)

The use of hook blade razor, like those in Figure 6-2, allow for faster and straighter cuts in the material as the bladed can be hooked into the material and then pulled. This type of blade also allows cutting a piece of liner without inadvertently cutting any liner beneath it. Only one or two of these knives is needed; however a good supply of blades is recommended as they will wear out quickly during this process. They are also quite useful for trimming extra liner after trenching. The hook also keeps the blade from digging into the soil beneath the liner.

Figure 6-2 Hook Razor Blades
(Harbor Freight, n.d.)

If the pond to be constructed is of relatively small proportions then a tape, Figure 6-3, can be used; however for most situations a measuring wheel, Figure 6-4, is preferable.

When measuring for a cut it is advised that an extra four to six feet be added to any final measurement as this guarantees that the tails of the liner will fill the trenches. Additionally the measurement for the next strip of liner should NOT be made on the edge of the preceding lining strip. The correct way to measure is to measure 21.5 feet (22 feet minus 6 inches for welding overlap, if the width of your liner is different subtract 6 inches from that width) away from the preceding edge and the measure the length. This may not be necessary on a square pond or catchment but a pond with a round edge makes this technique of measurement is required.

Figure 6-3 Measuring Tape
(The Home Depot, n.d.)

Figure 6-4 Measuring Wheel
(Jopp, 2009)

WELDING AND WELDERS

Generally there are three types of welders: Hand, Track and Extrusion. This section will provide an overview of the applications and weaknesses of these different systems to allow users to best determine which system best fits their needs.

SAFETY NOTES:

WARNING: Regardless of the type of welder to be employed on a job it is always best to use a heavy gauge and well maintained extension cord. Smaller gauge extension cords will tend to heat up and fail but can also overload the welder causing damage to electrical components. It should be noted as well that these types of failures can not only harm equipment but also on site personnel. Checking cords before and after each project is a best management practice that will help keep maintenance costs down and ensure worker safety.

WARNING: All HDPE welders use heat in one form or another to weld. Gloves and long sleeve shirts should be worn at all times during operation of any welder. Great care should also be taken when setting any welder down on lining material as many parts, not just the heating elements, are very hot and can cause burn a through.

Types of Welders

Hand Welders

Hand Held Wedge Welders, illustrated by Figure 6-5, are the simplest of HDPE welders. They are used to heat the material with the large wedge shaped iron at the head then a hand roller is used to force the two pieces of liner together completing the weld. The technique is shown in Figure 6-6. These welders are most often run on 110v and are easily powered by small generators. These welders are excellent for use in patching or welding seams that are not uniform or that are vertical, i.e. seams that cannot be welded with a track welder. Their small size allows them to fit into tight spaces. While hand welders can be advantageous in some unique circumstances their use is very time consuming. Completing a weld that is uniform throughout is also very difficult. These tools are best used on small jobs or patching. Maintenance for these welders is very straight forward. Keep the welding iron clean and free of debris such as mud and melted lining material. Many of these welders also require a fuse that is housed in the butt of the device so keeping spare fuses on hand is a must during any project.

In addition to hand held wedge type welders there are also hot air type hand welders such as the one shown if Figure 6-7. These use a stream of heated air instead of a hot wedge but their application remains relatively unchanged. They work well in tight and awkward spaces and are very useful for tacking liner into place. Particular care must be taken when using these welders as it has been my experience that if dirt or debris enter the intake the motor can easily become locked up.

Figure 6-5 Hand Welder
(Nova Seal, n.d.)

Figure 6-6 Use of Roller with Hand Welder
(Nova Seal, 2002)

Figure 6-7 Hot Air Welder
(Ali Express, n.d.)

Track Welders

A track welder, such as the example in Figure 6-8 and often referred to as a wedge welder, is the most efficient way to create welds that traverse long distances and keep them uniform. These welders move under their own power reducing operator fatigue. “Hot wedge welding is carried out by a metal wedge which is heated to a temperature of 300-400 degrees C and is pulled between the overlapping lower and upper geomembranes. A system of guide rollers provides a complete surface contact between geomembrane and the two separate tracks of the dual hot wedge. The surface layers of the geomembranes are melted and the two melt layers are pressed together by a squeeze roller system immediately behind the wedge.”(Müller, 2007) Figures 6-9 and 6-10 provide cross sectional views of this process. As shown in the Figure 6-9 cross section, the Track Welder leaves a void for air pressure testing. This void is used to test the weld for leaks. A detailed explanation of this process can be found in Chapter 7. Track welder specifications vary from model to model. The voltage required for depends on the model in use and can either be 120V or 240V. Each model has different tolerance requirements for different thicknesses of material. The rollers used to squeeze the two layers together may need to be adjusted depending upon the material thickness. These adjustments are critical to producing proper track welds. Consult the owner's manual of the track welder to determine the proper setup process.

The largest drawback to using a track welder is that if the welder ever stops the hot wedge will almost certainly burn through the material to be welded. The welder relies on constant movement to apply the correct amount of heat to the material so as to melt it but not burn through it. This is why the speed and temperature of the heating element are crucial factors in performing a quality weld.

The movement of a track welder can be hindered by rocky or uneven surfaces. Residual vegetation left in the pond bottom can also hinder the welder by getting caught in the rollers. If either of these conditions exist they need to be rectified before lining commences. Both of these conditions can stop a track welder. If this occurs a burn through is almost a certainty. Reference Pond Preparation under Methods of Installation.

Smaller wrinkles in the material to be welded can often times be worked through the welder. While some larger ones can be worked through by lifting the welder and allowing it to ride over the curve of the wrinkle instead of allowing the material to bunch up in front of it more often it will cause the non-wrinkled side to be pushed out of the rollers. However there are times when these larger wrinkles will cause material to become trapped in the rollers stopping the welder's movement. In either case a "Fish Mouth" repair will likely be required.

Maintenance of the track welder is as simple as that of the hand welder but in the case of the track welder it is much more imperative that it be kept clean. Dirt and debris within the roller system can lead to slippage or possibly cause the welder to come off of track ending in a fish mouth patch. Additionally the tension of the rollers must be set to the mil thickness of the liner to be welded and needs to be checked periodically to ensure the best welds possible. The settings for the roller tension are unique to each make and model of track welder and can be found in the owner's manual.

Figure 6-8 Hot Wedge Track Welder
(Americover, 2015)

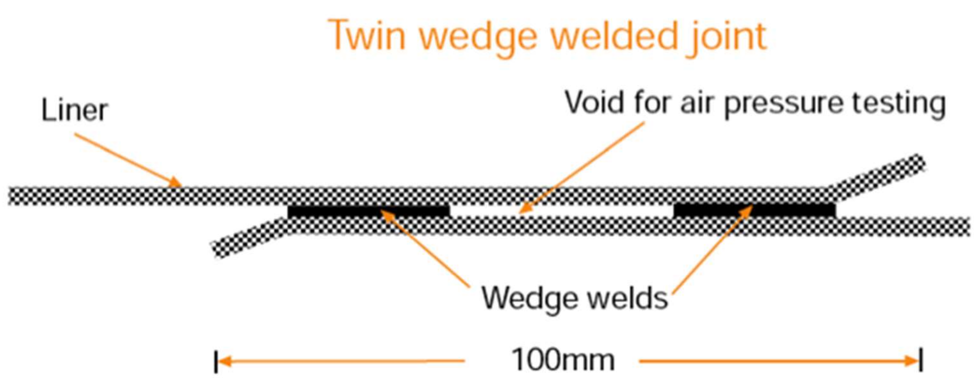

Figure 6-9 Two Track Weld
(Butyl Products Ltd., n.d.)

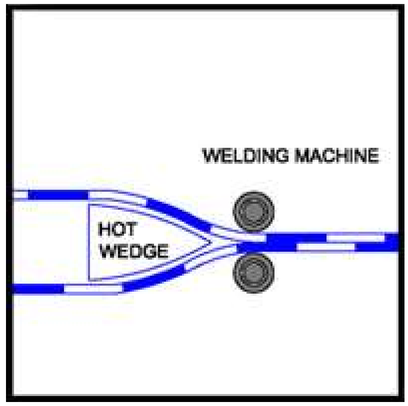

Figure 6-10 Side View of Wedge Welding Process
(Wisko America Inc., n.d.)

Extrusion

An extrusion welder, two types of which are shown in Figure 6-11 and 6-12, pumps a bead of molten HDPE onto the surface which is then spread with the use of a Teflon foot. For many extrusion welders there are multiple teflon feet to choose from however this choice comes down to personal preference and the task to be completed. The welder draws in weldrod, either spool (Figure 6-13) or rod type (Figure 6-14), through a port on the side. There is often many different sized ports and the correct one to use depends on the size of weldrod that is being employed, however it has been my experience that it is always best to go with the largest weldrod available. It is always preferable to have too much extruded material as not enough. The size of weldrod also dictates the operating temperature and extrusion speed. Temperature is set by the operator and based on the size of rod, however extrusion speed is a personal preference to the operator. After entering the welder the rod is drawn down through a heating element that melts it and then pushed out onto the Teflon foot where it can be spread onto the lining material by applying downward pressure on the welder.

