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Cost and Performance Report

(ER-200920)

Biopolymer as an Alternative to Petroleum-based Polymers to Control Soil Erosion: Iowa Army Ammunition Plant

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ACRONYMS AND ABBREVIATIONS

ATCC	American Type Culture Collection
Bgs	below ground surface
CRADA	Cooperative Research and Development Agreement
DoD	Department of Defense
EL	Environmental Laboratory
EPS	extracellular polymeric substance
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
ETS	Environmental Technology Solutions
GAO	Government Accountability Office
GOCO	Government-Owned Contractor-Operated
IAAAP	Iowa Army Ammunition Plant
LIDAR	Light Detection and Ranging
MSDS	Material Safety Data Sheet
SAFR	small arms firing range
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USPTO	U.S. Patent and Trademark Office

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The U. S. Department of Defense (DoD) uses petroleum-based soil amendments for a number of engineering purposes. These petrochemical-based biopolymers have been shown to be effective for producing soils with increased strength and resistance to erosion. These soil characteristics are important for areas where steep earthen constructs cannot be protected from erosion. This project examines the use of a non-traditional soil additive, a biopolymer, as a substitute for the petrochemical-based synthetic polymers currently used in these applications. The biopolymer offers several advantages over the synthetic polymers including rapid re-vegetation and reduced transport of solids in runoff water. The use of synthetic polymers can be problematic from the standpoint of biodegradation, cost, availability, and logistics. The biopolymers examined in this study are a low density, natural material, which can be transported in a dry state and reconstituted with local water supplies.

The overarching objective of the demonstration, was to validate soil erosion control by the biopolymer in the field at full-scale, and to transfer the technology to end users at Army industrial installations. The performance objectives were to:

- Maintain the original berm slope angle compared to an untreated control;
- Select the most effective soil application method;
- Establish treatment longevity; and
- Evaluate ease of use.

These objectives were met.

TECHNOLOGY DESCRIPTION

A technique has been developed through which *R.tropici*-derived biopolymer can be produced in an aerobic bioreactor. The polymer is separated from the growth media and derivatized in order to produce a non-reactive (non-crosslinking) material that can be used as a soil amendment (U.S. Patent and Trademark Office [USPTO], 2010). When wetted, the biopolymer will form a gel within the soil matrix. Individual soil particles are linked together within the biopolymer matrix, producing a soil in which individual soil particles have greatly reduced mobility and significantly reduced hydraulic conductivity. This change in the physical form of the soil, on a particle level, results in increased soil strength and decreased erodibility. The nature of the *R. tropici* biopolymer is to aid development of plant root systems. The enhanced root development also contributes to decreased soil erodibility by water and wind.

The earthen explosion protection berm at the Iowa Army Ammunition Plant (IAAAP) suffered from water erosion, slumping (loss of protective height), and was sparsely vegetated. The berm was mechanically recontoured and biopolymer was applied, along with grass seed, in three different ways in order to assess the effectiveness of each application method. Light Detection and Ranging (LIDAR) imaging was used to record effects of biopolymer soil application on soil erosion. Visual inspection and plant collection evaluated re-vegetation efforts.

DEMONSTRATION RESULTS

The use of biopolymer derived for *R. tropici* was evaluated as a soil modifier for erosion control and sediment transport was evaluated through slope stability and surface soil durability studies at bench- and meso-scale (Larson et al., 2012). Simulated berms were constructed to evaluate erosion at the angle of repose characteristic on earthen berms and were used to empirically measure soil loss mass. A Silty Sand (SM), Silty Clay (SC) and a Silt (S) soil types were used in the experiments as these soil types represent the worst case for soil erosion. Soils were treated at dosing rates of 0.2%, and 0.5% biopolymer (w:w) and compared to an untreated control of the same soil type. In addition, mesoscale rainfall lysimeters were used to evaluate the ability of the biopolymer to reduce soil erosion and the transport of sediment in both surface runoff water and leachate. Following a series of rain events equivalent to one year rainfall, the mass lost from each "berm" was measured. The untreated soils each lost the greatest soil mass. The Silt soil treated with either 0.2% or 0.5% biopolymer (w:w) and the Silty Sand treated with 0.5% biopolymer (w:w) each maintained a stable mass throughout a year of simulated weathering. The biopolymer-treated soils continued to demonstrate surface durability and resistance to erosion after 20 rain events, the equivalent of more than 2.5 years of weathering.

Sediment loads were measured in runoff water from treated and untreated Silty Clay soil during the slope stability experiments. Biopolymer amendment resulted in a 78% decrease in total suspended solids (TSS) in the runoff water, compared to the untreated control. Particle size analysis of treated and untreated soil demonstrated that the percentage of material in the >0.3-mm particle-size fraction increased by 22% in the biopolymer-treated soil. The biopolymer, performing its natural function as a soil binder, was very effective in this soil type at reducing the loss of sediment in runoff water.

Soil modification by the addition of biopolymer has also been demonstrated to reduce the production of fugitive dust by wind erosion, compared to commercially available, petroleum-based polymers (Larson et al., 2012). The lowest concentrations of respirable dust from a Silty Clay soil were produced when the soil was amended with 1% molasses-derived biopolymer applied in either a single or double application. The third best performance was given by the sorghum-derived biopolymer. A commercial, petroleum-derived polymer was the fourth most effective treatment.

Soil stability is also increased by enhanced plant root formation and development. Treatability studies in this area demonstrated that soil amendment with biopolymer encouraged rapid seed germination, enhanced root development (particularly of the fine root structure, thus increasing plant root density) and increased overall drought tolerance.

In summary, the treatability study on the use of biopolymer amendment to improve slope stability of bermed soil and reduce loss of sediment in surface water runoff showed that the biopolymer:

1. Effectively maintained the slope stability of a simulated berm;
2. Reduced transport of soil particulates in surface runoff;
3. Performed effectively in soils with a high concentration of fines; and

4. Enhanced plant growth, particularly root development, to reduce transport of soil fines.

To achieve the objectives of the field demonstration, an explosion protection berm at IAAAP was reconstructed and treated with biopolymer and fescue seed, applied using a hydroseeder. Different application methods for the biopolymer were tested:

- **Double at depth:** 2 feet of soil was removed, biopolymer was applied, the area was re-covered, and then additional biopolymer and grass seed was applied.
- **Double:** a double surface spray application. The second application was made with grass seed approximately 24-hr after the first application.
- **Single:** a single surface spray application of biopolymer with grass seed.
- **Control:** the control received no biopolymer, only water and grass seed.

Light detection and ranging (LIDAR) was used to virtually survey the ground conditions of the berm following completion of the berm reconstruction, treatment and seeding, and again six months later. For berm change calculations, the data was decimated to 2cm point spacing on an equal interval grid resulting in 2cm vertically and 2cm horizontally. All of the measurements and results were derived from this data sampling. Changes in berm slope and soil elevation were calculated from the differences in the pixels of each area.

Vegetative growth was collected from each treatment area and the control area. Below and above ground biomass was calculated and compared for treatments vs. control. In summary, the average biomass of fescue grass in the biopolymer treated areas increased 223% versus the untreated control area. The ratio of root mass to the above ground plant mass was approximately 7% for the treated areas and 5% for the untreated soil.

Following 6 months of weathering (October 2012 to March 2013), LIDAR imaging showed that the *R. tropici* biopolymer successfully met all performance objectives. The simplest and most effective application method, established by a change in surface roughness over time, was a single surface application of biopolymer and grass seed using a hydroseeder. The double application of biopolymer on the surface was next most successful, followed by a double application at depth; the first application at 1-2 feet below ground surface (bgs) and the second on the surface. The double application at depth demonstrated greater soil compaction due to settling of the lower soil layer. All treated soils had greater biomass than the control area and higher root to above ground mass, adding to the soil stabilization.

The majority of the costs associated with the biopolymer are material cost (biopolymer production and delivery to the site) and labor. The quantity of biopolymer required for slope stabilization is based on soil type and size of the area to be treated. The biopolymer works well at low dosing rates for Silty Sand and Silt soil types. The biopolymer is less successful stabilizing soils with large, heavy grain sizes, such as Sand and Glacial Till and requires higher dosing rates. A dosing rate of 0.5% has been successful with the majority of soils studied. Freight cost for delivery of the biopolymer to the site is dependent on the distance from the manufacturing plant, but biopolymer can be delivered in a dry state and reconstituted onsite. This should reduce shipping charges. Reconstitution does not require use of potable water supplies. The cost of treating a berm with a single application of biopolymer is approximately half (0.52) of what it costs for a traditional earthen berm over a 30-yr time frame.

IMPLEMENTATION ISSUES

There are no issues preventing implementation of this technology on DoD installations and facilities with soil erosion issues. There are no known regulations that apply to the use of this technology and no permits are required to implement this technology. The *R. tropici* bacteria are not added to the soil, just the processed biopolymer they produce. End users for the technology are installations and facilities with erosion control issues such as dirt roadbeds and berms.

Technology transition successes include: a patent, a reviewed Proceedings paper, an ERDC report, and six platform presentations to diverse commercial, industrial, military and academic audiences. Three journal articles are pending as well as a second ERDC report. The biopolymer technology has been the recipient of ERDC Research and Development Awards, the USACE Green Sustainability Award, and the ESTCP Project of the Year.

1.0 INTRODUCTION

1.1 BACKGROUND

1.1.1 Problem Statement

From the standpoint of installation management personnel, the ability to provide non-eroding soils for operational areas is a critical aspect of the modern Army and Army Engineer. Soil berms are used for small arms firing ranges (SAFRs), explosion protection devices, and water control. The methods currently used to reduce soil erosion from berms include placement of geotextiles, use of vegetated areas, and addition of petroleum-based polymers as soil modifiers. Synthetic petroleum-based soil strengthening and stabilizing additives are used for erosion control in areas where vegetation and/or geotextiles are inappropriate, such as SAFRs and explosion protection areas (Newman et al, 2005; Tingle et al., 2007) or where these materials are difficult to apply. Petroleum polymers are based on an increasingly expensive and scarce natural resource. In addition, they are often difficult to transport and apply. The use of petroleum-based polymers also has an increasingly negative public perception due to their limited biodegradability and petrochemical nature (Lentz et al., 2008; Weston et al., 2009). Explosion control berms are used by the Army industrial base in areas where manufacturing and load-and-pack activities present an explosion hazard. In the event of an explosion or fire on one line, the berm prevents the spread to additional areas of the manufacturing plant. Maintaining berm height is a critical parameter to explosion containment.

1.1.2 Technology Description

Rhizobium tropici American Type Culture Collection (ATCC®) 49672, a catalogued symbiotic nodulator of leguminous plants (Martinez-Romero et al. 1991), is also known for its prolific production of a gel-like, extracellular polymeric substance (EPS), a biopolymer (Gil-Serrano et al., 1990). The natural functions of the EPS in the rhizosphere include surface adhesion, self-adhesion of cells into biofilms, formation of protective barriers, water retention around roots, and nutrient accumulation (Laspidou and Rittmann, 2002). The secretion of EPS by bacteria is recognized as a cohesive force in promoting surface erosion resistance in sediments (Droppo, 2009; Gerbersdorf et al., 2008a, 2008b).

