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Scenarios for Wetland Restoration

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Scenarios for Wetland Restoration

Scope

This technical note is for use by wetland restoration planners and presents common wetland types and situations. Each scenario is based on a specific hydrogeomorphic (HGM) wetland type. This technical note only covers structural and hydrologic measures; it does not include vegetative and habitat measures.

The intent of this technical note is to convey general principles for wetland restoration as defined in the National Handbook of Conservation Practices (NHCP) Conservation Practice Standard (CPS) Code 657, Wetland Restoration, and does not present techniques for enhancement or creation as defined in CPS Codes 658, Wetland Creation, and 659, Wetland Enhancement. It is not meant to be a how-to manual with detailed information that can be applied directly for design. The scenarios are chosen to represent real situations from known wetland types. The options illustrated have been shown to provide sustainable restorations that require a minimum of maintenance.

The reader should have a general understanding of the HGM classification system and its basis in landscape position, hydrodynamics, and dominant water source.

Background information

Information on the HGM classification system can be found in the National Engineering Handbook (NEH), Part 650, Chapter 13, Wetland, Enhancement, or Creation, section 650.1301, HGM wetland classes. An explanation of wetland water budgeting and movement can be found in the section 650.1304(b), Hydrodynamics of Wetland Systems.

The reader should also see Technical Note 210–4, Understanding Fluvial Systems, Wetlands Streams, and Floodplains for background on the scenarios involving RIVERINE and SLOPE HGM wetland types. This document also describes the use of the Strahler Stream Order system and the Channel Evolution Model (CEM).

Descriptions of ditch plugs and other restoration features mentioned in this document can also be located in NEH, Part 650, Chapter 13. All of these documents are available at: http://www.wli.nrcs.usda.gov/.

HGM taxonomy

In the HGM classification system, there is a hierarchy for taxonomic notation. The seven HGM classes are named with all capital letters. Subclasses are named with the first letter capitalized, and the remaining letters lower case. This taxonomic hierarchy will be maintained throughout this document. It is important to note that the HGM subclass names presented are not meant to portray any officially developed HGM model, but are used only for illustration. A description of the HGM classification system is located in Technical Note 190–B–76, Hydrogeomorphic Wetland Classification System: An Overview and Modification to Better Meet the Needs of the Natural Resources Conservation Service (http://www.wli.nrcs.usda.gov/).

Water budgeting

Where appropriate and useful, the wetland water budget parameters have been shown on the illustrations, and the water budget is described in the scenarios.

The water budget parameters are defined as:

- E = evaporation from a water or bare soil surface
- ET = the combination of evaporation from the soil or water surface and plant leaves and stems. This can be significantly different from E.
- R_i = surface runoff into the wetland
- R_o = surface runoff out of the wetland
- G_i = groundwater inflow
- G_o = groundwater outflow
- P = direct precipitation on the wetland
- Q_2 = 2-yr return period peak discharge
- Δs = change in storage

A full description of the wetland water budget can be found in NEH 650.1304(a)(3)(i). The water budget is not further described in this document.

Description of macrotopography features

Macrotopographic (macro) features are defined as surface depressions and highs that are greater than 6 inches in height or depth. Microtopographic (micro) features are less than 6 inches in magnitude. A useful distinction is that macro features can be removed by agricultural tillage. Macro and micro features are critically important in wetland function, as they create diversity in the duration (hydroperiod) and depth (regime) of water in the wetland. In definition, they differ by the magnitude of their dimensions. In reality, the difference is much greater in their function and morphology. Micro features are created by the interactions of weather events, vegetation, and soil processes. They are ephemeral, but are constantly being created at the same rate that they are destroyed. Macro features are usually created by the actions of flowing water during catastrophic events. The RIVERINE wetland type is dominated by macro features that exist as natural levees, splays, abandoned oxbows, backswamps, scour channels, and other features. These are created or changed only during extreme flood events and tend to be long-term features once created.

Macro features figure prominently in restoration, especially in RIVERINE wetland systems. Macro features create hydrologic diversity, can serve to direct flows away from erosion or deposition prone areas, and can be used to enhance hydroperiod and regime without the use of constructed dikes and water control structures. The scale can be made to match the scale of the associated stream. The height and depth, however, should be limited to no more than needed for the wetland function, and slope should be constructed to be as flat as possible. Slopes that are at least 8:1 will preclude damage from all but the most ambitious burrowing animals, and low heights combined with flat slopes will ensure that the feature survives all but the severest flooding events. If properly planned, they do not fall under the purpose and criteria of engineering practice standards.

In some cases, the restoration of dynamic flow to the floodplain can be relied upon to create and maintain macro features fairly rapidly, and there is no need to create them initially with artificial excavations and fills. In systems with a high sediment supply and erodible soils, artificially created features may silt in, enlarge, or otherwise become altered.

Stream order

The scenario descriptions for RIVERINE HGM wetland types include the stream order. The stream order is based on the Strahler Stream Order system, and is described in the hydrology Technical Note 4, Understanding Fluvial Systems: Wetlands, Streams, and Flood Plains (http://www.wli.nrcs.usda.gov/). Lower order streams are small headwater stream reaches, and higher order streams are large streams that receive tributary inputs from several lower order streams. In many cases, the scale of a wetland restoration project can include the entire stream corridor width of a lower stream order system. For this reason, wetland restorations on these systems can include the restoration of the stable stream geometry. On higher order systems, the wetland restoration project typically is only a small part of a large floodplain where there is no potential to modify the stream itself.

Episaturation and endosaturation

Episturation is a condition where surface water provides the source of saturation or inundation. In RIVERINE wetlands, this surface water is supplied by periodic flooding events. Endosaturation is a condition where groundwater inflows create saturated conditions. Many RIVERINE wetlands as well as SLOPE and some DEPRESSIONAL wetlands have wetland hydrology due to endosaturation. In floodplains, the endosaturation is driven by the stream water surface profile. The floodplain soils are coarse textured and the stream water surface moves readily into and out of the floodplain wetlands with the rise and fall of the stream hydrograph. Many of these RIVERINE wetlands maintain wetland hydrology with little or no actual surface flooding.

Scope of RIVERINE wetland planning boundaries

RIVERINE wetlands are unique in that actions taken in restoration can have large effects both laterally across the floodplain, as well as up and downstream (longitudinally). The longitudinal boundaries are best defined as the extent of change to the water surface profile during all flow ranges. In practical terms, the high flow range is set by one of two circumstances:

- a return period discharge set by local or State regulation, such as the 100-year (1% chance probability) annual peak
- the discharge at which water surface profile effects are no longer seen in successively higher discharges

The lateral boundary is more difficult to define quantitatively. It should include the extent of flooding at the discharges described at a minimum. However, restorations can effect groundwater levels at locations outside the lateral extent of flooding. The extent of soils mapped as part of the geomorphic floodplain should be considered. The definition of floodprone width used by fluvial geomorphologists can also be used. In any case, the lateral extent should include the floodplain landscape where the movement of surface water, groundwater, and sediment are driven by fluvial processes.

Scenario 1

HGM type—RIVERINE, lower stream order, Episaturated

Dominant water source—Surface flooding from high stream flows

Hydrodynamics—Horizontal, bidirectional

Scale—1 to 10 acres

This wetland planning unit comprises the entire width of a floodplain and extends longitudinally for a distance at least 10 times the floodplain width. This longitudinal distance is important because the restoration measures presented will raise the stream water surface profile. There must be sufficient distance to the upstream boundary for the increased water surface to converge with the original or at least decrease to a level acceptable to the upstream landowner. This planning scenario is usually applicable to the lower order reaches of a stream system. On the larger floodplains found in third or higher stream orders, it is unusual for a planning unit to include the entire extent of the floodplain.

The original stream channel's horizontal geometry is intact, but it has incised. Channel incision is simply lowering of the stream bottom due to erosion. Many activities occurring upstream, downstream, or within the stream's watershed cause channel incision. In this scenario, the original floodplain features, such as natural levees, abandoned oxbows, and backswamps, are intact. The channel's incision has given it the ability to carry a much higher flow when full to the top of the bank. The floodplain wetland features no longer receive frequent, long-duration surface flooding events.

Since the planning unit includes the entire floodplain width and a sufficient reach length, the restoration should focus on reducing the original stream channel's capacity to its original state. This will provide surface flooding closer to the duration and frequency that existed prior channel incision. The flow illustrated in this scenario is the 50-percent chance (2-year return period) annual peak discharge. This specific value is used only as an example. The magnitude and frequency of flows that enter the floodplain in a stable stream floodplain system varies with stream type, location, and other factors. Determination of this flow is part of the discipline of fluvial geomorphology, and guidance can be located in NEH, Part 654, Stream Restoration Design.

There are many techniques available for raising a stream's water surface profile. Any measure used must follow the guidance provided in NEH, Part 654. The resulting water surface profile should provide a stable channel design and the flooding needed for wetland functions. This scenario shows the use of generic grade stabilization structures that can be built of rock, wood, steel, sheet piling, or combinations of each. They must be designed and built in accordance with CPS Code 410, Grade Stabilization Structure, with specific attention to the criteria for island structures. Additional guidance on structure height, capacity, and spacing can be found in Technical Note No. 2, Stream Water Surface Profile Modification for Wetland Restoration (http://www.wli.nrcs.usda.gov/).

In addition to the installation of the structures, the scenario incorporates shallow excavations and fills. These features mimic the natural macro features of the floodplain and provide hydrologic complexity for wetland functions. Just as importantly, they also direct overbank flows to move away from the streambank and through the floodplain at a shallow depth and low velocity. This prevents high-velocity, concentrated flow from moving directly around structures and causing erosion when reentering the stream channel immediately downstream. A great deal of flow direction can be accomplished with cuts and fills of less than 12 inches in height or depth. At very high flows, the entire floodplain is inundated, and there is no longer any water surface profile drop across the structures capable of causing overbank erosion.

The prerestoration condition is illustrated in figure 1(a). The original stream planform is unchanged. The original floodplain macro features are in place. These features include the natural levee, abandoned oxbow, and backswamp landscapes.

The floodplain cross section shown in figure 1(b) indicates that the 50 percent chance annual peak discharge is easily contained within the current channel cross section. The channel bottom is significantly lower than it was in the original, stable state. The stream is in stage II as defined by the CEM.

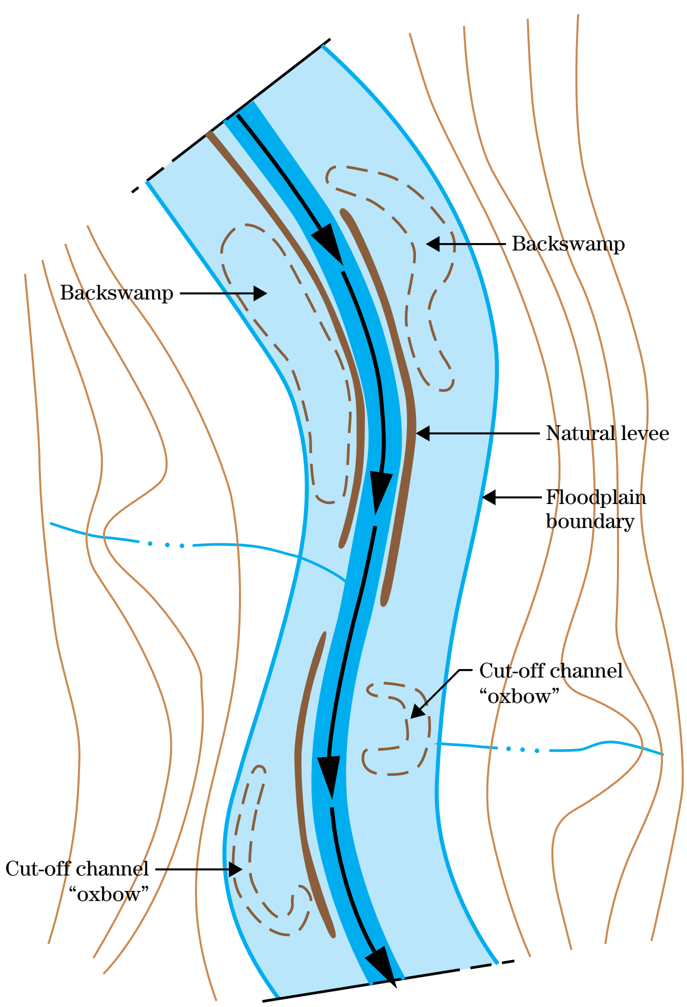
The grade stabilization structure shown has raised the 50 percent chance annual peak discharge upward so that the new water surface inundates the adjacent floodplain and restores wetland hydrologic conditions, as shown in figure 1(c).