To use an extrusion welder requires more steps and attention to detail than using a hand welder. First if weldrod from a spool is being used the weldrod must be clean and free of dust. Dust particles that come out in the molten HDPE can keep it from adhering to the liner so it must be removed. This is easily accomplished by taking a small strip of cloth and tying it to the weldrod itself. As the weldrod is pulled into the welder the cloth will brush away any dust or dirt as the weldrod slips through it. The second and equally as important consideration when using an extrusion welder is the preparation of the liner surface. As with the weldrod, dust must be removed from the liner surface, however in addition to this step the liner needs to be roughed up. For the molten HDPE to adhere the liner it needs to be abraded with a flap disk grinder. This reduces the slickness of the lining material, removes any oxidation and allows the weldrod to adhere to the surface of the liner. Many extrusion welders are also equipped with a hot air gun. As the extrusion welder runs down the material the gun will heat up the next piece making it tackier and thus allowing the molten HDPE to adhere better but the operator must heat up the initial piece of liner to be welded before extruding onto it.

As the HDPE is melted it will lose some of its resistance to cracking. "Most stress cracking is observed at the edges of extrusion weld beads in the lower sheet, so it is important to monitor this location." (Peggs, 2008) Additionally, extrusion welders can be quite fragile. The hot air blower that is mounted to most extrusion welders can be quite susceptible to dirt and debris. If allowed to enter the blower housing dirt can quickly lock up the motor, rendering it inoperable.

Welding rod is required to operate this welder. For smaller applications the rod comes in short sticks but in larger scale operations it is on a large spool. When using rod that is of the spool variety it is best to cut a long strip instead of pulling directly from the spool. Cut a longer strip than is perceived to be needed as the extrusion welder will use more rod than is typically thought necessary. This also allows any excess to be utilized more readily as it is easier than feeding in very short strips.

Figure 6-11 Extrusion Welder Large Type
(RJM Equipment Sales, n.d.)

Figure 6-12 Extrusion Welder Small Type
(RJM Equipment Sales, n.d.)

Figure 6-13 Spooled and Coiled Weldrod
(Abbeon, n.d.)

Figure 6-14 Weldrod Sticks
(Delta International Inc., n.d.)

Methods of Installation

There are a number of different installation methods that can be used to line a pond, but as with the rest of the HDPE lining process certain situations require different methods. Pond preparation is of equal importance to any of the methods disclosed in this section and must be taken into account. How to plan out the construction of the pond is also detailed.

Pond Preparation

Perhaps the most important and helpful step in the whole lining process is pond preparation. During this phase the existing basin is evaluated to determine if it has characteristics necessary to successfully line it. Evacuation of the basin, or dirt work if the basin did not exist prior to construction, begins with the slope. The slope of the bank is of great importance. In my experience the optimal slope is 2:1. The determination of this slope was made by a year of observations conducted on Dr. Jim Roger's pond through analysis of scuff and scrape marks made by animals of different slopes present on his pond. On areas of the bank with a slope ratio of 2:1, less scuffing was present and more tracks were observed leading to the conclusion of higher usage by wildlife and thus a preference by the animals to use these areas of bank. This means for every foot of elevation there is two feet of horizontal run. This ratio allows for wildlife to escape the pond should they fall into it. This also aids in lining as the slope is not so steep that the liner will slide down it. This slope is not always possible and as will all projects the end use should be evaluated to determine if this slope is necessary.

The next evaluation to make is that of the smoothness of the basin. While some slightly uneven terrain is not of a great hindrance, sudden drops and ruts should be smoothed out prior to lining as they will interrupt a track welder.

As much vegetation as possible should be removed from the bottom of the pond. Not only will grasses and vines become entangled in the rollers of the track welder, if there are any woody stems left sticking out of the ground they can puncture the liner after the weight of the water is added.

Lining Plan

It is entirely possible to line a pond without a plan. However, to best and most efficiently line a pond, with the lowest amount of waste and fuel usage, a lining plan is a must. To begin formulating a plan determine which direction requires the least amount of trimming. This requires measurements be taken of the pond. Take time to figure out where problem areas will be. If at all possible make a written plan. This ensures that as the project advances steps will not be lost in the process. Without a plan large amounts of time, material, and fuel can be lost to trimming. Your lining plan should also include proposed trench lines. Refer to Chapter 5 for instructions on trenching and surveying. The plan should also take into account the length and weight of the liner. The area where the liner is to be unrolled should be taken into account as an average roll of HDPE is 22 feet long. The machinery used to move and unroll the liner should likewise be evaluated as a typical roll of HDPE weighs 4000lbs on average. Refer to Chapter 4 Lining Condition and Considerations for recommendations on environmental factors that affect the lining process.

Unrolling

To drag out a piece of HDPE liner takes considerable force due to the fact that a fresh roll weighs upwards of two tons. A machine, truck, loader or similar piece of equipment, is required to roll out the liner as well as weigh down the trailing end.

The liner can be unrolled using a few methods. The most effective is to run a length of pipe through the center of the roll. A diagram of this Chain Suspension Method can be found in Figure 6-15. This pipe must extend at least a foot past either end of the roll. Holes should be cut in the wall of both ends of the pipe just large enough to fit a chain or strap hook through the hole and attach it to the wall of the pipe. Attachment points that are welded onto the pipe have a tendency to break under load so these are not suggested.

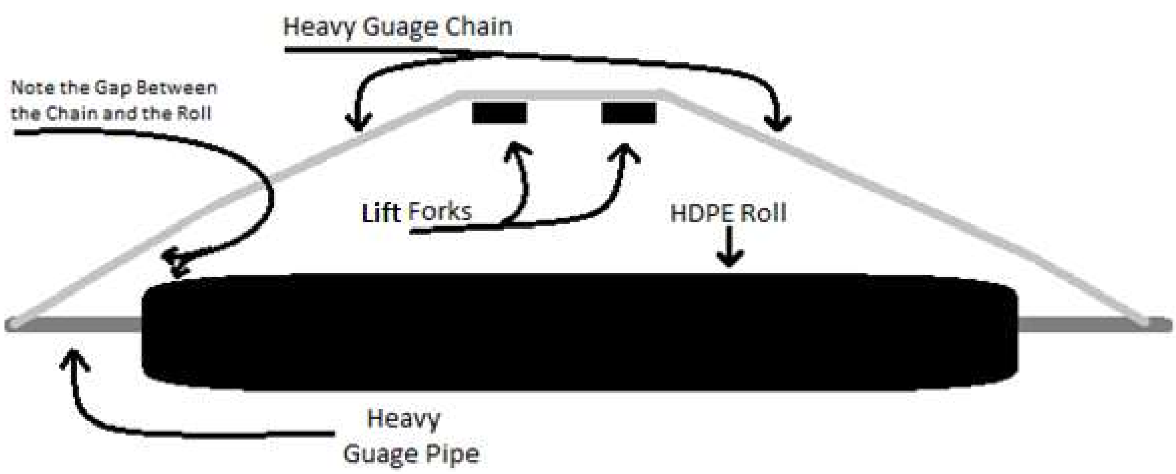

Figure 6-15 Chain Suspension Method
Created in Microsoft Paint 2009

Moving Panels into Place

Fold Method

For shorter pieces of liner a team can simply drag the piece into place. For longer pieces of liner where mechanical means are either unavailable or cannot be used for some other reason the liner can be folded in half and dragged into place. The reason for folding the piece in half is it reduces the friction that is caused by dragging it along the ground. This has the twofold benefit of also reducing the likelihood of the liner being shifted or taken by the wind. The liner is dragged into place with the fold trailing behind. Pull the liner up to the trench on the opposite side. Attach clamps to the top layer of the fold and pull it over to the starting trench. This method allows the top layer of the fold to be drug along bottom layer reducing friction and the energy needed to pull it up the opposite slope.

Cut and Drag

Liner can be drug into place with a 4-wheeler if it is too heavy to move by hand or the sides of the pond are too steep. This method requires a fairly flat surface on which the liner will be rolled out and cut to measurements. The cut piece is then attached to the 4-wheeler by taking the edge of the liner and rolling it around a piece of pipe or 2x4. One or two rolls is all that is needed taking care to make sure that the roll is snug. Two slits are then made right where the roll ends with three to four inches of pipe or wood sticking out past the slits. A tow strap or chain is then run through each slit around the rolled material and attached to itself. The middle of the strap or chain can then be attached to the 4-wheeler. The wood or pipe allows the pressure exerted on the liner during towing to be spread out over a larger surface area reducing the risk of tearing. There will be some tearing of the slits made in the liner however and this should be accounted for when measurements are taken for the cuts as the slits should either end up in the trench or cut off as excess.

Drag from Roll

Use the loader to lift the roll suspended on a bar by chains. The liner is then drug across the pond by a 4-wheeler by attaching the liner to it. As the 4-wheeler drives across the pond the roll will unspool. Note that personnel should be mindful of any kinks or stoppages during the unspooling as this is a common occurrence. To traverse long distances with this technique it may be necessary to weigh down the middle of the liner if the possibility of wind gusts exists.

Premanufacture

This method is not often employed due to the irregular nature of sites to be lined. However if the pond is deemed sufficiently small enough both in size and depth, this can only be determined by personnel at the site, and is of a simple shape a premanufactured liner can be used. To accomplish this measurements of the pond are taken and then a liner of appropriate size is welded on flat ground either on or off site. If the liner is manufactured right next to the pond it can then be dragged into place and anchored. If the liner was created off site additional steps are required. To transport the liner to the site it must first be folded to reduce its size. As the liner is folded each fold should be numbered. This allows personnel to work backwards ensuring that the liner is unfolded into the correct place. Additionally some type of directional marker should be drawn when the last fold is made allowing personnel to determine at a glance the orientation in which to place the bundle so that it unfolds correctly. If the unfolding is done incorrectly it will have to refolded to correct the mistake. Great care should be taken when folding the liner. This should be done by hand without the aid of machine to avoid putting too much pressure on the folds and causing cracks.