A technique has been developed through which *R.tropici*-derived biopolymer can be produced in an aerobic bioreactor. The polymer is separated from the growth media and derivatized in order to produce a non-reactive (non-crosslinking) material that can be transported as a low density, dry solid (U.S. Patent and Trademark Office [USPTO], 2010). This salt can be applied to the soil in the dry form or pre-mixed with water and applied as slurry. When wetted, the biopolymer forms a gel within the soil matrix, reacting and cross linking to yield a form of the biopolymer that has a larger molecular weight and reduced water affinity. Through this action, individual soil particles are linked together within the biopolymer matrix, producing a soil in which individual soil particles have greatly reduced mobility and significantly reduced hydraulic conductivity. This change in the physical form of the soil, on a particle level, results in increased soil strength, reduced air transport, and decreased erodibility.

1.1.3 Advantages and Limitations of the Biopolymer Technology

Commercially, there are numerous products available used for soil strengthening (Tingle et al., 2007); traditional stabilizers such as cement and lime, and non-traditional stabilizers such as polymers and fibers. The synthetic, petroleum-based soil additives are gaining popularity due to their ease of handling and lower safety and environmental concerns compared to traditional soil stabilization agents such as asphalt, cement, and lime. Most synthetic soil-stabilizing compounds are copolymers of ethylene/vinyl acetate or are acrylic copolymers. In some soils, these additives produce soils with improved engineering properties. However, these products can also leach toxic products into the soil (Lentz et al., 2008; Weston et al., 2009) and their production uses a valuable natural resource. The use of biopolymers reduces the generation of hazardous substances in the design, manufacture, and use of the petroleum-based polymers currently in use as well as the use of petroleum in general.

Biologically produced polymers have a number of unique benefits when compared to petrochemical-based polymers, beyond the reduction of chemicals derived from oil. Because biopolymers are produced as a result of complex biosynthesis by bacteria and algae, the polymeric structure is more diversified than the regularly recurring units in traditional plastics. This provides enhanced functionality, including post-application cross-linking, ease of derivitization for specific uses, and a long-lived, but ultimately biodegradable, material without the environmental concerns associated with synthetic polymers (Cabaniss et al., 2005, Decho, 2009, Goto et al., 2001). In addition, the use of these materials acts as a carbon storehouse for readily biodegradable sugars that would otherwise be oxidized to CO2 and contribute to elevated greenhouse gasses in the atmosphere. Biopolymers have been shown to be effective alternatives for the petrochemical-based polymer soil additives currently in use. An advantage noted during preparation of the berm with the biopolymer, was the ease of application and hydroseeding with the liquid biopolymer.

1.1.4 Demonstration Design

The Iowa Army Ammunition Plant (IAAAP) is an active, government-owned, contractor-operated (GOCO) facility in Des Moines County near Middletown in southeast Iowa. It is located approximately 10 miles west of Burlington, Iowa and the Mississippi River. IAAAP is under the command of the U.S. Army Joint Munitions Command, Rock Island. Explosion protection berms separate munition manufacturing lines. Maintaining berm height is an integral part of the plant fire protection plan. Large sections of an earthen berm at IAAAP had eroded from the steep angle and berm height was reduced, leading to ongoing high maintenance costs. During the course of the field demonstration, soil was added to the berm, the berm was recontoured and biopolymer was added to the soil, along with grass seed, to stabilize the steep slope and help reestablish vegetative growth. The Project Manager was Mr. Gary Nijak, Jr. of Environmental Technology Solutions (ETS).

Biopolymer was applied with grass seed using a hydroseeder when the berm construction was complete. Three biopolymer application methods were employed: a single surface application, a double surface application separated by 24-hr, a double application in which 1-2 ft of soil was removed from the face, treated with biopolymer, replaced on the berm and then given a second surface application. The control area received only water and grass seed. Light Detection and

Ranging (LIDAR) is an optical remote sensing technology that can measure the distance to, or other properties of, a target by illuminating the target with light, often using pulses from a laser. It can map physical features with very high resolution. In this instance, it was used at the completion of berm construction and again 6 months later, to detect changes in berm height and soil distribution on and around the berm to establish effects of biopolymer soil modification on soil erosion.

1.2 OBJECTIVES OF THE DEMONSTRATION

The overarching objective of the demonstration was to validate soil erosion control by the biopolymer in the field at full-scale, and to transfer the technology to end users at Army industrial installations. The performance objectives were to:

- Maintain the original berm slope angle compared to an untreated control
- Select the most effective soil application method for the biopolymer
- Establish treatment longevity; and
- Evaluate ease of use.

1.3 REGULATORY DRIVERS

According to Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management," Energy Independence and Security Act, the U.S. military is currently the nation's single largest consumer of petrochemicals produced from oil. Under Department of Defense (DoD) Directive 4140.25, "DoD Management Policy for Energy Commodities and Related Services," Pentagon officials put the total energy costs at $13 billion for 2007, and $20 billion for 2008. The Army is "building green, buying green and going green", per Addison Davis, the service's Deputy Assistant Secretary for Environment, Safety and Occupational Health. The development and use of biopolymers that can replace petrochemical polymers currently in use will be part of that process. The Government Accountability Office (GAO) has recently released a report (No. GAO-08-523T, March 13, 2008) entitled 'Defense Management: Overarching Organizational Framework Could Improve DoD's Management of Energy Reduction Efforts for Military Operations'. Biopolymer technologies will deal with the non-energy related petrochemical uses associated with polymeric chemicals, soil additives, and products that can be replaced with biologically produced polymers. In addition, Pollution Prevention [Maps to Contingency Operations/Weapons Systems and Platforms], Waste Management Utilizing Waste Characteristics, Sustainable Technologies for Military Facilities and Sustainable Lubricants and Fluids are identified as requirements PP-5-06-01, CM-6-06-02, CM-9-06-01, and PP-6-02-03 FY09 of the Army Environmental Requirements and Technology Assessments report.

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2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

Both synthetic and biologically-produced polymers are made of repetitive monomeric units. The term “primary structure” is used to describe the chemical composition and the sequence of the repeating units. Most synthetic polymers prepared using petroleum-based monomeric units have a much simpler, less varied structure and are typically random copolymers where the repeat unit sequence is statistically controlled. In contrast, many biopolymers can fold into functionally compact shapes through crosslinking (via hydrogen bonding, hydrophobic associations, multivalent ion coordination, etc.). This changes not only their shape, but their chemical properties. Unlike petroleum-based polymers with their uniform molecular structure and reactivity among monomers, one advantage of the biopolymer is its ability to crosslink due to reactive moieties within a single polymeric component.

The natural functions of the *R. tropici* EPS in the rhizosphere include surface adhesion, self-adhesion of cells into biofilms, formation of protective barriers, water retention around roots, and nutrient accumulation (Laspidou and Rittmann, 2002). The secretion of EPS by bacteria is recognized as a cohesive force in promoting surface erosion resistance in sediments (Droppo, 2009; Gerbersdorf et al., 2008a, 2008b). A technique has been developed through which *R.tropici*-derived biopolymer can be produced in an aerobic bioreactor. The biopolymer is then separated from the growth media and the *R. tropici* bacteria and derivatized in order to produce a non-reactive (non-crosslinking) material that can be transported as a low density, dry solid (USPTO, 2010). This salt can be applied to the soil in the dry form or pre-mixed with water and applied as slurry. When wetted, the biopolymer will form a gel within the soil matrix. With the soil acting as a buffer, the ionic character of the polymer salt is neutralized and the polymer can begin reacting with itself and cross linking to yield a form of the biopolymer that has a larger molecular weight and has reduced water affinity. Through this action, individual soil particles are linked together within the biopolymer matrix, producing a soil in which individual soil particles have greatly reduced mobility and significantly reduced hydraulic conductivity. This change in the physical form of the soil, on a particle level, results in increased soil strength, reduced air transport, and decreased erodibility. The use of a biopolymer as a soil modifier for erosion control and sediment transport was evaluated through slope stability and surface soil durability studies at bench- and meso-scale (Larson et al., 2012). The report concluded that application of the biopolymer to soil at economically feasible loading rates could effectively maintain the slope stability of a simulated berm. In addition, the biopolymer was able to reduce the transport of soil particulates in runoff water from the berm. The biopolymer performed effectively across a range of soil types, including those with a high concentration of soil fines, and, thus, at highest risk for erosion.

2.2 CHRONOLOGY OF DEVELOPMENT

Biopolymer research was initially sponsored (2007) by the Engineer Research and Development (ERDC)-Geotechnical and Structures Laboratory, through the Military Engineering 6.1 program. The Environmental Security Technology Certification Program (ESTCP) funded the current project, ER-200920. Since 2007, one patent has been granted on the process, three licenses have been signed for production, and over 12 Cooperative Research and Development Agreements

(CRADA) have been signed with private companies and other government agencies, including the U.S. Department of Agriculture (USDA). In addition, two Small Business Innovation Research grants were awarded in 2012 for biopolymer research and development. The biopolymer project has been honored with several awards:

- 2009 – ERDC Research and Development Achievement Award, *Biostabilization of Soils;*
- 2009 – U.S. Army Research and Development Award, *Biostabilization of Soil;*
- 2011 – U.S. Army Corps of Engineers (USACE) Green Innovation Award, *Biopolymer Alternatives to Petroleum-based Polymers for Soil Modification;*
- 2011 – Federal Laboratory Consortium Technology Transfer Award, *Biopolymer Alternatives to Petroleum-based Polymers for Soil Modification;and*
- 2012 – ESTCP "Project of the Year."

2.3 TECHNOLOGY APPLICATIONS

The biopolymer technology could be applied to soil stabilization and erosion control in both military and civilian situations. Some of the potential applications include stabilization of SAFR berms, dirt roadsides, and areas with disturbed soil, such as post-wildfires and construction areas, and levees. The biopolymer can play a role in rapid re-vegetation of disturbed soils around construction and mining sites and repair of riparian habitat. The biopolymer is also effective in the reduction of fugitive dust in many soil types (Larson et al., 2012).

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Commercially, there are numerous products available used for soil strengthening (Tingle et al., 2007); traditional stabilizers such as cement and lime and non-traditional stabilizers such as polymers and fibers. The synthetic, petroleum-based soil additives are gaining popularity due to their ease of handling and lower safety and environmental concerns compared to traditional soil stabilization agents such as asphalt, cement, and lime. Most synthetic soil-stabilizing compounds are copolymers of ethylene/vinyl acetate or are acrylic copolymers. In some soils, these additives produce soils with improved engineering properties. Examples of commercial-off-the-shelf petroleum-based products include RhinoSnot, GorillaSnot, and SoilTac. However, these products can also leach toxic products into the soil (Lentz et al., 2008; Weston et al., 2009) and their production uses a valuable natural resource. The use of biopolymers reduces the generation of hazardous substances in the design, manufacture, and use of the petroleum-based polymers currently in use as well as the use of petroleum in general.

