Appendix C. Conveyance Channel Lining Memorandum

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From	Shane Cline		
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RE: Conveyance Channel Lining

The proposed Mid-Barataria Sediment Diversion (MBSD) would be a new channel to convey sediment-laden water from the Mississippi River to the Barataria Basin. The channel is targeting a diversion rate of nearly 70,000 cubic feet per second and would measure approximately 1.6 miles long, 600 feet wide, and 30 feet deep. HDR anticipates that this conveyance channel would need to be lined to protect against erosive forces during periods of diversion. This memorandum summarizes investigations of different lining options and provides a recommendation for conveyance channel lining.

The purpose of this memorandum is to conceptually evaluate several erosion protection measures in order to identify a preferred alternative. Final design will be completed for the preferred alternative during subsequent design phases. This memorandum should not be considered an actual design for any of the erosion protection measures identified.

To document the investigations, the following topics will be discussed:

- potential failure modes
- existing conditions
- investigated erosion protection measures
- summary and recommendations

Potential Failure Modes

It is anticipated that three failure modes will need to be protected against by lining of the channel. These failure modes include shear stress failure, upwelling failure, and wave failure; they are discussed below.

Shear Stress Failure

When water is diverted through the conveyance channel, hydraulic forces may be of sufficient velocity and depth to mobilize material and ultimately transport downstream. Additionally, if erosion protection is provided but is not provided with a filter material, the smaller native material can be drawn up through the rock. Unless the erosion protection and filter material are properly sized, hydraulic forces can gradually remove material from the channel's sides and bottom. Left unchecked, significant erosion could be experienced that could eventually threaten the system's functionality. To investigate potential erosion protection requirements, erosion protection measures were conceptually sized using results from project-related FLOW-3D modeling.

Upwelling Failure

Periods of high water along the Mississippi River or Barataria Basin combined with low water stage in the conveyance channel (as could happen during times of no diversion), may result in upwelling through the bottom of the channel. If upwelling occurs, it is possible that hydraulic forces would mobilize material. Left unchecked, material removal from upwelling could result in erosion that could affect the system's functionality. It should be noted that a seepage analysis was not performed for the failure mode. This information was used to determine the amount of protection potentially required.

Wave Action Failure

Similar to the coastline, the conveyance channel could be subject to wave activity. If rock protection is not of an adequate size, during large wind events and storm surge, waves could dislodge protective measures and leave native material exposed. If left unchecked, erosion could occur and may eventually threaten the set back levee. To assess wave forces at the site, a preliminary assessment of potential wave heights was conducted.

Existing Conditions

Dispersive Clays

The MBSD conveyance channel would be located in an area that—according to initial geotechnical investigations—features very soft clays and silts. These soils are very young and are part of the former Barataria Basin shoreline prior to reclamation. The channel would be founded at elevation –25 feet, about 20 feet below the ground surface. Double hydrometer dispersion tests conducted between the depth of 8 and 35 feet indicate the presence of dispersive clays. Dispersive clays are structurally unstable and prone to erosion.

Tables 1 and 2 show the criteria for evaluating the degree of dispersion determined from the double hydrometer test.

Table 1. Double hydrometer test results – classification

Double hydrometer test results	Degree of dispersion
<30	Non-dispersive
30 to 50	Intermediate
>50	Dispersive

Table 2. Double hydrometer test results – dispersion by depth

Depth (feet)	Degree of dispersion (%)
8–10	72.7
18–20	77.1
22–23	63.6
28–30	72.7
33–35	92.7

All results exceed the 50% degree threshold for dispersion and, thus, the soils should be considered dispersive or even highly dispersive. These soils will need to be accounted for during design and selection of channel lining material.

Hydraulic Forces

A three-dimensional numerical model was developed to investigate hydraulic forces and to estimate hydraulic criteria used for determining appropriate channel lining requirements. To accomplish this, HDR developed a FLOW-3D model to represent the design currently being advanced toward the 30% design submittal. Figures 1 to 3 graphically represent the results of this analysis.

