SOX EROSION

ENVIRONMENTAL BENEFITS ACROSS SEVERAL DIMENSIONS

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1 INTRODUCTION

We have prepared this alternatives analysis document to assess the environmental benefits that may result from the use of installation of the SOX Erosion DredgeSOX® [1]Erosion Control product. The product, which is used as a shoreline stabilization measure (Exhibit 1), has been successfully deployed to prevent soil erosion in such settings. The purpose of this assessment is to determine how its use in a hypothetical application compares with other alternatives with respect to efficacy and derived primary and secondary environmental benefits. For the purposes of this analysis, we have compared a DredgeSOX installation with a steel bulkhead/concrete deck alternative (Exhibit 2) as well as a "do nothing" alternative.

EXHIBIT 1: DredgeSOX Installations (Source: SOXErosion)

The DredgeSOX Erosion Control product (DredgeSOX) is a geotextile based system with a patented anchoring design that is used to stabilize shorelines, hillsides and other earthen environments and prevent soil bank erosion. The DredgeSOX product consists of a double layer of knitted high-density polyethylene (HDPE) mesh. When installed, the polyethylene mesh is filled with approved or appropriate organic materials, often obtained from dredging shallow sediment, blown-in compost mix, or other situationally appropriate fill material. When collected, the fill or dredged material is placed into the SOX containment system. To stabilize a shoreline or hillside, DredgeSOX can be deployed as a single unit or may be stacked in lifts. Typically, the individual thickness can range from as little as 1 foot to as much as 6 feet per lift. In addition to reclaiming a variable slope height, the DredgeSOX system will typically reclaim between 2 and 9 feet of top-of-slope property (land lost to erosion).

[1] DredgeSOX® Registration number 5237519

Once installed, the DredgeSOX can be covered with a layer of vegetation. This may include turf grass or native plants, such as grasses, broadleaf cover plants, or shrubs. Additionally, the SOX system can accept cast seed and vegetate from the inside out. The DredgeSOX technical mesh allows for penetration of the root systems of plants without damage to the plant roots or to the DredgeSOX technical mesh. As a result, plants are able to root, further stabilizing the protected shore against erosion, and thrive through the uptake of stabilized nutrients.

2 CONCEPTUAL PROJECT DESCRIPTION

To assess the efficacy of the DredgeSOX product, we have developed a hypothetical stabilization application. For comparison, we have assumed the stabilization of a creek or canal bank, approximately 6 feet in height. We have assumed a do-nothing alternative, which assumes no construction or other stabilization effort, but would result in bank erosion and/or failure. The alternatives include the following.

- Alternative 1 – No Bank Improvements

- Alternative 2 – Steel sheet pile bulkhead and concrete decking
  - Shoreline Steel SZ-18 bulkhead section; unit weight 18 pounds per square foot (psf)
    - 18 feet in height (12-foot embedment depth; 6-foot retained height)
    - 18 psf x 18 feet/foot of bulkhead = 324 pounds per linear foot parallel to bank
  - Concrete deck
    - 5-inch-thick deck; tributary width = 10 feet
    - Unit weight = 150 pounds per cubic foot (pcf)
    - 150 pcf x 5 inches x (1 foot = 12 inches) x 10 feet = 625 pounds per linear foot of parallel to bank

- Alternative 3 – DredgeSOX retained slope with turfgrass vegetated layer
  - One lift of DredgeSOX filled with adjacent dredged spoils or adjacent excavated soils
    - Lift = 6 feet in height
    - Lift uses 12 feet of DredgeSOX
    - Unit weight = 1.07 ounces (0.067 pound) per square foot = 0.8 pounds per 12-foot section per linear foot parallel to bank
  - Turfgrass vegetated layer
    - 15-foot tributary width per linear foot of parallel to bank

EXHIBIT 2: Typical Sheet Pile Bulkhead (Source: Duncan Marine Contractors)