Biologically produced polymers have a number of unique benefits when compared to petrochemical-based polymers, beyond the reduction of chemicals derived from oil. Because biopolymers are produced as a result of complex biosynthesis by bacteria and algae, the polymeric structure is more diversified than the regularly recurring units in traditional plastics. This provides enhanced functionality, including post-application cross-linking, ease of derivitization for specific uses, and a long-lived, but ultimately biodegradable, material without the environmental concerns associated with synthetic polymers (Cabaniss et al., 2005; Decho, 2009; Goto et al., 2001). In addition, the use of these materials acts as a carbon storehouse for readily biodegradable sugars that would otherwise be oxidized to CO_2 and contribute to elevated greenhouse gasses in the atmosphere. Biopolymers have been shown to be effective alternatives for the petrochemical-based polymer soil additives currently in use. An advantage noted during preparation of the berm with the biopolymer, was the ease of application and hydroseeding with the liquid biopolymer.

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3.0 PERFORMANCE OBJECTIVES

The quantitative and qualitative criteria that were used to evaluate the performance of the biopolymer-amended soils in the management of soil erosion and slope stability are presented in Table 1.

Table 1. Performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Determine effectiveness at maintaining the original angle of berm slope compared to an untreated control	Pre- and post-treatment measurement of soil elevation through LIDAR analysis	• <10% change from the original slope	Successful. All treated areas maintained the slope of the berm and reduced the surface roughness that is indicative of erosion
Determine which application method is most effective and efficient	Compare changes in soil elevation and surface roughness for three application methods against an untreated control area	• <10% change from the original slope	Successful. A single surface application using a hydroseeder was most effective and efficient at applying biopolymer to the soil.
Determine remediation effectiveness through longevity of treatment effects	Pre- and post-treatment measurement of soil elevation through LIDAR analysis.	• <10% change from the original slope	Successful. All treated areas have maintained the slope of the berm and reduced the surface roughness that is indicative of erosion.
Determine remediation effectiveness through establishment of vegetation.	Post-treatment measurement of above and below ground biomass.	• Increase in biomass over the control (increase variable over time)	Successful. Treated areas showed an increase in biomass over the control areas. All treated areas continue to be well grassed at 18 months post-treatment.
Qualitative Performance Objectives			
Ease of use	Feedback from field technicians on time and ease of application and berm maintenance compared to traditional methods	• Berm construction time using biopolymer is not greater than traditional construction methods. • Biopolymer requires less time to apply and is easier to use than the petroleum-based amendments • Biopolymer-amended berms require less maintenance time than traditional berms	• Successful, based on conversations with facility personnel • Successful, based on manufacturer estimates of application times • Successful, based on conversations with IAAAP maintenance personnel

The explosion protection berm at IAAAP was monitored for 12 months. The biopolymer-treated areas showed no change in slope over this time. The treated slopes were well grassed. However, the control area showed cracking and signs of slippage after 6 months. A full landslip occurred in the control area at 20 months. The biopolymer-treated soils have remained stable. A 36 month performance update was included as Appendix D of the Final Report.

4.0 SITE DESCRIPTION

4.1 SITE LOCATION

The IAAAP is an active, GOCO facility in Des Moines County near Middletown in southeast Iowa. It is located approximately 10 miles west of Burlington, Iowa, and the Mississippi River. The IAAAP is under the command of the U.S. Army Joint Munitions Command, Rock Island. Approximately one-third of the IAAAP property is occupied by active or formerly active munitions production or storage facilities.

There is a need to strengthen the soil in areas where soil depletion by hydrological erosion has occurred. A specific example is the soil slippage of earthen mound 3A-05-1 (Figures 1 and 2), located at IAAAP. The berm, used for explosion containment and protection is located between two manufacturing buildings. Ongoing maintenance costs for the berm have been high due to large amounts of soil erosion. Large sections of the berm have eroded from the steep angle of the berm.

Figure 1. East face of Berm 3A-5-01 at Iowa Army Ammunition Plant showing evidence of erosion, vegetation loss, soil slope degradation and loss of protective height.

Figure 2. West face of Berm 3A-5-01 at Iowa Army Ammunition Plant showing evidence of erosion, vegetation loss, soil slope degradation and loss of protective height

4.2 SITE GEOLOGY/HYDROGEOLOGY

The region of the IAAAP has a mean temperature of 51.8 °F. The average annual precipitation is 40.6 inches. This precipitation is well distributed throughout the year. Southeast Iowa is wetter and warmer than most of the rest of the State. Winters are generally mild, with infrequent heavy snows. Ice storms, however, are common, with one or two destructive storms occurring each year. The potential for frost lasts through the middle of April. March is the month with highest winds; May and June typically have the most rain. Thunderstorms, especially common in June and July, occur on an average of 55 days per year. In the six months between LIDAR evaluations (October 2011 to March 2012) the site received 12.93 in of rainfall and 12.4 in of snow. In the 14 months since the last evaluation, the site has received just over 50 inches of rain, 7 and 11inches in April and May 2013, respectively, and 25 inches of snow. Total rainfall in 2012 was just over half of what is normally received in a year making it a drier than normal year. The unusually heavy rainfall that occurred in April and May 2013, as indicated above, was the heaviest monthly rainfall on record during the demonstration timeframe. Snowfall was also unusually heavy during 2013 with two months recording total snowfalls of over 11 inches.

Hard fescue (*Festuca brevipila*) is the grass of choice in this area for re-vegetation following construction activity, stabilizing roadsides and ditch banks. Fescue is an introduced cool-season, fine-leaved perennial bunchgrass. It is long-lived, persistent and competitive with other grasses and weeds (USDA, NRCS Plant Fact Sheet, http://plants.usda.gov).

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

Several different testing approaches to evaluate biopolymer application methods were taken during reconstruction of Berm 03-50-A at the IAAAP (Figure 3).

- Area A was untouched during the course of the project. The rest of the berm was recontoured. This area was not included in any erosion calculations.
- Area B, two feet of soil was removed, biopolymer was applied, the area was re-covered, and then additional material was applied (Double at depth).
- Area C was a double surface spray application (Double).
- Area D was a control that received no biopolymer application (Control, C).
- Area E was a single surface spray application (Single).

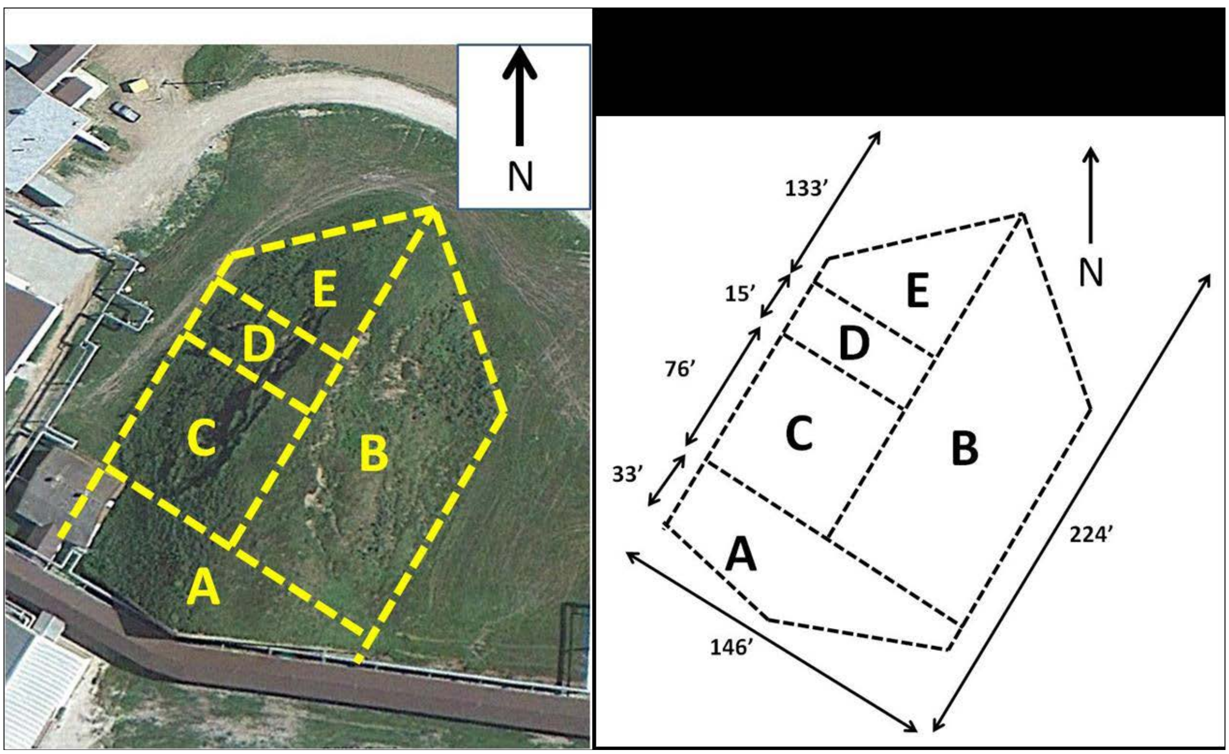

Figure 3. Site layout of different testing approaches for biopolymer application at the IAAAP, Berm 03-05-A.

5.2 BASELINE CHARACTERIZATION

The results of baseline characterization activities have been discussed in Section 2.1 of this report and in Larson et al. (2012). Application of the *R. tropici* biopolymer to soil at economically feasible loading rates could effectively maintain the slope stability of a simulated berm. In addition, the biopolymer was able to reduce the transport of soil particulates in runoff water from the berm. The biopolymer performed effectively across a range of soil types, including those with a high concentration of soil fines, and, thus, at highest risk for erosion.

5.3 TREATABILITY STUDY RESULTS

Biopolymer treatability studies have been detailed in Larson et al. (2012) and published in the ESTCP ER-200920 Final Report (2014). Only results pertinent to erosion control and rapid re-vegetation are summarized here. Simulated laboratory berms were constructed to evaluate erosion at the angle of repose characteristic on earthen berms and were used to empirically measure soil loss mass. A Silty Sand, Silty Clay and a Silt soil types were used in the experiments as these soil types represent the worst case for soil erosion. Soils were treated at dosing rates of 0.2%, and 0.5% biopolymer (w:w) and compared to an untreated control of the same soil type. In addition, mesoscale rainfall lysimeters were used to evaluate the ability of the biopolymer to reduce soil erosion and the transport of sediment in both surface runoff water and leachate.

Following a series of rain events equivalent to one year rainfall, untreated Silty Sand soil lost 40.0 kg of soil mass (69% of the total soil mass) and untreated Silt soil lost 32.0 kg, or 66% of the total mass. In contrast, the same soils when treated with 0.2% biopolymer (w:w) lost 8.0 kg (approximately 17% of the total mass, Silty Sand) and 1.0 Kg (approximately 1% of the total mass, Silt soil). The mass lost from each "berm" is shown in Figure 4 for each soil type and each biopolymer loading rate. The untreated soils each lost the greatest soil mass followed by the Silty Sand treated with 0.2% biopolymer (w:w). The Silt soil treated with either 0.2% or 0.5% biopolymer (w:w), and the Silty Sand treated with 0.5% biopolymer (w:w) each maintained a stable mass throughout a year of simulated weathering. The biopolymer-treated soil continued to demonstrate surface durability and resistance to erosion after 20 rain events, the equivalent of more than 2.5 years of weathering.

