

APPENDIX E

Conceptual Designs

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Conceptual Designs

This section is divided into a general description of the potential measures, a discussion of the habitat considerations for each of the measures, and a presentation of conceptual designs that incorporate the best measures, or combinations of measures, and would successfully address the hazards at each of the eight existing problem sites.

For each of the potential measures for alleviating flooding and erosion hazards along the White River, the following information is provided:

- A general physical description
- The expected life span and maintenance requirements
- The direct impacts on the site during construction, including the relative area of disturbance and the amount of excavation and/or embankment required
- The effectiveness of the measure in controlling either flooding or erosion of the highway
- Potential mitigation measures that would provide added benefits, performance, effectiveness, or decrease the costs or negative impacts of the solution
- Whether the measure adds to or detracts from the aesthetics of the sites
- Relative costs of construction, excluding environmental and mitigation work
- Relative costs of performing the environmental protection work to control and prevent construction impacts and performing the mitigation work to offset any negative impacts.

Earthen Dike

One of the most common measures for protection from flood hazards is to construct an earthen dike to provide separation between floodwaters and the object to be protected (see Figure E-1). Typical unreinforced earthen dikes have trapezoidal cross-sections with side slopes in the range of 3:1 (horizontal to vertical) to 2:1, depending on the geotechnical properties of the soils used. Although earthen dikes used along waterways for flood protection are exempt from the Washington State Dam Safety Regulations (WAC 173-175), their design should incorporate all the technical requirements. Major variables that need to be determined for the design an earthen dike are the geotechnical properties of the borrow soil and subgrade, the permeability of the soil,

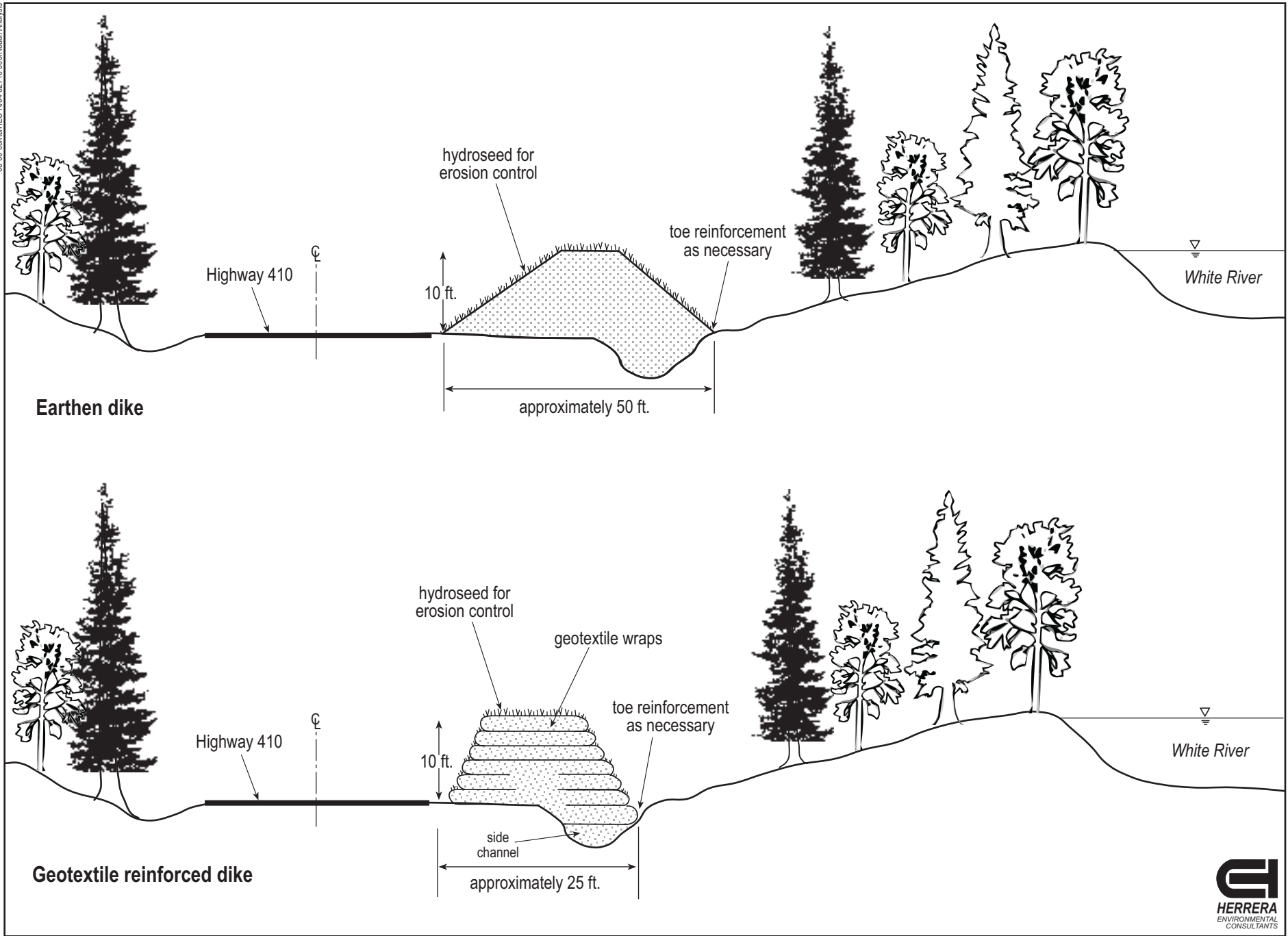


Figure E-1. Cross-sections of an earthen dike and a reinforced dike to provide flood protection of a highway.

the height of flood stage relative to the road pavement, and the topography/grade adjacent to the road. Additionally, the velocity of flood flows along the interface of the dike are necessary to determine the necessary level of protective measure(s) to eliminate erosion and/or undermining of the dike. These measures could range from simple hydroseeding and planting to geotextile reinforcement or riprap armoring.

Advantages—Earthen dikes are technically simple to construct with readily available materials.

Disadvantages—Earthen dikes require a relatively wide footprint, creating a large area of ground disturbance. Earthen dikes require a large amount of imported borrow, and their construction is earthwork-intensive. Dikes have erodible side slopes, or banks, that may require protection from river flows. Dikes present a barrier to stormwater drainage and both pedestrian and wildlife passage that needs to be addressed in design. A dike requires frequent inspection and maintenance and, in terms of aesthetics, is likely to be undesirable in a national park setting as it may block views of the river from the highway.

Costs—The costs for construction of an earthen dike are likely lower than the costs of all the other flood protection measures, with the exception of LWD flow deflectors.

Reinforced Dike

A reinforced dike is similar to an earthen dike except that it is constructed of horizontal layers of earth wrapped with woven geotextile for added support (Figure E-1). Geotextile reinforcement allows for steeper side slopes, allowing less fill and a smaller footprint. The geotextile reinforcement also provides for erosion resistance on the side slopes.

Advantages—A reinforced dike has the same advantages as an earthen dike, with the added benefits of a smaller footprint, technically simple construction with readily available materials, and greater erosion resistance than an unreinforced earthen dike.

Disadvantages—While less than that of an unreinforced dike, geotextile-reinforced dikes have a moderately large area of ground disturbance and require a large amount of imported borrow and earthwork. The inspection and maintenance needs are similar to those of an earthen dike. Dikes present a barrier to stormwater drainage and both pedestrian and wildlife passage that needs to be addressed in design. Aesthetically, a geotextile-reinforced dike is undesirable in a national park setting as it may block the view of the river from highway.

Costs—The costs for construction of a reinforced dike are likely higher than those for an earthen berm and LWD flow deflectors but lower than the costs of all the other flood protection measures.

ELJ Flow Deflectors

This measure involves strategic placement of ELJ structures at critical locations in the river, or alongside the river, to deflect flows and prevent the river from engaging side channels or

remnant channels that could convey floodwaters toward the highway (see the photographs of ELJ flow deflectors in the section “Potential Measures for Erosion Hazards,” under the heading “ELJs and Deflector Structures”). Primarily effective at providing erosion protection, the ability of ELJ flow deflectors to provide flood hazard protection to the highway is highly dependent upon the physical relationship between the highway, the river, and any side channels.

Additionally, the design and siting of ELJ flow deflectors need to carefully consider reach and site characteristics including main stem and side-channel geometries, substrate conditions, flow magnitude and potential alignments, and potential wood loading scenarios. Although the use of ELJ flow deflectors as a sole flood hazard protection measure would result in limited success in only very rare circumstances, ELJ flow deflectors can be extremely effective when used in conjunction with other flood hazard measures.

This solution was implemented as an emergency flood protection measure in 2003 where the White River had jumped the existing bank and engaged a side channel that was immediately adjacent to a portion of SR410. This measure worked effectively to stave off flooding of the road from 2003 to 2005. However, it is no longer a realistic flood protection measure by itself given that the current elevation of the river is above the highway. ELJ flow deflectors could be used in conjunction with other measures to produce an effective conceptual design.

Advantages—Installation requires a fairly minor footprint and disturbance. They are aesthetically in keeping with a natural river system, and may be locally applicable to redirect main stem and side channels. ELJ flow deflectors also provide very effective erosion protection.

Disadvantages—The effectiveness of ELJ flow deflectors as a flood protection measure is limited to rare occasions where side channels are at risk of being engaged by flood stage flows.

Costs—The costs for construction of LWD flow deflectors are lower than the costs of all the other flood protection measures.

Sheet Pile Wall—A sheet pile wall consists of a continuous line of interlocking sheet piles driven partially into the ground to form a wall (Figure E-2). Piles are traditionally manufactured of steel, but precast-concrete and vinyl piles are available as well (Figure E-3). In this application, the piles would be driven into the ground adjacent to the highway to form a barrier wall between the highway and the river and any side channels. Installation could be easily performed from the highway with minimal clearing and ground disturbance (Figure E-4). Various commercially available sheet pile sections allow for various strengths while providing water-tight capabilities. Geotechnical investigations, including borings, would be necessary to determine the suitability of this measure. The presence of shallow bedrock may preclude the use of sheet piles. A sheet pile flood wall is probably the least attractive measure with respect to aesthetics, but it does have the least environmental impact. Precast or cast-in-place architectural concrete panels and plantings could be used to mitigate the appearance of a sheet pile flood wall. However, the addition of architectural panels would likely make this measure prohibitively expensive compared to the other flood hazard measures.