Figure 1. Hydraulic parameters downstream of transition structure (Station 125+00)

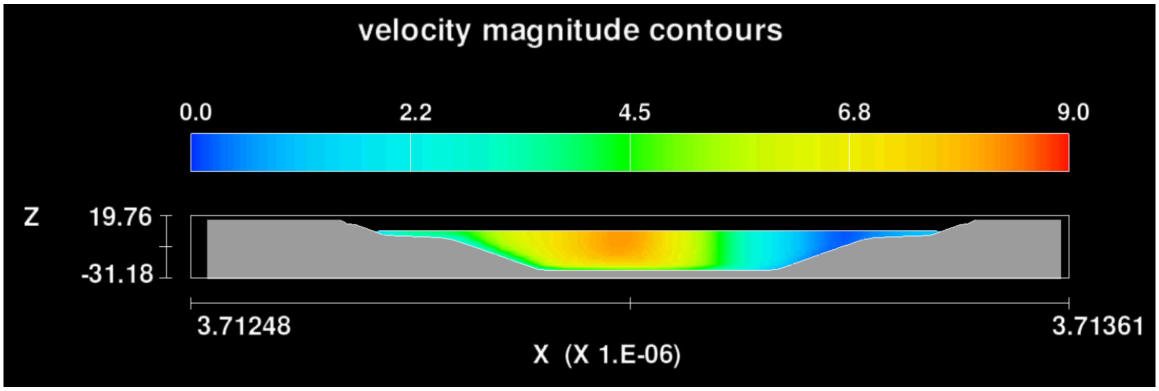


Figure 2. Hydraulic parameters midway between diversion structure and back structure (Station 85+00)

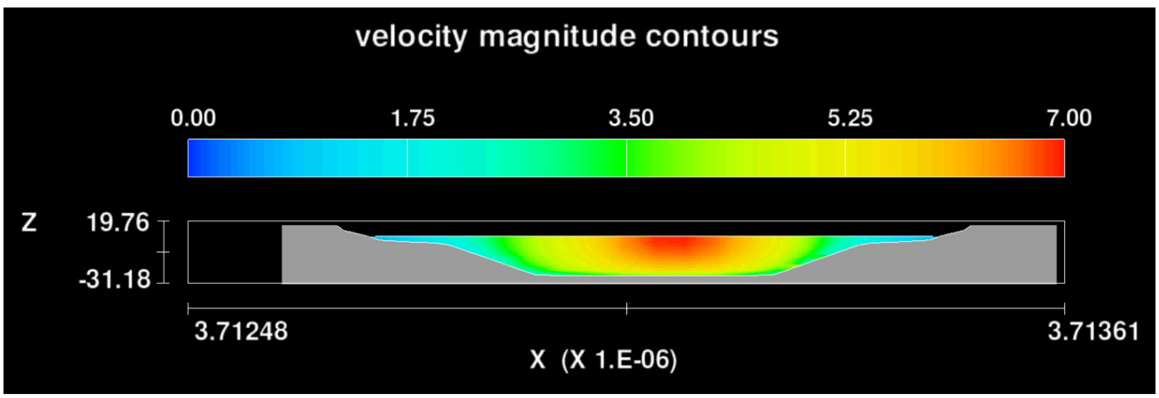
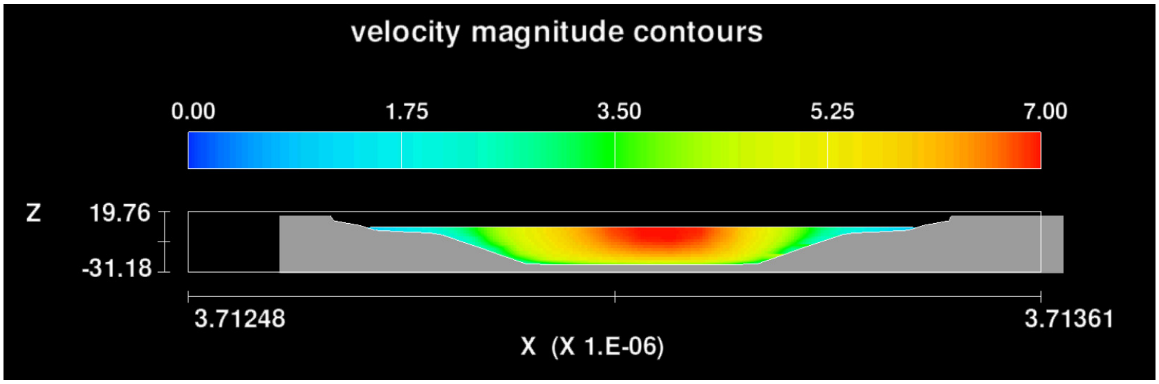


Figure 3. Hydraulic parameters upstream of back structure (approximately Station 45+00)



Based on the results shown in Figures 1 to 3, the hydraulic parameters shown in Table 3 were used to estimate channel lining requirements.