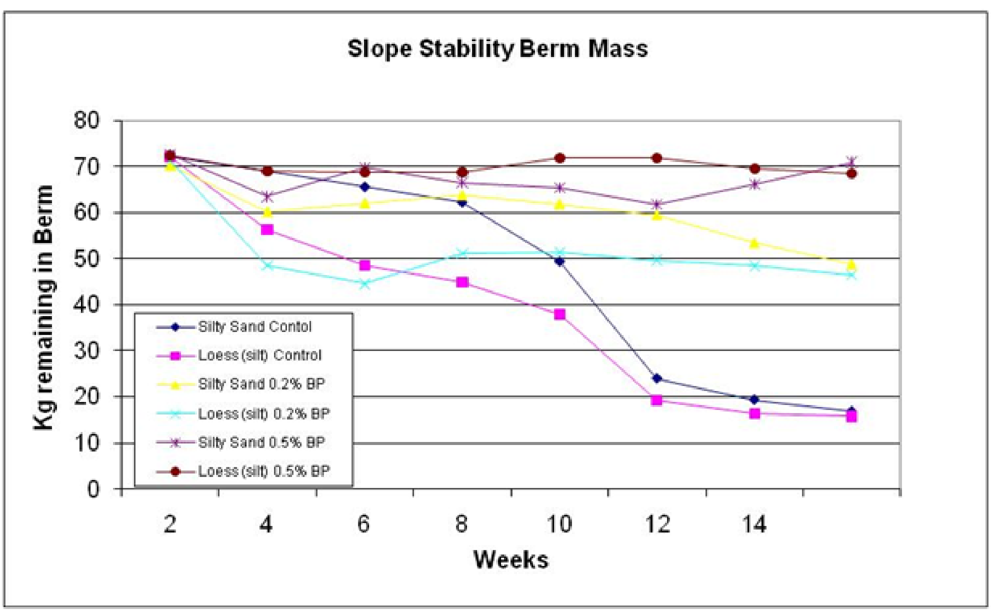

Figure 4. Mass lost from simulated berms by soil type and biopolymer loading rate.

Sediment loads were measured in runoff water from treated and untreated Silty Clay soil during the slope stability experiments. Biopolymer amendment resulted in a 78% decrease in TSS in the runoff water. Particle size analysis of treated and untreated soil demonstrated that the percentage of material in the >0.3-mm particle-size fraction increased by 22% in the biopolymer-treated soil. The biopolymer, performing its natural function as a soil binder, was very effective in this soil type at reducing the loss of sediment in runoff water.

Soil modification by the addition of biopolymer has also been demonstrated to reduce the production of fugitive dust by wind erosion, compared to commercially available, petroleum-based polymers (Larson et al., 2012). Silty Sand soil was treated with either biopolymer, commercial petroleum polymer, or distilled water (control). The wind erosion test was performed as described in Rushing and Newman (2010). Additionally, during the air impingement test, 300 grams (g) of Ottawa sand (US sieve size #20-30) was injected into the air stream. The sand injection increases surface scour and is intended to replicate actual conditions as suspended dust particles impart additional abrasion to the ground surface. Ottawa sand provides a uniform, consistent material that does not impact the optical sensor measurements.

The lowest concentrations of respirable dust were produced when the soil was amended with 1% molasses-derived biopolymer applied in either a single or double application (Figure 5). The third best performance was given by the sorghum-derived biopolymer. A commercial, petroleum-derived polymer was fourth most effective treatment.

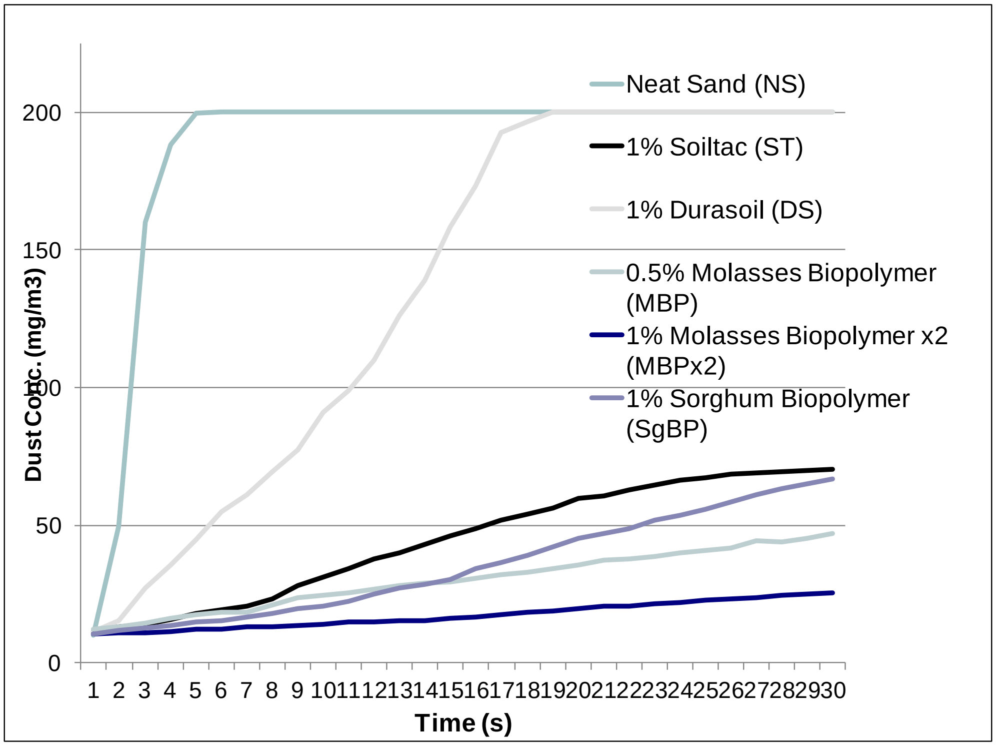

Figure 5. Concentrations of respirable dust produced from soil amended with commercial petroleum-based polymers and the *R. tropici* biopolymer.

Soil stability is also increased by enhanced plant root formation and development. Treatability studies in this area demonstrated that soil amendment with biopolymer:

- encouraged rapid germination;
- enhanced root development, particularly of the fine root structure, increasing plant root density; and
- increased drought tolerance.

Greenhouse studies examined the germination rate of seeds grown in soil amended with either 0 mg, 10 mg or 30 mg of biopolymer. There was a statistically significant increase in germination rate between either of the biopolymer-amended soils and the untreated soil (Figure 6, Left). When these seedlings were then subjected to 10 days of simulated drought, seedings grown in biopolymer-amended soil had a significantly improved survival rate (Figure 6, Right).

Plant growth studies conducted in a greenhouse established the development of enhanced below ground mass that results in a higher rate of carbon sequestration, nitrogen fixation (with nitrogen-fixing species such as clover), and greater soil stability (measured through decrease in TSS in the run-off water). A dense root mat on the surface of a slope provides an armoring effect, reducing surface erosion and making the berm shape less susceptible to failure (slumping). Increased above ground biomass provides vegetative thickness and greater soil coverage. When root mass only is compared, there is both greater root density and increased development of the fine root structure in plants grown in the biopolymer-amended soil.

In summary, the treatability study on the use of biopolymer amendment to improve slope stability of bermed soil and reduce loss of sediment in surface water runoff showed that the biopolymer:

1. Effectively maintained the slope stability of a simulated berm;
2. Reduced transport of soil particulates in surface runoff;
3. Performed effectively in soils with a high concentration of fines; and
4. Enhanced plant growth, particularly root development, to reduce transport of soil fines.

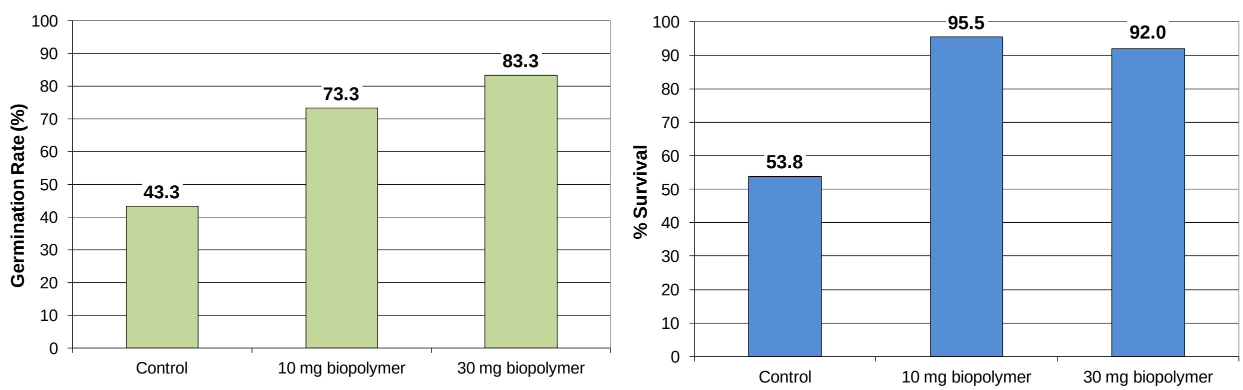

Figure 6. Improvement in germination rate (Left) and drought resistance (Right) in seedlings grown in soil amended with *R. tropici* biopolymer.

5.4 FIELD TESTING

A Gantt chart is provided (Table 2) to show the schedule for each phase of the field demonstration and the relationships between each phase.

Table 2. Gantt chart of the IAAAP berm field demonstration schedule.

Task		1Q	2Q	3Q	4Q
Phase 1	Site visit to acquire soil samples for baseline characterization				
	Laboratory testing of soil to determine the quantity of biopolymer required				
	Biopolymer production*				
Phase 2	Berm reconfiguration				
	Biopolymer and grass seed application				
	Initial LIDAR				
Phase 3	Berm monitoring				
	LIDAR re-measurement				
Phase 4	Sample analysis				

*Key decision point

5.5 SAMPLING METHODS

The number and types of sampling conducted during the field demonstration are summarized in Table 3 and detailed below.

Table 3. Samples collected during the field demonstration.

Component	Matrix	Number of Samples	Analyte	Location
Pre-demonstration sampling	Soil	2-5 gallon buckets	Soil characterization and biopolymer amendment determination	Collected by grab samples from the entire berm
Technology performance sampling	LIDAR	1	Soil elevation	All surface monitoring devices
Post-demonstration sampling	LIDAR	1	Soil elevation	All surface monitoring devices
	Vegetative growth		Site survey	5 locations from each demonstration area

Post-treatment, each area was observed at various stages throughout the demonstration period. Onsite evaluations and analysis of photographic data in 5, one-meter areas, randomly selected to establish biomass of the fescue grass were used to evaluate vegetative growth.

LIDAR measurements depend on point spacing. The point spacing collected varies with how close the laser is to what it is measuring, but for modeling purposes the data was decimated to

2cm point spacing on an equal interval grid resulting in 2 cm vertically and 2cm horizontally. All of the measurements and results were derived from this data sampling.

For berm change calculations, the berm was visualized, as shown in Figure 7, and changes in slope and elevation were calculated from the differences in the pixels of each area.