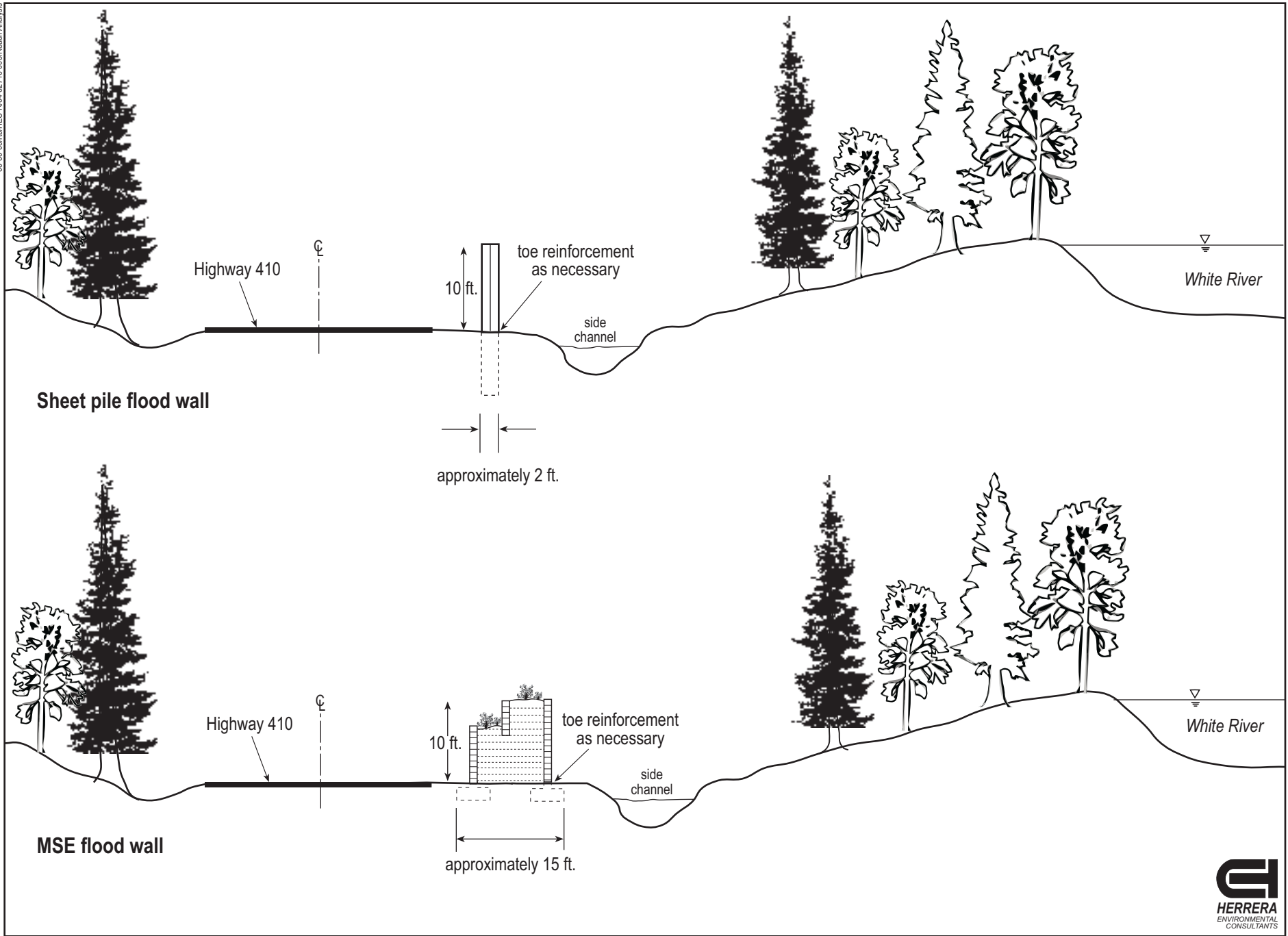


Figure E-2. Cross-sections of a typical sheet pile flood wall and MSE flood wall to provide flood protection of a highway.

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Figure E-3. Example of a precast-concrete sheet pile installation between a river and a roadway. Although the primary function of this wall is to structurally retain the roadway and prevent erosion of the embankment, the installation would be similar in a flood wall application.

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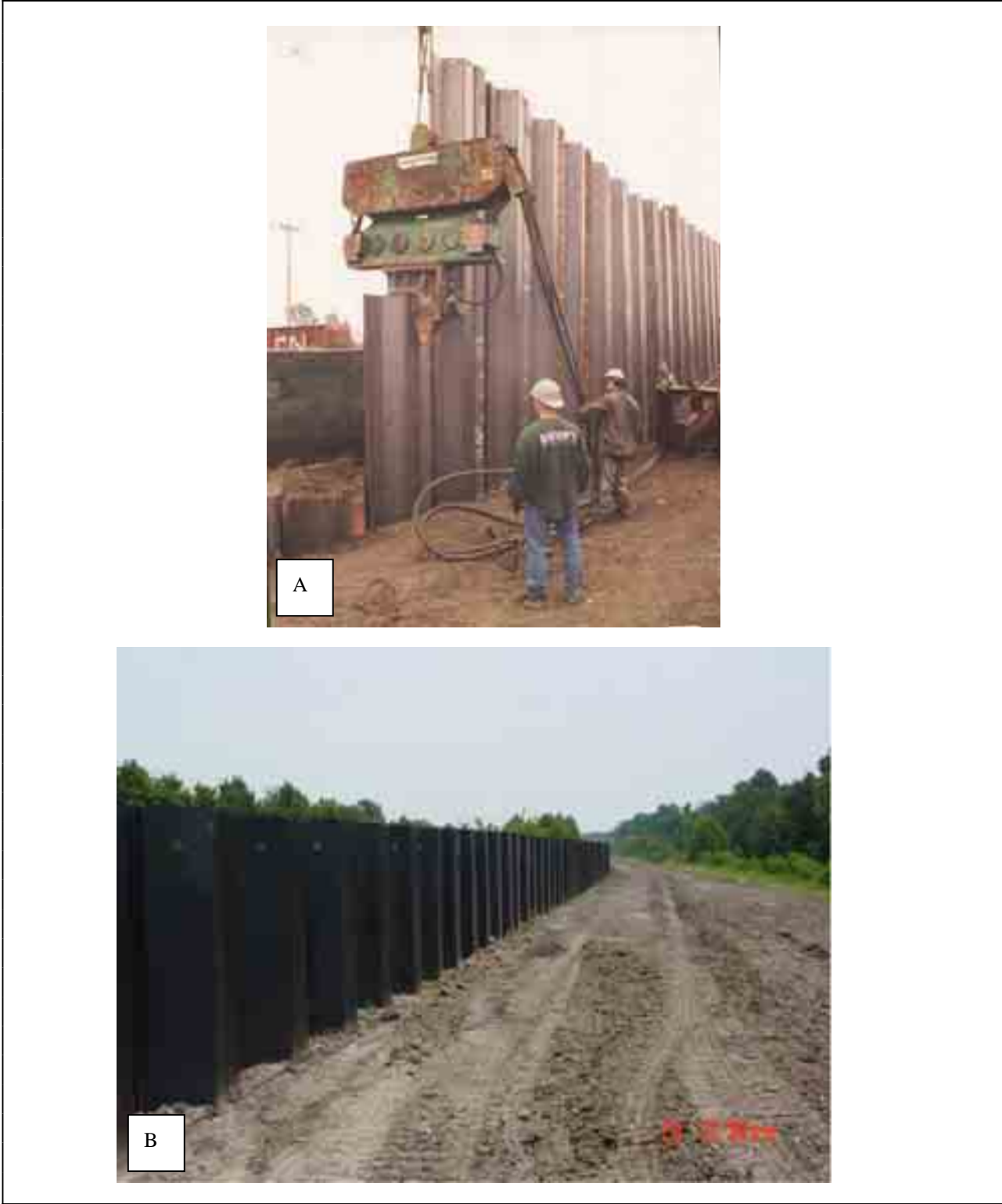


Figure E-4. Examples of a vibratory sheet pile installation (A) and a completed sheet pile flood wall (B).

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Advantages—Smallest disturbance footprint of all the flood protection measures. Easily and quickly installed with a minimum of disturbance and earthwork. Sheet pile can be removed and recycled or incorporated into long-term solutions. If used as a short-term measure, piles may be leased or rented to reduce the project costs.

Disadvantages—Current market price for steel is high and will likely result in a relatively high installation cost. Sheet pile walls, like dikes, present a barrier to stormwater, pedestrians, and wildlife that needs to be addressed in design. Like all flood wall options, the longevity of a sheet pile wall will be significantly enhanced if erosion control measures are used to prevent scour along the river side of the structure. This may not be a realistic long-term solution since the highway remains below flood inundation levels; therefore, a structural failure could have catastrophic consequences.

Costs—The costs for construction of a sheet pile flood wall are likely higher than those of an earthen dike, reinforced dike, LWD flow deflectors, and MSE flood wall. The costs for a construction of the elevated highway measures and highway relocation are much higher than those of a sheet pile flood wall.

MSE Flood Wall

An MSE flood wall is similar to a reinforced dike, except the sides of the dike are finished nearly vertical using a commercially available modular precast-concrete wall system (Figure E-2). The area of ground disturbance, completed footprint size, and amount of borrow material are reduced approximately in half compared to a geotextile-reinforced dike, and the erosion resistance of the wall is quite good. However, the addition of the wall complicates the construction due to the need for a cast-in-place concrete footing beneath the full length of the wall. Furthermore, the wall presents a barrier to stormwater, pedestrians, and wildlife that requires specialized designs. Because the width of the MSE flood wall is much less than that of an earthen dike, the permeability of the MSE flood wall and backing embankment need to be considered carefully in the design, and the addition of a geomembrane may be required.