ANCHORING

The most common and cost effective form of anchoring HDPE liner is to create a 1.5 to 2 foot deep trench that traces the boundary of the area to be lined. The line of the trench must first be surveyed in by beginning at the lowest point that requires lining or where the highest point which water can reach. The trench needs to be at least four inches in width to allow for enough dirt to be backfilled into the trench. The liner should be cut 2 feet beyond the end of the trench. The liner is then pressed into the trench by either tamping post or by stepping it in. The liner should follow the inner wall of the trench down and up the opposite side. The amount of liner required to follow the trench also allows extra liner to be pulled into the pond due to shrinkage imposed by the addition of cold water. Finally either by hand or mechanical means backfill the trench with dirt filling in the cavity. Any excess that extrudes from under the backfill can be removed. A diagram of a properly anchored trench can be found in figure 6-16

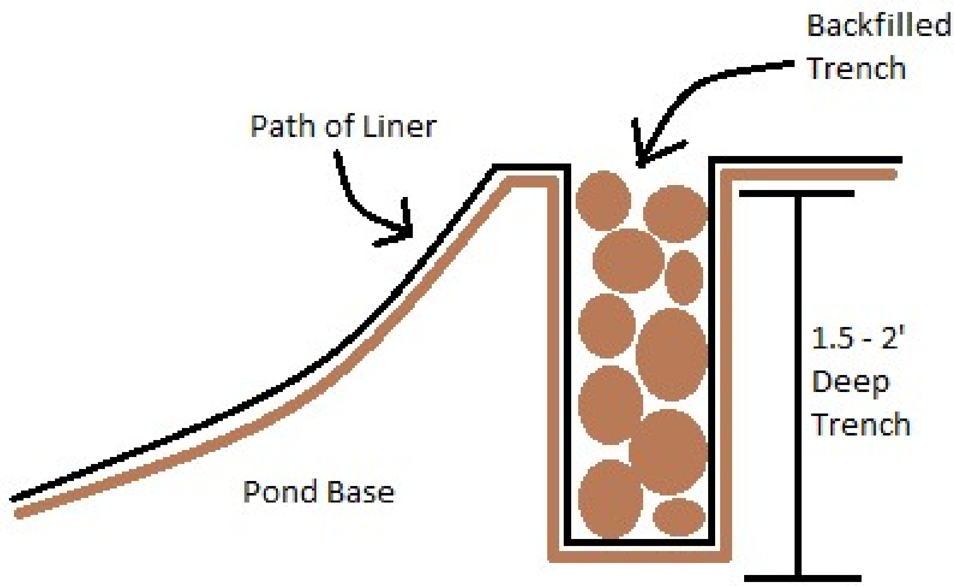

Figure 6-16 Trench Anchoring
Created in Microsoft Paint 2009

Boots for Covering Protrusions

During the lining of ponds it is not uncommon to encounter protrusions that come through the liner that are necessary. These are usually in the form of filling or drainage pipes, or the poles that support a dock. Lining around these can be accomplished with the addition of a boot. These consist of a long tube of HDPE, the tube can be constructed by either rolling up a portion of liner or taking the pipes that support the inside of the liner roll and cutting them once lengthwise, and a plate of HDPE at the bottom. Figure 6-17 shows a diagram of how these are constructed.

After the boot is constructed it is either slipped over the pipe and the plate welded into place or a slit boot is wrapped around the protrusion and then a seam is welded down the length of the boot. If an HDPE pipe is the basis for the tube of the boot it needs to be welded shortly after being cut as it will try to flatten out over time.

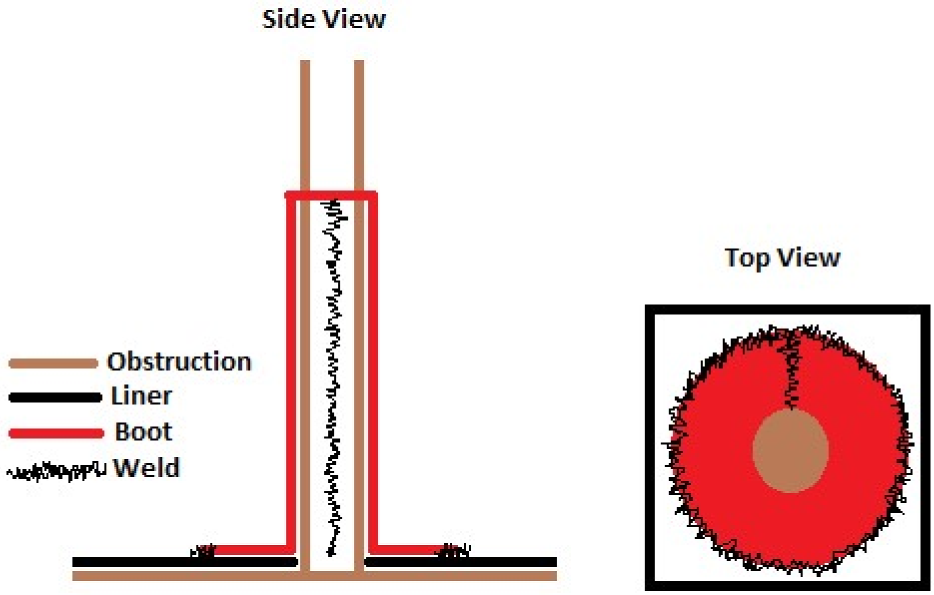

Figure 6-17 Slit Boot Construction Side and Top Views
Created in Microsoft Paint 2009

The welds in these boots need to be tested with a spark tester. The method for accomplishing this can be found in Chapter 7 Liner Testing.

CHAPTER 7

LINER TESTING

Testing equipment

Certain projects, depending upon the regulations attached to the task, require testing of seams and welds. These tests can be performed in a number of different ways. In general there are two types of testing: Non-Destructive and Destructive.

One test for the integrity of a seam when using a double track welder is to weld the ends of the seam closed. Then take a bicycle pump needle, heat the tip and insert it between the two tracks of the weld. The needle must only pass through one layer of the liner for the test to be accomplished. Using a specialized pump with a pressure gauge, or small compressor pressurize the seam. If it does not lose pressure the integrity of the seam has not been compromised. This is considered a Non-Destructive form of testing.

A vacuum box can is used to test track seam welds as well as patches. These devices can be purchased or constructed from 2x4 planks of wood, foam padding that is 2" wide and plexiglass that is the same area as the box you plan to construct. The 2x4's are cut into equal lengths then screwed or nailed together at the ends to form a square. The foam padding is attached to one side of the square and the plexiglass to the other. Duct tape is used to make an air-tight seal around the joints of the box and the plexiglass on top. A hole is cut into the plexiglass just big enough to allow a vacuum hose or nozzle to fit. The hose or nozzle is then taped to the plexiglass. Figure 7-1 shows a diagram of the construction. Soapy water is applied over the patch or seam and the box is pushed along the surface of the liner. The vacuum is then turned on and the box is slid over the seam or weld. The soapy water will show no bubbles as long at the weld is intact. If bubbles are witnessed this means that air is being drawn up from beneath the liner through a puncture of hole in the weld. These can then be marked and patched as needed.

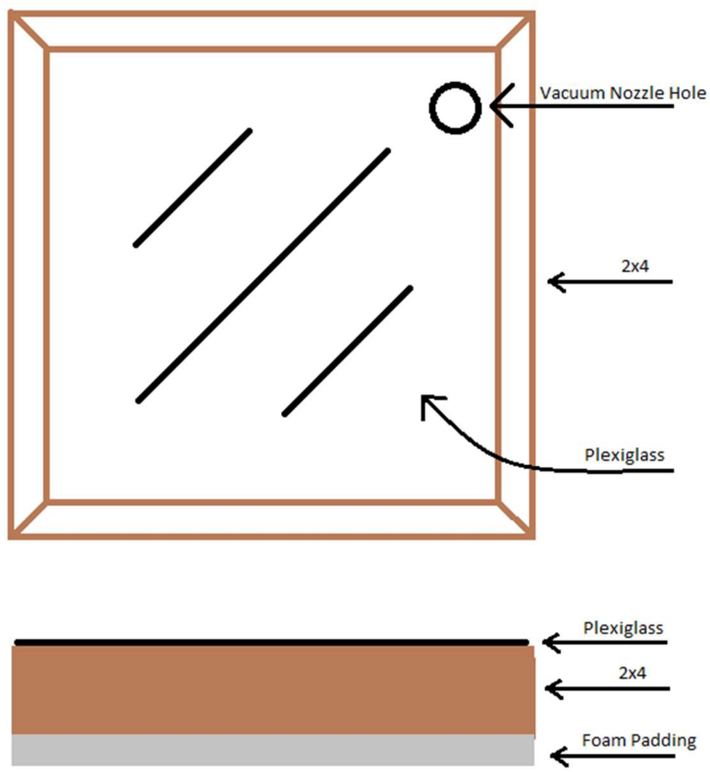

Figure 7-1 Vacuum Box Diagram
Created in Microsoft Paint 2009

“Test strips. In preparation for liner placement and field seaming, you should develop test strips and trial seams as part of the construction process. Construction of such samples should be performed in a manner that reproduces all aspects of field production. Providing an opportunity to test seaming methods and workmanship helps ensure that the quality of the seams remains constant and meets specifications throughout the entire seaming process.” (Environmental Protection Agency, Protecting Ground Water) These strips are tested with a tensiometer as shown in Figure 7-2 and can be tested in two different ways: Shear and Peel. As shown in Figure 7-3, a shear test pulls at both ends of the strip, while a peel test pulls from one end of the strip and as well as at the point of the weld.