Figure 1(d) shows the stream reach profile with the grade stabilization structures in place. As flows increase, the incremental water surface profile drop across each structure decreases. In general, for channel systems formed in cohesive soils, a water surface profile drop of up to 1 foot can be tolerated at the flow that just enters the floodplain at each structure location. Physically filling the channel between structures will decrease the channel capacity and reduce this water surface profile drop. After restoration, channel deposition will occur, which will decrease the channel capacity naturally.

Figure 1(e) shows a plan view after restoration. Grade stabilization structures are placed in series along the channel reach to force flooding across the floodplain. Shallow excavations and spoil placement may be used to direct these flows. They also may be used to direct flow away from areas where they may pose an erosion hazard or potentially damage an individual structure. Attention is given to flow discharges from upland runoff, as well. Careful consideration must be given to the structure at the downstream end of the reach. Since it will have no downstream tailwater protection, there is the potential for a large, erosive overfall as the flood flows reenter the high-capacity channel downstream. If needed, this structure is designed according to the criteria for CPS Code 410, Grade Stabilization Structure, with an auxiliary spillway to handle the appropriate return period storm discharge.

Figure 1 Plan view

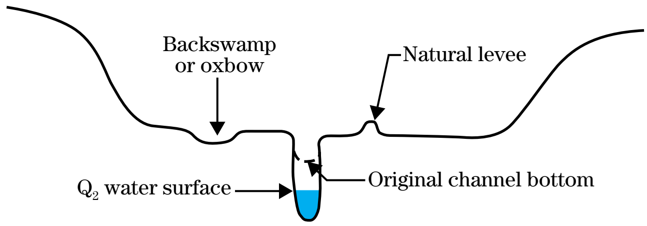
(a) Before restoration



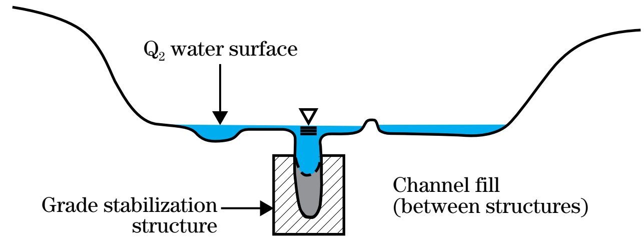
Incised channel—not straightened, original morphological features in place

Figure 1 Plan view—continued

(b) Cross section before restoration



(c) Cross section after restoration



(d) Channel profile after restoration

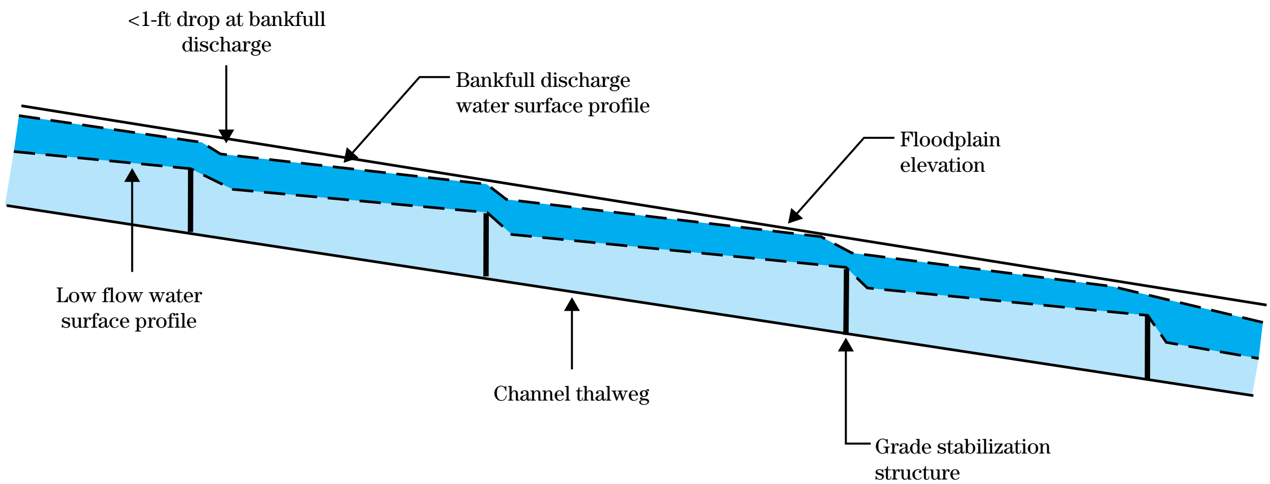
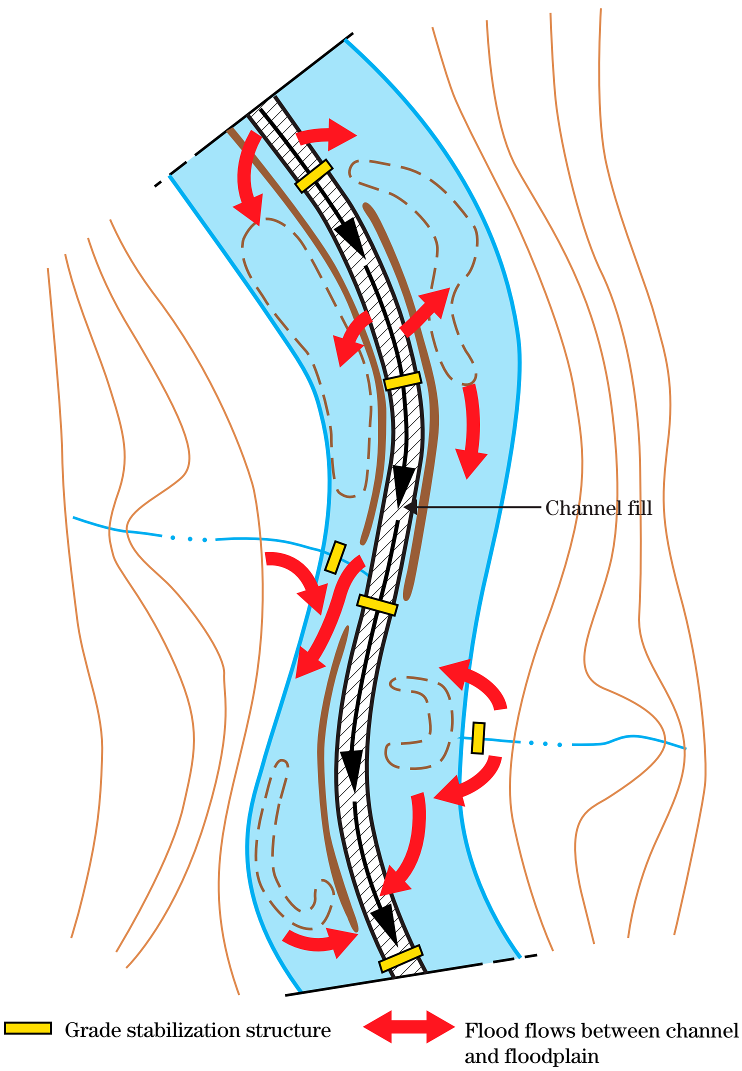


Figure 1 Plan view—Continued

(e) Plan view after restoration



Incised channel—not straightened,
original morphological features in place

Scenario 2

HGM type—RIVERINE, lower stream order, episaturated

Dominant water source—Surface flooding from high stream flows

Hydrodynamics—Horizontal, bidirectional

Scale—1 to 10 acres

This scenario is similar to scenario 1. The difference is that the stream channel has been straightened through the project reach, and the original floodplain macro features have been removed. This is common in floodplains that have been used for agricultural production.

This planning scenario includes the reconstruction of the original, stable channel planform and cross section that is referred to as a "meander reconstruction." Follow the guidance found in the NEH, Part 654. In addition, floodplain macro features are constructed with dimensions that mimic the original. The new channel excavations provide material for use in filling the current stream channel. There is usually a shortfall in excavation for use in channel fill. Fills are placed in those areas where the potential for damage due to flood flows reaccessing the current channel are greatest.

As in scenario 1 a grade stabilization structure is shown at the downstream end of the planning unit. This single structure is needed if the channel below the project is still incised. Out-of-bank flows must be safely returned to the downstream channel without creating an overfall condition.

Figure 2(a) shows the plan view of the project before restoration. Channel straightening has shortened the length of the stream, resulting in a channel sinuosity much less than the original. Concentrated flow from the adjacent uplands is crossing the floodplain to enter the channel. The original floodplain macro features have been removed.

The floodplain cross section for this scenario is the same as in scenario 1, illustrated in figure 1(b). The only difference is that the old floodplain macrotopography features have been leveled and filled. The current channel easily contains the 50 percent chance annual peak discharge. The original channel location and cross section is shown. This channel had a lower capacity, with a lower channel gradient. The current channel is a CEM stage II.

The plan view of the restored floodplain is shown in figure 2(b). A new meander reconstruction with a stable channel gradient and cross section has been constructed. The excavation from this work has been utilized to partially fill the existing channel at critical locations. A portion of this excavated material has been used to construct floodplain macro features. These have also been provided at the upstream end of all channel fill areas to direct flood flows away from the old channel. This is critical to prevent flows from reaccessing the former channel. Macro features are also used to safely direct concentrated flow from the adjacent uplands to the new channel in a manner that precludes scour or deposition.

The cross section shown in figure 2(c) shows the project after restoration. The original channel in this location has been filled. The fill at the cross section extends above the floodplain elevation to direct flows away from the old channel. The new channel cross-section has a significantly lower channel capacity and overflows at a higher frequency. Floodplain macro features have been created with the use of shallow excavations and spoil placements.