Advantages—An MSE flood wall is typically narrower in cross-section than a geotextile-reinforced dike. Therefore, there is less ground disturbance and the required amount of fill is significantly less.

Disadvantages—An MSE flood wall has a larger footprint than a sheet pile wall and takes longer to install. A continuous cast-in-place footing increases construction duration and requires a moderate amount of excavation along the highway, possibly involving shoring measures. Visual improvements such as texturing or imprinting concrete can be added to improve the aesthetic appeal of an MSE flood wall. As with the other flood wall options, an MSE flood wall may not be a realistic long-term solution since the highway remains below the flood inundation levels; therefore, a structural failure could have catastrophic consequences.

Costs—The costs for construction of an MSE flood wall are likely higher than those of an earthen dike, a reinforced dike, and LWD flow deflectors but less than the costs of sheet pile flood walls, the elevated highway measures, and highway relocation.

A variation of an MSE wall is a precast-concrete panel wall. Typically used for noise wall applications between freeways and residential areas, precast-concrete wall systems could be strengthened and adequately coupled to a continuous cast-in-place concrete footing to resist overturning due to the hydrostatic force of floodwater (Figure E-5). This option has advantages and disadvantages similar to those of an MSE flood wall; however, the construction may be expedited due to the larger structural wall elements.

Elevated Highway on Embankment

This measure consists of constructing a new highway on an embankment placed over the existing highway alignment to raise the pavement elevation above the flood stage (Figure E-6). This measure would require a significant amount of borrow and may disturb a large ground area because the road prism could extend to either side of the existing road embankment considerably. As with the earthen dike, the river side of the embankment would need to incorporate armoring measures to address potential erosion and scour. Additionally, the design would need to incorporate measures to convey stormwater and allow pedestrian and wildlife passage, such as a precast-concrete, open-bottom culverts (Figure E-7).

Advantages: Construction of an embanked highway is technically straight forward, and the elevation of the highway would be set above the flood stage, eliminating the flood hazard.

Disadvantages: Because of the significant amount of borrow and the large footprint of the embankment, this measure will require a large amount of clearing and ground disturbance. The large amount of imported fill and asphalt pavement required for this measure may result in a project cost greater than that of any of the flood wall options.

Costs: The costs for construction of an elevated highway on an embankment are higher than those of all the other flood erosion measures other than the elevated highway on an MSE wall, cantilevered and pile-supported elevated highway measures, and highway relocation.

Elevated Highway on MSE Prism

This measure is similar to the elevated highway on an embankment with the addition of MSE walls (Figure E-6). The MSE walls would allow for nearly vertical side walls that significantly reduce the area of disturbance and the amount of fill required. However, each MSE wall requires a continuous cast-in-place concrete footing that adds complexity to the construction effort and requires more time. Like the elevated highway on an embankment, this measure would require measures to provide for stormwater conveyance and both wildlife and pedestrian passage.



Figure E-5. Example of a precast-concrete panel flood wall.

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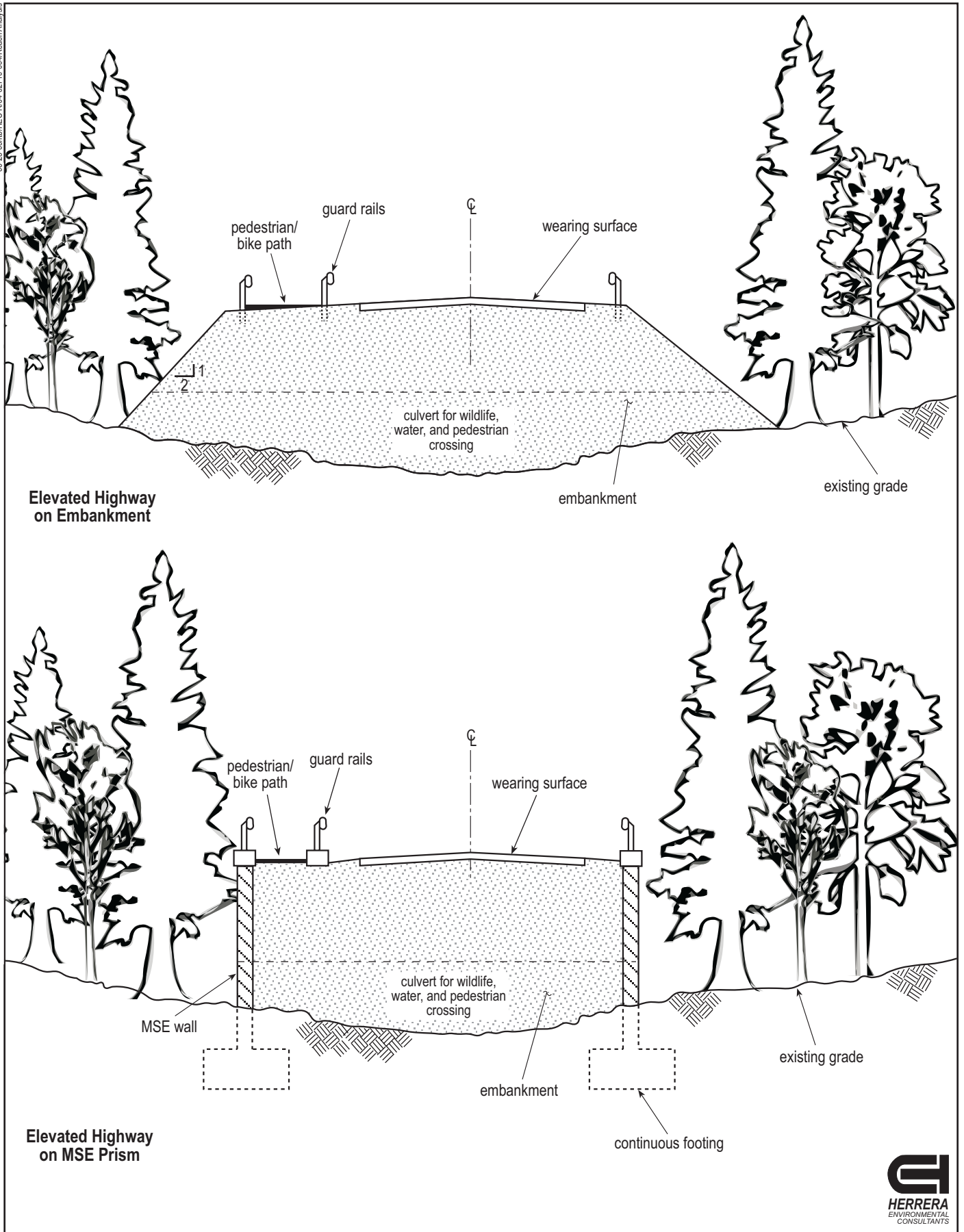


Figure E-6. Cross-section of an elevated highway on an embankment and an elevated highway on an MSE prism.

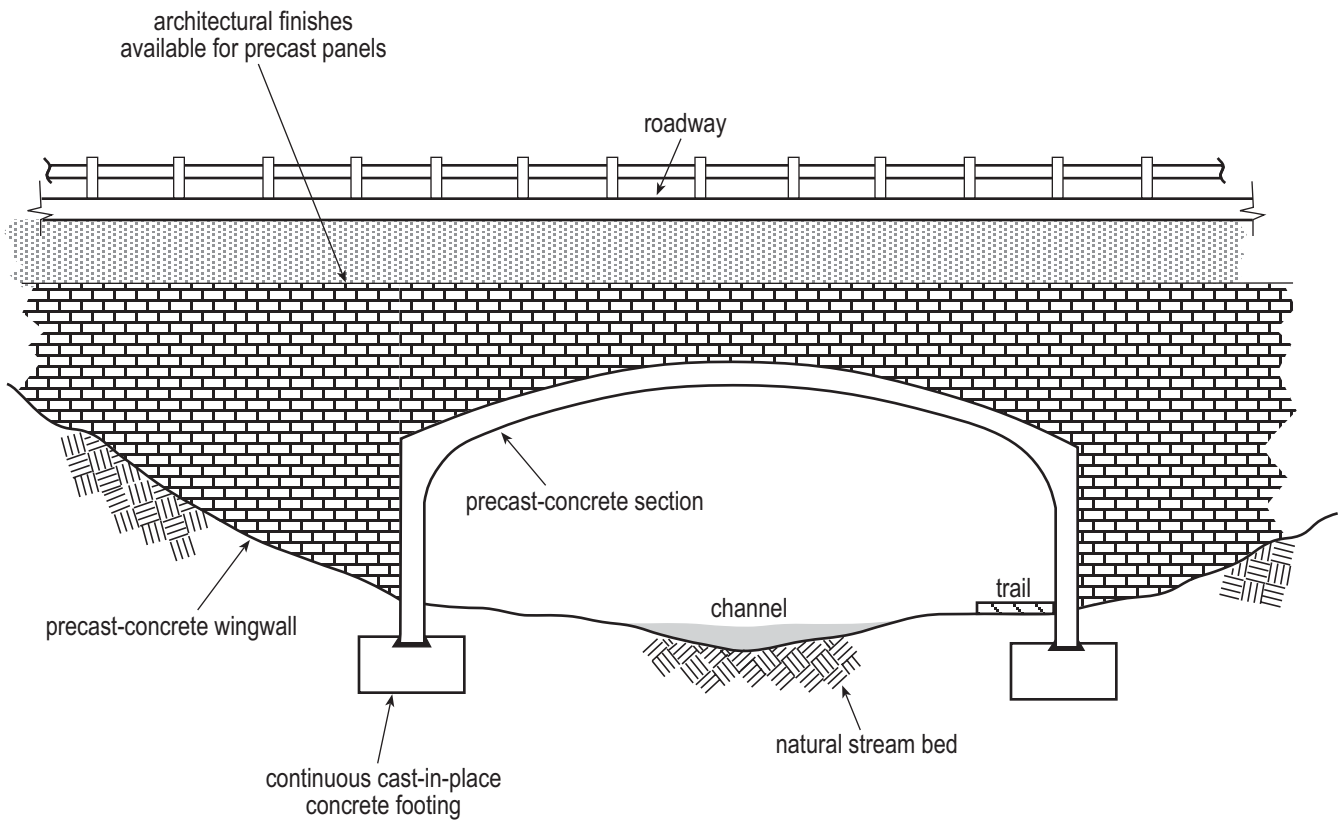


Figure E-7. Typical installation of an open-bottom, precast-concrete culvert in an embankment.