Figure 7-2 Tensiometer
(Inspections X-Ray & Testing, n.d.)

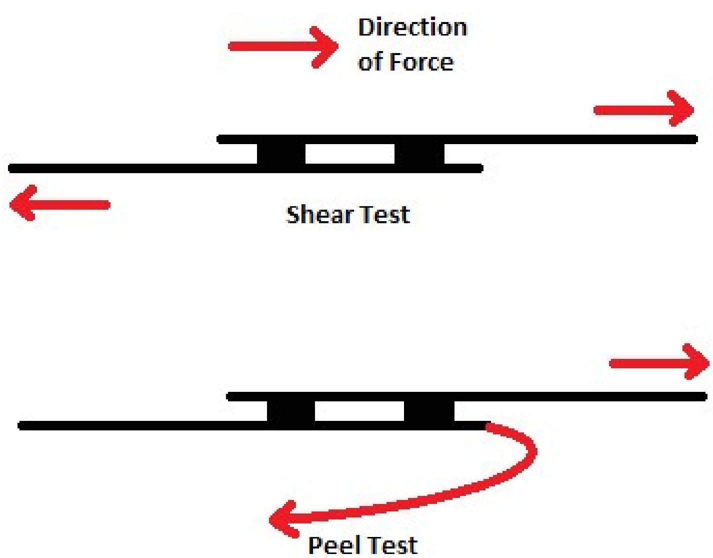

Figure 7-3 Shear and Peel Tests
Created in Microsoft Paint 2009

Testing boots requires a different type of equipment as none of the previously mentioned testing methods will work. This method is known as spark testing and it uses electrical arching to show possible pathways for a leak. To accomplish this test an uncoated metal wire is embedded within the extrusion weld that makes up a boot seam during construction. This wire is not necessary if the obstruction that is receiving the boot it made of metal. After the boot is in place a brush spark tester, as shown in Figure 7-4, is waved within an inch of every part of the seam. If an electrical arc occurs then there is a possible pathway for water to leak.

Figure 7-4 Brush Type Spark Tester
(Wegner Welding, 2016)

CHAPTER 8

LINER PATCHING

Patches are required in a number of scenarios when working with HDPE. Material can have puncture holes due to improper handling by shipping companies, holes can occur while moving the material into place, or a track welder coming off track. All of these scenarios require patches and a proper patch reduces the chance of and hopefully eliminates the possibility of seepage. Any puncture larger than a pinhole can drain a pond in a matter of days. If a leak is detected after filling the only recourse is to let the pond drain. This process will help to locate the leak as the water will only drain down to the level of the puncture. However, after this occurs additional water must either evaporate or be drained so that a dry working surface can be obtained. Additionally another problem can occur with a leak. The material that comprises the basin of the pond can be compromised by the water leaking beneath the liner. If it is made up of sandy soils purge holes can form. These purge holes can cause weak spots where the lining material is not properly supported. Alternatively if the pond has a clay bottom it can retain the leaking water and actually float the liner on top of the leaking water. Both of these situations are hard to correct so a proper patch and testing are paramount. There are different patching options available to an operator depending on the situation, equipment available, and type of puncture sustained by the material. As with seams it is a best management practice to check all patches with a vacuum box to ensure a proper seal.

Material Patch

A material patch is accomplished by taking another piece of material and cutting out a patch large enough to fit over the hole and then welding the piece in place. The best shape, in my experience, for the patching material is a triangle, as shown in Figure 8-1. If a square piece is used after welding three sides the fourth will almost always have a wrinkle and will not sit flush with the lining material as the material will warp due to the heat. When attempting a patch of this type it is best to cut an oversized piece as this ensures that the liner the patch is being welded to has not been compromised as well as allowing an attendant hold the patch in place with greater ease. Patches of this type can be accomplished with either the hand or extrusion welder. While patching with the hand welder is no different than any other welding operation patching with the extrusion welder, while being less time consuming, is easier with two people. The portions of both the liner and patch material must be roughed up if the extrusion welder is to be used. A hand welder should be used to tack the patch to the liner before extruding as this ensure that it will stay in place during the extrusion process.

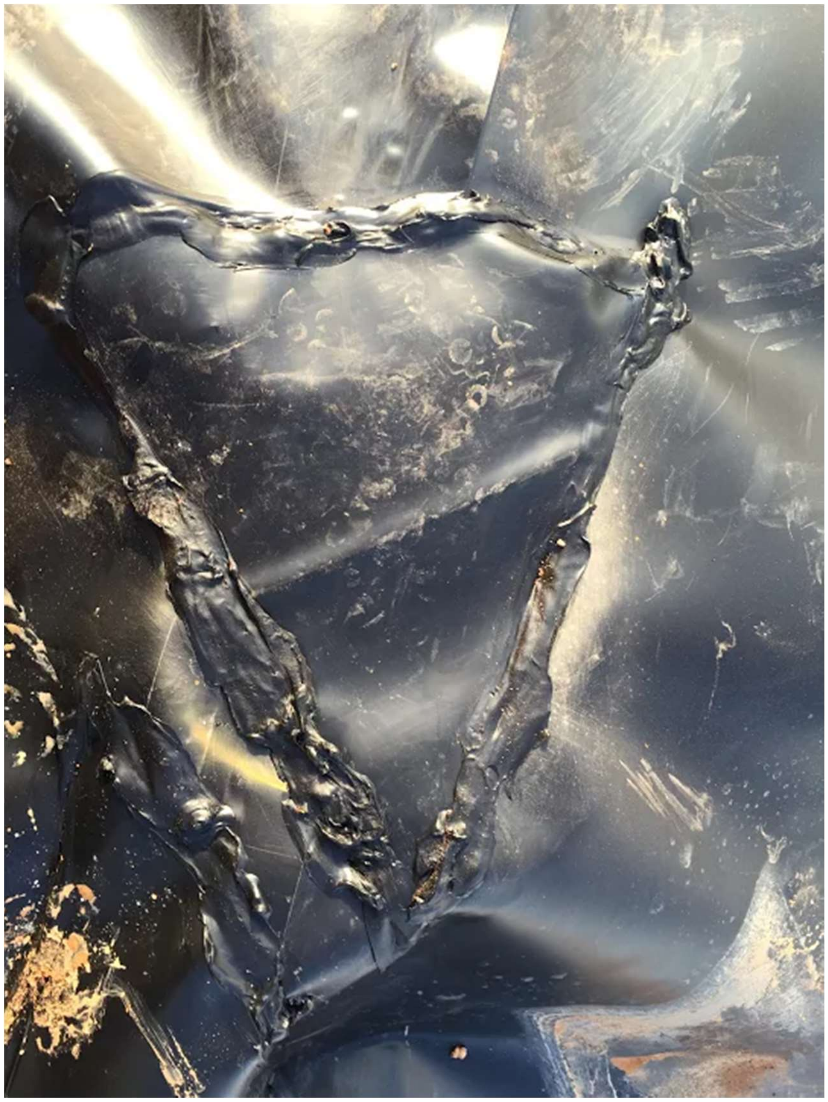

Figure 8-1 Material Patch
(Topliff, 2015)

Extrusion Patch

An extrusion patch is used to cover smaller puncture holes in the material. This is accomplished by roughing up the puncture hole by means of either a wire brush or grinder equipped with a flap disk, then extruding enough weld rod onto the hole and then pushing down on it with welders Teflon foot. The patch must be pressed against the liner until it has cooled sufficiently due to the fact that as the extruded material begins to cool it will begin to contract and if not held in place can detach from the liner. If the welder being employed is equipped with a hot air gun it is also recommended that the punctured material be heated as to better accept the extruded weld rod. This method is only acceptable on relatively small punctures such as the one shown in Figure 8-2.

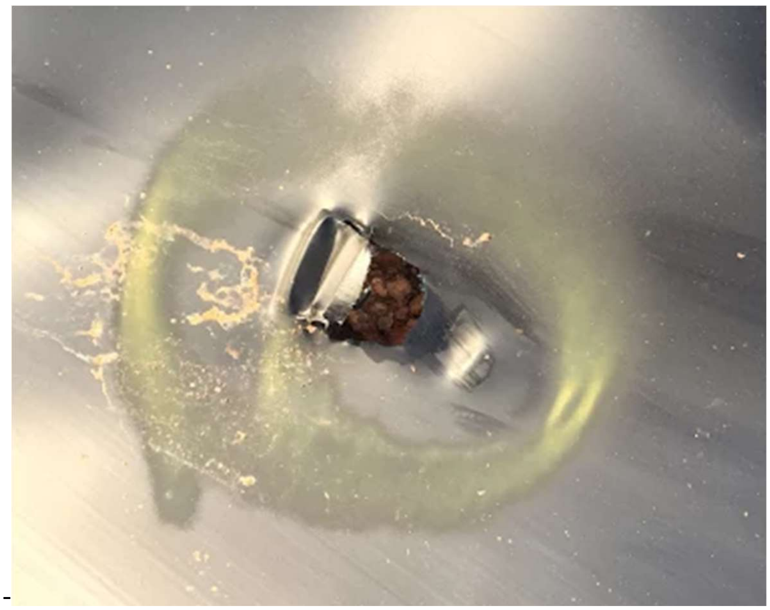

Figure 8-2 Small Liner Puncture
(Topliff, 2015)

Fish Mouth Patch

A fish mouth patch is named as such due to the fact that the liner must be cut in such a way as to create what looks like the mouth of a fish. These patches are most often used when a track welder has been knocked off its path and either burned through the material, such as is shown in Figure 8-3, or the material simply came out of the rollers, shown in Figure 8-4. After the track welder has be lined back up and the rest of the weld finished, the material at the site of the fish mouth needs to be cut at an angle horizontal to the seam so that the liner can be laid back on itself. This cut can be seen in Figure 8-3. In these situations there will be a large wrinkle in the material due to the fact that the liner had to be pushed back together to allow for a straight track weld. This wrinkle is where the cut is to be made. Often times the cut can be as long as two feet so to allow enough room for the material to be laid flat. The addition of a “Material Patch” over the top of the fish mouth, Figure 8-5, can add an extra barrier against seepage but this is not always necessary. Be sure to check the track welds on either side of the fish mouth to ensure there is no route for seepage as incomplete seams on either side of the fishmouth are very common. These can be sealed with either a hand or extrusion welder.