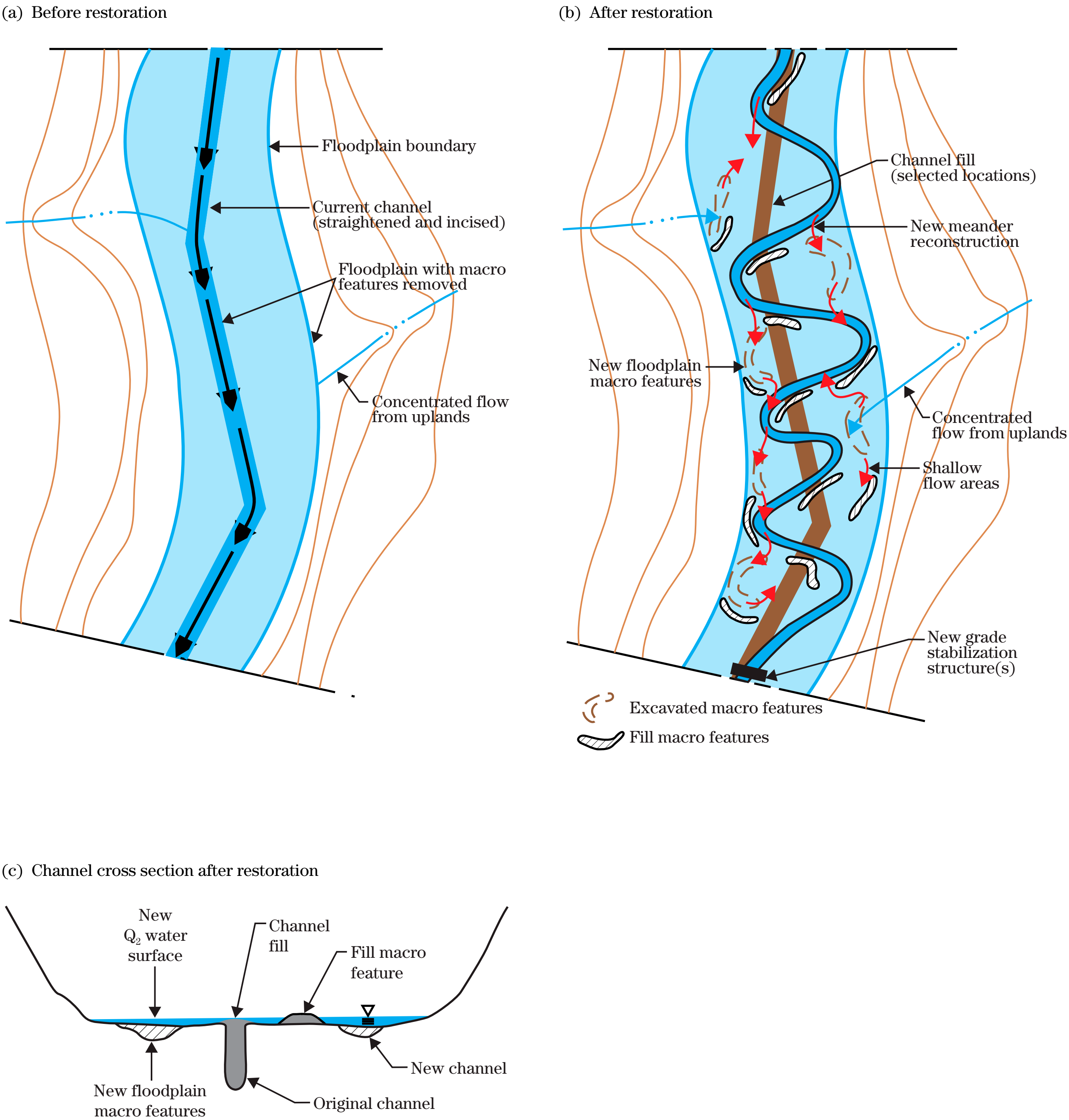
The goal of this restoration scenario is to restore the stream's stable channel cross section, planform, and channel capacity. The channel's capacity is such that the original flood frequency is restored, and this flood frequency also provides the needed wetland hydrology.

Endosaturated floodplains

The restoration actions in both scenario 1 and 2 can be applied to endosaturated floodplains. The difference is that wetland hydrology requires that the higher stream water surface reach the required stream stage for the required duration to maintain wetland hydrology. In episaturated floodplains, instantaneous peak discharges will supply water to floodplain macro features, and this water will persist after the hydrograph passes. In most cases, the duration is not critical. In endosaturated floodplains, the duration is also critical. Determination of this duration requires the determination of the probability-duration relationships of the stream gage data. This flow is expressed as a percent chance probability of a flow duration, for instance, the 50 percent chance, 15-day flow. Follow the procedures in the Engineering Field Handbook (EFH), Part 650, Chapter 19, Hydrology Tools for Wetland Determination, section 650.1901, Use of stream and lake gages.

The resultant flow is used to design a channel capacity that provides the required stream stage. Information on design is available in Technical Note 2, Wetland Restoration by Water Surface Profile Modification (http://www.wli.nrcs.usda.gov/).

Figure 2 Plan view



Scenario 3

HGM type—RIVERINE, higher stream order, episaturated

Dominant water source—Surface flooding from higher stream flows

Hydrodynamics—Horizontal, bidirectional

Scale—40-plus acres

In this scenario, the planning unit is only a portion of a large floodplain and occupies a relative short reach length compared to the size of the system. The tract is prevented from flooding by a constructed levee. Upland runoff is directed through the tract with a drainage ditch that delivers water through the levee by means of a culvert with a flap gate. The floodplain either has existing macro features or has suitable locations for construction of these features.

In this case, the existing levee system must be maintained. An intentional breach of this levee would allow floodwater to impact areas downstream of the project boundary and may impact upstream land, as well.

No surface floodwater from the stream is available for use in restoring the wetland's hydrology. The restoration of the system's hydrology must be done using the available surface runoff from the adjacent upland, as well as the precipitation that falls directly on the site. Filling the existing drainage ditch either partially or completely will force surface runoff to spread across the floodplain surface. Shallow excavations and fills can be provided to pond water in constructed macro features, as well as carefully direct flows across the floodplain before the water exits the system through the existing culvert. In many of these systems, a low-conductivity perching soil layer exists across the floodplain landscape or in the bottom of macro features. The integrity of this soil layer must be maintained. If existing macro features have sediment deposited in them, this may be removed down to this perching layer only.

In figure 3(a), the plan view shows the existing river dike, drainage ditch with adjacent field dikes, concentrated surface flow from uplands, existing macro feature, and project boundaries.

The plan view shown in figure 3(b) shows the restoration. The drainage ditch is filled and adjacent field dikes are taken down where needed to force shallow flow from surface runoff onto the adjacent floodplain. The ditch need not be filled completely. If available fill material is inadequate, one or more ditch plugs can be utilized to accomplish the flow redirection. The inlet structure is optional and is only needed if the potential for gully erosion exists where flow enters the macro feature. The macro fill feature on the northeast side of the abandoned oxbow is in a location that blocks water from exiting the oxbow and creates a deeper water depth. If management is desired, it can be fitted with a water control structure. The large macro fill at the south boundary serves as a containment levee to keep the upland surface water from entering the adjacent property during high storm runoff discharges. Even though stream flooding is still excluded from the site, the decommissioning of the drainage ditch may cause off-site flood damages from upland runoff.

Figure 3(c) includes details of the restoration of the large abandoned oxbow feature. Any removal of sediment should be limited in depth. A water budget can be conducted to determine what initial water depth is required to maintain water for the duration of the desired hydroperiod. If the maintenance of water depends on the integrity of a perching layer, the excavation must not remove any of this low-permeability soil material. In addition, buried A soil horizons contain soil organic matter that is valuable to wetland biological functions, so it is recommended that this layer be left intact, as well.

Figure 3(d) shows cross sections of spoil placement used as macro features and ditch plugs. Minimizing the heights of fills and maximizing side slopes benefit the hydraulic safety of the structure. Also, damage from burrowing rodents are minimized or eliminated, and the diversity of wetland regimes is greatly increased as small changes in water level have a larger lateral effect on the wetland surface.

Figure 3 Plan view

(a) Before restoration

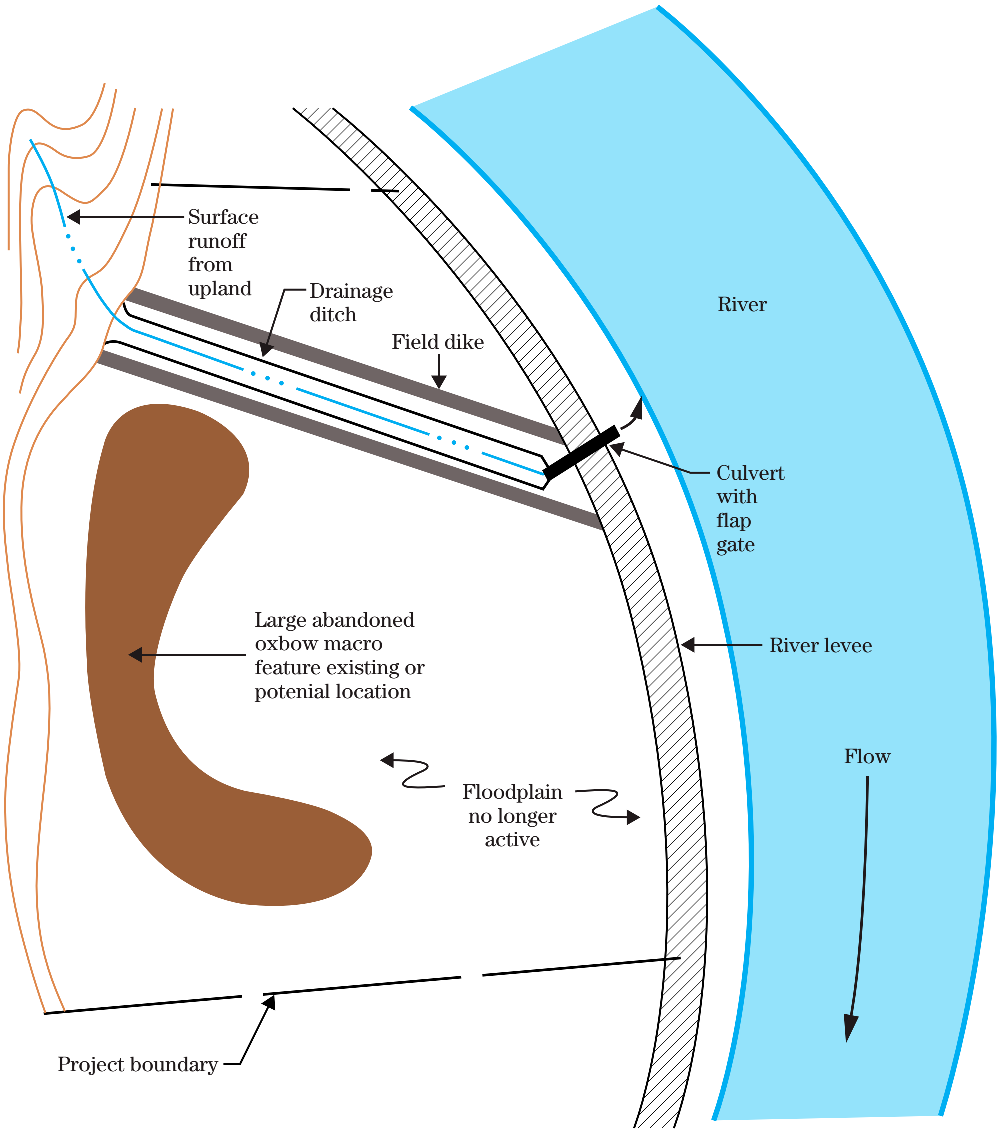
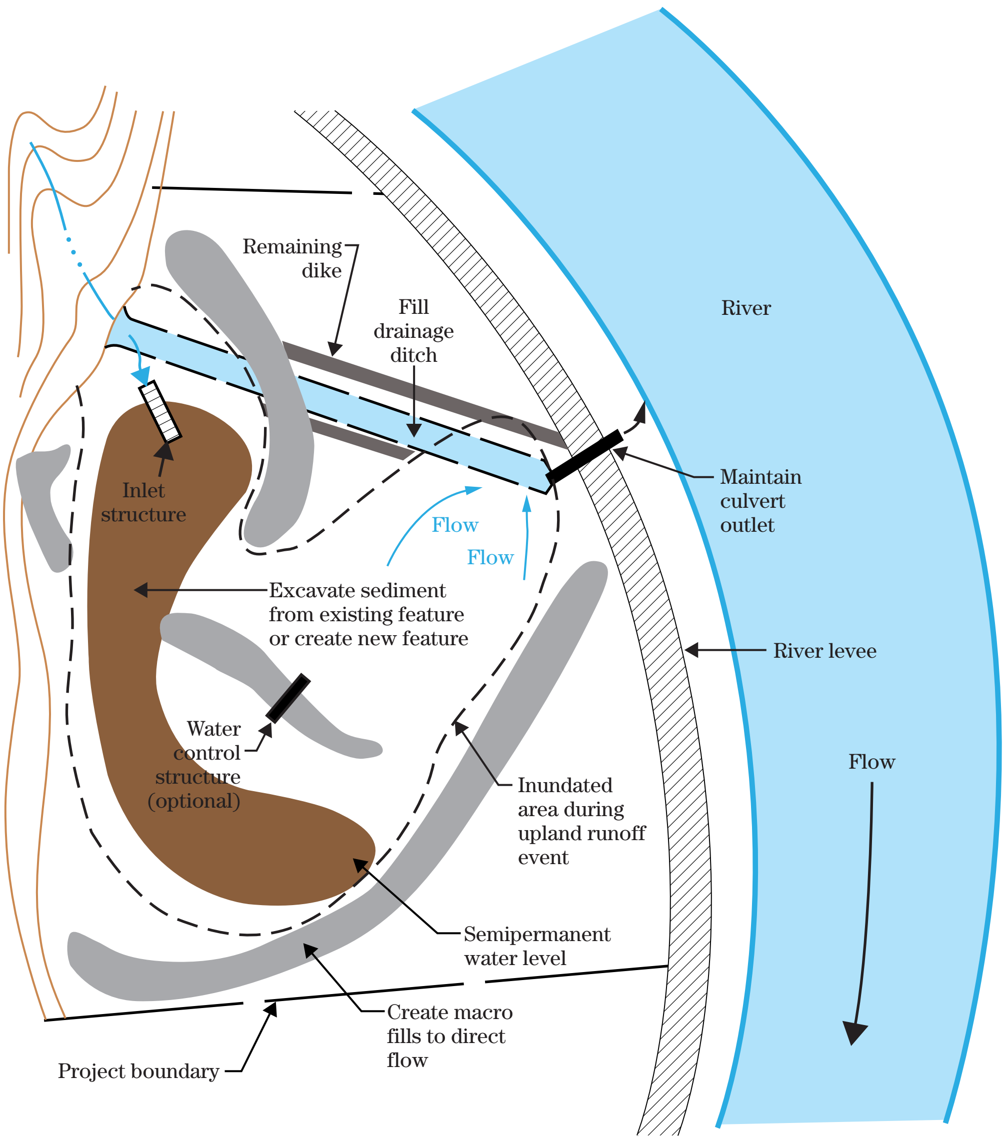
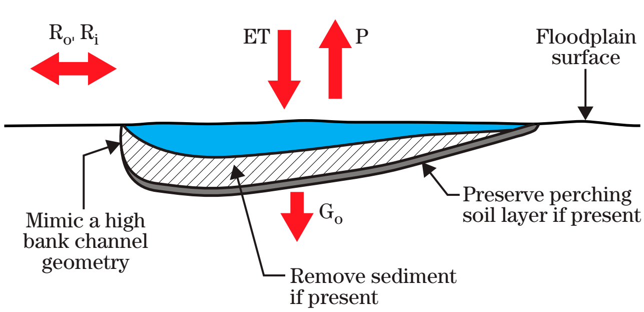