Advantages: Provides a high level of effectiveness to prevent flooding of the highway while reducing the area of ground disturbance relative to an elevated highway on an embankment.

Disadvantages: Continuous cast-in-place footings increase construction duration and may require significant excavation and shoring. While requiring approximately 40 percent less imported fill than the embanked highway, this measure still requires a significant amount of imported fill.

Costs: The costs for construction of an elevated highway on an MSE prism are higher than those of all the other flood erosion measures other than an elevated, cantilevered highway, a pile-supported elevated highway, and highway relocation.

Elevated, Cantilevered Highway

This measure is similar to the elevated highway on an MSE prism, except that structural concrete walls replace the MSE walls, the prism is reduced in width, and the road surface is supported on either cantilevered concrete slabs or bents with beams (Figures E-8 and E-9).

Advantages: This measure provides a high level of effectiveness to prevent flooding of the highway while reducing the area of ground disturbance and amount of imported fill relative to an MSE prism.

Disadvantages: The continuous cast-in-place footings for the structural concrete side walls increase the time required for construction. The structural concrete components (e.g., cantilevered slabs, t-beams, and bents) may significantly increase the construction costs.

Costs: The costs for construction of a cantilevered, elevated highway are higher than those of all the other flood erosion measures other than a pile-supported elevated highway and highway relocation.

Elevated Highway on Piers

This measure would replace the existing highway with an elevated roadway of precast and cast-in-place concrete members supported on concrete piers and footings (Figures E-9 and E-10). This would require removal of the existing highway and ultimately could allow the White River to reclaim floodplain that is now occupied by the highway.

Advantages—This measure provides a high level of effectiveness to prevent flooding of the highway while allowing the White River to reclaim former floodplain, and it provides nearly unrestricted crossing for wildlife and pedestrians. Stormwater and streams would be allowed to flow uninhibited to the White River.

Disadvantages—Construction of an elevated highway on concrete piers is associated with significant project engineering and construction costs.

Costs—The costs for construction of an elevated highway on piers are higher than those of all the other flood erosion measures other than highway relocation.

Highway Relocation

This measure involves the removal of the existing highway and its reconstruction in a new location where the flooding hazards are low. It is possible that relocating the highway to the east and outside of the floodplain may result in lower project costs and less impacts than all of the elevated highway options. Relocating the highway would entail moving the highway alignment onto the valley hillside. Detailed topographic survey data and geotechnical data would need to be evaluated to determine a viable route.

Advantages—Relocating the highway outside the floodplain would eliminate flooding hazards to the highway. Relocation may also result in less ground disturbance, less clearing, and a much smaller quantity of imported fill than the amount that would be required to elevate the highway on an embankment.

Disadvantages—This measure is potentially the most extreme in cost, impact, environmental mitigation and would take the longest to complete due to the large required design, permitting, and construction effort.

Costs—The costs of highway relocation are likely the highest of all the flood protection measures.

Sheet Pile Walls

A sheet pile wall consists of a continuous line of interlocking sheet piles driven partially into the ground to form a retaining wall to stabilize an overly steepened slope (Figure E-11). Piles are traditionally manufactured of steel, but precast-concrete and vinyl piles are available as well (Figure E-3). In this application, the piles would be driven into the west embankment, stabilizing the embankment and providing armoring. Additional armoring at the toe is likely necessary and can be accomplished with rock or LWD placement. Installation could be performed from the highway with minimal clearing and ground disturbance (Figure E-4). Various commercially available sheet pile sections allow for various strengths, while the addition of soldier piles and anchored tie-backs can greatly increase the effective heights of sheet pile walls (Figure E-12). Geotechnical investigations, including borings, would be necessary to determine the embedment depths of the piles and the need for soldier piles or tie-backs. The presence of shallow bedrock may preclude the use of sheet piles. Although a sheet pile retaining wall is not aesthetically pleasing, it would not be visible from the highway and it may result in the least environmental impact. Precast or cast-in-place architectural concrete panels and plantings could be used to mitigate the view of the sheet pile installation. However, the addition of architectural panels would likely make this prohibitively expensive compared to an MSE wall.



Figure E-8. Example of a cantilevered elevated highway with underlying vegetation along the river corridor.

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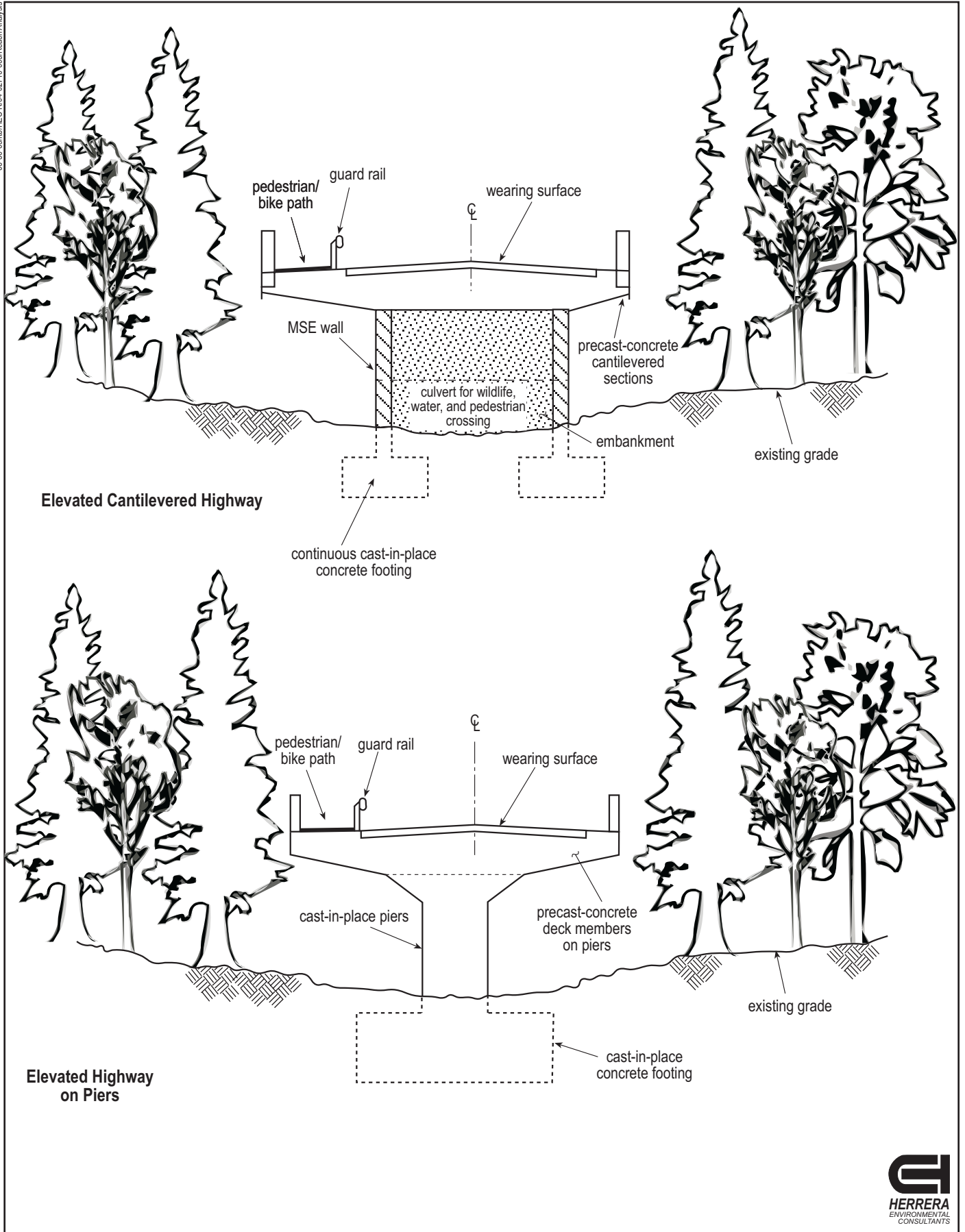


Figure E-9. Cross-section of an elevated, cantilevered highway and an elevated highway on piers.

