Performance Assessment of a RECP-Lined Channel 15 Years Following Installation

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ABSTRACT

During the autumn of 1998, a severely eroded diversion channel was repaired using a mixture of rolled erosion control products (RECPs). In order to address the severe erosion, fabric-formed concrete revetment was installed in the bottom of the perennially flowing channel, whereas a woven polypropylene high performance turf reinforcement mat was installed along channel banks subjected to high shear stresses during the design run-off event. A non-woven polypropylene conventional turf reinforcement mat was used on channel banks subjected to moderate shear stresses. The channel lining performance was assessed during a visual reconnaissance conducted in April 2014, after 15 years in service. Although a few areas of distress were observed, the channel linings have performed satisfactorily. Photographs and visual observations of the RECPs made during a detailed reconnaissance conducted in spring 2014 are provided, as well as the author’s opinions regarding the overall performance and suggestions for future designs.

1. INTRODUCTION

A stream was rerouted into a constructed drainage channel during the initial stages of a landfill development project in the late 1980s. A portion of the drainage channel was considerably narrower and steeper than the natural stream. Within 10 years following construction, significant erosion resulted. Despite attempts by the landfill operator to arrest the erosion using recycled concrete, channel erosion continued to a point that it threatened the stability of an old landfill.

In 1998, the stream was stabilized using a hybrid rolled erosion control product (RECP) system consisting of fabric-formed concrete revetment and two types of turf reinforcement mat (TRM) materials, high performance turf reinforcement mat (HPTRM) and a conventional TRM. This paper summarizes the design of the hybrid RECP system and documents its performance 15 years following its installation.

2. EROSION CONTROL SYSTEM DESIGN

2.1 Site Location and Setting

Clinton Landfill, which accepts municipal and non-hazardous solid waste, is located about 3 kilometers south of Clinton, Illinois. Clinton is in central Illinois, approximately mid-way between the cities of Bloomington and Decatur.

The area surrounding the landfill is characterized as rural, with upland farmlands to the north. Salt Creek, a regional drainage system that has incised the glacial deposits approximately 25 meters, lies to the south. The landfill is located along the margin between the uplands and Salt Creek, an area of actively eroding bluffs.

2.2 Site Development

The site was originally developed as a landfill in the 1970s. As a result of various stages of expansion, four distinct landfill units exist (Figure 1). Clinton Municipal Landfill operated from about 1970 to 1975; Clinton Landfill No. 1 operated from 1976 to 1989; and Clinton Landfill No. 2 opened in 1989 and closed in 2010. The 63.5 hectare Clinton Landfill No. 3 is currently operating and is expected to be filled to capacity in about 2060.

A stream that drains approximately 365 hectares was relocated into a constructed drainage channel in 1988 as part of the initial development of Clinton Landfill No. 2. An approximately 1,430 meter long meander with a natural gradient of about 0.006 meters per meter was eliminated as part of the stream relocation. The stream relocation resulted in an unlined drainage channel with a concrete culvert. The portion of the channel downstream of the culvert, which is the subject of this paper, is about 330 meters long and was constructed at an overall gradient in excess of 0.026 meters per meter. The upstream portion of the drainage channel was constructed at a much flatter gradient and has not eroded.

The west bank of the subject drainage channel lies at the bottom of a 2.5:1 (horizontal to vertical) slope. The slope rises approximately 20 meters. Clinton Municipal Landfill lies above the slope. The east bank lies at the bottom of an 8 meter high, 2.5:1 slope that serves as part of the containment berm for Landfill No. 2.