3 ALTERNATIVES ANALYSIS

To perform an alternatives analysis, we have assumed the dimensions as indicated above in the conceptual project description section, and we have assumed a 50-year design life for both constructed alternatives. Please note that we have not considered other structural elements unless explicitly stated for the bulkhead wall alternative, including struts, tieback rods, or “deadmen.” We have assumed that the identical delivery routes for materials in each constructed scenario. We have also assumed the same grading volumes and effort for both constructed scenarios. As a result, there is no net benefit between the constructed scenarios for materials procurement, delivery, or grading work for the carbon calculations presented below. Further, although anecdotal and empirical evidence exists that “soft” or green spaces can provide a positive social benefit as compared to “hard” finishes (i.e., the bulkhead and the concrete deck), we have not incorporated an assessment of this dimension at this time.

4 PREVENTION OF SOIL EROSION/RUNOFF FLOW VELOCITY

The purpose of the project contemplated by this alternatives analysis is to stabilize a creek bank. Of primary importance is the ability of the project alternatives to prevent bank slope or top-of-bank soil erosion.

Under a do-nothing alternative (Alternative 1), no improvement would be made to the creek bank. As a result, no additional protection would be provided to the bank slope or top-of-bank, and mass wasting processes from erosion would occur. As a result, the bank would be susceptible to failure from long-term chronic processes or from infrequent but high-impact flow events.

Both the bulkhead/decking (Alternative 2) and DredgeSOX (Alternative 3) provide sufficient erosion protection. Both have been assumed to have an effective service life of 50 years, and assuming appropriate inspection and as-needed maintenance, both can be expected to minimize the potential for soil erosion and/or bank failure, except at the adjacency point of the hardened, non-permeable structure and the permeable, non-stabilized earth. Increased sheet flow can be seen at point of adjacency to hardened, non-permeable structure. However, the DredgeSOX alternative does provide an advantage – it will provide for reduced surface water flow velocity. The presence of the turfgrass in Alternative 3 provides an increased roughness coefficient – and a reduced surface water runoff velocity – as compared to the generally smoother surface of the concrete decking of Alternative 2. The reduced flow velocity may help protect the degree and rate of flow-surface flow-related wear and damage as compared to Alternative 3. As a result, while both Alternative 2 and 3 provide a similar degree of erosion protection, Alternative 3 (DredgeSOX) may be considered a slightly better alternative for reducing surface flow velocity and reducing the potential for related deleterious effects. As a do-nothing alternative, Alternative 1 offers no additional protection with respect to soil erosion.

5 REDUCTION IN SURFACE FLOW CONTAMINANT AND NUTRIENT LOADING

In addition to affecting the velocity of surface flow, the slope facing and top-of-slope ground covering can affect the water quality of surface flow that flow over these surfaces. Surface runoff can be contaminated with a variety of pollutants. Flows emanating from agricultural, residential, or recreational areas (e.g., parks or golf courses), surface runoff may have been impacted with herbicides, pesticides, fertilizers, or sediments from bare-earthen areas. In urban settings, surface runoff may be impacted with petroleum hydrocarbons, volatile organic compounds (VOCs), or heavy metals.

The hardscape surfaces associated with Alternative 2 would likely affect surface runoff quality. Dusts and contaminants that accumulate on these surfaces would become mobilized into surface runoff flowing over these surfaces. The impermeable nature of the concrete would not allow flow to infiltrate, nor would the general smoothness of the texture decrease flow velocity and accelerate residence time of the surface, which could allow pollutants to settle out of the surface flow. As a result, surface flows contacting the concrete deck of Alternative two would likely be negative affected, leading to deleterious effects on receiving water quality.

In the do-nothing approach of Alternative 1, the natural soils of the slope bank would allow for infiltration of surface flow, which could lead to a reduction of select contaminants in the surface flow. However, the exposed soils of the bank would be subjected to the erosive effects of the surface flow, which could mobilize soil and negatively affect the flow and the quality of the receiving water. Ultimately, water flow into an unmanaged, unstable slope condition could result in slope failure.