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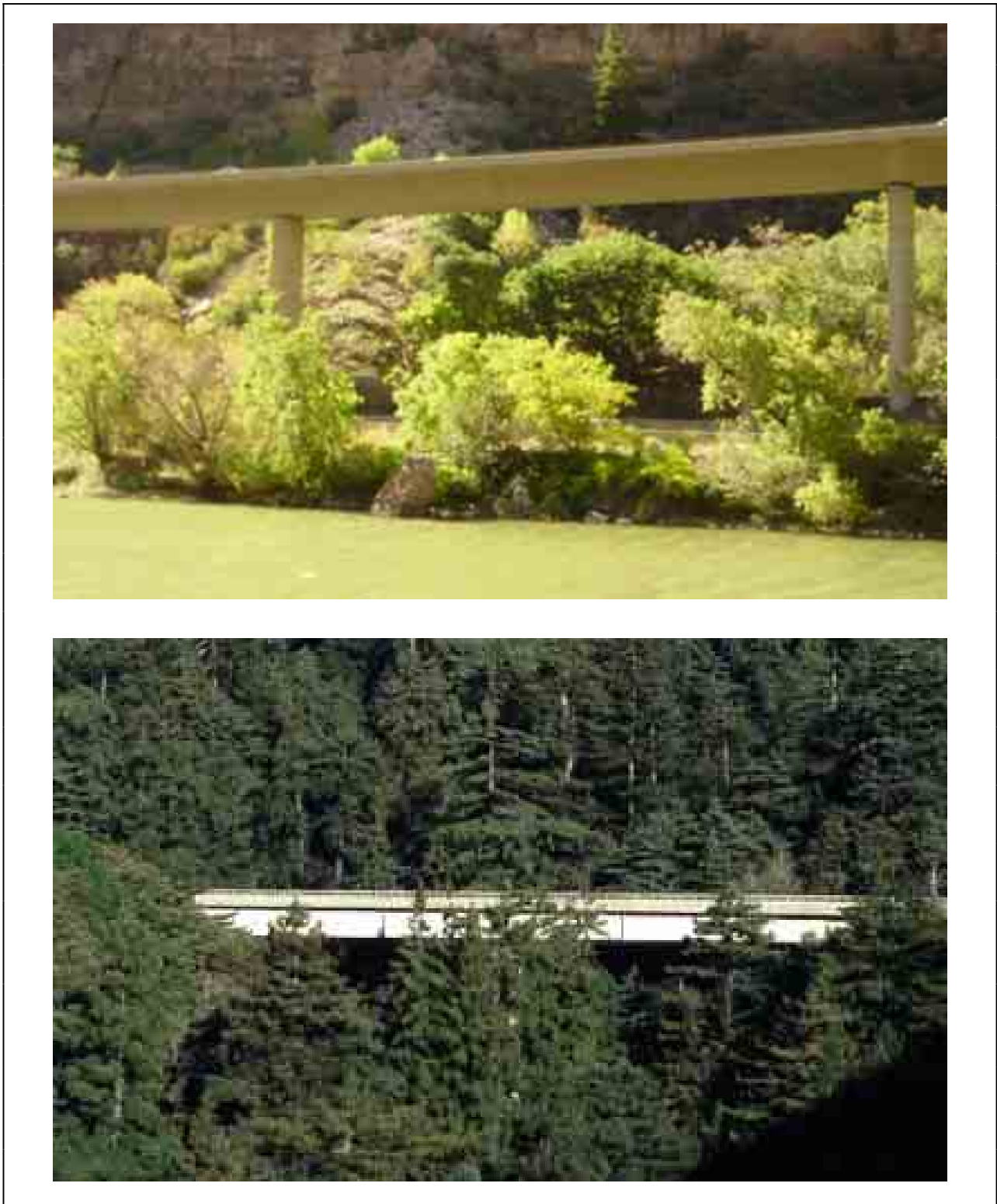


Figure E-10. Examples of an elevated highway on piers.

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Figure E-11. Example of a sheet pile retaining wall.

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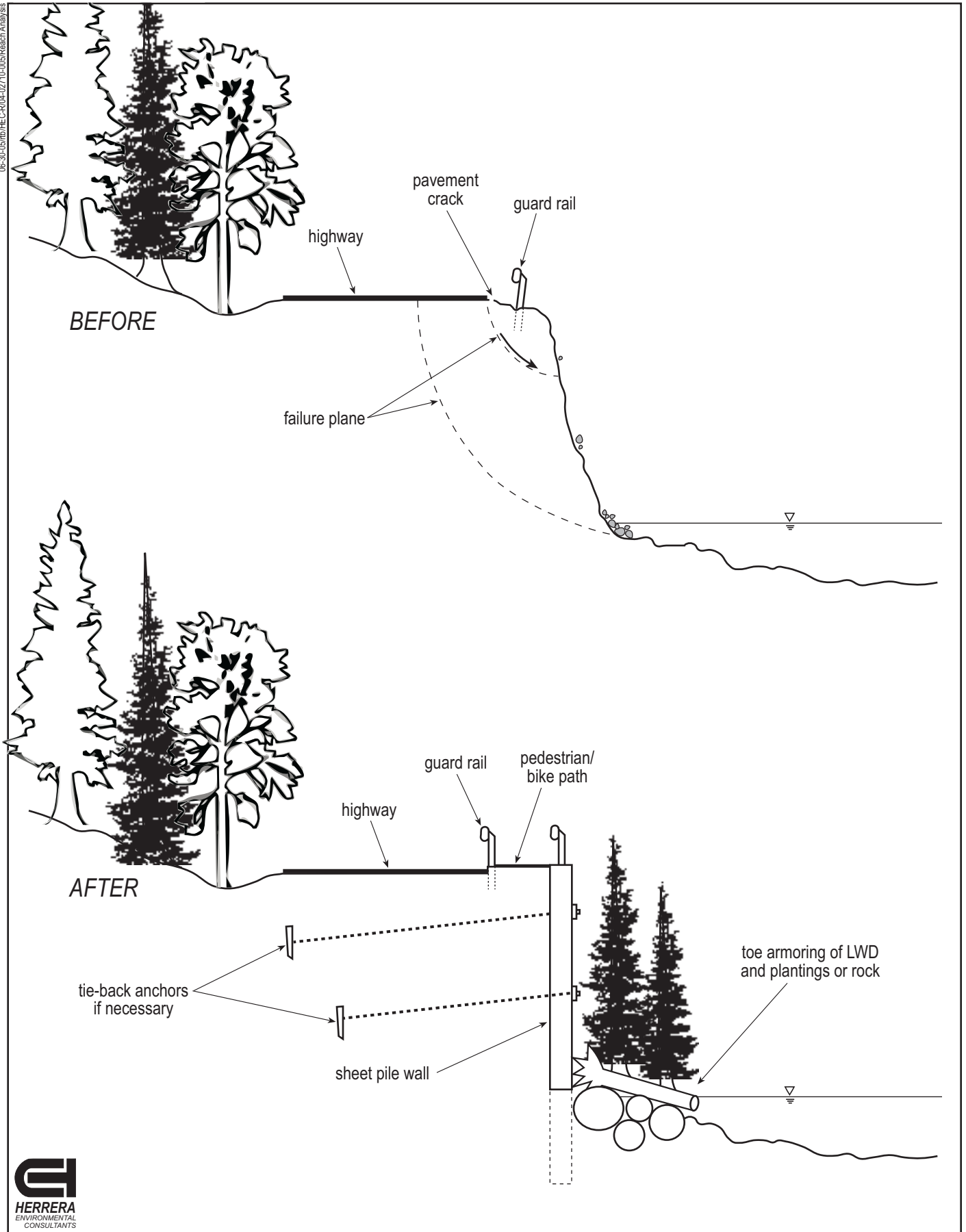


Figure E-12. Cross-section of a typical sheet pile wall reinforced with tie-backs to support a failing highway embankment adjacent to a river.

Advantages—Smallest disturbance footprint of all the flood protection measures. Easily and quickly installed with a minimum of disturbance and earthwork. Sheet piles can be removed and recycled or incorporated into long-term solutions. If used as a short-term measure, piles may be leased or rented to reduce the project costs.

Disadvantages—The current market price for steel is high and may result in a relatively high installation cost. The aesthetics of sheet piles is not consistent with the national park setting.

Costs—The costs for construction of a sheet pile wall are likely higher than those of all the other erosion control measures except for riparian buffer construction and highway relocation.

Rock Armoring

The most common and widely used measure for protecting river banks and embankments from erosion is the installation of a layer of rock armoring on the eroding slope (Figure E-13). Depending on the flow velocities and potential scour depths, rock armoring may consist of a thin veneer of quarry spalls, or it may need to be large riprap-sized rock installed both on the slope and also extending down below the water line at the toe.

Advantages: Rock armoring is technically simple to design and construct with readily available materials. Materials would need to be imported, and the installation costs could be moderately expensive.

Disadvantages: Rock armoring has no aesthetic value. It is susceptible to damage from large floods and requires routine inspection and maintenance efforts to ensure longevity.

Costs: The costs for installation of rock armoring are the second lowest of all the erosion protection measures. Riparian buffer enhancement is the only measure that would cost less than rock armoring.

Geotextile-reinforced wall with vegetation

Another common erosion control measure for slopes and embankments is the installation of a geotextile-reinforced wall and establishment of vegetation (Figure E-14). The geotechnical conditions need to be assessed to achieve a proper design and determine the effectiveness and lifespan of this measure. This method is limited to relatively short slope lengths and becomes less effective as the steepness and height of the embankment increases. In addition, the toe of the embankment would need to be protected from further erosion using rock armoring, LWD armoring, or riparian buffer enhancement.

Advantages—A geotextile-reinforced wall with vegetation would provide very effective slope stabilization when coupled with appropriate erosion control at the toe. The completed installation would look natural after the vegetation has become established.



Figure E-13. Example of rock blanket revetment in the Cispus River.