Figure 8-3 Fishmouth Burnthrough

(Topliff, 2015)

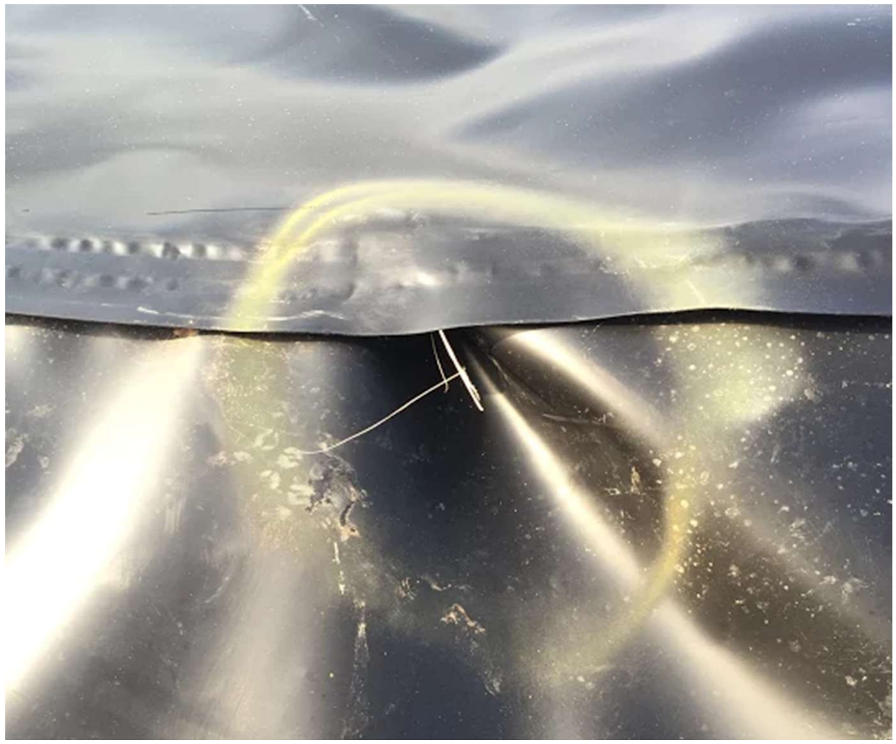

Figure 8-4 Fishmouth Off Track

(Topliff, 2015)

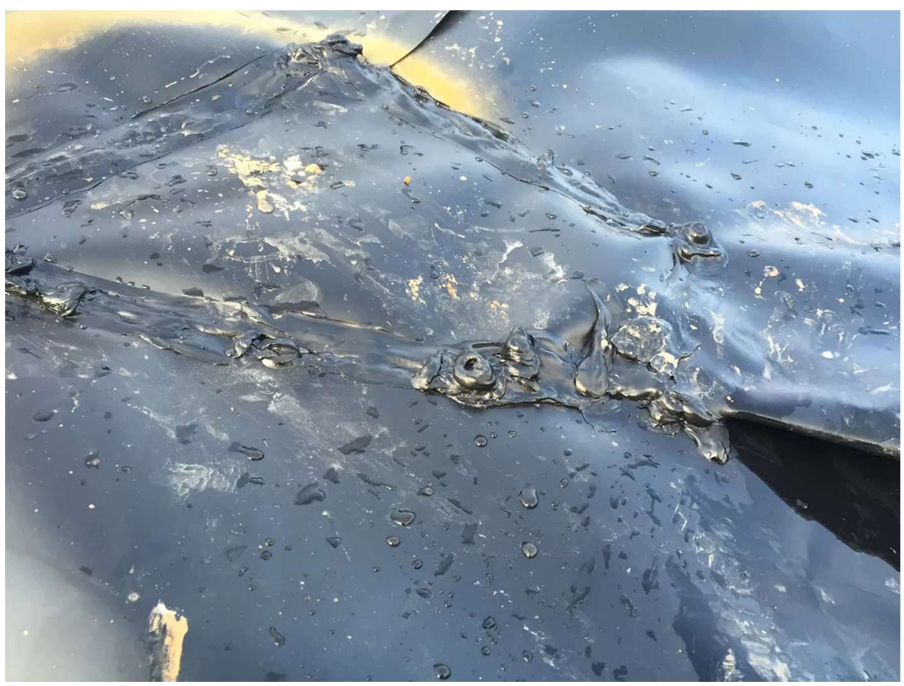

Figure 8-5 Fishmouth Patch Covered with Material Patch

(Topliff, 2015)

CHAPTER 9

CASE STUDIES

During the course of the production of this manual, a study was conducted to determine the soil holding capabilities for soil stabilizing liner. The liner used was comprised of an expanded grid pattern with a layer of unwoven HDPE fabric on either side, the same as the picture above with the exception of black fabric.

Case Study No. 1

Study Description

The pond used was owned by Dr. Jim Rogers. The reason for this decision was namely due to the fact that this client wanted the soil stabilizing liner integrated into his pond. This pond is directly in front of the house located on the property so aesthetics were of vital importance to the client. For the study he allowed certain parts of the bank of his pond to remain as standard smooth HDPE liner for controls. The liner was attached immediately post construction with space in between the panels of stabilized liner for controls. No soils or sediments had time to build up thus keeping the controls within the same timeline as the stabilizing liner to be tested. Two years were allowed to pass. In this time the pond was filled and stocked with Bass and Crappie. During this period the pond developed its own ecosystem including aquatic plants and benthic invertebrates. As the pond had an established ecosystem it was determined that an appropriate amount of time had elapsed for soils and sediments to establish themselves and provide a good overall picture of the differences between the two types of liner.

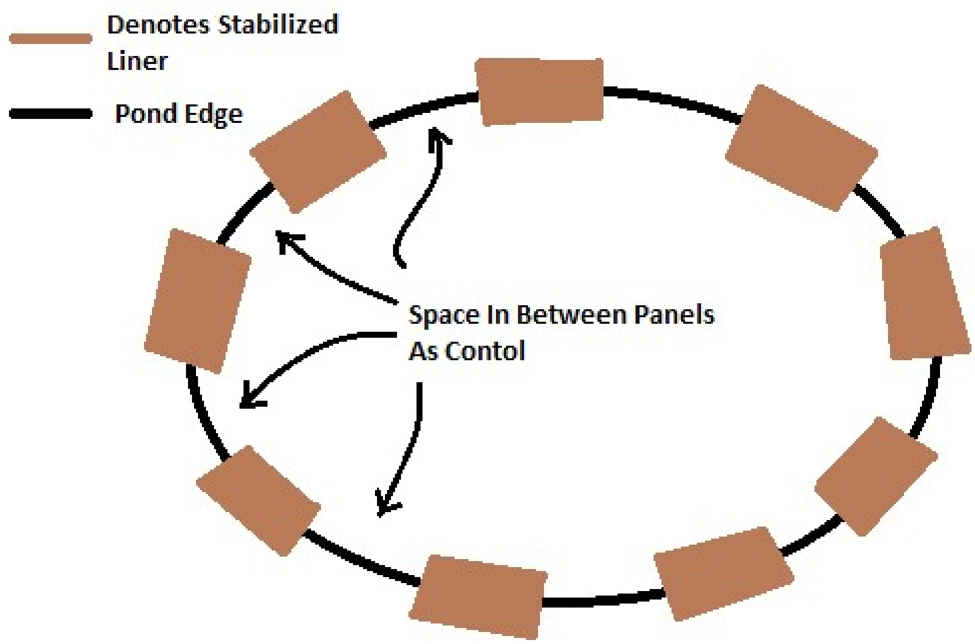

Figure 9-1 Dr. Jim Roger Pond Treatments

Study Method

Starting from the inlet pipe on the Southwest side of the pond, a measurement of the soil depth was taken every six feet. These measurements were collected two feet from the trenched portion of the liner towards the water. If that two foot mark was in the water, the measurement was taken at the water's edge. The measuring instrument was an aluminum speed square calibrated in inches. The measurements were taken in quarter inch increments. In total, 111 points were measured in quarter inch increments. These points are denoted in Table 9-1.

The average depth in inches for the smooth liner was 2.389 with a sample size of 43 points, while the average depth in inches for the stabilized points was 2.268 with a sample size of 68. The reason for the discrepancy between the two sample sizes is that the stabilized liner covered up more area than was left smooth. To gather unbiased data the sample sizes had to be different.

When these points are plotted on a bar graph (Figure 9-2) it would appear that there were more points that were stabilized that had a larger amount of soil. However, when a single factor ANOVA test (Table 9-2) was conducted on the two sets of data, an F Value of .1174 was returned which did not meet or exceed the Critical F Value of 3.928. The data points do have a normal distribution as shown on the Normal Distribution Probability Plot (Figure 9-3). According to the statistical analysis of the data, there is not enough difference between the means of the two sets of data to conclude that there was any difference that could not be explained by chance. The data would seem to indicate that the null hypothesis that the stabilizing liner had little effect on soil retention was correct. However, this does not take into account vegetation growth as the areas with the stabilizing liner are not as affected by wave action and thus have a greater amount of vegetative growth due to a more stable soil bed.