In the case of Alternative 3, the use of turfgrass or similar vegetation on the slope face and at the top of the slope act as a vegetative filter strip (VFS), a useful best management practice (BMP) commonly implemented for stormwater runoff treatment. A VFS is an area of vegetation designed to remove sediment and other pollutants from surface water runoff through filtration, deposition, infiltration, adsorption, absorption, decomposition, and/or volatilization (Smyth et al., 2018). The United States Environmental Protection Agency (EPA) encourages use of engineered VFSs to reduce nonpoint source (NPS) pollution (USEPA, 2002).

Three distinct layers are present within the VFS – the surface vegetation, the root zone, and the subsoil horizon (Grismer and O'Geen, 2006). The vegetation and its ability to slow surface flow velocity increases the residence time over the turf surface, allowing sediments and contaminants to settle out. Additionally, the permeable surface and presence of organic matter allows surface flow to infiltrate into the root zone. Within the root zone, some of the water flow continues to infiltrate into the underlying soil horizon, while some continues as lateral “interflow” within the root zone (Grismer and O’Geen, 2006). For nutrients, the most important VFS capture mechanism is infiltration. Nitrogen is primarily removed via uptake by the vegetation or resident microbial activity, while phosphorus and heavy metals are captured via adsorption to soil particles (Grismer and O’Geen, 2006).

As a result, surface water quality is improved due to the removal of sediments, contaminants, and nutrients from the flow, resulting in a beneficial effect on the quality of the receiving water. Recent research has indicated that the vegetated feature is effective in reducing sediment, contaminant, and nutrient loads in surface runoff, including total suspended solids (TSS), select nutrients, and select heavy metals (Water Research Foundation, 2020). Although the degree of contaminant removal is highly dependent on vegetation type, soil conditions, VFS dimensions, slope angle, and climate conditions, VFS systems such as those simulated by the use of Alternative 3 can be very efficient at contaminant removal. Field studies indicate that VFSs can successfully remove more than 90 percent of sediments, 50 to 80 percent of nutrients (Smyth et al., 2018), and over 60 percent of certain pathogens (Grismer and O’Geen, 2006). Empirical studies of prairie filter strip use adjacent to agricultural fields have demonstrated reduced nitrate-nitrogen (NO_3-N), total nitrogen (TN), and total phosphorus (TP) concentrations by 35 percent, 73 percent, and 82 percent, respectively (Zhou et al., 2014).

Contaminant and nutrient removal continues over the life span of the VFS feature, provided basic maintenance activities are performed. To maintain optimal pollutant removal efficiency, permanent vegetative plants should be harvested properly to encourage dense growth and removal of sediment, nutrients, and other pollutants trapped in the plant tissue (Smyth et al., 2018). Other straightforward maintenance practices include activities at the surface to maintain uniform sheet flow across the vegetation, removal of excessive sediment accumulation, repair of bare spots or distressed vegetation, and limitations of foot or vehicular traffic across the vegetated surface (Grismer and O’Geen, 2006).

6 EMBODIED CARBON AND CARBON SEQUESTRATION

A third dimension considered in this alternatives analysis is the carbon footprint of the project alternatives. In considering the overall carbon footprint, we have considered both the construction carbon footprint as well as the operational carbon footprint.

The construction carbon footprint considers the net of carbon sources (emissions) and sinks associated with the manufacture, delivery, and installation of the project. The operational carbon footprint considers the net of carbon emissions or sequestration that occur during the presence, operation, and maintenance of the alternative. As discussed in a previous section, we have assumed that the delivery and the installation, including earthwork and grading activities, are neutral with respect to Alternatives 2 and 3. With the elimination of these activities from consideration, the analysis is simplified to consider “cradle-to-gate” carbon footprint considerations for fabrication of the construction materials as well as the carbon sequestration and emissions associated with post-construction function of Alternatives 2 and 3.