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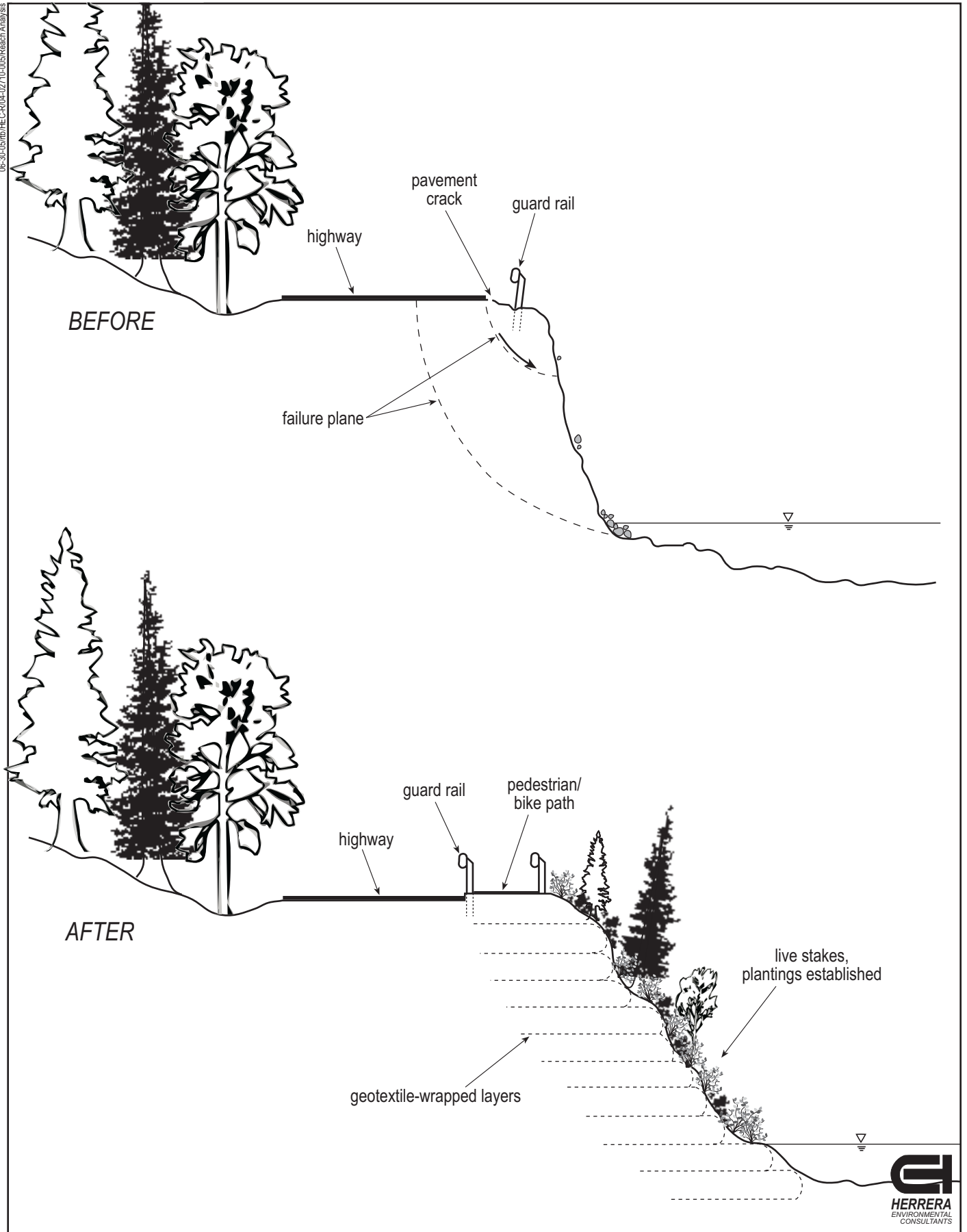


Figure E-14. Cross-section of a typical geotextile-reinforced slope with vegetation.

Disadvantages—Establishment of vegetation may be difficult and requires watering and maintenance during the establishment period. This measure is limited to short slope lengths and does not provide much erosion protection at the toe, especially if high water velocities are expected.

Costs—The costs for installation of a geotextile-reinforced wall are less costly than those of all the other erosion protection measures except for rock armoring and riparian buffer enhancement.

Large Woody Debris Armoring

This measure involves excavation of the embankment, placement of LWD (timber and logs with rootwads) alongside and into the river bank to form a matrix that is then partially backfilled (Figures E-12 and E-15). The LWD forms an erosion-resistant fabric at the edge of the embankment.

Advantages— Once installed and established, LWD armoring will provide a long service life and present a natural aesthetic while effectively mitigating bank erosion. LWD bank armoring provides habitat complexity and stable bank protection.

Disadvantages—Installation of LWD armoring requires access to the embankment at the water's edge, which would likely require temporary access roads and result in potential impacts on the river. LWD with rootwads can be difficult to attain and could be a limiting factor in terms of both a logistics and cost.

Costs—The costs for installation of LWD armoring are less than those of all the other erosion protection measures except for rock armoring, a geotextile-reinforced wall, and riparian buffer enhancement.

ELJs and Deflector Structures

This measure involves placement of ELJs and timber structures at critical locations in the river, or alongside the river, to deflect flows and slow the flow velocities in the vicinity of the erosion hazard locations (Figures E-16 and E-17). Mitigation measures during construction, including temporary sheet piling, temporary dams and water diversions, dewatering and water treatment/sedimentation facilities, are necessary to minimize the potential impacts on the river.

Advantages—This measure requires a fairly minor footprint for installation and is aesthetically in keeping with a natural river system. Properly engineered, placed, and constructed ELJs and deflector structures are effective in preventing long-term erosion, deflecting flows and providing roughness, and reducing river velocities.

Disadvantages—Installation of this measure may require access to the river and the area along the river. Mitigation measures can add significant costs and increase the duration of construction efforts. Construction of ELJs requires large logs with rootwads that can be difficult to attain and can be a limiting factor in terms of both logistics and cost.



Figure E-15. Example of LWD armoring in the Cispus River.

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Figure E-16. Installation of ELJs flow deflectors in the Cispus River after a flood event that razed a poorly developed riparian buffer and damaged a portion of the highway.



Figure E-17. View of ELJ flow deflectors in the Cispus River, (shown in Figure E-16) 1 year after installation. Note the establishment of the riparian buffer along the highway.

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Costs—The costs for installation of ELJs and deflector structures are likely greater than those of all the other erosion protection measures except for sheet pile walls, MSE/precast concrete walls, riparian buffer construction, an elevated highway on piers, and highway relocation.

MSE Wall

This measure involves the installation of an MSE wall along the existing embankment/river bank to prevent erosion using one of the many commercially available modular-block wall systems (Figure E-18). MSE walls are widely adaptive and can be used to stabilize slopes up to 100 feet in height using anchored tie-backs. MSE walls typically require installation on top of a continuous cast-in-place concrete footing, which may complicate the construction in riverside locations. The required depth of the footing depends on the flow velocities and scour potential. An MSE wall should be complemented by the placement of rock or LWD armoring or ELJ flow deflectors and the construction of a riparian buffer along the toe of the wall.

Advantages—MSE wall systems can simplify and speed installation activities and are extremely effective in preventing erosion. MSE walls can be provided with various panel textures and colors to better blend into the environment.

Disadvantages—Installation of an MSE wall requires a continuous cast-in-place footing that increases the time required for construction. High flow velocities and scour potential along a smooth boundary such as an MSE wall require either a deep foundation or the construction of toe armoring (LWD or ELJ structures and a riparian buffer strip).

Costs—The costs for installation of an MSE wall are likely greater than those of all the other erosion protection measures except for riparian buffer construction, an elevated highway on piers, and highway relocation.

Riparian Buffer Enhancement

This measure involves the restoration of a conifer-dominated forest buffer by either thinning red-alder-dominated stands and under-planting with conifer tree species or planting conifers in existing unvegetated areas (Figure E-19). The conifer riparian forest will increasingly stabilize the river and road embankment as the forest matures.

Advantages—Riparian buffer enhancement provides an excellent measure for erosion control and is very cost effective. Riparian conifer forests reinforce the river and road embankment by means of root cohesion. Riparian forests provide valuable fish and wildlife habitat and are in keeping with a natural setting.

Disadvantages—Successful establishment of plantings requires periodic inspection and maintenance throughout the establishment period.

Costs—The costs of riparian buffer enhancement are likely the least of all the erosion protection measures.

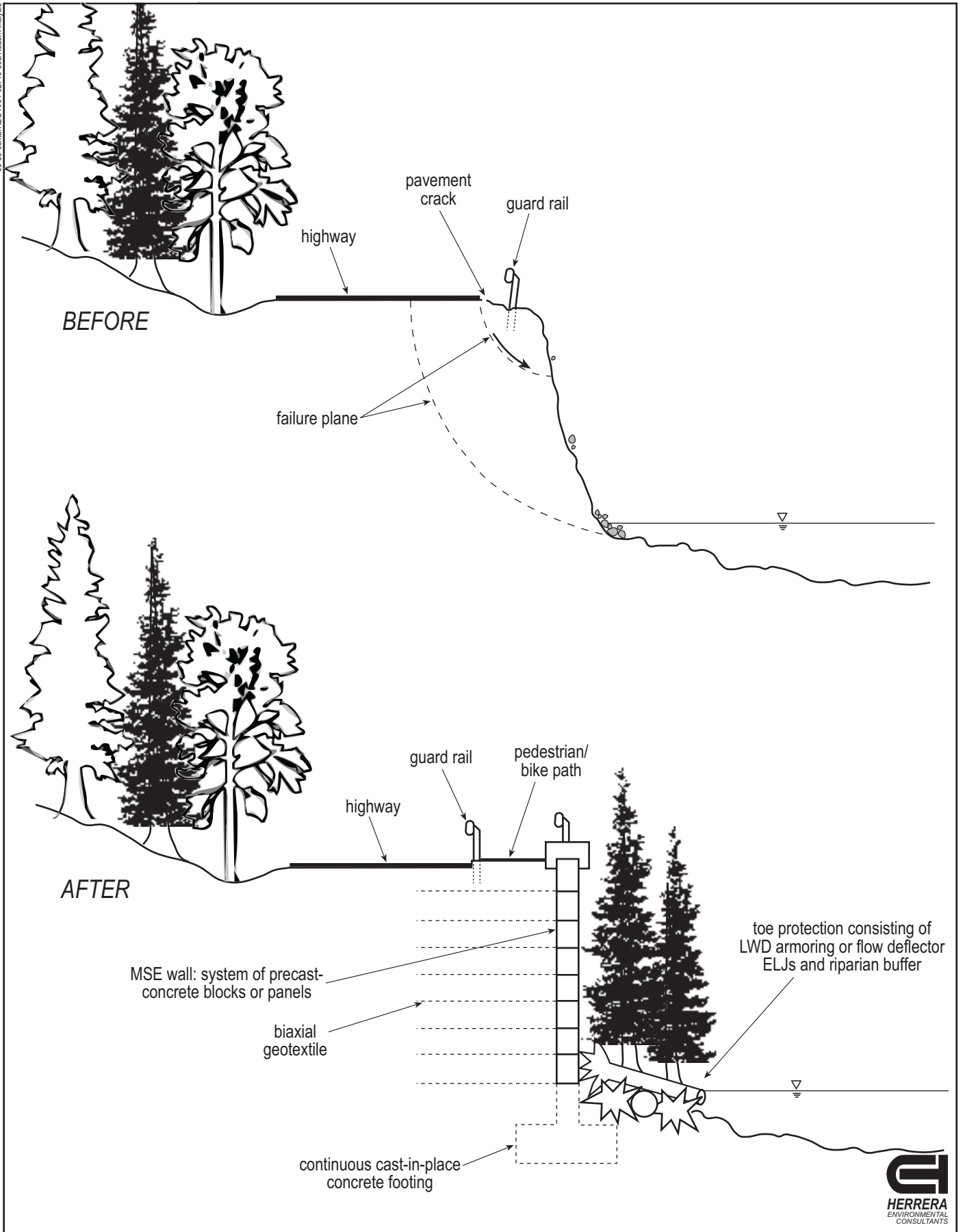


Figure E-18. Cross-section of an MSE wall used to stabilize an erosion-prone highway embankment adjacent to a river.



