Performance Enhancing Devices for Stormwater BMPs

Iron Amendments

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Iron Enhanced Sand Filtration

1. Definition & Applications

Iron (Fe) aggregate is an amendment that has been shown to capture soluble phosphorus from urban and agricultural stormwater in both laboratory (Erickson *et al.* 2007) and field applications (Erickson *et al.* 2012, 2017a, 2017b). The iron surface becomes positively charged as it oxidizes, then binds with negatively charged phosphate ions through surface adsorption. Field installations include a mixture of approximately 5% by weight iron aggregate (a.k.a. filings, shavings) with ASTM C-33 concrete sand (ASTM 2002) to create an **iron-enhanced sand filter (IESF)**.

IESFs can be installed as stand-alone filtration basins, as trenches installed adjacent to wet ponds, as horizontal-flow filters within ditch check dams, or as a component within a bioretention system. These applications can also be incorporated into BMP retrofits where soil media will be added or replaced as part of the retrofit process (e.g., converting or replacing older practices).

2. Source Selection & Procurement

Iron aggregate can be obtained from a variety sources and delivered in various amounts and containers. Common shipments include 50-pound bags or pallets with a 3000-pound sack (see Figure IESF-1).

Figure IESF-1: 3000-pound sack of iron aggregate.

There are several criteria required for the iron to effectively capture soluble phosphorus from urban or agricultural runoff, including the size distribution, reactivity with phosphate, and purity. These are described in detail below:

- When installed within concrete sand, iron aggregate must have a similar size gradation as the concrete sand (ASTM 2002). If the iron aggregate is smaller than the sand, it can wash out of the filter media during flow events. If the iron aggregate is larger than the sand, the effectiveness is reduced because the total surface area of large particles is less, and separation may occur if the media is fluidized. Table IESF-1 outlines a size distribution of iron aggregate commonly used in IESF.

Table IESF-1. Recommended Size Distribution for Iron Aggregate		
US Sieve Number	Opening Size (mm)	Percent Passing
4	4.75 mm	100%
8	2.36 mm	95 – 100%
16	1.18 mm	75 – 95%
30	0.600 mm	25 – 45 %
50	0.300 mm	0 – 10%
100	0.150 mm	0 – 5%

- The iron aggregate must be reactive with phosphate. Iron can exist in various mineralogical forms, some of which react with phosphate while others do not. It is recommended that the supplier or the builder provide proof that the iron material is reactive with phosphate, or submit a sample to an analytical lab to be tested for reactivity with phosphate. For a simple test, see Erickson *et al.* 2018.
- The iron aggregate must be of sufficient purity and lack contaminants of concern. Recommended thresholds for iron elemental analysis are provided in Table IESF-2. Material containing greater than these recommended thresholds should not be used or further processed until the proper level of purity is achieved. It is recommended that iron aggregate have a purity of at least 85% elemental iron to ensure adequate performance and longevity. In addition, iron aggregate that includes significant amounts of pollutants of concern (e.g., toxic metals) can leach these pollutants during the filtration process, resulting in pollution instead of treatment. Also, iron aggregates procured from machining facilities or other metalworking industries may have coatings or toxic contaminants or lubricants used in the machining process. Lubricants could contribute toxic petroleum or hydrocarbon-based pollutants. Many analytical laboratories are equipped to perform leaching experiments, which can identify the type and amount of pollutant that can be released when iron aggregates are exposed to clean water.

Table IESF-2. Recommended Thresholds for Iron Elemental Analysis

Component	Percent Composition[1]
Metallic Iron[2]	> 85%
Total Carbon	< 4%
Manganese	< 1%
Sulphur	< 0.1%
Phosphorus	< 0.1%
Silicon	< 2%
Nickel	< 0.5%
Chromium	< 0.5%
Vanadium	Below Detection
Molybdenum	< 0.2%
Titanium	< 0.2%
Copper	< 0.2%
Aluminum	< 0.1%
Cobalt	Below Detection
Magnesium	< 0.01%
Boron	< 0.01%
Zinc	< 0.01%
Zirconium	< 0.01%

[1]These are based on testing so far but not absolute specifications
[2]Must be reactive with soluble phosphate

3. Design Variations

There are several design variations of iron enhanced sand filters (IESFs), several of which are described with performance data (Erickson *et al.* 2012, 2017b). A typical design schematic for a surface sand filter enhanced with iron aggregate is shown in Figure IESF-2. In this design variation, water is conveyed to a basin with IESF media in the bottom. Water stored in the basin moves vertically downward through the IESF media while particulates are captured on the surface and phosphate is adsorbed by the IESF media. Below the IESF media is a system of perforated pipe underdrains that collects treated water and delivers it to the outlet structure and subsequent conveyance system.