As a do-nothing alternative, Alternative 1 is assumed to be carbon neutral for this analysis, although it is likely that slope erosion or failure would require future slope rebuilding and/or dredging. This would result in measure carbon emissions and eliminate the carbon neutrality assumption for Alternative 1.

With respect to Alternative 2, it is important to note that ***steel and concrete manufacturing are two of the most carbon-intensive industries in the world, especially in terms of cumulative carbon emissions generation***. Globally, steel production is responsible for 7 percent to 9 percent of all direct emissions from fossil fuels, with each metric ton of steel produced resulting in an average 1.83 metric tons of CO_2 emissions production, according to the World Steel Association (Pooler, 2019).

For concrete, the manufacture of Portland cement is a major contributor of carbon emissions. Portland cement manufacturing is responsible for 8 to 11 percent of global CO_2 emissions; if the concrete industry were a country, the concrete industry would be the third-highest emitter of CO_2 after China and the United States. These emissions are generated from fuel combustion as well as the chemical processes that occur to manufacture Portland cement. The cement used in concrete is produced by burning limestone in kilns at very high heat (2,300° to 3,000°F), commonly using powdered coal or natural gas as fuel; while the chemical reaction involved in producing cement releases more CO_2 as a byproduct (Emerson, 2021). Producing one ton of Portland cement produces 0.9 to 1 ton of CO_2 emissions, and 79 percent of concrete's CO_2 emissions come from the cement, even though it is only 13 percent of the material, with the other emissions associated with the extraction and incorporation of concrete's other constituents — sand, aggregate, and water (Emerson, 2021, Goguen, 2013). Since cement is only a fraction of the constituents in concrete, manufacturing a cubic yard of concrete (about 3,900 pounds) is responsible for emitting about 400 pounds of CO_2 (Goguen, 2013).

In calculating the embodied carbon, we assumed a sheet pile unit weight of 324 pounds per linear foot of slope, and a concrete deck unit weight of 625 pounds per linear feet of slope. Using the World Steel estimate of 1.83 metric tons of CO_2 emissions per metric ton of steel, or 1.83 pounds of CO_2 emissions per pound of steel, we estimate 592.92 pounds of CO_2 emissions per linear foot of bulkhead. Citing the National Precast Concrete Association (NPCA) estimate of 400 pounds of CO_2 emissions per 3,900 pounds of concrete (or 0.103 pound of CO_2 emissions per pound of concrete), we estimate 64.38 pounds of CO_2 emissions per linear foot of concrete deck. Combining the two elements, we estimate that Alternative 2 results in 657.30 pounds of CO_2 emissions per linear foot of slope.

In considering operational carbon, we assume no sinks or sources of carbon emissions. Although routine operations and maintenance, such as cleaning and repair, may occur on a periodic basis, it is our opinion these will have a negligible contribution on this carbon calculation. Further, new concrete products have emerged that are able to capture and sequester carbon, and new products have been advanced that utilize lower emissions of carbon during fabrication. We have assumed a typical, widely available concrete mix for our calculations and have not considered these specialty products for this calculation. As a result, as stated, not net carbon emissions or sequestration occurs during the operational phase of Alternative 2.

- Alternative 2 - Steel sheet pile bulkhead and concrete decking
  - Embodied Carbon - 657.30 pounds of CO_2 emissions per linear foot of slope
  - Operational Carbon – 0 pounds of CO_2 emissions per linear foot of slope
  - TOTAL: 657.30 pounds of CO_2 emissions per linear foot of slope

For Alternative 3, carbon is generated during refining of petroleum-based raw materials and the manufacture of the DredgeSOX product. To determine these emissions, we classified the product as a HDPE-based geotextile. For our calculations, we estimated an embodied carbon unit value of 1.9 kg of CO_2 emissions per kg of polyethylene, or 2.35 pounds of CO_2 emissions per pound of HDPE (Hammond and Jones, 2011, Raja et al., 2015). As noted, we have assumed a unit weight of 1.07 ounces (0.067 pound) per square foot of DredgeSOX. Assuming a 12-foot-long section per lift, this results in a DredgeSOX weight of 1.2 pounds per linear foot of slope. Applying the embodied carbon unit value for HDPE geotextile, we estimate 1.52 pounds of CO_2 emissions per linear foot of DredgeSOX slope.