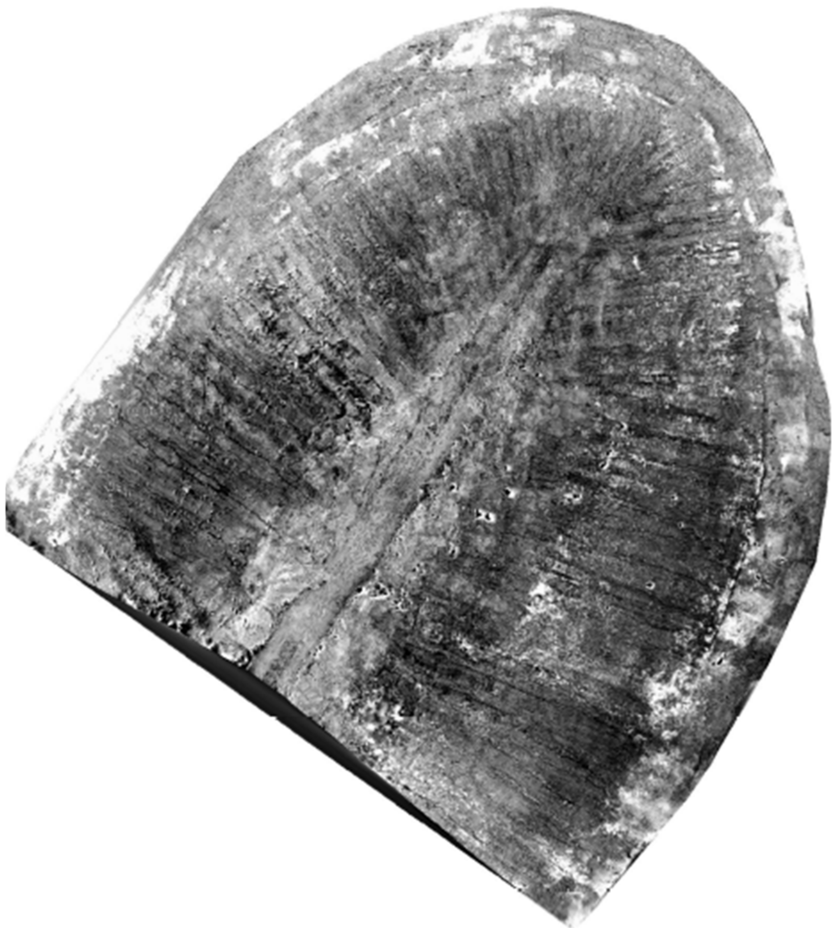

Figure 7. Top view of the berm structure based on soil elevation. Darker color indicates a loss of soil elevation (rutting). Light areas indicate an increase in elevation (soil deposition).

The software used to collect the measurements with the laser was FXController; the software that the Project team used to join the scan data together with the registration spheres, as well as apply the real world GPS coordinates to the point clouds was Trimble's RealWorks Survey Advanced version 7.0. Each treatment area was divided into equal size rectangles for data analysis. The analysis done on the 14 individual rectangles was performed using ESRI's ARCMAP version 10.0, using both the Spatial Analyst and 3-D Analyst extensions. The LIDAR used was Trimble's FX terrestrial 3-D Laser Scanner. Instrument calibration followed manufacturer's guidelines.

5.6 SAMPLING RESULTS

5.6.1 Berm Reconstruction

The final reconstructed berm following biopolymer amendment and seeding with fescue grass is shown in Figure 8.

Figure 8. Berm 3A reconfigured, treated with biopolymer for soil stabilization, and seeded with fescue grass.

5.6.2 Vegetative Growth

The average biomass of fescue grass in the biopolymer treated areas increased 223% versus the untreated control area. The ratio of root mass to the above ground plant mass was approximately 7% for the treated areas and 5% for the untreated soil.

5.6.3 LIDAR Imaging

An initial LIDAR image of the East face of the completed berm is shown in Figure 9. This face was treated with a double application of the biopolymer; the first at 1-2 feet bgs and the second application on the surface. Biopolymer (first application), and biopolymer plus seed (second application), were applied using a hydroseeder.

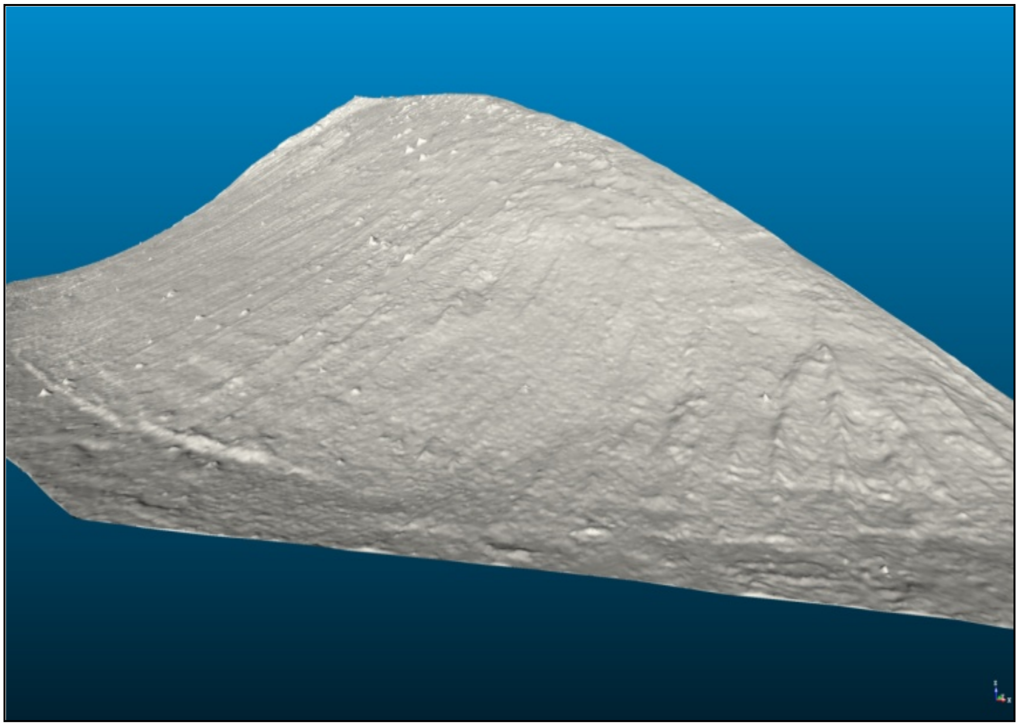

Figure 9. Initial LIDAR image of the completed East face of the explosion protection berm at the Iowa Army Ammunition Plant.

Following six months of weathering (October 2012 to March 2013), the LIDAR team returned to IAAAP and re-measured the berm surface elevation using the original points. A map was constructed of surface elevation changes (Figure 10). The pixels themselves were used to calculate the change in soil volume across the berm. All volume changes were assumed to be the result of erosion and vegetative growth was not factored into the calculations. The total volume change and surface roughness by treatment are shown in Figure 11. The smallest change in surface roughness was seen in the area treated with a single surface application of the biopolymer. The greatest change in soil volume was observed in the area treated with biopolymer at depth. Each of the other areas, including the control, demonstrated very little change in soil elevation over six months. We believe this compaction is due to settling of the disturbed lower layer of soil.

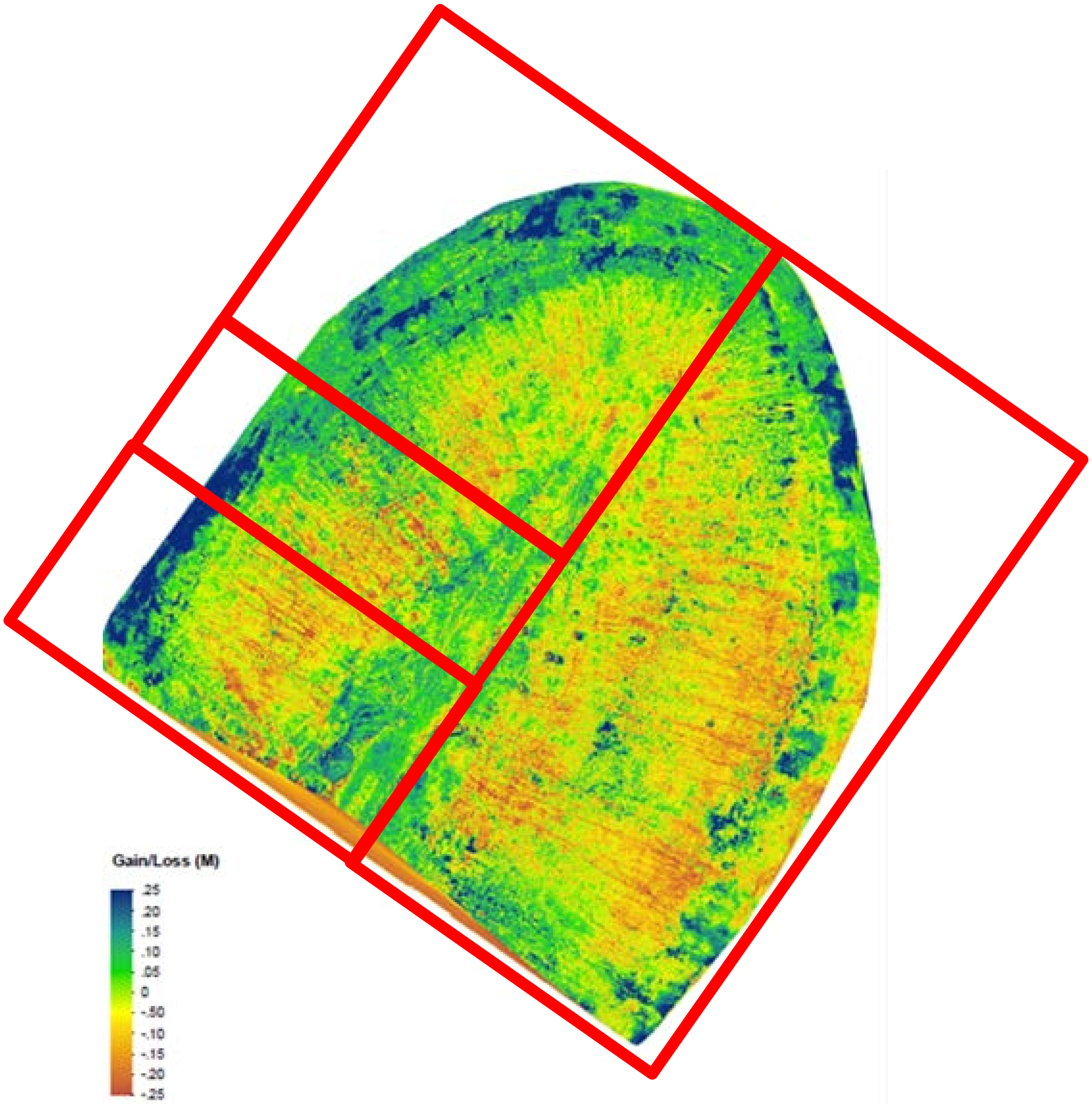

Figure 10. LIDAR image of the top view of berm showing changes in soil elevation (net gain and loss) by color differences.