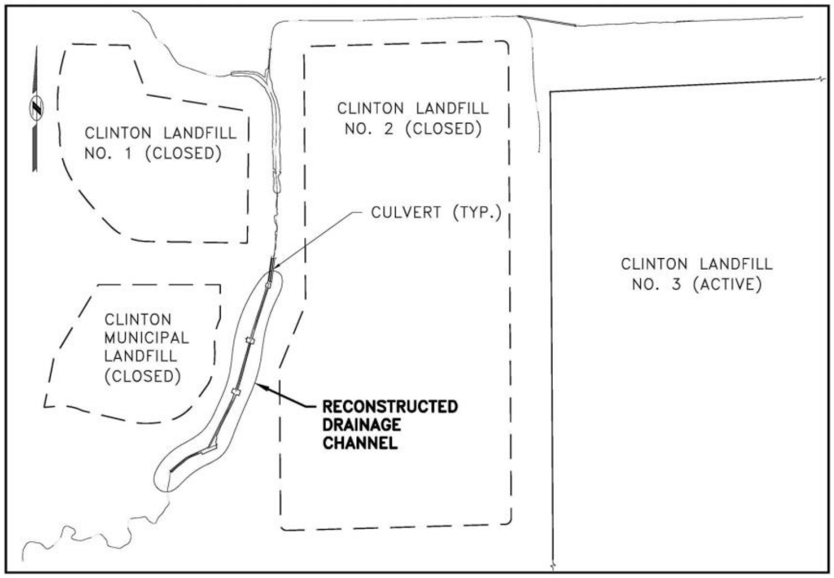

Figure 1. Site Plan

2.3 Drainage Channel Erosion and Earlier Control Attempts

The southern one-third (approximately) of the reconstructed drainage channel was cut into glacial outwash sand near elevation 205 meters above Mean Sea Level datum. This corresponded to an elevation about 3 meters above the original stream bed near the confluence of the drainage channel with the natural stream. This material proved to be highly erodible.

The drainage channel began to erode shortly after construction, with the channel bottom migrating upstream. The landfill operator attempted to arrest the erosion by placing recycled concrete in the channel bottom. Although this slowed the erosion, it did not sufficiently control the erosion. Within 8 years following the drainage channel construction, the erosion undercut the west slope resulting in an approximately 8 meter high 1.5:1 scarp. With continued erosion, engineers were concerned about the future long-term integrity of the adjacent landfill units.

2.4 Preliminary Design and Alternatives Analysis

Engineers initially conducted hydrologic modeling of the drainage basin to estimate the hydraulic design criteria for the drainage channel. Using the United States Soil Conservation Service TR-55 method, a peak runoff of 33 cubic meters per second for the 25-year, 24-hour (design) event was calculated. The routing curve indicated that the peak runoff would have a duration of about 1 hour. The average runoff over a 24 hour period was substantially less at 4 cubic meters per second. A base flow of 0.6 cubic meters per second was assumed for design purposes.

As shown on Figure 2, the previously constructed culvert over the drainage channel established the upstream grade of the subject drainage channel. Furthermore, the channel grade approximately 80 meters downstream of the culvert was constrained by multiple power poles with transformers at the top of the side slope above the east bank. The downstream grade was constrained by the outfall of a previously constructed sedimentation basin. The width of the drainage channel was limited to 3 meters in order to achieve the desired grades at the top of both side slopes.