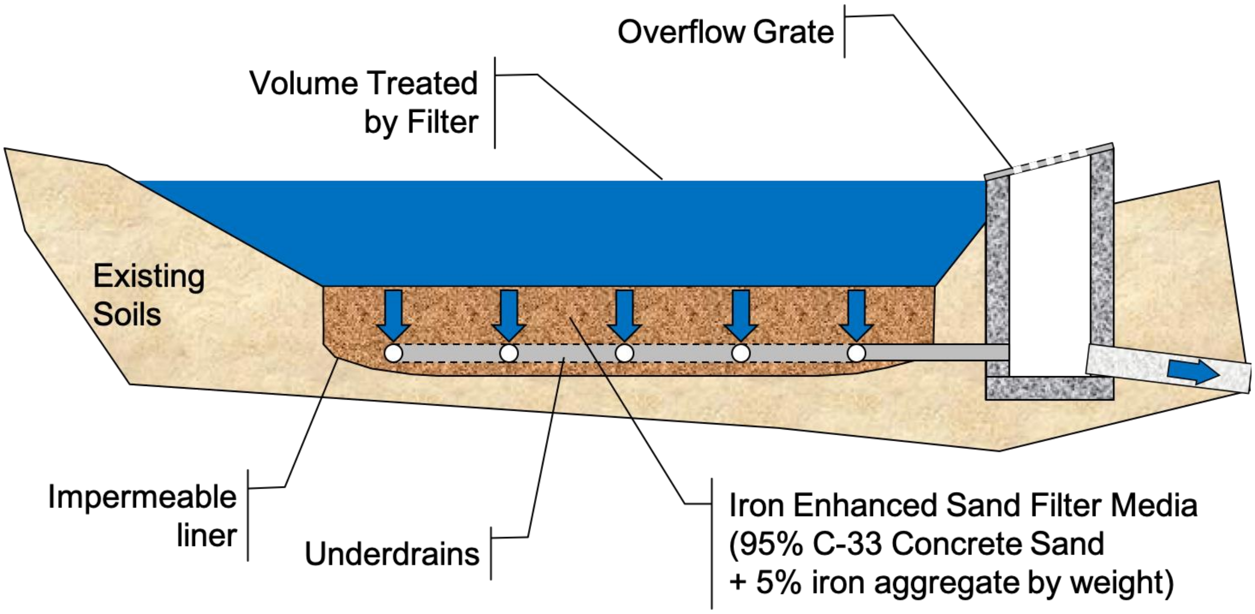

Figure IESF-2: Iron Enhanced Sand Filter Typical Schematic.

Another design variation that can be installed during initial construction or retrofit into an existing wet retention pond is the pond-perimeter IESF trench. A typical schematic for this design variation is shown in Figure IESF-3. In this design variation, water is captured by a wet retention pond to remove suspended sediment. When the water level increases above the normal water level, stored water flows into the pond-perimeter IESF trench, which captures particulates on the surface and phosphate on the IESF media. Treated water is collected by an underdrain that is connected to the outlet structure. The outlet structure for the pond is designed to force a volume of water to flow through the pond-perimeter IESF trench prior to overflowing the outlet structure from the pond.