Table 3. Hydraulic modeling summary

Location	Velocity (feet per second)	Water surface elevation (feet)	Depth (feet)
Downstream of transition structure (~ Station 125+00)	9	8.00	33.00
Mid channel (~ Station 85+00)	7	7.50	32.50
Upstream of back structure (~ Station 45+00)	7	7.25	32.25

Note: Velocity and water surface elevations were conservatively estimated from FLOW-3D graphical output.

Given the hydraulic modeling results shown in Table 3, HDR estimated riprap size and filter requirements using guidance established Equation 3-3 in the U.S. Army Corps of Engineers guidance, *Hydraulic Design of Flood Control Channels* (EM 1110-2-160, June 1994). The process is summarized below (also see Table 4):

$$D_{30} = S_f C_s C_v C_T d \left(\left(\frac{\gamma_w}{(\gamma_s - \gamma_w)} \right)^{0.5} \frac{V}{(K_1 g d)} \right)^{2.5}$$

Where:

D_{30} = Riprap size of which 30% is finer by weight

S_f = Safety Factor = 1.2

C_s = Stability Coefficient = 0.3 for angular rock

C_v = Vertical velocity distribution coefficient = 1.0

C_T = Thickness Coefficient

d = Local depth of flow

γ_w = Unit weight of water = 62.4 lbs/cf

γ_s = Unit weight of riprap = 155 lbs/cf

V = Local depth averaged velocity

K_1 = Side slope correction factor

Where

$$K_1 = \sqrt{1 - \frac{sin^2\theta}{sin^2\varphi}}$$

ϴ=angle of side slope = 12.5 degrees

□=angle repose = 40 degrees normally assumed

K_1 = 0.996

g = Gravitational Constant = 32.2 ft/s2

Table 4. Parameters required to determine conveyance channel lining

Location	S_f	C_s	C_v	C_T	V (fps)	WSE (ft)	d (ft)
Downstream of transition structure (~ Station 125+00)	1.2	0.3	1.0	1.5	9	8.0	33.0
Mid channel (~ Station 85+00)	1.2	0.3	1.0	1.5	7	7.5	32.5
Upstream of back structure (~ Station 45+00)	1.2	0.3	1.0	1.5	7	7.25	32.25

Notes: fps = feet per second, ft = feet

Based on the information in Table 4 and using the riprap classification (shown in Table 5) outlined in Section 711 of the Louisiana Department of Transportation and Development's (LADOTD's) *Standard Specifications for Roads and Bridges Manual* (2006), riprap sizes and depths were estimated as summarized in Table 6.

It should be noted that the U.S. Army Corps of Engineers' *Hydraulic Design of Flood Control Channels* (EM 1110-2-1601, 1994) Section 3-2e states:

- Thickness should not be less than the diameter of the upper limit W_{100} stone or 1.5 times the upper limit W_{50} stone, whichever is greater.
- Thickness determined by above should be increase by 50% when riprap is placed under water.

It is anticipated that in-water construction would be required for this project; therefore, all thickness has been increased by 50% to comply with EM 1110-2-1601 for in-the-wet construction.

Table 5. LADOTD riprap classification

Riprap class	Stone size (lb)	Spherical diameter (ft)	Percentage of stone smaller than
2 lb	10 4 2 0.75	0.51 0.38 0.30 0.22	100 40–100 15–50 0–15
10 lb	50 20 10 5	0.88 0.65 0.31 0.41	100 50–100 15–50 0–15
30 lb	140 60 30 10	1.24 0.94 0.74 0.51	100 42–100 15–50 0–15
55 lb	275 10 55 20	1.50 1.11 0.88 0.63	100 42–100 15–50 0–15
130 lb	650 260 130 40	2.00 1.46 1.17 0.79	100 45–100 15–50 0–15
250 lb	1,250 500 250 80	2.50 1.83 1.46 1.00	100 45–100 15–50 0–15
440 lb	220 900 440 130	3.00 2.23 1.76 1.17	100 40–100 15–50 0–15
1,000 lb	5,000 2,000 1,000 300	4.00 2.91 2.31 1.55	100 45–100 15–50 0–15