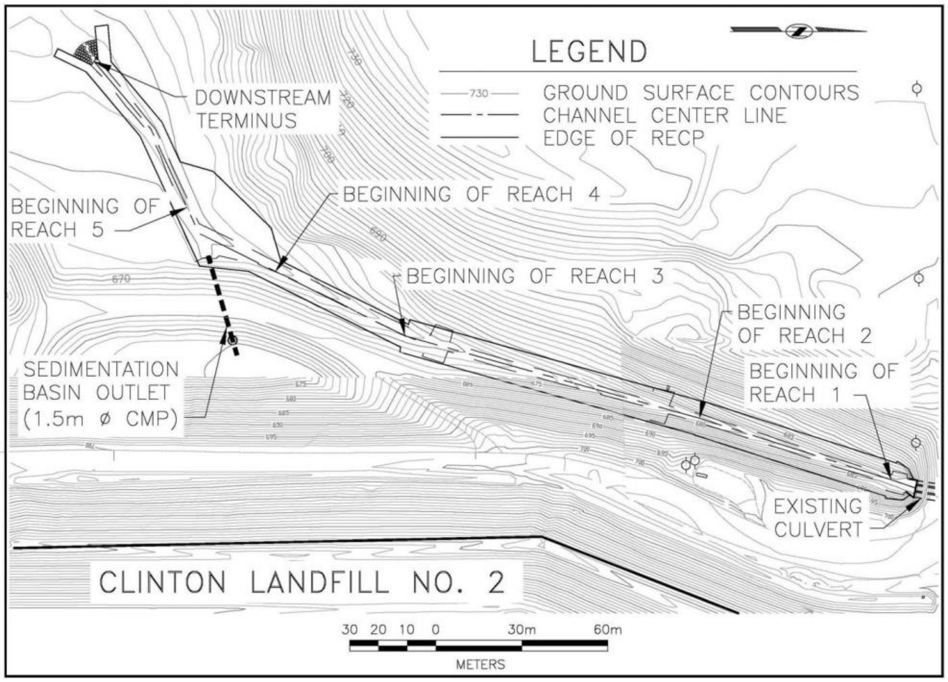

Figure 2. Drainage Channel Plan

Once the hydrology and channel grade constraints were identified, engineers evaluated several channel lining alternatives. These alternatives included riprap, fabric-formed concrete revetment, HPTRMs/TRMs, and concrete drop structures. Preliminary construction and long-term maintenance cost estimates were prepared for each alternative. Based on this analysis, a hybrid RECP lining system was chosen as the most-cost effective channel lining alternative. The hybrid RECP system consisted of fabric-formed concrete revetment along the bottom to resist the base flow, a woven UV-stabilized polypropylene HPTRM (Pyramat®) along channel banks subjected to high shear stresses during the design run-off event, and a non-woven UV-stabilized polypropylene conventional TRM (Landlok® TRM 450) along channel banks subjected to moderate shear stresses.

2.5 Final Design

Following selection of the RECP lining materials, the engineers refined the channel grades as needed to minimize the earthwork and to ensure that the flow velocities were reduced at the end of the lining to prevent downstream erosion (i.e. less than or equal to 1.8 meters per second). Five channel reaches of varying grades, as summarized in Table 1, resulted.

Additional hydraulic modeling was conducted once the grades were established. At this time, the engineers modeled both the peak flow, and the average 24-hour flow resulting from the design event. This data were compared to the TRM manufacturer's permissible velocities and shear stresses for short-term (1/2 hour) and long-term (50 hour) flows. For conservatism, the 24-hour average flow conditions were compared to the manufacturer's long-term permissible values. The results of this modeling are summarized in Table 1. Manufacturer's permissible velocities and shear stresses for the TRMs are summarized in Table 2.

Table 1. Hydraulic Design Criteria

Reach	Length (meters)	Grade	Velocity (meters / second)		Shear Stress At Invert (Pascals)	
			Peak	Long-term	Peak	Long-term
1	70	1.6 %	4.1	2.3	206	67
2	107	3.8 %	5.4	2.6	397	129
3	81	3.3 %	5.2	2.8	359	115
4	40	1.6 %	4.0	2.2	206	67
5	30	0.5 %	1.9	1.1	57	24

Table 2. – Manufacturer's Vegetated Permissible Velocities and Shear Stresses
(adapted from manufacturer literature circa 1998)

Class of TRM	Maximum permissible velocity (meters/sec)		Maximum permissible shear stress (Pascals)	
	Short-term	Long-term	Short-term	Long-term
HPTRM	7.6	4.3	480	285
Conventional TRM	5.5	3.0	335	190

Because shear stress decreases with decreasing water depth, the modeling also indicated that, even in the reaches with the highest velocities and shear stresses, the shear stresses in the upper channel side slopes were within the permissible range for the selected conventional TRM. In order to reduce costs, engineers were able to further reduce the quantity of the HPTRM by only placing it in the lower portions of the channel reaches which exhibit the highest shear stresses. The conventional TRM was specified elsewhere, where a TRM was required.

Typical cross-sections of the five drainage channel reaches are shown in Figure 3. These cross-sections illustrate the placement of the various RECP components of the hybrid lining system. The final design called for 1630 square meters of fabric-formed concrete revetment, 14 rolls of HPTRM (each roll 1.8 meters by 27.4 meters), and 44 rolls of conventional TRM (each roll 2 meters by 42.2 meters).