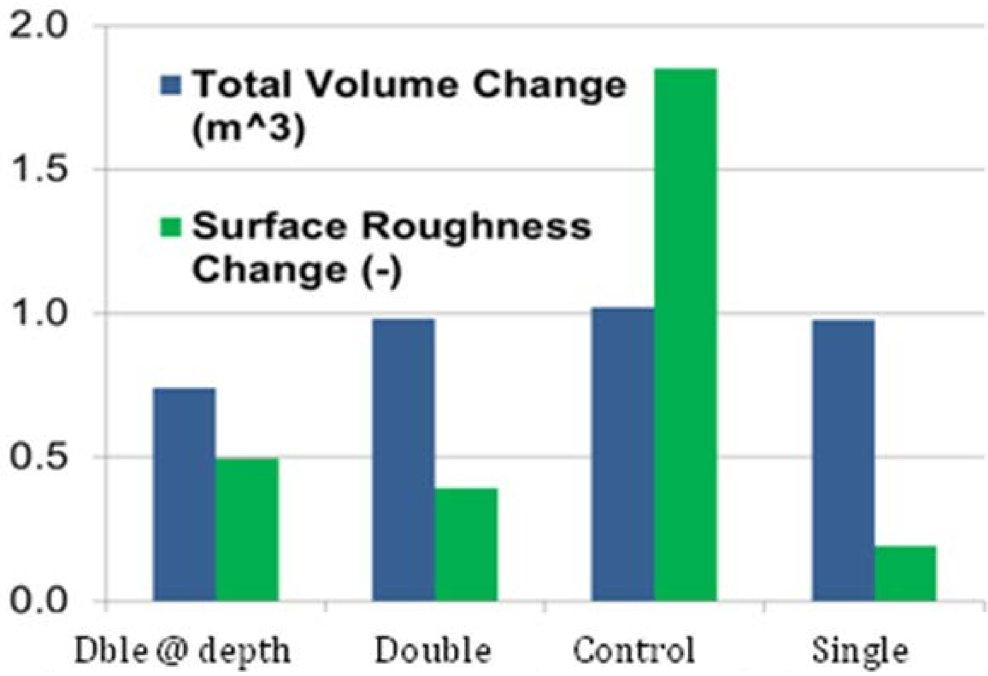

Figure 11. Changes in soil volume and surface roughness of the berm six months post-treatment by application method and compared to the untreated but grassed control.

6.0 PERFORMANCE ASSESSMENT

The objective of the biopolymer demonstration was to confirm on a large scale, that biopolymer soil amendment can stabilize a steep slope and prevent soil slumping and erosion. Secondary objectives were to establish the most effective and efficient means of applying the biopolymer and to compare the establishment of vegetation on the treated and untreated slopes. The performance objectives are summarized in Table 4.

Table 4. Results in meeting performance objectives for soil stabilization of slopes with biopolymer.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Determine effectiveness at maintaining the original angle of berm slope compared to an untreated control	Pre- and post-treatment measurement of angle of slope through LIDAR analysis	• <10% change from the original slope • Effectiveness determined by statistical analysis of data by Student t-test or ANOVA	Successful. All treated areas maintained the slope of the berm and reduced the surface roughness that is indicative of erosion.
Determine which application method is most effective and efficient	Compare changes in soil elevation and surface roughness for three application methods against an untreated control area	• <10% change from the original slope • Effectiveness determined by statistical analysis of data by Student t-test or ANOVA	Successful. A single surface application using a hydroseeder was most effective and efficient at applying biopolymer to the soil.
Determine remediation effectiveness through longevity of treatment effects	Pre- and post-treatment measurement of angle of slope through LIDAR analysis.	• <10% change from the original slope • Effectiveness determined by statistical analysis of data by Student t-test or ANOVA	Successful. All treated areas have maintained the slope of the berm and reduced the surface roughness that is indicative of erosion.
Determine remediation effectiveness through establishment of vegetation.	Post-treatment measurement of above and below ground biomass.	• >50% increase in biomass over the control • Effectiveness determined by statistical analysis of data by Student t-test or ANOVA	Successful. Treated areas showed an increase in biomass over the control areas. All treated areas continue to be well grassed at 18 months post-treatment.
Qualitative Performance Objectives			
Ease of use	Feedback from field technicians on time and ease of application and berm maintenance compared to traditional methods	• Berm construction time using biopolymer is not greater than traditional construction methods. • Biopolymer requires less time to apply and is easier to use than the petroleum-based amendments • Biopolymer-amended berms require less maintenance time than traditional berms	• Successful, based on conversations with facility personnel • Successful, based on manufacturer estimates of application times • Successful, based on conversations with IAAAP maintenance personnel

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7.0 COST ASSESSMENT

The cost of using a biopolymer as a replacement for petroleum products for soil slope stabilization is dependent on the area of slope to be stabilized, the current cost of petroleum-based products, and the availability of earth moving equipment and a hydroseeder. In the treatability study (Larson et al., 2012), three highly erorodible soils were amended with biopolymer at three dosing levels and exposed to both water and wind erosion. The results were compared to both controls and commercial petroleum-based products. The field demonstration used the best performing biopolymer amendment and examined alternate application methods, using LIDAR imaging to evaluate slope stabilization over time.

7.1 COST MODEL

Stabilization of the explosion protection berm at IAAAP was a full-scale field demonstration. The relevant costs are documented in Table 5. Total cost is expressed as per square foot of soil being treated. No permitting or environmental reporting costs were incurred. No bacteria are applied to the soil as the exopolymer is separated from the bacteria during processing. No waste disposal costs were incurred.

The majority of the costs associated with the biopolymer are material cost and labor. The quantity of biopolymer required for slope stabilization is based on soil type and size of the area to be treated. The biopolymer works well at low dosing rates for Silty Sand and Silt soil types. The biopolymer is less successful stabilizing soils with large, heavy grain sizes such as sand and glacial till and requires higher dosing rates. A dosing rate of 0.5% has been successful with the majority of soils studied. When this technology is applied to a different site, baseline soil characterization should not be needed because these areas generally have already been characterized to support ongoing monitoring of range activities. Minor treatability costs incurred prior to the installation would determine the optimal biopolymer dosage. The material costs should scale linearly with increasing area. Freight cost for delivery to the site is dependent on the distance from the manufacturing plant, but biopolymer can be delivered in a dry state and greatly reduces the cost of shipping.

Equipment and labor costs depend on the availability of equipment and operators provided by the installation. Most installations have earth-moving equipment, trained operators, hydroseeders and grass seed. Labor must still be accounted for, and this may be overtime work depending on the range situation. If a range is in use through the week and maintenance must be done on the weekend, scheduling and additional labor costs must be taken into account. If equipment and operators must be hired from local contracting companies, costs will be greater. For the field demonstration, additional soil had to be purchased by the contracting company in order to restructure the explosion safety berm to the original specifications. If soil for this purpose was available on-site, this cost would only be reflected in labor.

Table 5. Cost for berm slope stabilization using biopolymer.

Cost Element	Data Tracked During the Demonstration			Total Cost ($)
Treatability study	• Labor	Engineer	40 hr	8000
		Engineer technician	80 hr	4800
	• Travel	Sample collection		2500
	• Materials	Lab supplies		1000
	• Analytical laboratory costs			5000
	Total treatability study			**21,300**
Material cost	$ per gal of biopolymer	$ provided by vendor	5.00	
	• 11,000 gal needed based on surface area to be treated			55,000
	• Additional soil for re-contouring berm			2500
	Total material cost			**57,500**
Installation	$ per gal of biopolymer	$ provided by vendor	1.10	
	• Delivery costs			19,100
	• Dozer rental (2 days)			2000
	• Hydroseeder (2 days)			3800
	• Labor			4020
	• ETS per diem travel			2500
Waste disposal	No waste disposal required			NA
Operation and maintenance costs	No unique requirements			NA
Long-term monitoring	No cost tracking			NA
	Total Installation Cost			**31,420**
Grand Total Technology cost				**110,220**

7.2 COST DRIVERS

The major cost driver for implementing this technology is the biopolymer production and delivery to the site. This will vary according to the distance from the production site. Biopolymer can be delivered and used in a dry state, which reduces the cost of shipping. If the biopolymer is reconstituted on-site, the water used does not need to be potable water but can come from an installations “grey water” system, conserving water resources.

The second cost driver, although not unique to this technology, is the availability of heavy earth-moving equipment and trained operators for berm reconstruction, and the availability of a hydroseeder. If these items need to be rented, the cost of technology implementation greatly increases, as can be seen in Table 5. The total cost of equipment and labor, not counting the cost of additional soil needed for restructuring the berm, was $9820. No permitting or environmental reporting costs were incurred.

The biopolymer has been demonstrated to be effective at slope stabilization in a variety of highly erodable soil types. Soil characterization of each single site to determine the concentration of biopolymer to be added should not be necessary. Soils with little organic matter or nutrient content, however, may need to be supplemented with compost and/or fertilizer prior to re-vegetation.

7.3 COST ANALYSIS

The basic site description this cost is based on is a berm (sloped soil structure) lasting 30 years. It is assumed that heavy equipment and operators are provided by the installation. The cost of the biopolymer is based on gallon/ area of soil surface. The biopolymer was produced and delivered to the site by a commercial source and CRADA partner, ETS, Inc. A cost assessment for implementation of this technology, based on report of the commercial partner and based on the assumptions listed above, has been presented in Table 5.

Comparative costs for construction and maintenance of a traditional earthen berm are shown in Table 6. The costs have been adjusted to reflect 2012 dollars. The cost of treating a berm with a single application of biopolymer is approximately half (0.52) of what it costs for a traditional earthen berm over a 30-year time frame.

The explosion protection berm at IAAAP was monitored for 12 months. The biopolymer-treated areas showed no change in slope over this time. The treated slopes were well grassed; the control areas showed signs of slippage after 6 months. A landslip occurred in the control area after 20 months. The biopolymer-treated soils remained stable. The 36-month performance update has been included as Appendix D of the Final Report.

Table 6. Comparative cost and maintenance of an earthen berm and a biopolymer-treated berm.

Cost Parameter	Earthen Berm (2012 $)	Biopolymer-Treated Berm (2012 $)
Construction[a]	134,973	90,787
Yearly O&M[b]	6210	2553
Years in Operation	30	30
30 Yr O&M cost	186,300	76,590
Overhaul at 10 yr[c]	67,487	35,143
Number of overhauls	2	2
Cost for overhaul	134,974	70,286
30 yr Total Cost[d]	**529,976**	**275,391**

[a] Based on100 ft of berm
[b] Estimated cost of soil addition
[c] For the biopolymer-treated berm, this is conservatively estimated at half the biopolymer cost and 1 day of labor and equipment rental
[d] All costs adjusted for inflation to 2012$

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8.0 IMPLEMENTATION ISSUES

There are no known regulations that apply to the use of this technology and no permits are required to implement this technology. An material safety data sheet (MSDS) for the *R. tropici* biopolymer, as applied to the IAAAP soil, is provided in Appendix C.

End-user concerns are that the actual bacteria producing the biopolymer are being added to the soil. The demonstration addressed these concerns by discussing the production method.