Figure 3 Plan view—continued

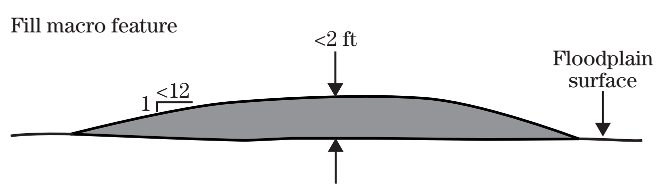
(b) After restoration



(c) Cross section of macrotopography feature after restoration



(d) Cross section of spoil placement for macrotopography



Scenario 4

HGM type—DEPRESSION, recharge

Dominant water source—Surface runoff from adjacent watershed

Hydrodynamics—Horizontal, unidirectional, vertical, downward

Scale—1 to 10 acres

In this scenario, the planning unit includes the entire areal extent of a DEPRESSIONAL wetland. The depression is referred to as a "recharge wetland." It receives surface runoff and delivers water to a water table through vertical percolation through the wetland substrate.

Figure 4(a) shows a plan view of the prerestoration conditions. The scenario includes a storage terrace (CPS Code 600, Terrace) constructed around most of the perimeter of the depression. The terrace intercepts all of the surface runoff that formerly provided water to the wetland and stores it in a terrace channel, where it evaporates, is transpired by plants, or is lost through deep percolation. The scenario also includes a drainage channel excavated through the adjacent landscape that allows any water that finds its way into the depression to be diverted out of the depression. Concentrated flow areas are shown where surface runoff formerly entered the depression, and are now intercepted by the terrace.

Figure 4(b) shows a cross section of the existing depression. The perching soil layer that is common to this wetland type causes very low vertical downward movement of water. A layer of sediment from accelerated soil erosion on the adjacent watershed lays atop an intact A soil horizon with a high soil organic carbon content. The current water storage zone spreads water well past the areal extent of the low-permeability perching soil layer, allowing more loss due to deep percolation. In addition, the storage zone is shallower and broader, allowing more loss due to evapotranspiration.

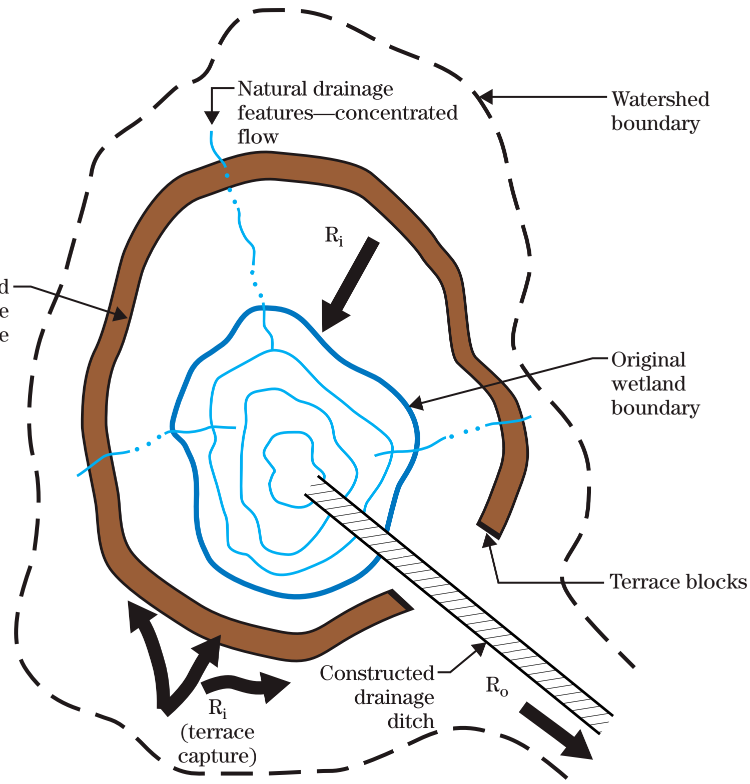
The restoration plan view is shown in figure 4(c). The first restoration measure is to breach the existing terrace at the locations where concentrated flow formerly entered the wetland. The terrace may be completely removed, but these discrete breaches are usually sufficient to restore the original quantity of surface runoff. The terrace may be left intact to provide its original erosion control function. The breaches must be designed so that the terrace outlets are stable. The adjacent land around the perimeter is seeded to establish the appropriate vegetative plant community. The center of the depression is lower in elevation and will be subject to a longer hydroperiod and a deeper wetland regime. The elevation gradually increases from the center outward, and the regime transitions to nonwetland. For revegetation, species should be selected based on the planned depth and hydroperiod. In some cases, the entire system may be established to a succession of plant communities, beginning with emergent marsh vegetation in the depression bottom, wet meadow vegetation at the wetland perimeter, and native grasses and forbs within the surrounding uplands (nonwetland). In other cases, only the nonwetland zone around the perimeter will be planted. The discrete concentrated flow areas are planted to vegetation, usually nonwetland species. This is mainly to prevent soil erosion, but also provides complexity to the wetland edge and increases habitat functions. The drainage ditch is either completely filled or provided with a ditch plug structure. If possible, watershed treatment practices should be installed that decrease sediment delivery.

In cases where the stability of the concentrated flow areas is in question, the terrace breaching effort can be replaced by the installation of underground outlets that deliver water to the depression bottom with no erosion potential.

The restored cross section in figure 4(d) shows the removal of excessive sediment. This will have the effect of concentrating the available water more to the original footprint of the depression, where the most highly impermeable soils occur. Although the surface area will be less, the storage depth will tend to increase. The low-permeability soil layer has been left intact. In addition, the buried A soil horizon has been left intact.