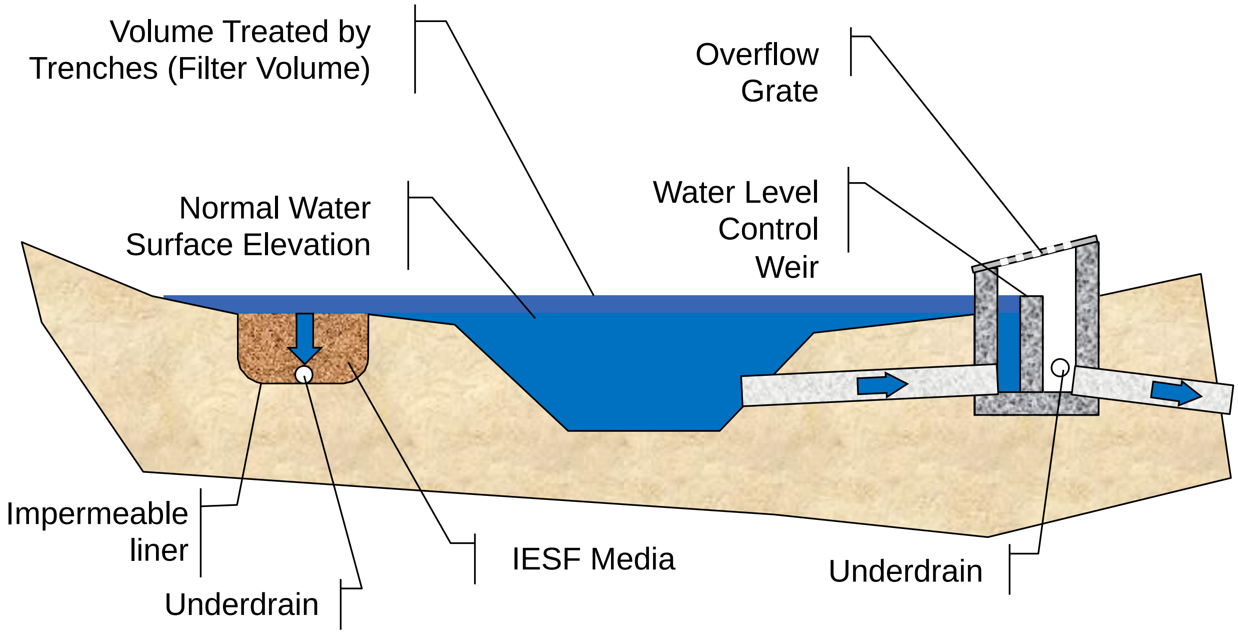

Figure IESF-3: Pond-Perimeter IESF Trench Typical Schematic.

Another design variation is to incorporate IESF media within the profile of a typical biofiltration practice, as shown in Figure IESF-4. In this variation, water is stored within a shallow basin and subsequently treated by a combination of bioretention media and IESF media to achieve particulate capture on the surface, metals, nitrogen, and polycyclic aromatic hydrocarbon capture and conversion within the biofiltration media (LeFevre *et al.* 2015), and phosphate capture within the IESF media. This application would involve modifying or offering an alternative in existing Bay jurisdiction bioretention design specifications.

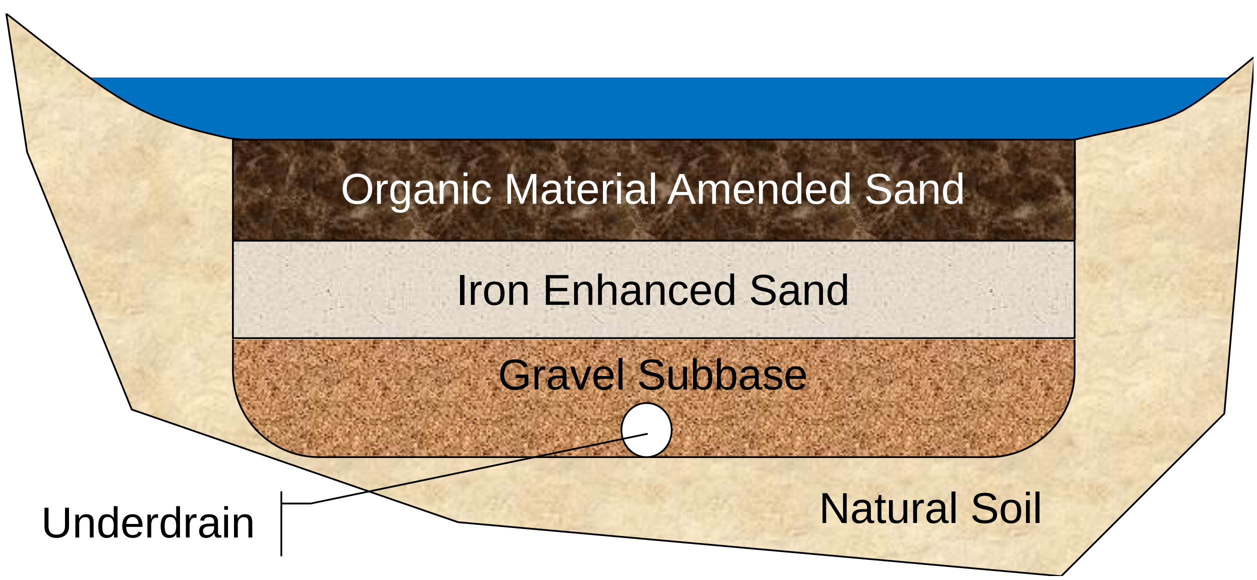

Figure IESF-4: Iron Enhanced Filtration Bioretention Typical Schematic.