The biopolymer is newly commercialized and can be procured through ETS, Inc. or through UXB International. Contact information for these providers and CRADA partners is provided in Appendix A.

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APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone Fax E-Mail	Role in Project
Steve Larson	US Army ERDC-Environmental Lab 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Phone: (601) 634-3431 Fax: (601) 634-3518 E-mail: Steven.L.Larson@usace.army.mil	Lead-PI
J. Kent Newman	US Army ERDC-Geotechnical and Structures Lab 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Phone: (601) 634-3858 Email: john.k.newman@usace.army.mil	Co-PI
Gregory O'Connor	ARDEC PM-JS	Phone: (973) 724-5008 Email: gregory.j.oconnor@us.army.mil	Co-PI
Chris Griggs	US Army ERDC-Environmental Lab 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Phone: (601) 634-4821 Fax: (601) 634-3518 Email: chris.s.griggs@usace.army.mil	Biopolymer production coordination
Andy Martin	US Army ERDC-Environmental Lab 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Phone: (601) 634-3710 Fax: (601) 634-3518 Email: andy.martin@usace.army.mil	IAAAP coordination
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Elizabeth Lord	US Army ERDC-Environmental Lab 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Phone: (601) 634-4066 Email: mildred.e.lord@usace.army.mil	LIDAR data collection and analysis
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APPENDIX B

HEALTH AND SAFETY PLAN

This site specific Health and Safety Plan (HASP) was developed to support field activities conducted at Iowa Army Ammunition Plant (IAAAP) as part of the ESTCP ER-0920 field demonstration for "Biopolymer as an Alternative to Petroleum-based Polymers to Control Soil Erosion". This HASP is consistent with requirements of the Occupational Safety and Health Administration (OSHA) Hazardous Waste Site Regulations; 29 CFR 1910.120 and 29 CFR 1926.65; and the U.S. Army Corps of Engineers (USACE) Safety and Health Requirement Manual (EM385-1-1). This HASP is applicable to all personnel who enter work areas described in this HASP and who are under the supervision of US Army Engineer Research and Development Center – Environmental Laboratory (ERDC-EL) or Environmental Technology Solutions (ETS). The HASP describes the procedures to be followed and the protective equipment to be used by ERDC-EL and ETS employees and their subcontractors working at the site.

The primary objective of the HASP is to establish, before field activities begin, work safety requirements and protection procedures to minimize the potential for exposure of field personnel to physical hazards at the site. There are no known chemical hazards at this site. The health and safety requirements presented in this HASP are based on information available at this time and are subject to revision upon subsequent discoveries regarding potential hazards at the site. The contractor for the performance of this phase of the field demonstration was Environmental Technology Solutions (ETS), whose representative, Mr. Gary Nijak, Jr., was on-site throughout berm re-contouring and biopolymer application.

Site Information

The Iowa Army Ammunition Plant (IAAAP) is an active, government-owned, contractor-operated (GOCO) facility in Des Moines County near Middletown in southeast Iowa. It is located approximately 10 miles west of Burlington, Iowa and the Mississippi River.

Field Activities

The objective of the field demonstration, was to validate soil erosion control by the biopolymer in the field at full-scale. This was accomplished through re-contouring an explosion protection berm at the Iowa Army Ammunition Plant and applying biopolymer and grass seed to encourage rapid re-vegetation.

Hazard Assessment

Hazards at the IAAAP for this project all focus on the proper use of heavy construction equipment such as bulldozers, excavators and hydroseeders.

Heavy Equipment Operation

All personnel, including contractor and subcontractor personnel, involved in heavy equipment operations shall be familiar with the potential safety and health hazards associated with the conduct of this operation, and with the work practices and control techniques to be used to reduce or eliminate these hazards. The operator prior to use on each shift shall inspect heavy equipment and determine that operating components are not defective.

- Vehicles will not have cracked windshields or windows.
- Blades, buckets, dump bodies, and other hydraulic systems must be fully lowered when equipment is not in use.
- Parking brakes will be engaged when equipment is not in use.

Seat belts and Rollover Protective Structures (ROPS) will be provided and used on heavy equipment and motor vehicles including:

- Crawler and rubber tire tractors;
- Self-propelled pneumatic tire earth movers;
- Motor graders;
- Water tank trucks with tank height less than the cab; and
- Self-propelled construction equipment such as front-end loaders, backhoes, rollers, and compactors.

Mechanical and Material handling equipment with an obstructed rear view must have (when being operated in reverse) an audible alarm sufficient to be heard under normal working conditions and will operate automatically upon commencement of backward motion. Self-propelled equipment must be equipped with a backup alarm unless the equipment allows the operator to face the direction of motion.

Hard hats, safety glasses, safety shoes, high visibility vests and other protective gear are to be worn when working within 25’ of heavy equipment such as providing safety observer support. When working in an environment with multiple pieces of heavy equipment, continued operations or situations which limit visibility all personnel in the work are will wear specified PPE. The SSHO will define the heavy equipment work area.

When heavy equipment and verbal communication is difficult, standard hand signals shall be used. Designate one person per equipment operator to give hand signals.

1. The operation of heavy equipment shall be limited to authorized personnel specifically trained in its operation;
2. A competent person shall visually inspect heavy equipment daily prior to operation, and report any abnormalities/deficiencies to the SSHO;
3. The operator shall use the safety devices provided with the equipment, including seat belts, and backup warning indicators and horns shall be maintained in operable order;
4. While in operation, personnel not directly required in the area shall keep a safe distance from the equipment;
5. The operator's cab shall be kept free of non-essential items and loose items shall be secured;
6. Personnel shall avoid moving into the path of operating equipment and areas blinded from the operator's vision shall be avoided;

7. Heavy equipment requiring check-out shall not be permitted to run unattended;
8. Except for equipment designed to be serviced while in operation, equipment shall be shut down and positive means taken to prevent its operation while repair or servicing is being conducted;
9. All equipment shall be secured at the end of the day, or when not in operation, with the blades/buckets of earth moving equipment placed on the ground;
10. Stationary machinery and equipment shall be placed on a firm foundation and secured before being operated;
11. All points requiring lubrication during operation shall have fittings so located or guarded to be accessible without hazardous exposure;
12. Heavy equipment operating within an off-highway job site not open to public traffic, shall have a service brake system and a parking brake system capable of stopping and holding the equipment fully loaded on the grade of operation;
13. All equipment with windshields shall be equipped with powered wipers, and equipment that operates under conditions that cause fogging or frosting of windshields shall be equipped with operable defogging or defrosting devices;
14. Whenever the equipment is parked, the parking brake shall be set, and equipment parked on inclines shall have the wheels chocked or track mechanism blocked and the parking brake set;
15. Personnel shall not work or pass under the buckets or booms of loaders in operation;
16. When heavy equipment must negotiate in tight quarters, or if operators of earth moving equipment cannot see the bucket, a secondary person shall be stationed to guide the operator;
17. Additional riders shall not be allowed on equipment unless it is specifically designed for that purpose (i.e., there is an additional seat with a seat belt);
18. Only trained or licensed people are to operate heavy equipment;
19. Use chains, hoists, straps, and any other equipment to aid in safely moving heavy materials;
20. Never walk directly in back of, or to the side of, heavy equipment without the operator's knowledge;
21. Be sure that no underground or overhead power lines, sewer lines, gas lines, telephone lines, or other utilities present a hazard in the work area. This includes marking of underground utilities and flagging support wires for utility poles. Guy lines will be marked with yellow caution tape at eye level and several other points to aid in visual identification;
22. Be knowledgeable of marked "swing zones" for rotating equipment, e.g., backhoes, track hoes and excavators.

PPE: Level D Protection

- Coveralls (cotton or Tyvek) or work clothes;

- Boots (steel toe, as appropriate) or work shoes;
- Safety glasses or goggles (as required by OSHA); and
- Hard hat (as required by OSHA).

Slips, Trips and Falls

Personnel should be aware that any protective equipment worn, including coveralls, hard hats and gloves, may limit manual dexterity, hearing, visibility, and may increase the difficulty of performing some tasks. This may result in greater physical hazards, such as slip, trip, and fall incidences, while wearing protective equipment. Personal Protective Equipment (PPE) places an additional strain on the wearer when performing work that requires physical activity. Heat exhaustion or heat stroke is possible, especially during warm weather.

Climate-Heat Stress

- **Heat Exhaustion**: nausea, headache, weakness, dizziness, pale, cool, moist skin, or extreme perspiration.
- **Heat stroke**: a sudden lack of perspiration; dry, pale to red skin; and strong rapid pulse. This condition requires immediate medical attention.

All field personnel shall be monitored for heat stress when air temperatures become excessive. Equipment for monitoring heat stress, such as thermometers and scales, will be maintained by the SSO at the field office and other support areas. Note that USACE guidance requires that 8°C be subtracted from ACGIH heat stress TLVs when personnel are wearing Tyvek coveralls, and 10°C subtracted for polyethylene Tyvek coveralls. These correction factors shall supersede those listed in Attachment 3 for all work performed at the IAAAP.

- All personnel should be aware of the physical condition of themselves and their fellow workers. One or more of the following control measures may be implemented:
- **Acclimatization:** Personnel not accustomed to working in hot environments will be eased into a full work schedule over several days.
- **Adequate Liquids**: Provide sufficient cool (not cold) liquids to replace lost body fluids. Employees must replace water and electrolytes lost from sweating. Employees will be encouraged to drink more than the amount required to satisfy thirst since thirst satisfaction is not an accurate indicator of adequate fluid replacement. Replacement fluids can be commercial mixes such as water, Gatorade, or fruit juices.
- **Work/Rest Regimens**: Implementation of a work-rest regimen that will provide adequate break periods for cooling down. This may require additional shifts of workers or suspending work during the hottest parts of the day.
- **Breaks:** All breaks are to be taken in a cool and shaded rest area. Impermeable protective garments are to be removed during rest periods. Employees shall not be assigned other tasks during rest periods.

Climate-Cold Stress

Exposure to cold or wet and cold environments can result in cold stress (hypothermia) or cold injury (frostbite). In the event field activities are conducted during cold weather, ACGIH cold stress TLVs will be followed. Appropriate first-aid treatment for cold stress will be provided until medical care is available.

Special precaution must be taken when operating machinery in the vicinity of overhead electrical power lines. Contact with electricity can shock, burn, and result in death. All overhead electrical power lines are to be considered energized and dangerous. Walk completely around the machine and look up before beginning work at a site in the vicinity of power lines. Determine what the minimum distance from any point on the machine to the nearest power line will be when operating.

Working around heavy machinery can pose a noise hazard for site personnel. Hearing protection is required for personnel working where a noise-producing source forces a person to raise their voice to communicate with someone 3 feet away.

Personnel should be aware of wind directions and attempt to coordinate field activities and gasoline powered equipment so that exhaust fumes and chemical vapors are located downwind from work areas.

Incident Reporting

In the event of an accident or incident, the SSO shall immediately notify the HSO and the Project Manager. The ERDC HSO will be notified by the Project Manager or his/her designee. Injuries, exposures, illnesses, safety infractions, and other incidents must be reported within 24 hours of occurrence. Within 2 working days of any reportable accident or incident, the SSO or HSO shall complete and submit to the USACE Contracting Officer an Accident Report on ENG Form 3394.