Figure 4 Plan view

(a) Before restoration



(b) Cross section before restoration

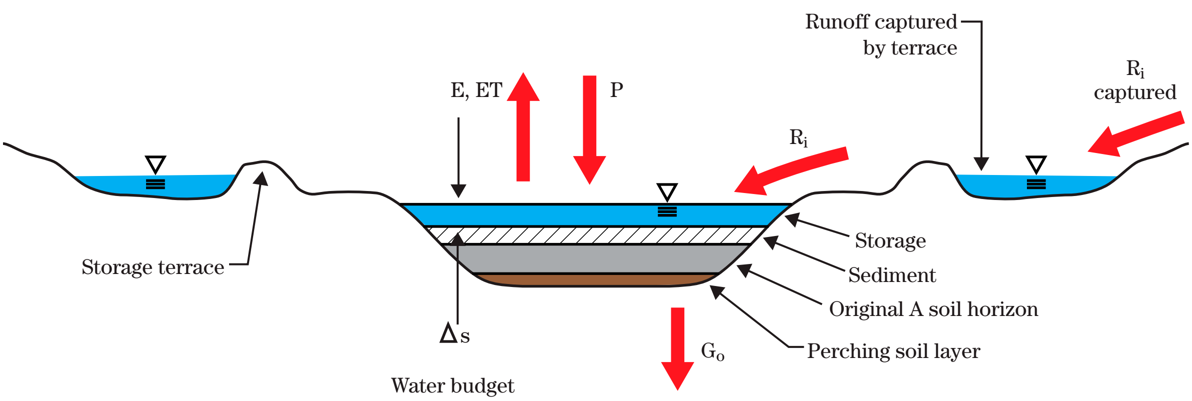
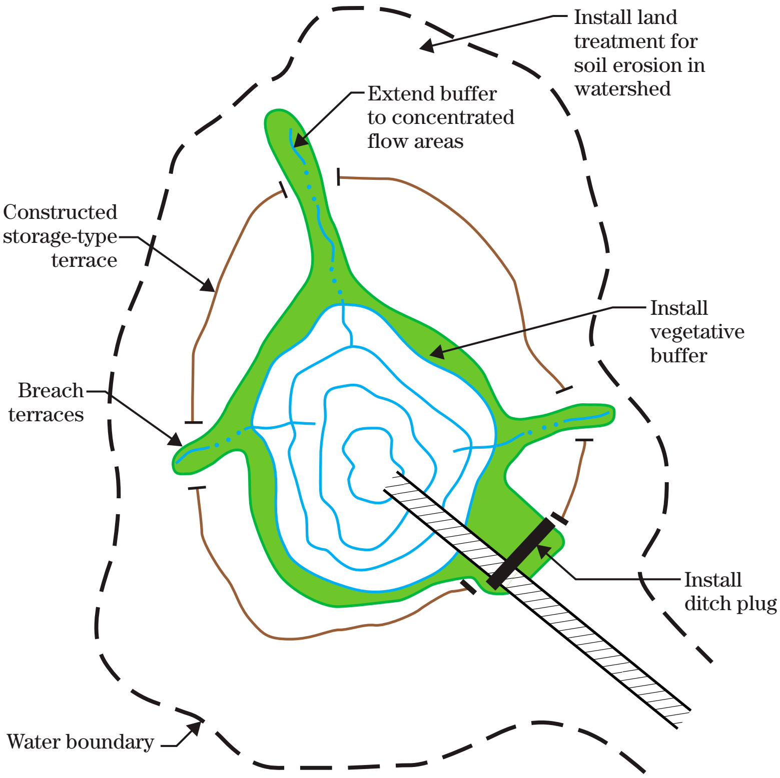
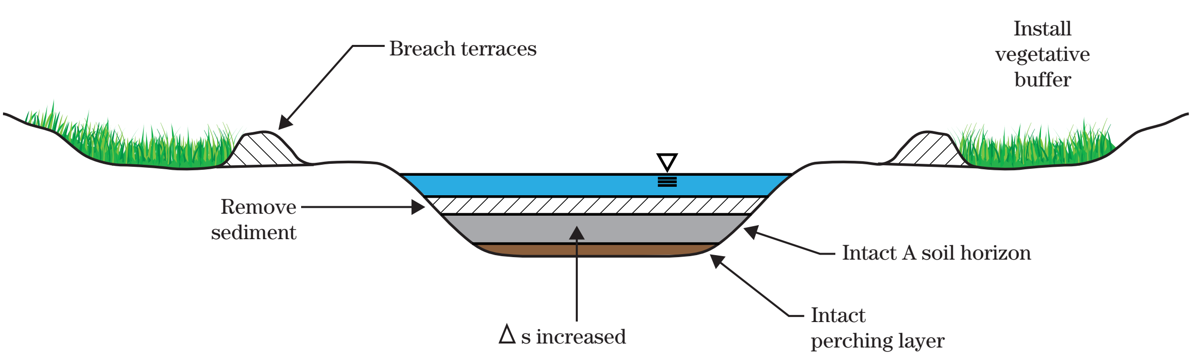


Figure 4 Plan view—continued

(c) After restoration



(d) Cross section after restoration



Scenario 5

HGM type—SLOPE, topographic, small scale

Dominant water source—Groundwater

Hydrodynamics—Horizontal, unidirectional

Scale—Approximately 2 acres

The subject of this scenario is a small-scale topographic SLOPE site. The system originally existed as a completely vegetated system where the surface contours of the landscape forced groundwater to the surface of a gently sloping wet meadow site at the extreme headwaters of a stream system. The surface water moved as overland flow downslope where it concentrated to form a first-order stream at the downstream end of the wetland system boundary. Surface runoff from the adjacent watershed entered the area as concentrated flow and moved downstream as shallow overland flow when it encountered the gently sloping, heavily vegetated wetland area. The water needed to maintain wetland conditions for the required hydroperiod is provided by the groundwater flow. The surface runoff is not a significant contributor to the function of the wetland, as it is of short duration.

The actual scale of SLOPE systems can vary widely depending on climate and land slope. Groundwater typically emerges as surface flow as it enters the wetland system. In extreme cases, this shallow surface flow can move for several miles before a stream channel forms. Although large, these systems are still considered to be topographic SLOPE wetlands. This scenario specifically covers only those systems that are small in scale and transition directly into a lower order RIVERINE HGM wetland types.

As shown on the prerestoration plan view in figure 5(a), the stream system has advanced upstream into the SLOPE wetland through gully advance. The advancing gully has merged with the discrete concentrated flow areas entering the system from upstream to form a new stream network. The presence of these newly formed channels has lowered the groundwater surface of the site and converted the original wet meadow plant community to upland vegetation. The groundwater storage function of this site has also been lost. This gully advance can be caused by events both upstream and downstream of the site. Watershed changes can increase peak discharges of surface runoff providing the erosive energy needed to form gullies through the system. Channel straightening downstream can cause a headcut to form that advances upstream into the wetland system. Once a defined stream channel forms, the groundwater flow expresses itself at the surface through the channel banks and is converted into baseflow. The duration of this baseflow is shorter than that of the original groundwater discharge. The long-term surface saturation of the system in its original state often results in organic matter buildup at the surface. The soils may actually be Histosols or exhibit a histic epipedon. Lowering of the groundwater table results in the loss of the anaerobic conditions required to maintain the organic soil. As a result, aerobic decomposition or mineralization occurs.

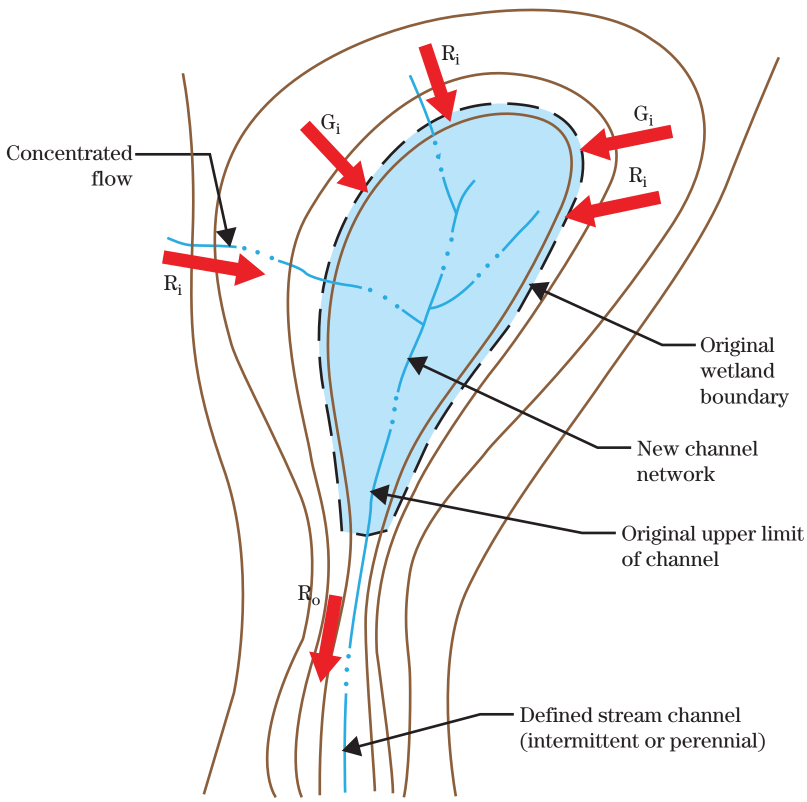
Figure 5(b) shows the prerestoration cross section, with the new gully advance, lowered groundwater table, and organic soils left that are now subject to mineralization.

The plan view of the site after restoration is shown in figure 5(c). A series of ditch plugs has been installed to force the water flowing in the newly formed gullies across the land surface. These structures must be closely spaced so that water reentering the channel will not experience an overfall condition. The crest of the structures must be high enough to force water out of the channel and onto the adjacent surface.

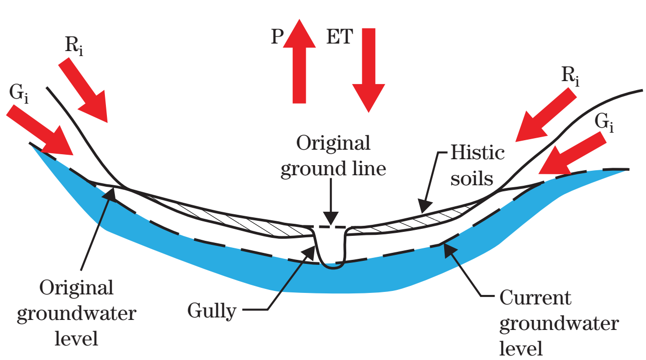
As an alternative, the entire gully network may be filled with soil and adequately compacted and/or overfilled to account for settlement. Both of these alternatives will restore the original conversion of groundwater to surface flow at the wetland margins. The adjacent land around the perimeter should be established to the appropriate vegetative plant community. The plants lower in elevation will be subject to a longer hydroperiod and a deeper wetland regime. The regime gradually transitions to nonwetland as the elevation above increases. In some cases, the entire system may be established to a succession of plant communities, beginning with wet meadow vegetation in the bottom and transitioning to upland, nonwetland plants. In other cases, only the nonwetland zone around the perimeter will be planted. The discrete concentrated flow areas are also vegetated to prevent soil erosion and provide complexity to the wetland edge. The cross section of the restored site is shown in figure 5(d).

Figure 5 Plan view

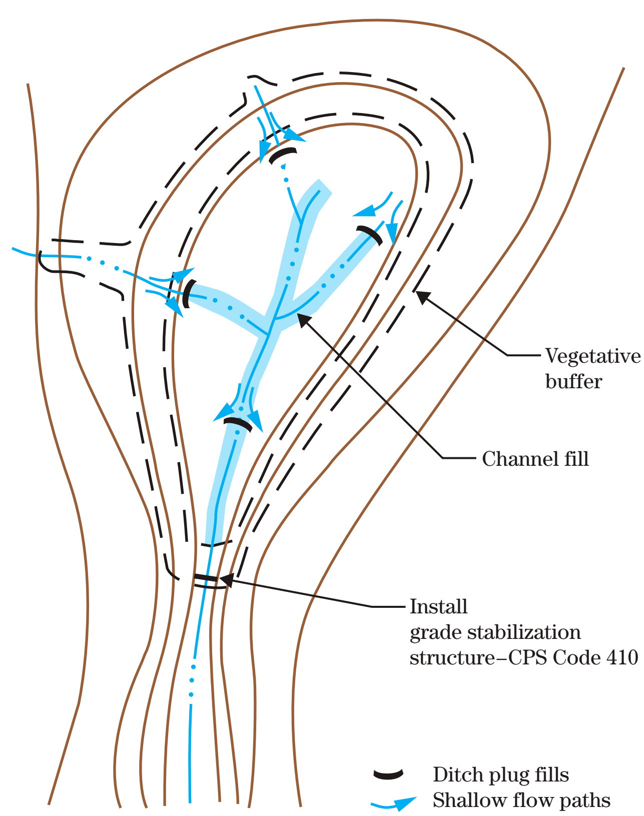
(a) Before restoration



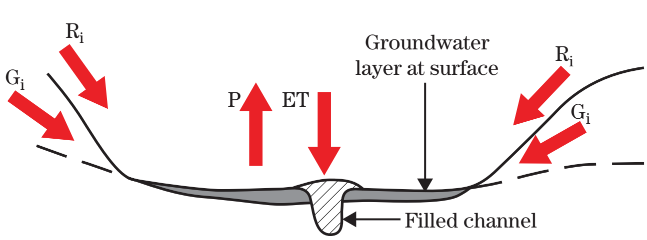
(b) Cross section before restoration



(c) After restoration



(d) Cross section after restoration



Scenario 6

HGM type—SLOPE, topographic, large scale

Dominant water source—Groundwater

Hydrodynamics—Horizontal, unidirectional

Scale—20-plus acres

The wetland in this scenario is a large SLOPE wetland system that is dominated by organic soils. The areal extent is at least 20 acres and can be much larger. Although surface runoff enters the system, it is not the dominant water source. Groundwater enters the system from upstream and from the valley margins. At the low part of the system that is roughly in the middle of the valley, the groundwater expresses itself as surface water. Visually, this flowing water may appear to be a stream. However, the system has no streambed or banks, and the stream hydrograph is very stable, with no prolonged low or high flows. The presence of organic soils is further evidence that the system's surface water discharge is very constant. These soils must have continuous saturation to the surface to form. If the saturation drops below the surface, the soil will aerobically decompose down to the saturation layer. If the area is surface inundated, the formation of organic soil ceases, as well.