Another design variation involves a modification of a typical ditch check dam design to include an IESF media within the center, which treats water as it flows horizontally through the ditch check dam and IESF media, as shown in Figure IESF-5. This design includes the benefits of the check dam (erosion prevention, infiltration promotion) and the IESF (particulate and phosphate capture). This design variation is currently (2018) under investigation at the University of Minnesota and more performance data will be made available in 2019. Preliminary results of field monitoring indicate that this design variation may not perform as well as other variations because most of the water is treated by the bottom of the filter, which may shorten the lifespan of the practice (Natarajan and Gulliver 2018). The maintenance of an IESF ditch check dam is similar to a conventional ditch check dam with the added maintenance activities described in Section 7 O&M Considerations below.

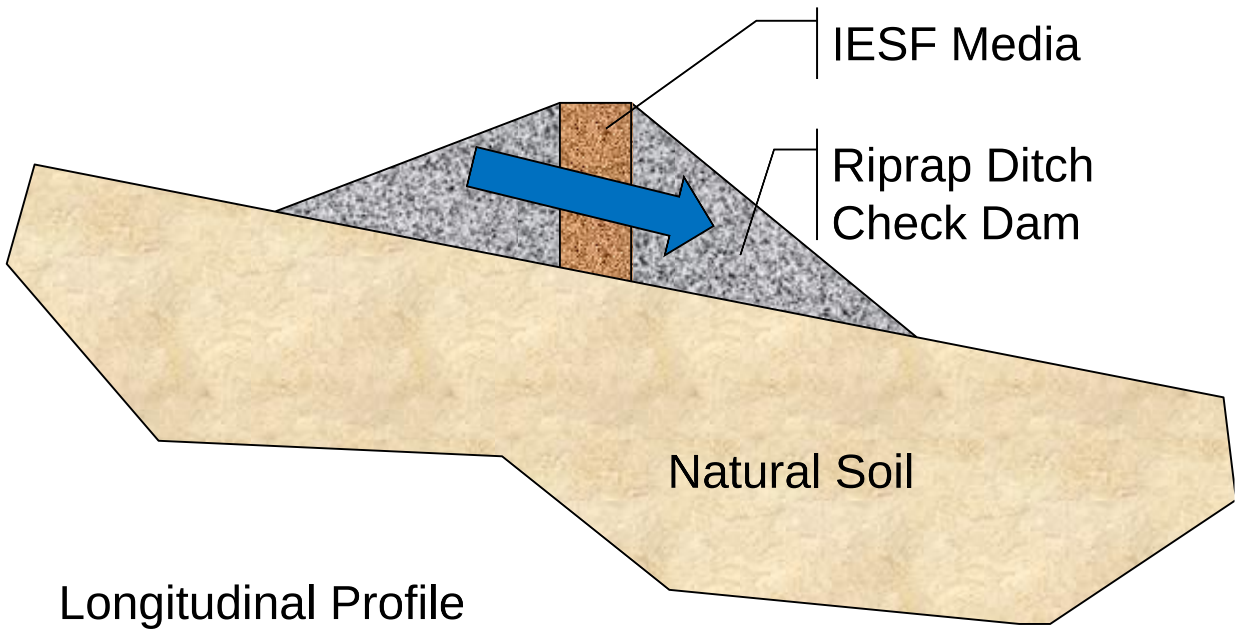

Figure 5: Iron Enhanced Filtration Ditch Check Dam.

4. Design Considerations

Design considerations for all of these design variations include underdrain elevation, draining and dry period, and access for maintenance. These considerations are outlined below.

- It is recommended that IESFs be designed such that the high-water level where the underdrains discharge is below the underdrain invert elevation. This will ensure that the downstream water cannot "backup" and inundate the underdrains and IESF media. Frequent and/or prolonged inundation of the IESF media can cause anoxic or anaerobic conditions within the IESF media, which may result in clogging.
- IESFs should be sized to allow rainfall events to drain quickly so a dry time of one or more days can occur prior to the next rainfall event. This is needed in order to allow the iron to oxidize during the dry interval.