Figure E-19. Example of riparian buffer enhancement showing establishment of newly planted conifers in a previously unvegetated buffer area.

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Riparian Buffer Construction

This measure involves using an LWD-hardened foundation and erosion protection measures to create a foundation for creating a riparian buffer between the highway and river (Figures E-20 and E-21). This method is similar to combining LWD armoring and riparian buffer enhancement, but it is more intensive. Buffer construction can require significant quantities of imported fill material to build the structural foundation upon which native alluvium, soil, and trees are placed. Successful establishment of plantings requires reestablishing the floodplain surface by placing alluvial fill and topsoil above the structural matrix laid down in the channel. When established, this method provides very effective and redundant erosion protection in two ways: (1) structural bank protection such as LWD or rock armoring and ELJs, and (2) riparian buffer.

Advantages—This method significantly restores native riparian and aquatic habitat while providing for extremely effective and long-term erosion protection. This measure replicates natural processes documented along the Hoko, Clallam, and Pysht Rivers and provides a significant environmental and aesthetic advantage over more engineered measures. Riparian buffer construction is potentially self-mitigating given the restoration benefits and improves the aesthetics of the project site.

Disadvantages—Construction of riparian buffer may involve encroachment into currently active river channel and may require significant amounts of timber for structures. The costs for timber and mitigation measures for in-river construction can add significantly to the project cost.

Costs—The costs for construction of a riparian buffer are greater than those of all the other erosion control measures other than an elevated highway on piers and highway relocation.

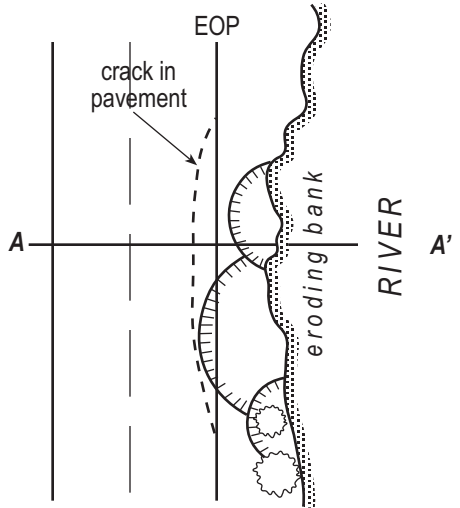
Elevated Highway on Piers

This measure would replace the existing highway with an elevated roadway of precast and cast-in-place concrete members supported on concrete piers and footings. This would require the removal of the existing highway. Following construction, the existing road would have to be decommissioned, leaving behind a potential pathway for the river. Depending on the height and width of the road deck, an elevated highway can significantly limit the amount of sunlight that reaches the underlying ground surface, which can further limit revegetation, resulting in greater risk of erosion. To mitigate the limited recovery of vegetation and erosion hazards, ground roughness can be added beneath the highway in the form of LWD armoring.

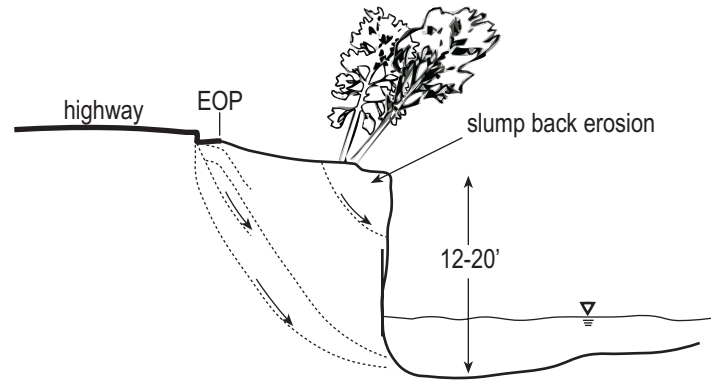
Advantages—An elevated highway on piers provides a high level of erosion protection while allowing river channel migration to progress naturally. In addition, the highway will not form a barrier to stormwater flow and streams, wildlife, or people accessing the river and floodplain. This is the most aesthetically pleasing structure with the smallest footprint on the landscape (Figures E-9 and E-10).

EOP= Edge of pavement

BEFORE

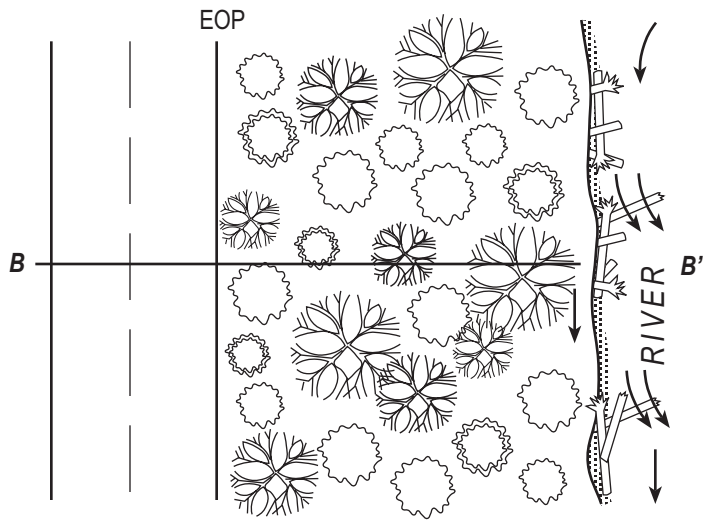


Plan

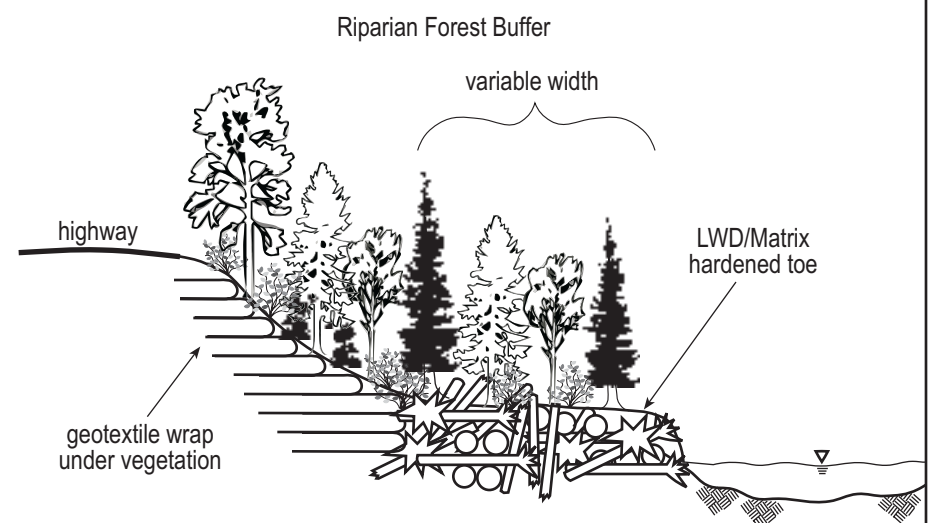


Section A - A'

AFTER



Plan



Section B - B'



Figure E-20. Illustration of erosion of steepened bank along a roadway (A) a conceptual design for riparian buffer build-up and protection (B).