Results

While the statistical analyses concluded that the soil stabilizing liner did not hold soil better than smooth liner, it is my conclusion that this had more to do with the angle of the liner as well as the propensity of the area to be lapped by wave action drawing any soil deposited into the water. Additionally, areas that we lined with soil stabilizing HDPE had a greater abundance of plant life, both terrestrial and aquatic, evidenced by Figures 10-1 through 10-4. The roots from these plants wound themselves into the unwoven fabric of the lining material allowing them to take greater hold and thus thrive.

Table 9 – 1 Soil Depth Data from Jim Rogers Pond

Point	Depth(In)	Stabilized	Point	Depth(In)	Stabilized	Point	Depth(In)	Stabilized
1	1		38	1.5		75	3	
2	1.75	x	39	0		76	2.25	
3	1	x	40	0.5		77	1	
4	5	x	41	0.25	x	78	2.5	
5	1.5	x	42	1.5	x	79	1.5	
6	3	x	43	1	x	80	3	
7	2.75	x	44	0.5	x	81	5	
8	5.25	x	45	4.25	x	82	4	
9	3.75	x	46	1.75	x	83	4	
10	2	x	47	1.25	x	84	0.25	x
11	1.5	x	48	0	x	85	0.5	x
12	2	x	49	0	x	86	0.25	x
13	2.5	x	50	1.5	x	87	1.5	x
14	2.25	x	51	1	x	88	1.5	x
15	2.5	x	52	4.5	x	89	2	x
16	4	x	53	1.75	x	90	0.25	x
17	0	x	54	1.75	x	91	1.25	x
18	3	x	55	3	x	92	1.25	x
19	2	x	56	3.5	x	93	1.75	x
20	4	x	57	1.5	x	94	2	x
21	0.75	x	58	1.75	x	95	1.25	x
22	0	x	59	1.5	x	96	1.25	x
23	0	x	60	2.75	x	97	1.25	x
24	1.75	x	61	2.5		98	4	x
25	6.75	x	62	1.75		99	1.5	x
26	7	x	63	1.75		100	4	x
27	6.75		64	0.75		101	1	x
28	3.5		65	0.75		102	3.5	x
29	5.5		66	1.5		103	5.25	x
30	4.5		67	1		104	9	x
31	0		68	2		105	6	x
32	2.5		69	3		106	2.75	x
33	0		70	3.5		107	2	
34	0.5		71	7		108	1.75	
35	0		72	1.75		109	5	
36	2.5		73	0.25		110	3	
37	2.5		74	1.5		111	4.5	

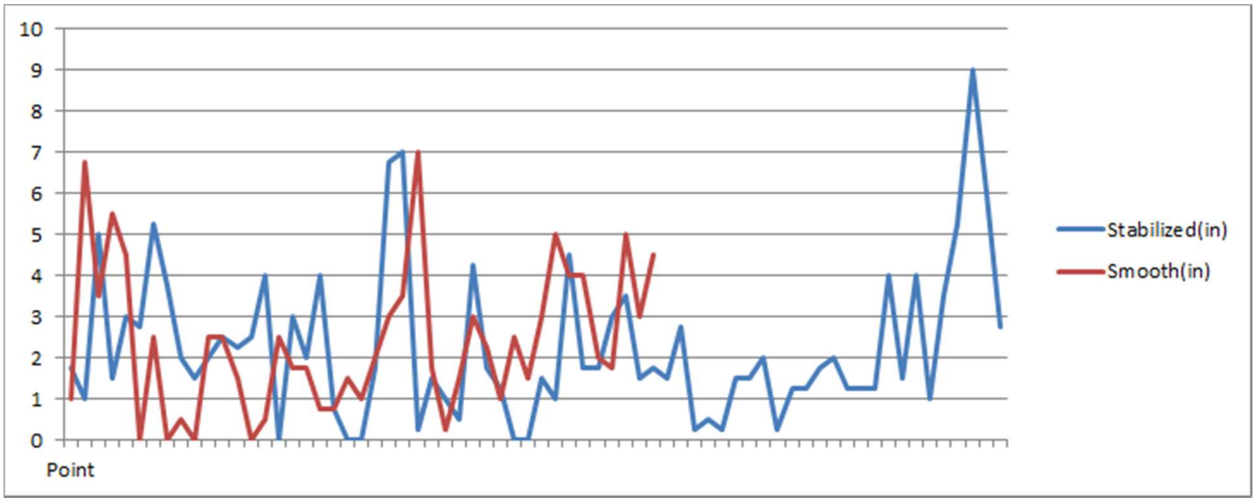

Figure 9-2 Line Graph of Depth Distributions

Table 9-2 Single Factor ANOVA for Soil Depth Data Null Hypothesis

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Stabilized(in)	68	154.25	2.268382	3.377456		
Smooth(in)	43	102.75	2.389535	3.155662		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.386651	1	0.386651	0.117452	0.732475	3.928195
Within Groups	358.8273	109	3.291994			
Total	359.214	110				

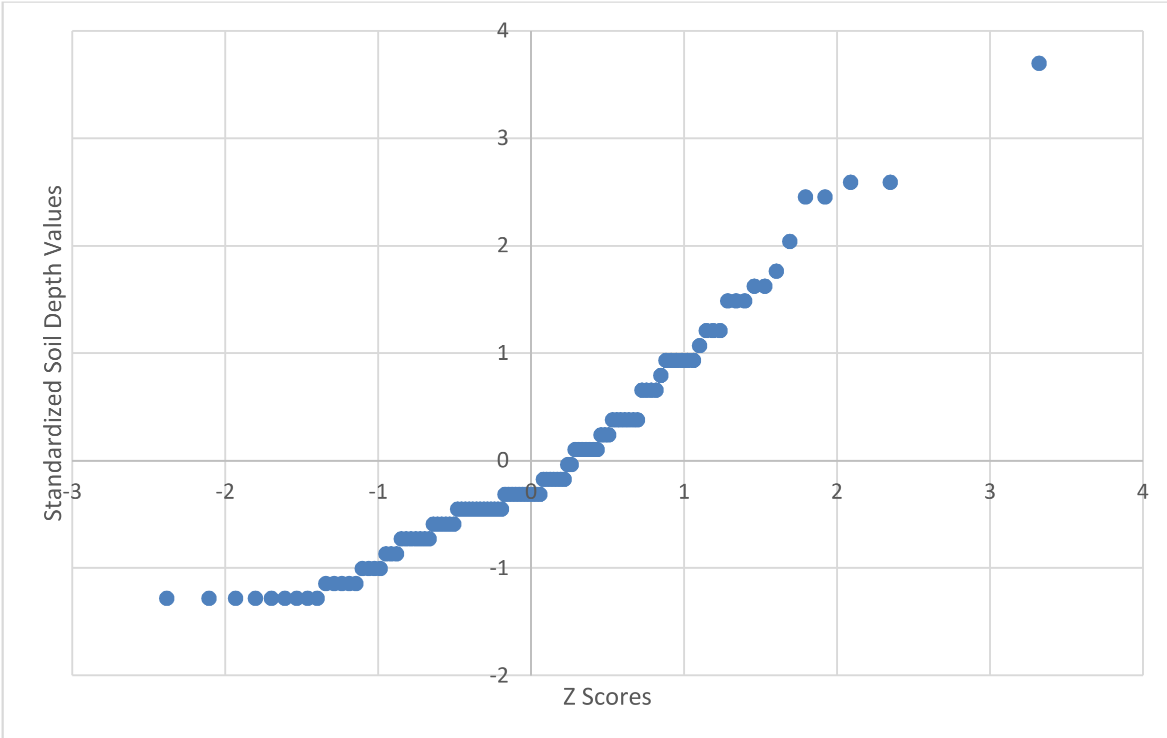

Figure 9-3 Normal Distribution Plot for Standardized Soil Depth Values

Supporting Photographs

While the study provided no quantitative data to support the claims in the conclusion, there is an abundance of qualitative results that support the conclusions made. These qualitative findings are found in the following pictures, taken of the pond on the same day as the measurements of soil depth.

Figure 10-1 Shoreline View
(Photo by Christopher Topliff, 2015)

The area directly in front of the inlet pipe and between the stands of grass has no soil stabilizer resulting in the inability of any plants to take hold due to lack of a stable soil bed. This would be difficult even with stabilizing liner to be sure, however without it there is almost no chance of any establishment. Additionally, even with soil stabilizing liner, there is the possibility of washout. This is evidenced by the area between the two stands of grasses in the foreground. The stalks between the two mature stands are much smaller and immature. It can be inferred from this and the sudden erosion in the soil on the bank that the soil in this location did at one time wash away due to wave action.

Figure 10-2 Unstabilized Shore Soil
(Photo by Christopher Topliff)

There is almost no accumulated soil underneath the water's surface here as wave action will pull it to the middle of the pond without the stabilizing effect of the unwoven HDPE mat. Without the stable base provided by the specialized liner and the sediment it collects, no aquatic plants can become established. However, this is not to say that they can never become established, it is possible with additional time but still is unlikely. This lining was installed two years prior to these photographs.

Figure 10-3 Contrasting Stabilized/Unstabilized Soil
(Photo by Christopher Topliff)

Here is an image contrasting the difference between a stabilized and unstabilized region. Note the aquatic plants that have taken root in the soil trapped by the unwoven HDPE mat of the stabilizing liner near the top of the photograph. One can see how the plants break up the wave action allowing for even better sediment retention while the areas that are void of vegetation look more like a beach due to their scoured and rocky appearance.