- IESFs designs should limit the amount of organic material that is deposited on the IESF media surface. In pond-perimeter IESF trench applications and other situations associated with wet ponds or wetlands, organic matter such as algae or duckweed can be captured on the surface of the IESF media. This material can cause a biofilm to develop, which can limit complete draining and drying of the IESF and oxygen transfer into the media from the surface. In addition, this material will decompose over time causing a release of soluble phosphate at potentially high concentrations, which can overload the IESF system or exhaust the media prematurely.
- IESF designs should provide access for maintenance of the IESF surface, underdrains, and media. Equipment such as bobcats, excavators, and flatbed trucks may need access to the IESF to remove accumulated sediment from the surface. Maintenance recommendations are provided in Section 7, O&M Considerations.
- IESFs should be designed without vegetation within the IESF media (sand filter variation shown in Figure IESF-1). In the bioretention IESF variation (Figure IESF-3), it is recommended that vegetation be confined to the bioretention soil media layer or to the perimeter so that vegetation does not grow into the IESF media. In filter systems, vegetative roots grow towards the underdrains because of the collection and flow of water through the system. Many vegetation species lose 30% of their root mass annually, resulting in macropores within the soil. These macropores can cause short-circuiting of the IESF media, resulting in water that bypasses treatment and delivered directly to the underdrains.
- IESF practices should be designed with an emergency overflow or bypass to allow water to bypass the filter when the storage volume is exceeded of if the filter media is clogged.
- IESFs should have cleanouts connected to the underdrain system that are accessible from the surface of the IESF filter. These cleanouts should be sealed to prevent flow from the surface entering directly into the underdrain but can be opened to facilitate cleanout or flushing of the underdrains (e.g., threaded caps). It is recommended that bends in cleanout connections consist of two 45° bends instead of elbows, to allow for small cameras to be easily inserted into the underdrains for inspection.

5. Mixing & Layering the Material

Nearly all the documented failures of IESFs are a result of poor mixing or layering, typically during construction. Thus, proper mixing is critical for successful IESF installations. The following are considerations for mixing ratios and creating different layers within an IESF system.

- Iron aggregate should be mixed at a ratio of 5% iron aggregate with 95% clean washed sand, by weight. Studies have shown that iron ratios greater than 8% are susceptible to oxidized iron (rust), which can fill pore spaces between iron particles and cause clogging within the filter media (Erickson and Gulliver 2010). The weight ratio can be approximated using the bulk density of iron and the bulk density of sand, though bulk density values should be verified with the supplier prior to ordering and shipment.
- The iron aggregate should be mixed thoroughly with sand to form a homogeneous filter media in both horizontal and vertical directions. Some suppliers can mechanically mix iron with sand prior to delivery. For large sites, mixing prior to delivery may be the most cost effective. For small sites, mixing can be completed on site during installation by placing incremental layers

(typically 3 inches) of sand with iron added and then rototilling the iron into each incremental layer.

- The IESF media layer should be at a depth of approximately 12 – 18 inches. As the depth of the IESF media increases, so does the total weight of iron within the filter and subsequently the IESF filter will have a longer lifespan. Increasing the depth, though, also requires longer times for full draining of the IESF media.
- The surface sand filter IESF design (Figure IESF-1) should have a 2 to 5-inch layer of clean sand on top of the IESF at the filter surface to allow for maintenance. This clean sand layer can be removed along with accumulated sediment or organic matter and replaced with clean washed sand without reducing the capacity of the iron to capture phosphate. Any design variations that do not have an exposed surface of the IESF (e.g., ditch check dam or bioretention IESF) do not require this maintenance layer.

6. Risks

Iron is a ubiquitous element in the Earth's crust, though high iron concentrations in water can cause aesthetic concerns of odor, taste, and staining. Iron leaching from IESFs is common though minimal. Unpublished monitoring data has shown that iron concentration in the effluent from an urban IESF is below the U.S. EPA's secondary drinking water standard of 0.3 mg/L (https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals). There is a risk associated with leaching of other pollutants of concern if the iron aggregate contains a significant amount of a toxic pollutant that can leach during the treatment process. Leaching tests should be performed on the iron aggregate prior to installation to ensure these risks are minimized (see Section 2, Source Selection & Procurement).

IESFs can clog due to accumulated sediment or organic matter on the surface, frequent or prolonged inundation, or poor mixing of the iron aggregate. Risks associated with clogging include premature exhaustion of the IESF media or failure of the filter media, requiring complete rehabilitation of the IESF media.