Notes: ft = feet, lb = pounds

Table 6. Channel armor size estimates

Location	Lining D_{30} (in)	Lining D_{50} (in)	Riprap classification[a]	Minimum lining depth (ft)	Minimum filter depth (ft)
Downstream of transition structure (~ Station 125+00)	5.26	6.3	10 lb	1.2	2.1
Mid channel (~ Station 85+00)	2.80	3.4	2 lb	0.5	1.1
Upstream of back structure (~ Station 45+00)	2.80	3.4	2 lb	0.6	1.1

Notes: ft = feet, in = inches, lb = pounds

[a] from Louisiana Department of Transportation and Development's *Standard Specifications for Roads and Bridges Manual* (2006)

Review of Wave Climate within MBSD Channel

A cursory review of anticipated wind-generated wave conditions within the MBSD channel outfall was conducted to approximate stone size for lining of the channel side slopes. Wave data were extracted from a previously completed preliminary numerical model, using industry standard equations to determine approximate stone size for the lining.

Wave Heights

Wave data were extracted from a previous analysis of wave heights at the MBSD (HDR 2013). The CMS-Wave module of the Surface-water Modeling System (SMS) 11.1 was used to model wave growth and propagation across Barataria Bay during a 50-year return period water level and a 50-year return period wind speed event. A sample output from the model at the MBSD outfall is shown in Figure 4. Results indicate that a significant wave height of 2.8 feet with a peak wave period of 2.9 seconds can be expected during the modeled scenario.

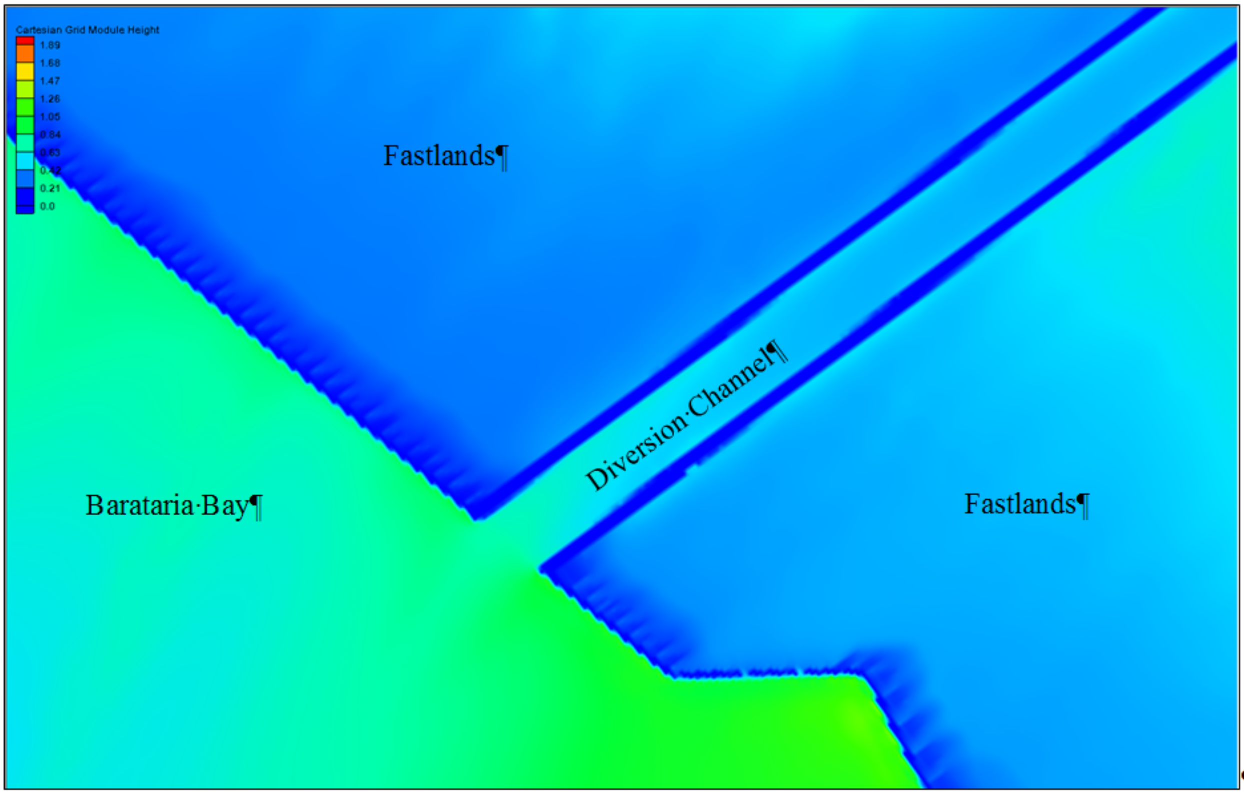
Additionally, the Automated Coastal Engineering System (ACES), a one-dimensional wave model within the Coastal Engineering Design and Analysis System (CEDAS), was used to approximate wave conditions generated in Barataria Basin that may approach the channel. Two cases were examined with ACES:

- Case 1 – 50-year return period wind speed (98 miles per hour) with a 10% exceedance water surface elevation (1.85 feet North American Vertical Datum 1988 [NAVD 88])
- Case 2 – 50-year return period wind speed with a 2% water surface elevation (10.4 feet NAVD 88)

For the one-dimensional analysis, the bottom elevation of Barataria Basin was assumed to be –1 foot NAVD 88. The 10% exceedance water surface elevation was calculated using data available from the Coastwide Reference Monitoring System (CRMS) Station 4103 (CRMS 2013) from 2008 to 2013. The fetch for both scenarios was assumed to be 6 miles based on the topography of the basin system.

Case 1 from the ACES model produced a zero-moment wave height of 2.2 feet and a peak wave period of 3.7 seconds. Case 2 produced a zero-moment wave height of 6 feet and a peak wave period of 4.7 seconds. Case 2 from the ACES model and the results from the CMS-Wave module produced significantly different wave environments despite modeling the same water level and wind speed. This difference is primarily attributable to added topographic and bathymetric definition available in the two-dimensional CMS-Wave model compared with the one-dimensional calculation in the ACES model.

Figure 4. Sample wave height output from CMS-Wave at the MBSD outfall



Investigated Protection Measures

Side Slope Lining to Protect Against Shear Stress Failure

The side slopes of the proposed conveyance channel would have a relatively flat slop of 4.5:1 (H:V). As discussed previously, HDR considered the potential for these slopes to erode. To protect against erosion, several types of channel linings were investigated, including riprap revetment, articulated concrete block mats revetment, and geotextile encapsulated soils. Table 7 summarizes the investigated improvements.

It should be noted that a minimum riprap thickness of 2 feet was assumed. This allows for the 50% thickness increase required to comply with the U.S. Army Corps of Engineers' EM 1110-2-1601 for placement of riprap in the wet.

Table 7. Conveyance channel side slope lining options

Option	Description	Advantages	Disadvantages	Estimated cost
Riprap revetment	LADOTD Class 10 lb riprap, 2-foot depth, 2.5-foot filter material, lining both side slopes	• Would provide required protection • Less expensive than articulated concrete block mats option	• May require dumping to place riprap in the wet • Does not provide protection for wave action • Would not allow for geotextile filter • Revetment would need to be avoided during dredging operations	~$15 million
Articulated concrete block mats	6-inch-deep articulated concrete block mats, 40 feet long × 8 feet wide	• Would provide required protection • Modular units can be assembled off site • 40-foot × 8-foot panels allow for more gentle installation using cranes • Allows for potential use of sand filter or geotextile filter	• High cost • Requires excavation of a relatively smooth surface prior to placing articulated concrete block mats—may be difficult to achieve in a wet installation with low-strength soils	~$42 million
Geotextile encapsulated soils	Install hydraulically stable material encased in sacrificial geotextile fabric (similar to method used for Oostershelde Barrier Storm Surge protector in the Netherlands)	• Would provide required protection • Modular units can be assembled off site • Allows for potential use of sand filter or geotextile filter	• Method considered experimental • Installation in the Netherlands required use of a specially equipped boat • Class I riprap may be too large to incorporate into geotextile encasement	Not evaluated given experimental nature of this application and concern that hydraulically stable material is too large to be encapsulated

Notes: LADOTD = Louisiana Department of Transportation and Development, lb = pounds

Side Slope Lining to Protect Against Wave Action

Industry standard methods including the Hudson and van der Meer formulas (Doorn 2007) were used for calculating armor stone size. A side slope of 4.5H:1V and stone-specific weight of 155 pounds per cubic foot were assumed for the calculations. Results using the wave data from the CMS-Wave module indicate that the median stone weight should be approximately 120 pounds per cubic foot, resulting in a nominal median (D_{50}) stone diameter of 11 inches. Results from Cases 1 and 2 of the ACES model indicate median stone diameters of 11 inches and 24 inches, respectively (Table 8).