Figure 10-4 View of Vegetation across Pond
(Photo by Christopher Topliff)

Note the lack of vegetation on the right hand side of this image. This area is unlined and while it does hold some soil it is not as stable as the areas to the left. With the sediment in these unstabilized areas being so transient there is not enough time for plants or grass to take root before it is removed by wave or wind action. Such is not the case on the left hand side of this bank. At this juncture the stabilizing liner is both in and out of the water. This allows both terrestrial and aquatic plants to take root. In this particular stand of grasses the main species was Buffalo grass which takes quite some time to establish itself. It should be noted that none of these plants were imported to the pond. Just as with any natural ecosystem the species of plant were brought in from outside of the ecosystem either by wind or wildlife.

Additional Case Studies

Case Study No. 2 – Shamrock, Texas

The clients of this project owned a large hunting ranch on which an intermittent stream ran. This stream had been dammed up in an attempt to create a large pond with an island at its center. As the water table dropped the stream dried up and as with many other unlined ponds in the region, the pond no longer held water year round and was almost never full. This is what led the clients to have it lined.

Figure 11-1 Satellite View of Case Study No. 2 – Shamrock, Texas

Location

Shamrock, Texas

35.300443, -100.370565

Challenges

The stream bed that was being lined had a natural island within its boundaries. The clients wished to retain this island and its trees but the spillway was equal to or higher in elevation to the island. The anchor trench had to be cut almost even with the base of the trees on the east side. An additional issue encountered originated with the clients themselves. The spillway on the North East was not lined to the proper height as the behest of the client. They felt that the liner would be an eyesore. This left much of the spillway exposed and caused areas of erosion in the exposed portion leading to the ponds capacity being limited. This was later remedied after construction on the rest had been completed but posed an additional problem in that the pond had been filled. A temporary dam had to be constructed down the spillway to keep water away from the edge of the liner so that additional pieces could be welded to it. Though the spillway was successfully lined at a later date the client did incur substantial costs for remobilization of equipment to the site as well and the additional lining cost and man hours.

Case Study No. 3 - Jim Rogers' Recreation Pond

The property that this pond was built on is used mainly for hunting wild game. The owner wished to add a fishing pond that would double as a watering location for wildlife. Adding permanent water to a hunting ranch will also add value to the property. The pond was constructed at the edge of an established wheat field which allowed for easy access to the construction area. The size, approximately one acre, and simple shape of the pond made for very straightforward construction as well. The water table on the property was very close to the surface, however the owner did not wish to dig down to it as fluctuation in the water table would mean that the amount of water would not be constant. After lining the pond was fed by a submersible pump well.

Figure 11-2 Satellite View of Case Study No. 3 – Jim Rogers' Recreation Pond

Location

Briscoe County, Texas

34.673798, -100.926059

Challenges

Even with the simple shape and relatively small size of the pond some challenges arose during construction. Due to improper surveying, and compounded by improper trenching, the Northwest edge of the pond had to be raised to allow filling to capacity. This is evidenced in the picture as the water level is close to both the spillway, in the Southeastern portion of the pond, and the low spot in the contour of the pond on the Northeast side. Evening out the NW contour to match that of the rest of the pond was a fairly simple process. A skidsteer with bucket was used to lift as much of the berm as possible then backfilling dirt underneath the bucket. As the berm only needed to be raised around one foot this task was easily completed.

Case Study No. 4 – Quail, Texas

This sink pond located on this property and was around 2 acres in area and had historically been constantly full throughout the year falling only by a couple of feet at most during the hottest summer months. It was fed via an intermittent stream that ran very near to the pond and as the water table began to drop the pond began to dry up until it held no water except during short periods of wet weather. The sandy bottom of the pond meant that unless it had a constant source the water it would drain out of the pond.

Figure 11-3 Satellite View of Case Study No. 4 – Quail, Texas

Location

Quail, Texas

34.993756, -100.339352

Challenges

Pre-existing dock structure required HDPE lining material to be wrapped around the support beams and welded in place to avoid seepage underneath the pond liner. These wrappings were formed into a conical shape by spiraling the HDPE into the desired shape.

Excess material had to be added to avoid tearing due to the weight on the water on the wraps. After later studies, these conical shaped boots were deemed to be excessive and we began using the tube and plate type boots. Additionally, the slope of the pond bank coupled with the boggy bottom of the pond meant that pulling material across it had to be done by 4-wheeler as any heavy machinery became mired in the mud. Due diligence was not practiced on our part, as we started lining before removing large chunks of material that had been left by the dozer. This, and the fact that large amounts of weeds had grown up in the mud at the bottom of the pond meant that there were a great many burn throughs that occurred due to the track welder rollers becoming bound up with grass and other weeds. Eventually a tractor with attached mower had to be lowered down the embankment with the help of a skidsteer to remove the weeds.

Case Study No. 5 – Bill Craft's Irrigation Pond

This pond was constructed to collect pumped irrigation water to support two secondary pumps which in turn serviced two center pivot irrigation systems. The system includes a 1600gpm well in the Mulberry Creek bottom and operated ½ mile of low pressure delivery line. The water is delivered to a 1 acre by 10 foot deep pond.

Figure 11-4 Satellite View of Case Study No. 5 – Bill Craft's Irrigation Pond

Location

Briscoe County, Texas

34.689166, -100.962612

Challenges

The first attempt at lining was to use bentonite clay lining. Only 3" of clay was used and the pond liner failed with losses equaling the delivery of 1600gpm. The breach was near a stand pipe that was included to withdraw water for the pond. Our recommendation was to remove the stand pipe and use sucker pipes and floats then line the bottom of the pond. The clay liner soon failed above the liner due to wave action with the pond and mineral dissolution of the side wall. The pond was then lined with 40 mil HDPE to the high water mark. The pond is filled during irrigation season and is allowed to dry in the off season. Wildlife such as deer and wild hogs use the pond for water. It is fenced to keep cattle out of the pond. After 10 years of service there is no penetration of the liner and loss of wildlife. The pond uses the 2:1 recommended slope ensuring this.

CHAPTER 10

SUGGESTIONS FOR FUTURE RESEARCH

While drawing the conclusions for this thesis multiple areas were highlighted where future research could improve on the methods used. Additional types of research and methods were noted as areas of possible interest as well.

As the data for the statistical analysis was being analyzed it became abundantly clear that the resolution of the measurements was not precise enough to draw a clear conclusion. The measurement tool used was an aluminum speed square with a resolution of ¼ inches. This was deemed to be too course of a measurement. Any future measurements should be taken in no greater increments than millimeters. This would allow for a more accurate picture of what had transpired with the soil and wave action.

Any future studies that make use of stabilized and unstabilized portions of the liner to measure soil retention should ensure that there are equal amounts of each so that there are even amounts of data for both the treatment and control. When the treatment was applied to the pond for Case Study No. 1 the goal was to use all of the stabilizing liner and not enough thought was given to planning for data collection. This in turn may or may not have biased the results.

Additionally, soil depth may not be the greatest indicator for the benefits or lack thereof for soil stabilizing liner. Potentially, a vegetative cover study could yield more useful results. Using a square meter at different points around the shore could allow a researcher to discern the amount of aquatic plants growing in control and treatment areas. This data could then be used to determine the efficacy of stabilizing liner for fostering plant growth.

A possible variable that was not tested in this study was the effects of wave action on soil retention, although it was alluded to as a possible reason why the smooth liner was not able to retain soil as well. Any future study should take this into account more heavily with wave velocities and numbers on different days and in different conditions being considered in the final analysis. The degree of steepness of the bank should also be studied for its relation to soil erosion by wave action.

The ability of an animal to extract itself from a lined pond is a large concern to land owners. To determine the appropriate steepness for the shore a pond with different angles of shoreline could be studied to determine which angle was most preferred by wildlife such as deer and wild hogs. Using the same square meter technique, animal tracks would be tallied and different points around the pond and this could be cross referenced with the angle of the shore there. This would be best accomplished on a pond that was surrounded on all sides by the same topography and types of vegetation so that the likelihood of a preferential pathway for wildlife would play less of a role in the tallies.

CHAPTER 11

CONCLUSION

This thesis provides a description research conducted on HDPE liner thickness, slope and the evaluation of one soil stabilizing technique, as well as instruction on the lining process as well as making recommendations for successfully completing a lining project.

HDPE is an easily manufactured product that is readily available the world over. It is used nearly every day by nearly every person due to the shear amount of products that are constructed with it. The reason for the proliferation of HDPE as a household product is the many qualities that also make it a nearly ideal geosynthetic lining material. Its resistance to puncture, chemical resistance and inertness and tensile strength lend it well to manufacturing from food containers such as milk cartons to keeping groundwater safe from leachates in landfills.

With the many different types of HDPE lining material available on the market there will almost certainly be a type of liner that will fit any project, pond or catchment. These types include both smooth and textured liner, colored and specialty liners meant to retain soil.

Lining with HDPE also presents its own challenges and risks, however, and during certain conditions special considerations must be taken such as wearing knee pads and gloves when the ambient temperature is high to avoid first degree burns due to the heat absorbed by the liner, or the use of weights when the wind is blowing due to the readiness of liner to catch the wind and act as a sail.

While these considerations are necessary, they are mute if the pond is not surveyed correctly. Precision surveying is the key to creating a pond that has the highest possible water line and does not show any more liner than necessary when full. Incorrect surveying and trenching can lead to catastrophic results as well due to the fact that an uneven water line can cause spillover resulting in compromised integrity of the bank or basin.