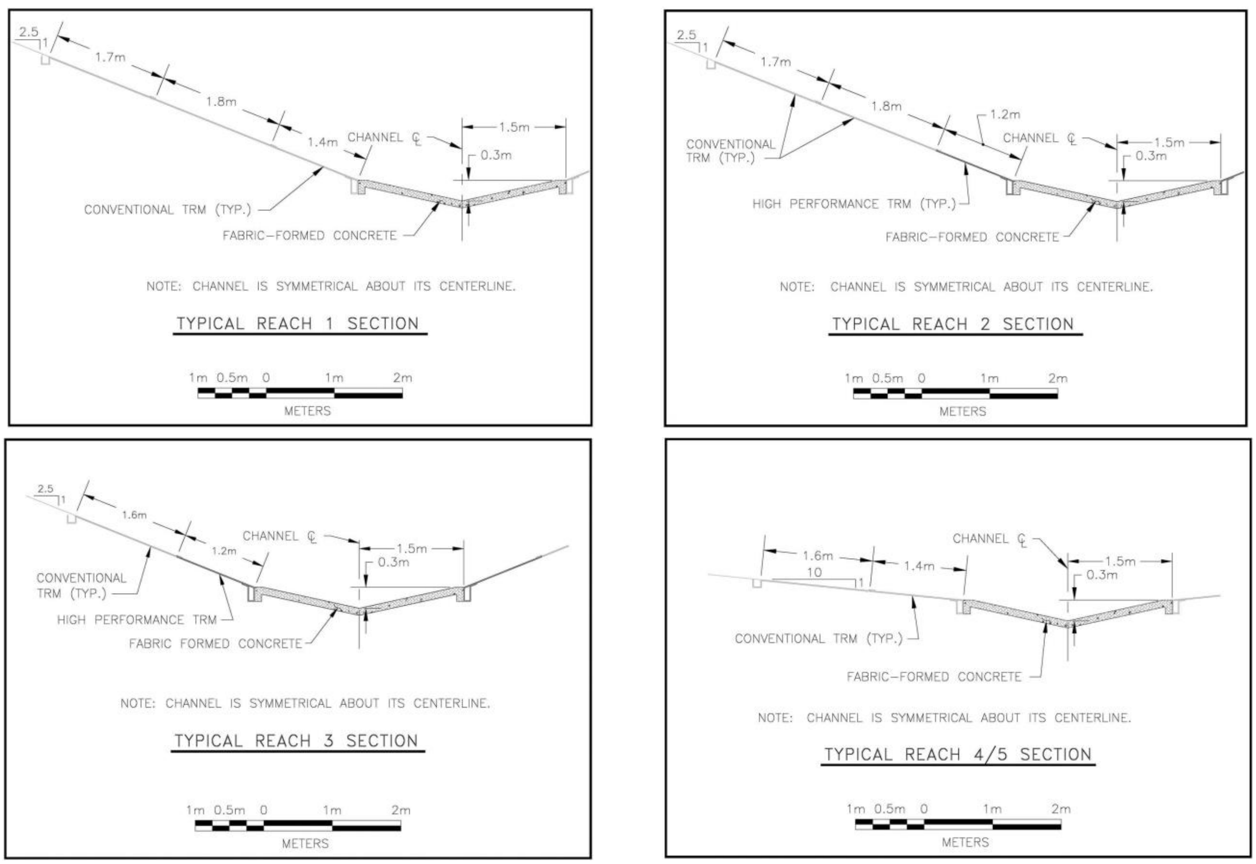

Figure 3. Typical Sections

2.6 Construction

Construction occurred in September and October 1998. Construction was completed in less than 3 weeks. Dry weather resulted in very little water in the channel at the start of construction. A temporary earthen dike that was constructed just upstream of the upstream culvert effectively cut off what little flow was present. Although the water flow was eliminated, extremely soft, wet subgrade soils were encountered in Reach 3. Channel grades were slightly modified to minimize the depth of excavation through the unstable subgrade.

The subgrade for the TRM materials consisted of at least 15 cm of topsoil. The TRM materials were placed and anchored in accordance with the manufacturer's and distributor's recommendations. A seed mix commonly used for slopes and drainage channels in the project area was then spread directly onto the TRM. Following seeding, a few centimeters of topsoil were placed on the TRM, and another application of seed was broadcast. Straw was then placed to protect the seed and to help conserve moisture.

The project only required one small track-mounted hydraulic excavator to grade the channel and to excavate RECP anchor trenches, and one small front load tractor to handle the RECP materials. A concrete pump was required to fill the fabric-formed concrete revetment. All other work was accomplished manually.

3. PERFORMANCE ASSESSMENT

3.1 Observations

The author conducted a visual reconnaissance of the RECP-lined channel in April 2014, more than 15 years following its installation. The following photos illustrate pertinent observations.