Table 8. Conveyance channel side slope lining options for wave protection

Option	Description	Advantages	Disadvantages	Estimated cost
11-inch wave protection	LADOTD Class 30 lb riprap, 2-foot depth, and 2.5-foot sand filter placed along side slopes	• Less expensive than articulated concrete block mats option • Would provide wave protection to the 10-year event	• May require dumping to place riprap in the wet • Would not allow for geotextile filter	$15 million
24-inch wave protection	LADOTD Class 250 lb riprap, 4-foot depth, and 2-foot sand filter placed along side slopes	• Would provide required protection • Less expensive than articulated concrete block mats option • Would provide wave protection to the 50-year event	• May require dumping to place riprap in the wet • Would not allow for geotextile filter	$29 million

Notes: LADOTD = Louisiana Department of Transportation and Development, lb = pounds

Channel Bottom Lining

HDR also investigated lining for the channel bottom (see Table 9). It should be noted that the channel is bounded by fixed elevation sills both upstream and downstream. The presence of these sills will constrain the bottom elevation of the channel and is not anticipated to allow for vertical adjustment of scour. The purpose of investigating channel bottom lining is to protect against upwelling forces and also local erosion at the toe of the channel, which could create some local instability.

Table 9. Conveyance channel bottom lining options

Option	Description	Advantages	Disadvantages	Estimated cost
Riprap lining	LADOTD Class 10 – 2 foot depth with 2.5-foot sand filter depth placed on bottom of conveyance channel	• Would provide required protection • Less expensive than articulated concrete block mats option	• No local source of Class 10 riprap • May require dumping to place riprap in the wet • Would not allow for geotextile filter	$19 million
Riprap toe protection only	LADOTD Class 10 – 2 foot depth placed on bottom of conveyance channel	• Less material means less cost • Provides side slope protection • No overexcavation anticipated	• Does not protect against upwelling • May have minor impacts on hydraulics • Toe would need to be avoided during dredging operations	$8 million

Table 9. Conveyance channel bottom lining options

Option	Description	Advantages	Disadvantages	Estimated cost
Articulated concrete block mats	6-inch-deep articulated concrete block mats, 40 feet long × 8 feet wide, liner provided with geotextile	• Would provide required protection • Modular units can be assembled off site • 40-foot × 8-foot panels would allow for more gentle installation using cranes • Allows for potential use of sand filter or geotextile filter	• High cost • Requires excavation of a relatively smooth surface prior to placing articulated concrete block mat—this may be difficult to achieve in a wet installation with low-strength soils	$50 million

Notes: LADOTD = Louisiana Department of Transportation and Development, lb = pounds

Filter Material

Filter material was investigated to protect against mobilization of dispersive clay and other erodible native soil particles. HDR investigated geotextile filters and sand filters to provide this protection. Table 10 summarizes this investigation.

Table 10. Conveyance channel filter material options

Option	Description	Advantages	Disadvantages	Estimated cost
Geotextile filter	A geotextile filter designed to prevent the loss of dispersive clay materials	• No overexcavation required • Relatively inexpensive • Could place articulated concrete block mats and geotextile simultaneously	• Only possible with articulated concrete block mats—not possible with riprap	$0.7 million
Sand filter	A 2.5-foot-thick sand filter designed to protect against the mobilization of clay materials	• Could be used with riprap or articulated concrete block mats • Product can adjust to potential future settling	• High cost	$5.7 million
Deep soil mixing	Addition of lime and/or cement to stabilize soil and reduce degree of dispersion of native clays	• Could stabilize dispersive soils using chemical treatment	• Treatment method not possible for in-the-wet construction	Not evaluated because this is not viable for in-the-wet construction

Summary and Recommendations

Based on results of the investigation, HDR makes the following recommendations:

- Channel side lining:
    - Lining material – LADOTD Class 30 riprap , 2-foot depth
    - Filter material – Sand filter, 2.5-foot depth
- Channel bottom lining:
    - Toe protection using LADOTD Class 30 riprap

References

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