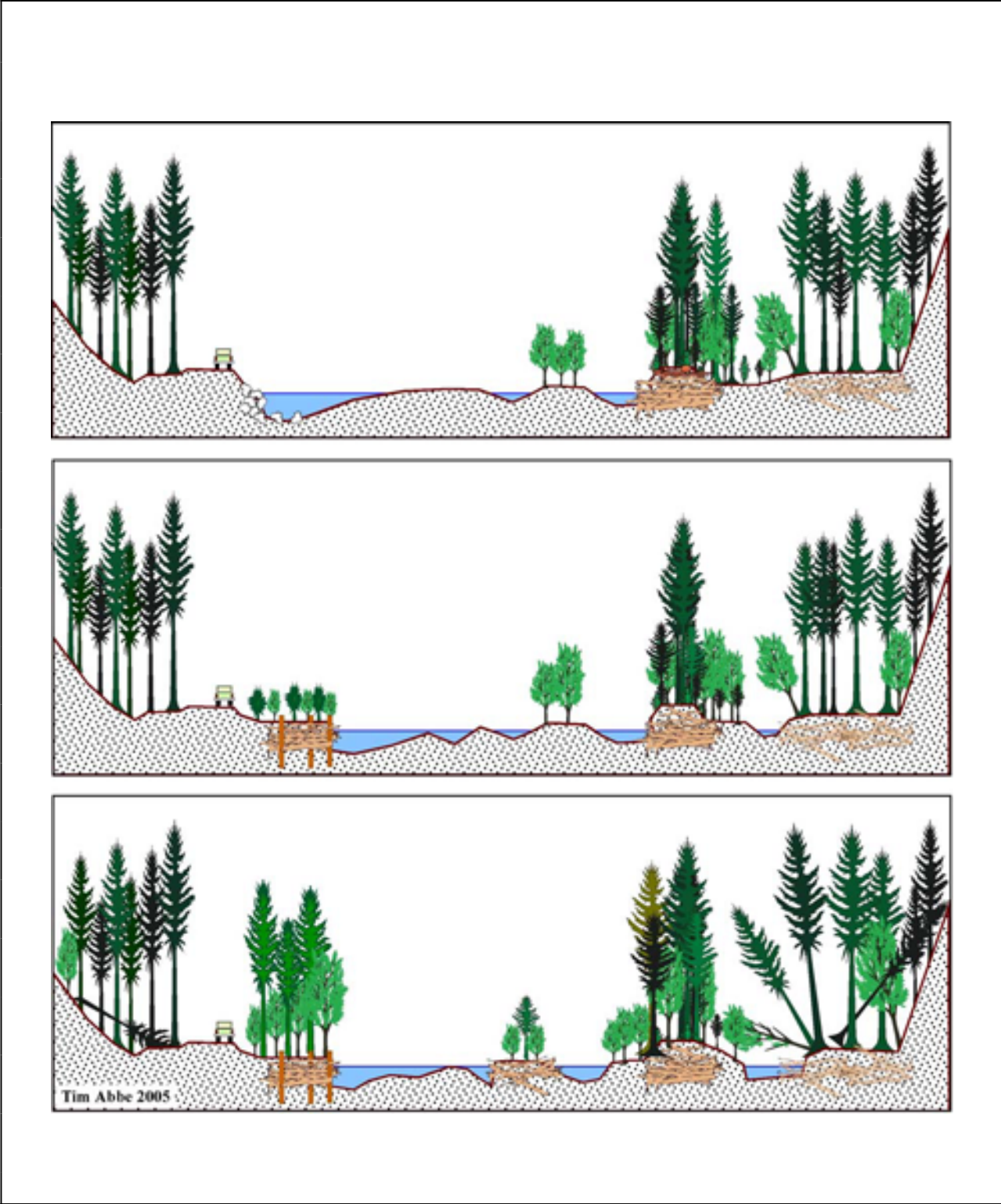


Figure E-21. Illustration of the establishment of a riparian buffer between a highway and a river using LWD armoring or ELJ flow deflectors.

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Disadvantages—Construction of an elevated highway on piers likely has the highest construction cost of any of the protection measures for erosion hazards.

Costs—The costs for construction of an elevated highway on piers is likely the most expensive erosion control measure other than relocation of the highway.

Highway Relocation

This measure involves the removal of the existing highway and its reconstruction in a new location east of the eastern edge of the floodplain, where the erosion hazards due to the river are eliminated. This would entail moving the highway alignment onto a hillside. Detailed topographic survey data and geotechnical data would need to be evaluated to determine a viable route.

Advantages—This measure eliminates the erosion hazards to the highway while providing nearly unencumbered stormwater and stream flows and pedestrian and wildlife passage.

Disadvantages—This measure is potentially the most extreme in terms of cost, impact, and environmental mitigation, and it would take the longest to complete due to the large effort required for design, permitting, and construction.

Costs—The costs for construction of a new highway along a new alignment are likely the highest of all the erosion control measures.

Following is a description of the specific potential benefits and impacts of each of the flood and erosion hazard protection measures for highway SR 410:

Emergency Measures

- F-1 Sheet Pile Wall – Given that the road already exists within the river floodplain, the impacts associated with the installation of a sheet pile wall are likely limited to noise impact and water quality degradation during construction. Relative to other options, the sheet pile wall option eliminates the need for use of fill and thereby minimizes habitat loss and disturbance. Mitigation may not be required.
- F-2 Earthen Dike – This option involves a significant amount of clearing and fill, potentially in wetlands. The use of this option will require significant compensatory mitigation.

Primary impacts of this alternative include a permanent loss of: physical habitat, riparian vegetation, floodplain storage capacity, and a reduction of floodplain roughness due to the placement of fill material within the floodplain. The construction of an earth dike will further disconnect the floodplain from the adjacent hillslopes and will reduce the channel evolution potential by limiting lateral channel migration in some areas. Further disconnecting the floodplain from the adjacent hillslopes will result in a barrier to wildlife movement. In addition, water quality degradation (i.e., increased turbidity) and

sedimentation impacts on fish are likely temporary impacts during construction. There are no habitat benefits associated with this option.

- F-3 Reinforced Dike – Other than a localized erosion reduction, there are no habitat benefits associated with this option, and its use will require significant compensatory mitigation. According to the USACE, moratoriums on the use of riprap have been established or are being pursued by the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USFWS), and several State Environmental Quality offices (Fischenich 2003).

Although commonly used to armor river banks, riprap affects salmonid populations and river and riparian function. Stream banks armored with riprap have fewer undercut banks, less low-overhead cover, and are less likely than natural stream banks to contribute large woody debris to the stream (Schmetterling et al. 2001). In addition, riprap can adversely affect juvenile salmonid species and may cause a loss in fish production (USACE 2001). Additional impacts associated with this option include those described under measure F-2.

- F-4 Large woody debris flow deflector – Temporary water quality degradation (i.e., increased turbidity) is the primary impact associated with LWD flow deflectors. Depending on the time of the year and the location where the deflector may be constructed, heavy equipment use during construction may destroy salmonid fish redds and macroinvertebrate communities. This self-mitigating measure introduces habitat complexity to the river and creates and maintains pool habitat area suited for juvenile salmonid rearing and adult fish holding.
- F-5 MSE flood wall – This option involves a significant ground disturbance and earthwork. The impacts of the fill placement associated with this option are of a lesser magnitude, but qualitatively similar to the impacts of measure F-3.

Long term Measures

- F-6 Elevated highway on embankment – The impacts associated with this option are qualitatively similar to measure F-3 but of a greater magnitude.
- F-7 Elevated highway MSE prism – The impacts associated with this option are of a lesser magnitude, but qualitatively similar to the impacts of measure F-3.
- F-8 Elevated cantilevered highway – This option incorporates conservation measures intended to protect sensitive fish and wildlife habitat. Relative to other options, the elevated cantilevered highway eliminates or minimizes the need for use of fill within the river floodplain and thereby minimizes habitat loss and disturbance. Mitigation may not be required if no fill is used within the river floodplain and the shading effects of the cantilevered section of the highway are deemed negligible. From the habitat impact

avoidance perspective, this option is better than both the elevated highway on embankment and the elevated highway MSE prism.

- F-9 Elevated highway on piers – This self-mitigating option incorporates conservation, restoration, and mitigation measures. This measure introduces restoration and mitigation measures because it will allow for habitat maintenance and forming processes to be restored in the area by removing the existing fill associated with SR 410 as a part of the option. Given its location and orientation, and if designed at the right elevation, the shading effects of the elevated highway on piers are likely to be negligible. Hence, from the habitat impact avoidance/restoration perspectives this is the best of all the options listed as long term measures. A caveat with this option is the assumption that the elevated highway on piers can be constructed from the existing road thus eliminating the need for significant earthwork and clearing of vegetation.
- F-10 Relocation of highway – This option will restore river and riparian processes by removing the fill associated with the existing SR 410 road prism. However, relocation of the highway will require significant ground disturbance and clearing of forest.

Erosion Protection Measure

Emergency Measures

- E-1 Rock Armoring – Same as for Option F-2
- E-2 Sheet Pile Walls – Same as for Option F-4.
- E-3 Geotextile and Plantings – This option eliminates the need for significant earthwork and clearing of vegetation and corrects a potential source of fine sediment and water turbidity. In addition, this option may improve localized vegetation conditions by restoring areas that have been disturbed by emergency actions. However, given that this option is not always effective, failure may lead to downstream sedimentation and water turbidity.
- E-4 LWD Armoring – This option minimizes erosion and thereby downstream sedimentation potential. It provides better habitat cover than the rock armoring option. Potential impacts associated with this option include noise disturbance during construction, temporary soil disturbance, and temporary water quality degradation. Depending upon the construction techniques, required access, and the amount and location of backfill, mitigation may not be required.
- E-5 ELJ's and Deflector Structures – Same as for Option F-3.

Long term Measures

- E-6 MSE/Precast Walls – Same as for Option F-5

- E-7 Riparian Buffer Enhancement – Loss of riparian vegetation can lead to simplified aquatic habitat and may reduce the potential LWD recruitment into the stream (Ralph et al. 1994; Young et al. 1994; Fausch et al. 1995). Consequently, riparian buffer enhancement activities that incorporate multi strata layers of vegetation are likely to reverse the adverse effects associated with loss of riparian vegetation. Benefits associated with this alternative include increased floodplain roughness, LWD recruitment potential, fish and wildlife habitat, and water quality moderation. Potential impacts include temporary water quality degradation and soil disturbance. Mitigation for this option is not required.
- E-8 Riparian Buffer Construction –This option restores riparian functions similar to those discussed for Option E-7. If successful though, this option has greater ecological benefits than Option E-7 because it restores areas that are not properly functioning under existing conditions. Noise disturbance during construction and temporary soil disturbance and water quality degradation are the primary impacts. Mitigation is not likely to be required
- E-9 Elevated Highway on Piers – Same as for Option F-9
- E-10 Relocate Highway – Same as for Option F-10

Effect of Forest Removal on Heat

Given that SR 410 is located adjacent to the White River and crosses national forest, consideration should be given to the potential effect of forest removal on heat. The replacement of forests with roads or other impervious surfaces and structures changes the relationship between incoming solar radiation and outgoing terrestrial radiation within watershed areas (Towson University 2005).

Heat energy not utilized in evapotranspiration is released to the atmosphere as sensible heat (i.e., heat energy which is felt and can be measured with a thermometer). The more energy that enters the atmosphere as sensible heat, the higher the relative air temperatures over watershed surfaces. Latent Heat (i.e., the heat energy stored in water vapor and that cannot be felt or measured with a thermometer) enters the atmosphere when water is evaporated from the surface. Since evaporation removes heat, it is a cooling process. The relationship between sensible heat and latent heat is described by the Bowen ratio and the sensible heat index. For example, the summer sensible heat indices for impervious urban surfaces and deciduous forests are 80 percent and 25 percent respectively. Here, the sensible heat index is the sensible heating divided by total heating (sensible + latent) and multiplied by 100, which is the total heat energy at the surface used to raise the temperature of air above it (Towson University 2005).

Stormwater runoff originated from impervious surfaces also likely contribute to increased water temperature, particularly in slow flowing habitats like those typically associated with floodplain side-channels and wetlands. Therefore, replacement of forests with impervious surface areas associated with the widening of SR 410 may affect the ambient as well as water temperature.

Other factors potentially contributing to increased water temperatures include a reduction in channel sinuosity and in hyporheic flows.

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