The scenario shown in figure 6(a) includes a surface perimeter ditch around the tract that intercepts groundwater, converts it to surface flow in the ditch, and directs it around and downstream of the area. The original surface flow area at the bottom of the site has a large main drain ditch installed to carry internal drainage downstream. Buried tile is installed to collect the water from direct precipitation that falls on the site, and deliver it to the main drain. The downstream boundary is a road, and the hydrologic outlet is a single culvert.

Figure 6(b) shows the unrestored site in cross section.

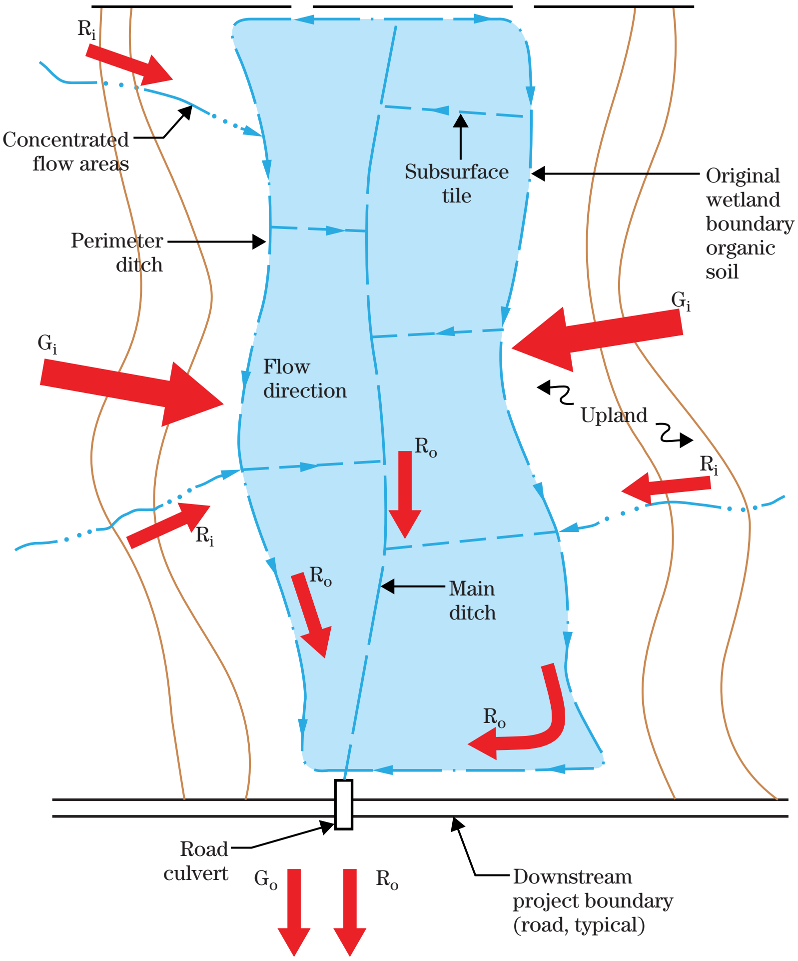
The agricultural productivity of the organic soils in this wetland type is high, and they have been extensively drained across large regions of the United States. Upon drainage, the soil begins to decompose or mineralize. The rate of mineralization depends upon the annual duration of the lower water table and the degree to which tillage exposes the soil to air. Mineralization causes the land surface to lower or "subside." Subsidences of 2 to 4 feet over a period of a few decades are common on organic soils in the Great Lakes region.

The restoration of the site in this scenario is shown in the plan view in figure 6(c). Restoration is done by reversing the drainage measures. The perimeter ditch and main drain are filled to the extent that soil is available. Ditch plugs are installed to perform the function of continuous ditch fill. The original spoil has usually mineralized, so macro excavcations in the wetland's interior provide material for fill. As shown in figure 6(b), the ditch plugs are installed to act as macro features. This fill material should be at least 50 percent mineral soil so that it can be relied on to provide a stable mass of soil until the organic soil formation process begins to occur again. The fills are oriented so that they direct flows away from the partially filled main ditch and force shallow, nonconcentrated flows across the land surface. Careful attention is given to the orientation and cross sections of the ditch plug features where concentrated flows enter the wetland from the adjacent uplands. These flows must be precluded from reentering the ditches in an overfall situation.

Figure 6(d) shows a cross-sectional view after restoration and illustrates the ditch plug fills and tile breaches.

Figure 6 Plan view

(a) Before restoration



(b) Cross section before restoration

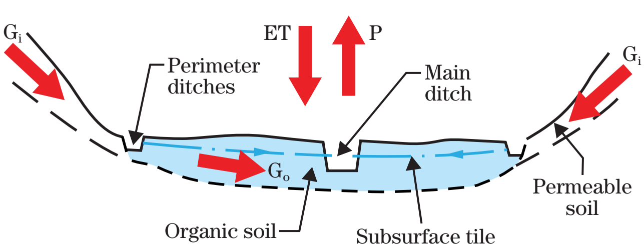
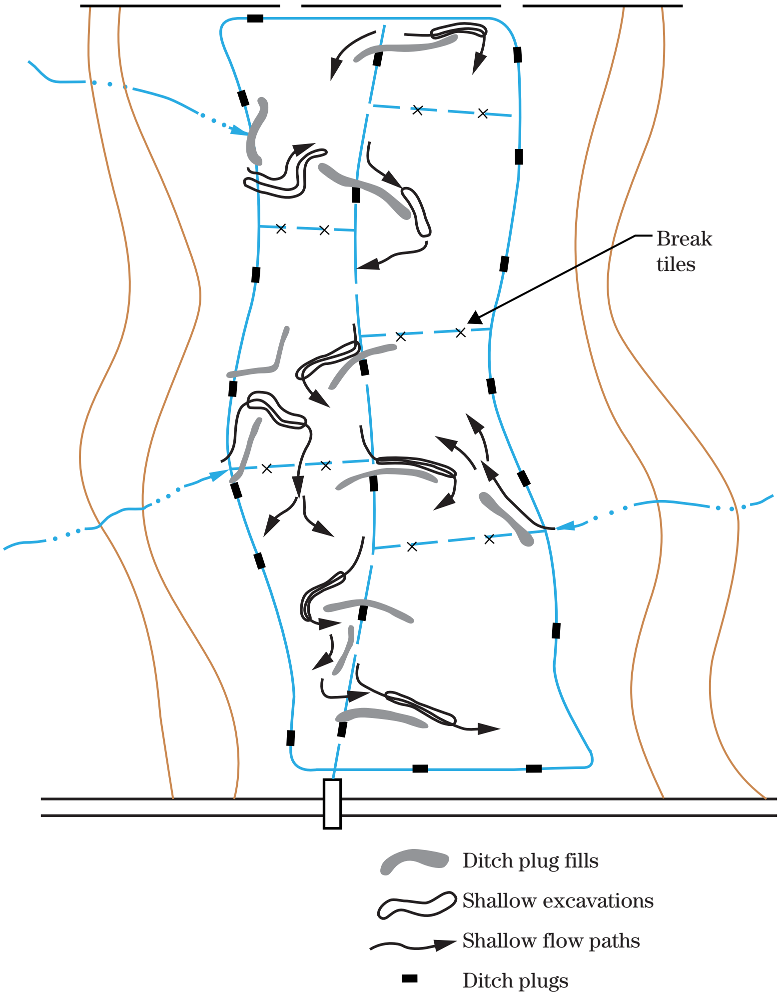
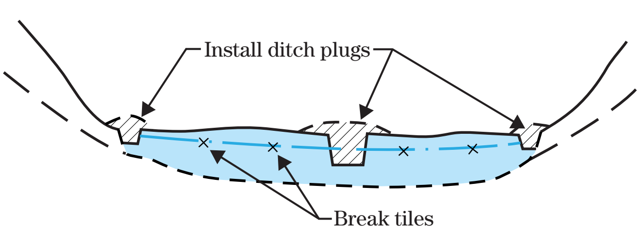


Figure 6 Plan view—continued

(c) After restoration



(d) Cross section after restoration



Scenario 7

HGM type—RIVERINE, Episaturated, higher stream order

Dominant water source—Surface floodwater

Hydrodynamics—Horizontal, bidirectional

Scale—Relatively small in comparison to the broad floodplain

In this scenario, an isolated floodplain tract is to be restored to wetland conditions. Its size is relatively small in comparison to the broad floodplain. A levee between the tract and the adjacent river prevents floodwater from entering the site. In addition, a ring levee occupies the remaining tract boundaries and separates the tract from adjacent farmland. The tract is isolated from any potential surface runoff water sources. The only water source available to support wetland hydrology is direct rainfall.

The plan view, figure 7(a), shows the river, levee, and ring levees. Also shown is the culvert and flap gate where surface rainfall is directed through the levee and into the river.

Figure 7(b) shows the plan view of the site after restoration. The main levee adjacent to the river has been breached in a single isolated location. The surface of the tract has been altered by the installation of macro features. These features are created by excavation and spoil placement and create diversity in the duration (hydroperiod) and depth (regime) of water on the site. They are also located in such a way as to prevent excess sediment deposition and scour on the site as water enters during the rising flood hydrograph and exits during the receding hydrograph. These features can also be used to increase the depth of ponding in topographic lows on the site by careful placement of spoil without the construction of dikes and water control structures.

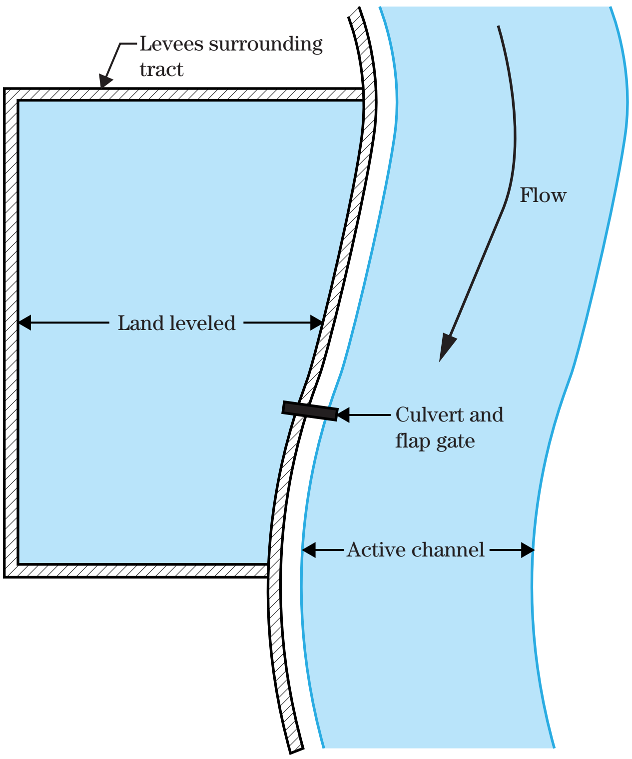
The levee breach is located on the downstream end of the tract to allow water to back into the site. This tailwater breach prevents high-velocity floodwater from flowing into the site from upstream. However, the low-velocity inflow can be expected to deposit sediment on the restoration site over time.