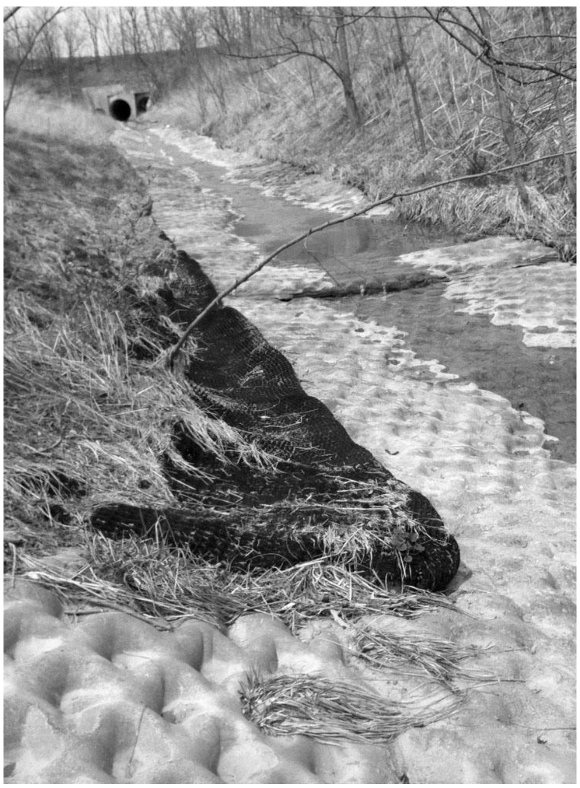

Photo 1. Reaches 1 and 2, looking northeast

Photo 2. Reach 3, looking north

As illustrated in Photo 1,the TRM-lined channel banks are well vegetated along Reaches 1 and 2, except near a fabric-formed concrete revetment apron onto which a culvert discharges (Photo 1) near the end of Reach 2. Photos of that area taken in 2000 also show exposed HPTRM, but not the extent found in 2014. Although the HPTRM is not damaged, it appears to have slid toward the channel. Similar conditions were observed along the eastern edge of Reach 3, as illustrated in Photo 2. Note that trees (which were not present along the channel during construction) grew through the HPTRM and conventional TRM and may have helped anchor the lining materials (see Photo 3).

Photo 4 illustrates the trees which have grown adjacent to the channel and through the HPTRM and conventional TRM materials. An approximately 20 feet long strip immediately adjacent to the eastern edge of the fabric-formed concrete revetment (Photos 4 and 5) has settled (or eroded), resulting in exposed HPTRM. The HPTRM itself appears to be in good condition and, although this areas has undoubted received high flow velocities, significant damage was not observed.

Photo 3. Tree Roots Anchoring HPTRM

Photo 4. Lower Portion of Reach 3, looking northeast

Photo 5. Settled or Eroded Area Along Reach 3

Photo 6. Reach 4, looking northeast

Reaches 4 and 5 are shown in Photos 6 and 7. The 1.5 meter diameter discharge culvert from a sediment basin is visible in both photos. It is apparent that the water velocity is such that a large volume of upstream sediment has been deposited along these reaches, beginning just upstream of the sediment basin discharge. Approximately 0.75 to 1 meter of sediment has blanketed the area, and the fabric-formed concrete revetment is partially buried.