General Safety Provisions

The following general provisions will be in effect during all site activities on the site governed by this HASP:

- There will be no activities conducted on-site without sufficient backup personnel. At a minimum, two persons ("buddy system") must be present at the site during all site activities.
- No employee may be allowed on-site without the prior knowledge and consent of the SSO.
- No loose jewelry, clothing, or long hair shall be permitted on or near equipment with moving parts.
- Field activities will be suspended during severe weather such as thunderstorms, tornado warnings, and winter storm warnings.
- Damaged PPE or clothing will be immediately repaired or replaced, as appropriate.
- Unauthorized removal of materials from the site is prohibited.

- Possession of controlled substances and items while working on-site is prohibited.

Emergency Response

In the event that an emergency situation, such as an injury, illness, or fire arises, the appropriate immediate response must be taken by the first person to recognize the situation. The field crew will immediately notify the site management of the incident, and the appropriate emergency organization will be contacted. A copy of the emergency telephone numbers, directions, and route map to the nearest hospital will be clearly posted at the work area and in vehicles (The emergency contacts and the hospital route are provided later in the text). The route to the hospital will be rehearsed by field personnel.

The Project Manager and HSO will be notified of any accident, injury, or illness. The ERDC Health and Safety Coordinator will be notified by the Project Manager or his/her designee.

In the case of injury or illness, the proper emergency first-aid care will be rendered by a trained person. First-aid equipment will be available at the area of fieldwork. Personnel will be notified as to the locations of first-aid stations during the initial safety briefing session. Decisions to cease all field activities and evacuate the site will be made by the Site Manager and SSO. Field personnel will report to the field office to sign-out.

The following emergency equipment will be kept at the field office and/or with each field crew:

- First aid kit;
- Emergency eye/body wash or bottles of clean water marked for emergency purposes;
- Radio communication equipment;
- Fire extinguisher;
- Telephone or cell phone; and
- Drinking water/cups.

Personal Injury: The following procedures will be implemented in the event of a personal injury:

- Administer first-aid
- Radio/phone the field office (Site Manager and SSO) to arrange for emergency care (ambulance and paramedics), as appropriate;
- When the situation has been stabilized, move the person to a support area if there is no risk of further injury.

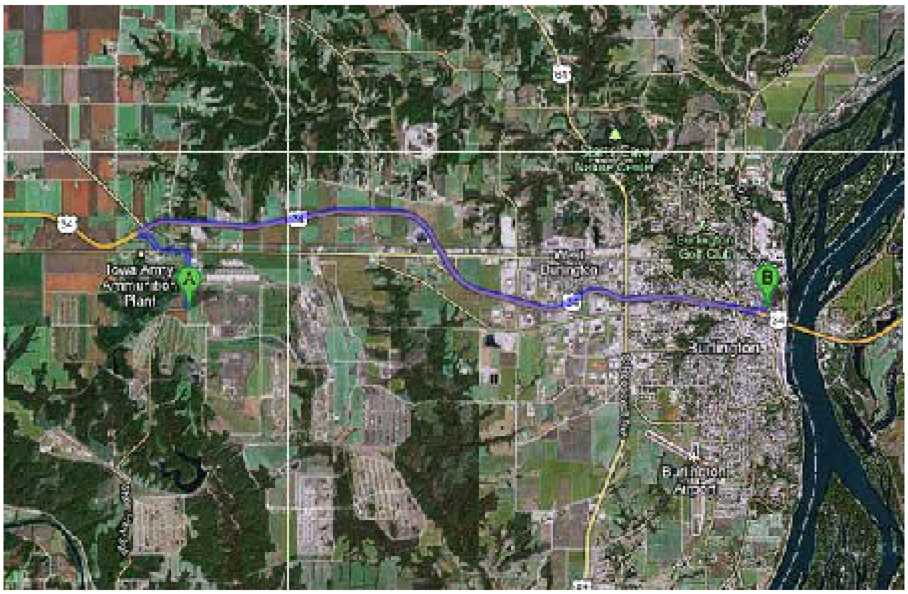
Severe Weather: Personnel should be aware of the possibility for the occurrence of severe weather such as tornados, thunderstorms, hail or high winds. Necessary precautions or response, directed by the SSO, will be taken in the event of severe weather. For example, operations involving heavy equipment will be suspended when the potential for lightning occurs.

In the event of a tornado, field personnel will seek shelter in a permanent structure. No attempts will be made to outrun a tornado in a vehicle. Personnel caught in the open will lie flat in a ditch or low area and cover their head. Personnel will seek cover (building or vehicle) immediately should hail develop during thunderstorms. Local weather broadcasts will be monitored by the Site Manager, SSO, or designee when the likelihood for severe weather exists.

Medical Treatment: The IAAAP Emergency Medical Service is located at Building 200-101-2, Plant Road F (north of Road D). To contact the office using an onsite phone, dial 17.

Site personnel requiring non-emergency treatment, will be taken to Corporate Medical Services located in Burlington, IA.

Non-Emergency Clinic Map and Directions
Corporate Medical Services Tel: 319-754-1555
823 N 6th Street, Burlington, IA , Iowa 53601
Est. Time: 14 min **Total Miles:** 11.1



Source: Google Maps

Instruction	For
Depart IAAAP heading north on Plain street toward Federal Street	0.1 miles
Turn left toward U.S. 34 E	0.6 miles
Turn left to merge onto U.S. 34 E	9.0 miles
Take exit 262B for Central Avenue toward Snake Alley	0.2 miles
Slight left onto High St	0.1 miles
Take the 1st left onto N 8th St	~374 feet
Take the 1st right onto Arch St	~0.1 miles
Take the 2nd left onto N 6th St (Destination will be on the left)	~262 feet

The nearest hospital is the Great River Medical Center located at 1221 S. Gear Ave., West Burlington. The Emergency phone number is: 319-768-4760.

HOSPITAL MAP AND DIRECTIONS

Great River Medical Center: Tel: 319-768-4700 (Emergency/Trauma)

1221 S. Gear Ave, West Burlington, Iowa 52655-1654

Est. Time: 10 min **Total Miles:** 7.1

Source: Google Maps

Instruction	For
Depart IAAAP heading north on Plain street toward Federal Street	0.0 miles
Turn Right on Iowa 79 (Historical)	2.7 miles
Continue onto W Mt. Pleasant St.	0.4 miles
Turn right onto 406th Rd	2.3 miles
Take exit 260 for Gear Avenue toward Bus Depot	6.8 miles
Turn right onto S. Gear Avenue, Hospital will be on the right.	~466 feet

APPENDIX C

BIOPOLYMER MATERIAL SAFETY DATA SHEET (MSDS)

ETS Environmental Technology Solutions

Material Safety Data Sheet

Environmental Technology Solutions **75 W. Baseline Rd. Suite 32** **Gilbert AZ, 85233**	**In Case of Emergency, Call** 1 480 648 1849
Date of MSDS Preparation 4/3/2011	**Superseded date** Original
MSDS Prepared By: G. Nijak	**For further information contact** 1 480 648 1849

Section 1: Product Identification

Product Identifier:	GreenTac	**Active Ingredient (%):**	
Registration No.:	Not Applicable	**Chemical Name:**	
Chemical Class:		**Product Use:**	Water Retention, Dust Suppressant
Synonym:	Absorbent, Suppressant		

Section 2: Composition/Information on Ingredients

Material	OSHA PEL	ACGIH TLV	NTP/IARC/OSHA Carcinogen	WHMIS
Poly Saccharide	None	None	No	NA
Yeast Extract	None	None	No	NA

Section 3: Hazards Identification

Symptoms of Acute Exposure:	Generally not hazardous in normal circumstances. However, good practices should always be followed. Avoid excessive exposure to skin and eyes
Hazardous Decomposition Products:	None known
Physical Properties:	Light to dark brown, Musky odor, Viscous
Unusual Fire, Explosion, & Reactivity Hazards:	None
Potential Health Effects:	May cause irritation of the eyes with prolonged exposure. May cause irritation to exposed skin and respiratory tract.

Section 4: First Aid Measures

Eye Contact: Wash with water and seek medical assistance if irritation persists.

Skin Contact: Wash exposed area with soap and water. If any irritation persists, seek medical attention.

Inhalation: Remove to fresh air.

Ingestion:	No known hazards. Drink water to dilute possible ingestion related problems
Note to Physician:	None
Medical Conditions Known to be Aggravated:	None

Section 5: Fire Fighting Measures

Flash point & method:	NA
Upper & lower flammable (explosive) limits in air:	NA
Auto ignition temperature:	NA
Hazardous combustion products:	NA
Conditions under which flammability could occur:	None
Extinguishing media:	NA
Sensitivity to explosion by mechanical impact:	None
Sensitivity to explosion by static discharge:	None

Section 6: Accidental Release Measures

Personal Precautions:

Avoid exposure to eyes and skin. Wear safety glasses to prevent splashing the product into eyes. Where there is a likelihood of product dust, the use of NIOSH approved respirator is recommended.

Procedures for dealing with release or spill:

If spilled, mop up and use or dispose. Product when in liquid form will be slippery. Water will dissolve and dilute until it is no longer slippery.

Section 7: Handling & Storage

Handling Practices:

Avoid unnecessary exposure, especially to the eyes. Wear eye protection and wash exposed skin after handling the product. General ventilation is usually adequate for the handling of this product.

Appropriate storage practices/requirements:

Keep material sealed until ready for use. Use good practices to avoid spilling in undesired areas.

National Fire Code classification:

NONE

Section 8: Exposure Control/Personal Protection

Applicable control measures, including engineering controls:

Generally, this is not a hazardous material. Good hygiene practices, general ventilation and appropriate eye protection is adequate for most handling situations.

Personal protective equipment for each exposure route:

General:

Ingestion: Wear dust mask when handling.

Eyes: Glasses with side shields or chemical goggles as appropriate to the handling circumstances.

Skin: Use safety gloves as with any chemicals.

Inhalation: None normally required. If dust possible, a NIOSH approved respirator should be worn.

Section 9: Physical & Chemical Properties

Appearance:	Light to dark brown	**Vapor Density:**	NA
Formulation Type:	Liquid	**Boiling point:**	>150°C
Odor:	Musty	**Melting point:**	NA
pH:	10.5	**Freezing point:**	NA
Vapor pressure and reference temp:	NA	**Specific gravity or density:**	NA
Evaporation Rate:	NA	**Viscosity:**	10.1 cP
Odor threshold:	NA	**Solubility in Water:**	81 g/L (time limited)

Section 10: Stability & Reactivity

Chemical Stability:	STABLE
Conditions to avoid:	NA
Incompatibility with other materials:	Strong acids
Hazardous decompositions products:	None
Hazardous polymerization:	May not occur

Section 11: Regulatory Information

WHMIS Classification for Product: This product is not a controlled material.

Canadian DSL: The ingredients in this product are on the Domestic Substance List.

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605
(571) 372-6565 (Phone)
E-mail: estcp@estcp.org
www.serdp-estcp.org