7. O&M Considerations

The maintenance recommendations for IESFs (Erickson *et al.* 2018) include the following:

- IESFs should be inspected between quarterly and annually, depending upon the quantity of water filtered, and after any event that exceeds a 2-year return period. These inspections will identify any indications of sediment accumulation, infrastructure failure, excessive vegetation, erosion, or other maintenance concerns. When documented over time, inspections will also determine the frequency of other maintenance activities.
- Depending on the contributing area, trash and debris may need to be removed annually or more frequently.
- Remove obstructions to outlet structures and underdrain systems as needed.
- Remove vegetation from filter surface as needed.
- Perform testing to determine filtration rates whenever visual inspection or other assessment indicates the need.

- Remove retained sediment, typically the top 2 – 5 inches of discolored surface media. Typically, this will occur once every five to ten years in stable watersheds or once per year in unstable (i.e., erosive) watersheds.
- Effluent sampling and analysis of enhanced media should occur annually or whenever media performance is in question.

BMPs in the Bay Watershed must undergo a verification process to ensure the BMP is still present and performing as designed (CSN, 2014). This verification is intended to take place every two permit cycles for MS4s, or every 9-10 years. For IESF practices, this would be an ideal time to retest the soil media and ensure that (reactive) Iron and other key constituents are still present and to possibly add new Iron amendments to the media. Since there is not a long track record of IESF use in the Bay Watershed, this procedure would generate valuable data on the longevity of IESFs.

8. Qualifying Conditions for IESF as a PED

The following conditions summarize the use of iron aggregate to qualify for the PEDs pollutant removal credit:

- Procured to meet all the criteria described in Section 2 Source Selection & Procurement of this fact sheet; material must be dried before mixing into soil media.
- Designed to meet all the recommendations provided in Section 3. Design Considerations of this fact sheet.
- A written O&M Plan, including a specific party responsible for maintenance, following the recommendations provided in Section 7 O&M Considerations of this fact sheet.

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Additional Photos

Figure IESF-6: Typical Surface Iron Enhanced Sand Filter

Figure IESF-7: Typical Pond-Perimeter Iron Enhanced Sand Filter

Figure IESF-8: Typical Bioretention with Iron Enhanced Sand Filter (Photo ©Barr Engineering)

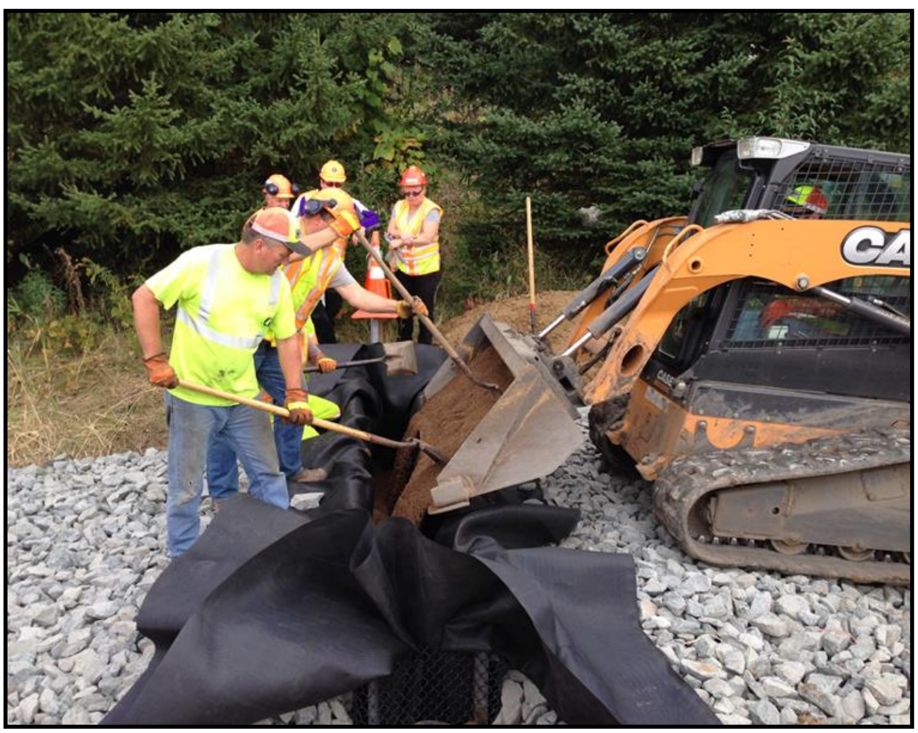

Figure IESF-9: Filling the Iron Enhanced Sand Portion of a Ditch Check Dam Variation