In considering operational carbon, the inclusion of turfgrass on the slope facing and at the top of slope provides a means to sequester carbon. During photosynthesis, plants take in carbon as carbon dioxide and fix the carbon into their structural (leaves, stems, roots, etc.) and non-structural (sugars and other metabolites) components (Putnam, 2016). In perennial grass ecosystems, a large portion of that carbon ends up in the soil organic matter because of their large fibrous root systems (Putnam, 2016). Further, as turfgrass roots die, they decompose into soil organic matter, fixing carbon in the soil, allowing turf areas to act as a carbon sink for greenhouse gases (Leslie, 2021).

Of course, ongoing maintenance activities and the use of power equipment can result in generation of carbon emissions. Further, a limit is reached as to the carbon sequestering capacity of grasses, such that over a long period of time, ongoing carbon emitting activities can result in a turf installation to go from a net carbon sink (sequestration) to a net carbon source. However, carbon-positive (sequestration) system has been estimated to range between 66 and 199 years in U.S. home lawns, with an average of 184 years (Selhorst and Lal, 2013). Our estimate of a 50-year design life is well within the sequestration timeframe. Additionally, because more efficient and reduction of carbon-intensive maintenance practices could increase the overall sequestration longevity of home lawns and improve their climate change mitigation potential (Selhorst and Lal, 2013), these time ranges of sequestration may be conservative for many applications of DredgeSOX, as they may be vegetated and subsequently subjected to little to no ongoing maintenance. Further, similar sequestration performance could be expected in native grasses/plants are used in place of turfgrass (Qian and Follett, 2002).

To determine the carbon sequestration potential of the turfgrass, we assumed a sequestration rate of 100 grams of carbon per square meter per year, or 0.0205 pounds of carbon per square foot per year. This is at the lower end of an range estimate of 25.4 to 204.3 grams of carbon per square meter per year to account for maintenance emissions generation and lower growth rates (and CO_2 utilization) that may occur in colder or drier climates (Zirkle et al., 2011). Assuming 15 square feet of turfgrass per linear foot of slope, this results in 0.31 pounds of sequestered carbon per year per linear foot of slope, or 15.3 pounds of sequestered carbon per linear foot of slope over a 50-year design life. When compared to the embodied carbon of the manufacture of the DredgeSOX product, its use in the conceptual project results in net negative carbon emissions, or positive carbon sequestration, over the design life of the installation.

- Alternative 3 - DredgeSOX retained slope with turfgrass vegetated layer
    - Embodied Carbon – 1.52 pounds of CO_2 emissions per linear foot of slope
    - Operational Carbon – -15.4 pounds of CO_2 emissions per linear foot of slope
    - TOTAL: -13.88 pounds of CO_2 emissions per linear foot of slope