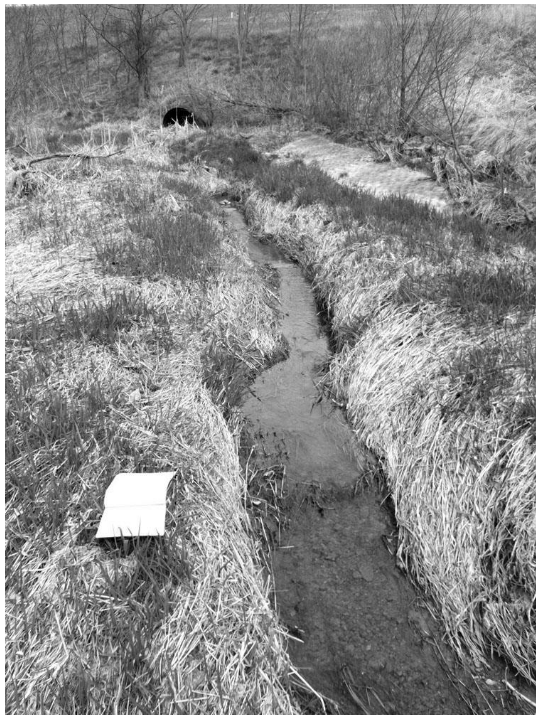

Photo 7. Reach 5, looking northeast

The most significant damage to the RECP lining occurred near the downstream terminus of the lining. In that area, riprap was placed at the end of the fabric-formed concrete revetment, and the conventional TRM was spread along the edges, as illustrated in Photo 8, which was taken during construction. The riprap, however, became completely buried with sediment as of 2014 and, it appears that at some point in the past, the water was diverted approximately 90 degrees and over the southeastern edge of the fabric-formed concrete revetment (see Photo 9). Although the conventional TRM remains in place, the force of the water eroded the underlying soil and formed a new channel.

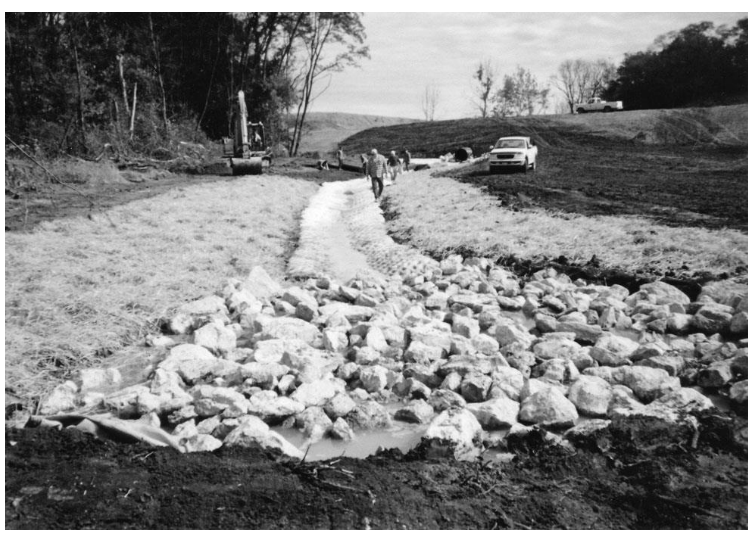

Photo 8. Downstream Terminus of the RECP Lining During Construction, looking northeast

Photo 9. Near Downstream Terminus of RECP Lining, looking southwest

The eastern edge of the fabric-formed concrete revetment and conventional TRM are visible in the right hand side of Photo 9. The riprap is apparently buried beneath sediments in the central portion of Photo 9. As stated above, water was diverted southeasterly approximately 90 degrees to the RECP-lined channel and cut a new channel. In doing so, the soil beneath the conventional TRM has been eroded.

3.2 Conclusions

The hybrid RECP lining system has performed admirably throughout the critical channel reaches between the two closed landfills. Although the TRM materials have become exposed in isolated areas and require relatively minor maintenance, the lack of vegetation does not appear to have resulted in significant erosion or damage to the TRMs.

A localized area of significant damage to the lining system has occurred near its downstream terminus. The damage is located in an area of the channel which exhibits a low gradient and does not threaten the overall integrity of the channel nor the nearby landfills.

No visible deterioration was observed in the HPTRM and conventional TRM materials. The lining system defects are likely to have resulted from less-than-ideal design and/or installation details.

4. SUGGESTIONS FOR FUTURE DESIGNS

The study of the long-term performance of an engineered system can provide a valuable resource for improving future designs and installation. As a result, the author offers the following suggestions for the future design and installation of similar systems:

- Careful attention should be paid to the details of the interface between TRMs (particularly bulky HPTRMs such as that used in this project) and rigid concrete, including fabric-formed concrete revetment. The details should ensure that the TRM tightly nests against the concrete, and should minimize the areas where the TRM must be folded over. Smooth transitions between the culvert apron and main fabric-formed concrete revetment (instead of the sharp 90 degree angles used during this project) might have reduced the amount of unvegetated TRM in the area shown in Photo 1.

- TRMs placed on steep banks should be securely anchored using non-degrading materials to prevent long-term downslope slip or creep. Planting of woody vegetation could possibly enhance the anchoring as evidenced by Photos 2 and 3.

- The effects that the lined channel will have on sediment transport and erosion potential at the downstream edge need to be carefully considered to determine the proper terminus details.

- Occasional inspections and, as necessary, maintenance should be conducted. This is particularly important during the first few years following installation.

ACKNOWLEDGEMENT

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