Flooding of the restored site must be contained within the tract boundary. Therefore, the integrity of the surrounding ring levee on the tract boundary must be maintained to provide flood protection to adjacent property.

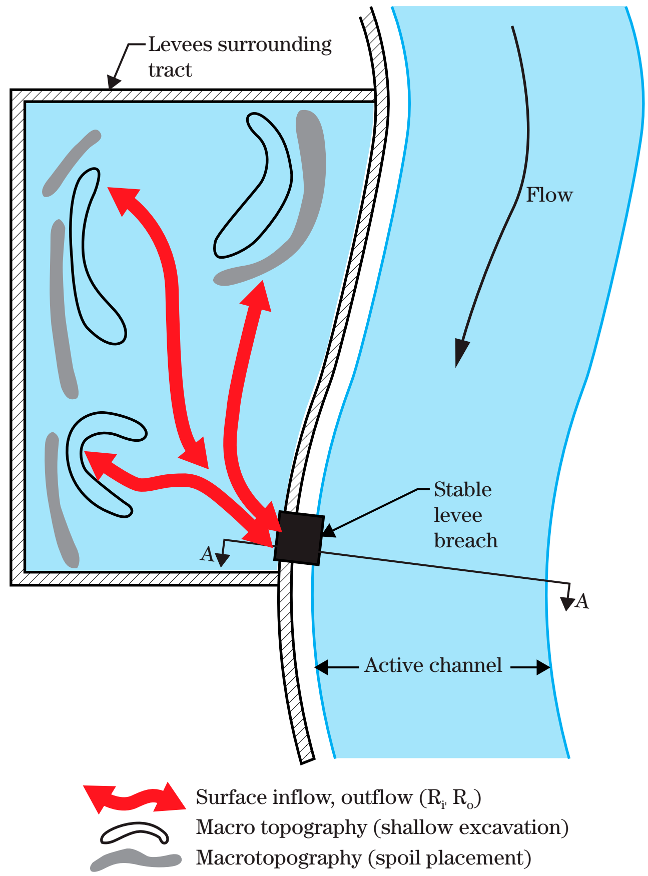
Figure 7(c) shows the levee breach location in cross section. Note that the bottom elevation of the excavated breach is above the grade of the adjacent floodplain. This allows the entire tract to maintain water in a ponded condition after the flood hydrograph recedes. Also shown is a layer of deposited sediment between the river and the adjacent levee. This floodplain accretion that is common in streams contained by levees must also be removed with the levee breach material to allow floodwater access. The bottom elevation of the breach is selected based on many factors. For example, ponding depth can be selected based on an analysis of the duration of stream flooding, coupled with a water budget analysis of the ponded water subject to percolation and evapotranspiration loss. The breach channel will also be affected by the tractive stress forces of the floodwater during inflow and outflow. The channel can be in an alternating state of deposition and scour during a single hydrograph. This dynamic can be affected by the initial selection of the bottom elevation of the breach, as well as the breach width. Currently, no method is available for the design of breach geometry. Local experience and observation of natural flow dynamics in the same stream reach must be used to determine the proper breach grade and width.

Figure 7 Plan view

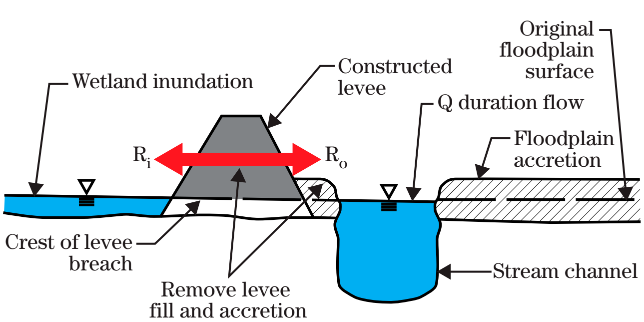
(a) Before restoration



(b) After restoration



(c) Cross section of levee breach, section A–A from figure 7(b)



Scenario 8

HGM type—RIVERINE, Endosaturated, higher stream order

Dominant water source—Groundwater (supported by stream water surface)

Hydrodynamics—Horizontal, bidirectional

Scale—Relatively small portion of a large floodplain

In this scenario, the restoration site contains one or more single discrete floodplain macro features. The floodplain soils are highly permeable sands and gravels. The stream system formed as a braided channel system with constantly shifting multiple channels across a very wide active channel and floodplain system. In this scenario, upstream water diversions have greatly reduced the historic peak discharges. The system now exhibits a much narrower active channel that is maintained within a relatively permanent boundary. In addition to being narrower, the current active channel is also deeper, and the long-term water surface profile is significantly lower in elevation. The macro features that were formerly within the active channel are now left as remnant features, and the groundwater table level is now below the bottom of these dry remnant braids.

The current floodplain may or may not flood on a frequent basis. In an endosaturated floodplain, surface flooding is not needed to support wetland hydrology. Long-term high groundwater levels create the saturated soil conditions needed to maintain the wetland. Figure 8(a) shows the plan view before restoration.

The project boundary includes all or part of three individual floodplain macro features that were formerly an active part of the channel system. These channel braids either had active flow or slack surface water. Groundwater still moves laterally between the stream and adjacent floodplain with the rise and fall of the stream hydrograph. However, the average groundwater elevation is lower than before the system was altered by upstream diversions of water. Thus, the floodplain no longer supports wetland hydrologic conditions.

In figure 8(b), detail A shows a single large channel braid. Wetland hydrology is to be provided by using excavation to lower the bottom of the channel braid to an elevation that is at or below the average groundwater elevation. In this manner, wetland conditions will be established only in the bottoms of the excavations. There are several considerations that must be addressed in this scenario.

First, the mere act of converting groundwater to surface water by excavation will move groundwater into the created surface pond. This tendency will be mitigated if the excavated areas are small and there is no significant groundwater surface drop between the upstream end of the excavation and the downstream end. In a typical large-channel braid, the linear distance along the valley gradient can be in the order of several hundred feet. If the entire feature is excavated to expose groundwater, the water at the upper end will be quickly moved on the surface by the valley gradient and will pond at the lower end of the braid. In some cases, enough water will be moved to cause the braid to overflow at the downstream end and cause a gully across the land surface. Performing the excavation in this manner is roughly analogous to constructing a drainage ditch. Detail A in figure 8(b) shows the excavation of multiple pools that are disconnected. Isolated areas of groundwater drawdown are balanced by areas adjacent to the created surface pools where the groundwater elevation will increase.

Finally, under no circumstances should the bottom end of the braid be connected with the active stream channel. Wetland hydrology in this system is not supported by surface water from the stream, but by groundwater. The excavation at the lower end of the braid will cause the groundwater level in this area to decrease and negatively impact wetland hydrology.

Figure 8(c), shows the cross section of a single excavated pool. The depth of excavation into the current groundwater level should be no more than needed to create the depth needed for the planned wetland function. The feature from figure 8(c) is highlighted in gray.

The relationship between the former active channel, flooplain macro features, and the groundwater level is shown in the floodplain cross section illustrated in figure 8(d).

The profile view shown in 8(e) shows the effect of the excavations and fills on the groundwater table. The water level in the created pools is at equilibrium and the groundwater level shows a drawdown at the upper ends of the pools that is balanced by an increase in elevation at the ditch plug locations. This is a lower risk scenario than that described in figure 8(f).

In the profile view shown in figure 8(f), the excavation is continuous, and the individual pools are separated by grade stabilization structures. The continuous excavations expose more bank to groundwater discharge. The potential for overflow around the structures exists during high groundwater periods. The design of these structures is beyond the scope of this document. However, the purpose of the structures is in keeping with CPS Code 410, Grade Stabilization Structure. Note the relationships between the excavations, structure spacings, groundwater level decreases, and surface pools.

The existence of long-term baseflow exiting an individual wetland excavation should be prevented. This condition is evidence that the groundwater elevation of the larger system is being lowered and has a negative effect on wetland function.