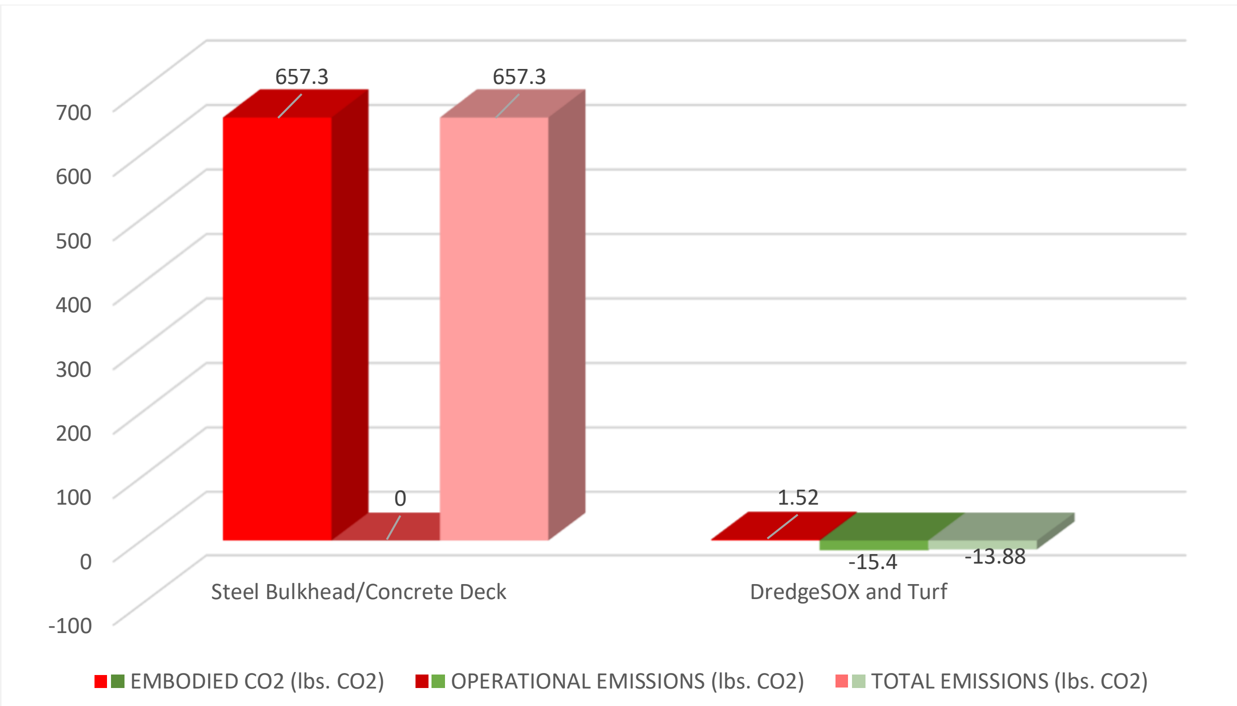
7 DISCUSSION

Across the assessed environmental dimensions, the DredgeSOX product presents a superior alternative to the use of a “hard-edge” alternative, such as the considered steel sheet pile bulkhead and concrete deck alternative, while both offer a range of advantages over a “do nothing” alternative (Table 1). The following table provides a summary of the performance of the considered alternative across the assessed dimensions. Of course, the do-nothing alternative could likely result in project failure.

TABLE 1: Summary of Alternatives Analysis

DIMENSION	ALTERNATIVE 1: DO NOTHING	ALTERNATIVE 2: BULKHEAD/DECK	ALTERNATIVE 3: DREDGESOX® AND TURF
Reduction of Runoff Velocity/Erosion	—	—	+
Reduction of Contaminant Loading	—	—	+
Embodied Carbon/Sequestration	—	—	+

EXHIBIT 3: Summary of Carbon Emissions per Linear Foot of Slope for Alternatives 2 and 3



With respect control of velocity of surface runoff flow, the incorporation of the DredgeSOX alternative with turfgrass results in a rougher surface, which reduces flow velocity and potential deleterious erosive effects as compared to the paved surface of the considered bulkhead/deck alternative. The inclusion of turfgrass also allows the DredgeSOX alternative to reduce loading of several contaminants before runoff reaches the protected water body, thereby improving water quality as compared to the bulkhead alternative. Finally, while the steel and concrete used in the bulkhead alternative results in an embodied carbon-intensive installation, the manufacture of DredgeSOX results in a fraction of the carbon emissions that occurs during steel and concrete manufacture, and the use of turfgrass (or other grasses/native vegetation) results in a ***carbon neutral or net carbon sink*** alternative for shoreline protection (Exhibit 3). As a result, in addition to providing an easy-to-install, technically effective, and cost-effective alternative, DredgeSOX offers an environmentally protective and sustainable shoreline protection solution.

8 REFERENCES

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