With a proper survey in place lining can begin but not without the proper tools. Sheet metal pliers and hook knives may be luxuries that allow for easier handling of the HDPE material, however tools such as hand, track and or extrusion welders are a necessity, without which a no lining project can even be attempted. Even with these specialized tools lining with HDPE is not an easy task. There are methods that make the task of unrolling, measuring and moving the liner easier but even with the methods discussed there is still quite a bit of work and planning that go into successfully welding in a strip of liner.

With that successful weld though comes the obligation of testing. The amount of testing required varies depending on the project and the regulations associated with it. Whether the soap box or another method is used, testing is a best management practice that will save a considerable amount of time, energy and money in the future as any leak larger than a pinhole can drain a pond in a matter of days leading to disastrous consequences. Any punctures discovered during the testing phase should be patched correctly and tested again to determine the watertightness of the patch. The three most common patches are the

Material, Fishmouth and Extrusion patch. Each has their place and are often combined to produce the best seal for any puncture.

During the writing of this document, many case studies were either witnessed or completed by the author. Each presented its own goals and challenges. On Dr. Jim Rogers pond, a study of the effects of specialized soil stabilizing liners was conducted, the results of which showed qualitatively that the addition of this type of liner allows for the flourishing of native terrestrial and aquatic plants and grasses. While the quantitative data did not show this same conclusion, the photographs presented provide evidence for the conclusion drawn.

The purpose of this document was to demonstrate the research into the efficacy of liner thickness, the optimum slope of lined ponds, the use of one type of textured liner and its soil retention properties, as well as how HDPE liners are constructed and the myriad of uses that they have in both regulated and unregulated environments. Due to its cost versus puncture resistance, 40 mil thickness liner was determined to be the best option for recreational pond lining. After a year of observations were taken it was determined that a slope of 2:1 was optimal for self-extrication of wildlife from a lined reservoir. With proper installation a textured liner can greatly reduce the amount of time required for reestablishment of vegetation along the banks of the pond. Finally, given the proper tools, adequate preparation and planning, an HDPE liner can be ideal for many situations.

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APPENDIX

Chemical Resistance Chart for HDPE (High Density Polyethylene)

The chemical resistance chart below is a general guide only. Please contact MENDA for specific applications.

Acetaldehyde - GF	Diethyl Benzene - FN	Methyl Ethyl Ketone - NN
Acetamide, Sat. - EE	Diethyl Ether - FN	Methyl-y-butyl Ether - FN
Acetic Acid, 5% - EE	Diethyl Ketone - GG	Methylene Chloride - GF
Acetic Acid, 50% - EE	Diethyl Malonate - EE	Mineral Oil - EE
Acetic Anhydride - FF	Diethylamine - FN	Mineral Spirits - FN
Acetone - EE	Diethylene Glycol - EE	Nitric Acid, 1-10% - EE
Acetonitrile - EE	Diethylene Glycol Ethyl Ether - EE	Nitric Acid, 50% - GN
Acrylonitrile - EE	Dimethyl Acetamide - EE	Nitric Acid, 70% - GN
Adipic Acid - EE	Dimethyl Formamide - EE	Nitrobenzene - FN
Alinine - EE	Dimethylsulfoxide - EE	Nitromethane - FN
Allyl Alchohol - EE	1,4-Dioxane - GG	n-Octane - EE
Aluminum Hydroxide - EE	Dipropylene Glycol - EE	Orange Oil - GF
Aluminum Salts - EE	Ether - FN	Ozone - EE
Amino Acids - EE	Ethyl Acetate - EE	Perchloric Acid - GN
Ammonia - EE	Ethyl Alcohol (Absolute) - EE	Perchloroethylene - NN
Ammonium Acetate, Sat. - EE	Ethyl Alcohol (40%) - EE	Phenol, Crystals - GF
Ammonium Glycolate - EE	Ethyle Benzene - GF	Phenol, Liquid - NN
Ammonium Hydroxide, 5% - EE	Pine Oil - EG	Phosphoric Acid, 1-5% - EE
Ammonium Hydroxide, 30% - EE	Ethyl Butyrate - GF	Phosphoric Acid, 85% - EE
Ammonium Oxalate - EE	Ethyl Chloride, Liquid - FF	Picric Acid - NN
Ammonium Salts - EE	Ethyl Cyanoacetate - EE	Ethyl Benzoate - GG
n-Amyl Acetate - EG	Ethyl Lactate - EE	Potassium Hydroxide, 1% - EE
Amyl Chloride - FN	Ethylene Chloride - GF	Potassium Hydroxide, Conc. - EE
Aniline - EG	Ethylene Glycol - EE	Propane Gas - FN
Aqua Regis - NN	Ethylene Glycol Methyl Ether - EE	Propionic Acid - EF
Benzaldehyde - EE	Ethylene Oxide - GF	Propylene Glycol - EE
Benzene - GG	Fatty Acids - EE	Propylene Oxide - EE
Benzoic Acid, Sat. - EE	Fluorides - EE	Resorcinol, Saturated - EE
Benzyl Acetate - EE	Flourine - GN	Resorcinol, 5% -- EE
Benzyl Alcohol - FN	Formaldehyde, 10% - EE	Sallcylaldehyde - EE
Bromine - FN	Formaldehyde, 40% - EE	Sallcylic Acid, Powder - EE
Bromobenzine - FN	Formic Acid, 3% - EE	Sallcylic Acid, Saturated - EE
Bromoform - NN	Formic Acid, 50% - EE	Salt Solutions, Metallic - EE
Butadiene - FN	Formic Acid, 100% - EE	Silicone Oil - EE
Butyl Chloride - NN	Freon TF - EG	Silver Acetate - EE
n-Butyl Acetate - EG	Fuel Oil - GF	Silver Nitrate - EE
n-Butyl Alcohol - EE	Gasoline - GG	Skydrol LD4 - EG

sec-Butyl Alcohol - EE	Glacial Acetic Acid - EE	Sodium Acetate, Saturated - EE
tert-Butyl Alcohol - EE	Glutaraidehyde - EE	Sodium Hydroxide, 1% - EE
Butyric Acid - FN	Glycerine - EE	Sodium Hydroxide, 100% - EE
Calcium Hydroxide, Conc. - EE	n-Heptane - GF	Sodium HypoChlorite, 15% - EE
Calcium Hydroxide, Sat. - EE	Hexane - GF	Stearic Acid, Crystals - EE
Carbazole - EE	Hydrazine - NN	Sulphuric Acid, 1-6% - EE
Carbon Disulfide - NN	Hydrochloric Acid, 5% - EE	Sulphuric Acid, 20% - EE
Carbon Tetrachloride -- GF	Hydrochloric Acid, 20% - EE	Sulphuric Acid, 60% - EE
Cedarwood Oil - FN	Hydrochloric Acid, 35% - EE	Sulphuric Acid, 98% - GG
Cellosolve Acetate - EE	Hydroflouric Acid, 4% - EE	Sulphur Dioxide, Liquid - FN
Chlorobenzene - FN	Hydroflouric Acid, 48% - EE	Sulphur Dioxide, Wet or Dry - EE
Chlorine, 10% in Air - EF	Hydrogen Peroxide, 3% - EE	Sulphur Salts - GF
Chlorine, 10% (Moist) - GF	Hydrogen Peroxide, 30% - EE	Tararic Acid - EE
Chloroacetic Acid - EE	Hydrogen Peroxide, 90% - EE	Tetrahydrofuran - GF
p-Chloroacetophenone - EE	Iodine Crystals - NN	Thlonyl Chloride - NN
Chloroform - GF	Isobutyl Alcohol - EE	Toluene - GG
Chromic Acid, 10% - EE	Isopropyl Acetate - EG	Tributyl Citrate - EG
Chromic Acid, 50% - EE	Isopropyl Alcohol - EE	Trichloroacetic Acid - FF
Cinnamon Oil - FN	Isopropyl Benzene - GE	1,2,4-Trichlorobenzene - NN
Citric Acid, 10% - EE	Isopropyl Ether - NN	Trichloroethylene - FN
Cresol - FN	Jet Fuel - FN	Triethylene Glycol - EE
Cyclohexane - FN	Kerosene - GG	2,2,4-Trimethylpentane - FN
Cyclohexanone - FN	Lacquer Thinner - FN	Tripropylene Glycol - EE
Cyclopentane - FN	Lactic Acid, 3% - EE	Tris Buffer, Solution - EG
DeCalin - EG	Lactic Acid, 85% I - EE	Turpentine - GG
n-Decane - FN	Mercury - EE	Undecyl Alcohol - EG
Diacetone Alcohol - EE	2-Methoxyrthanol - EE	Urea - EE
o-Dichlorobenzine - FF	Methoxyethyl Oleate - EE	Vinylidene Chloride - GF
p-Dichlorobenzine - GF	Methyl Acetate - FF	Xylene - GF
1,2-Dichloroethane - NN	Methyl Alcohol - EE	Zinc Stearate - EE
2,4-Dichlorophenol - NN		

Chemical Resistance Classification:
E – 30 days of constant exposure to reagent causes no damage
G – Little or no damage after 30 days of constant exposure to the reagent
F – Some effect after 7 days exposure to the reagent. Solvents may cause swelling and permeation losses
N – Not recommended for continuous use

First letter of each pair applies to conditions at 20°C (68°F); the second to those at 50°C (122°F).

Table A-1 Chemical Resistance Chart for HDPE

(Desco Industries, n.d.)