Figure 8 Plan view

(a) Before restoration

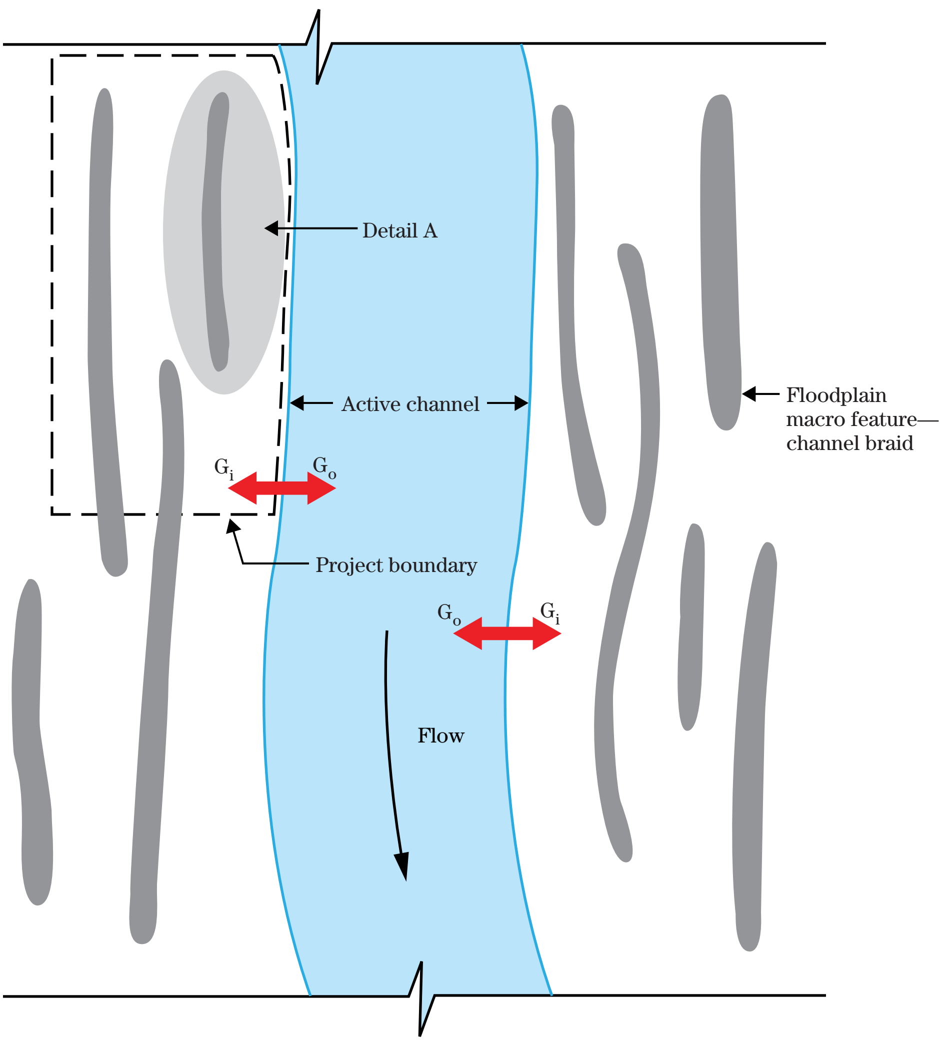
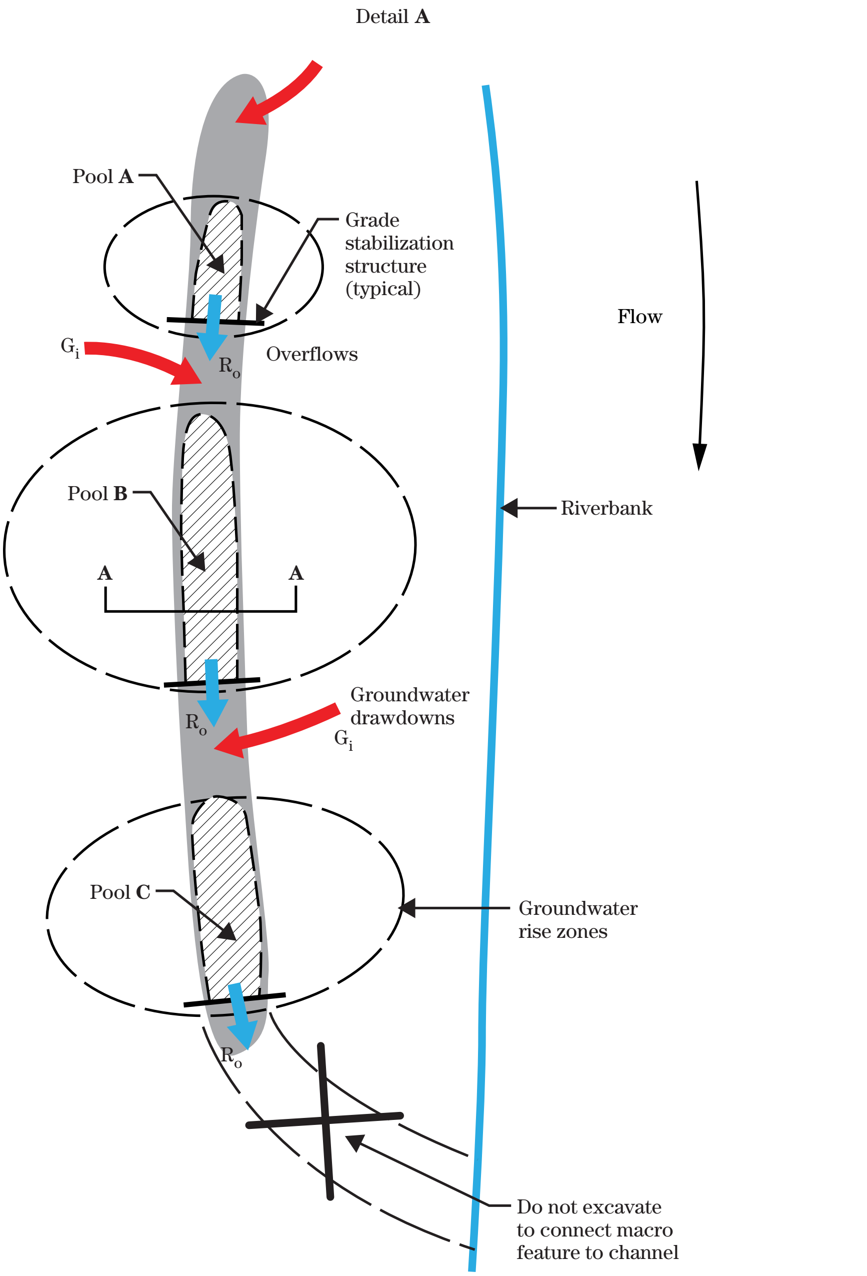


Figure 8 Plan view—continued

(b) After restoration



(c) Cross section of channel braid after restoration showing potential groundwater lowering

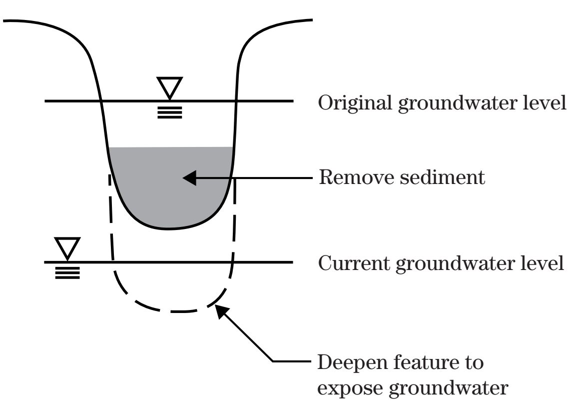
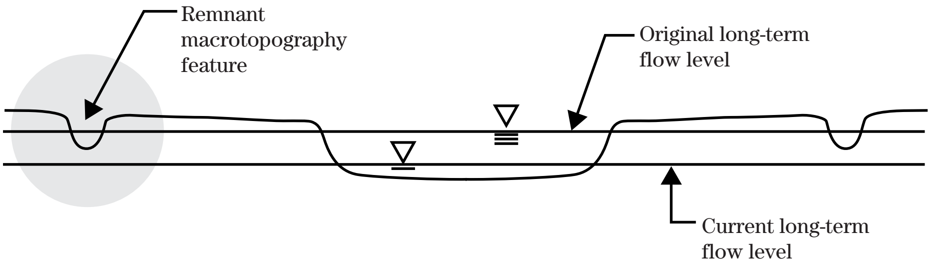
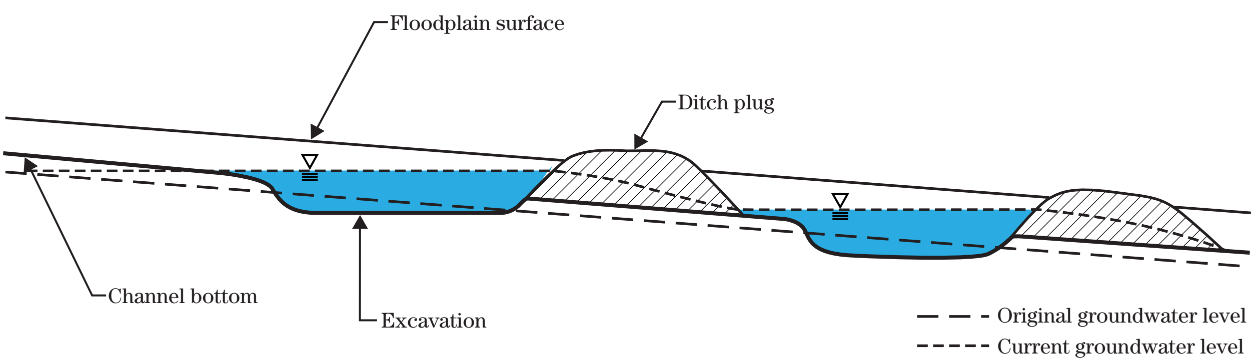


Figure 8 Plan view—continued

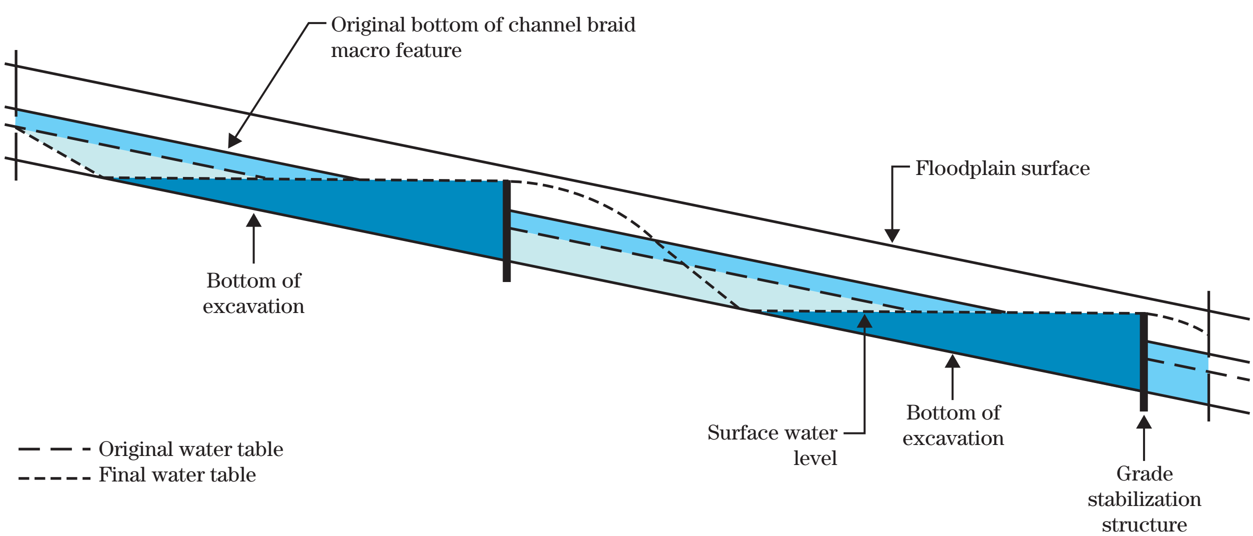
(d) Cross section of floodplain showing macro features in relation to current and former groundwater levels



(e) Profile of floodplain restoration showing resultant groundwater levels



(f) Restoration using grade stabilization structures with continuous excavation



Scenario 9

HGM type—SLOPE, Topographic

Dominant water source—Groundwater

Hydrodynamics—Unidirectional, horizontal

This scenario has the same HGM wetland type as scenario 5. However, in this scenario, the contributing watershed is occupied by farmland that has been extensively drained by subsurface tile. The drained areas in the watershed are DEPRESSIONAL and/or MINERAL FLAT HGM type wetlands. The individual tile mainlines discharge water onto the upper end of the altered wetland. The wetland itself has been drained by the excavation of a large surface main drain ditch. This ditch intercepts groundwater from the wetland site and moves it downhill as surface water. It also moves the surface water delivered from the buried tile lines. Typically, drained water from cropland contains a significant dissolved nitrogen (N) component. The removal of this nutrient is often the most important function of the wetland restoration.

The plan view, figure 9(a), shows the former SLOPE wetland area, existing drainage ditch, and individual tile lines and outlets. The project boundary includes only the degraded SLOPE wetland site and none of the drained wetlands in the watershed area. In this scenario, sufficient vertical relief exists to raise the groundwater level to the surface in the SLOPE wetland without raising the groundwater level in the watershed area.

Detail A is shown in figure 9(b). The restoration is accomplished by the installation of a series of ditch plugs that raise the water surface of the existing drainage ditch and convert the shallow concentrated ditch flow to shallow flow across the broad wetland surface. The groundwater intercepted by the drainage ditch is thus maintained as groundwater. The tile discharge is converted from a concentrated point discharge to a shallow surface flow. This surface flow may enter the soil and move as shallow subsurface flow, as well. Dissolved nitrogen (N) can be treated by conversion to the gaseous form by anaerobic decomposition as well as by nutrient uptake by the hydrophytic vegetation growing across the wetland surface.

Figure 9(b) also shows a single grade stabilization structure at the lower end of the project. This structure is required if the potential exists for gully erosion due to upstream surface water entering the downstream ditch in a significant overfall.

It is important to note that the unrestored SLOPE wetland in this scenario may be easily mistaken for a lower order RIVERINE wetland. True RIVERINE wetlands do not always exist in fluvial systems that are first or even second order. If organic soils exist in these low stream order landscapes, they are usually degraded SLOPE wetlands.

Figure 9 Plan view

(a) Before restoration

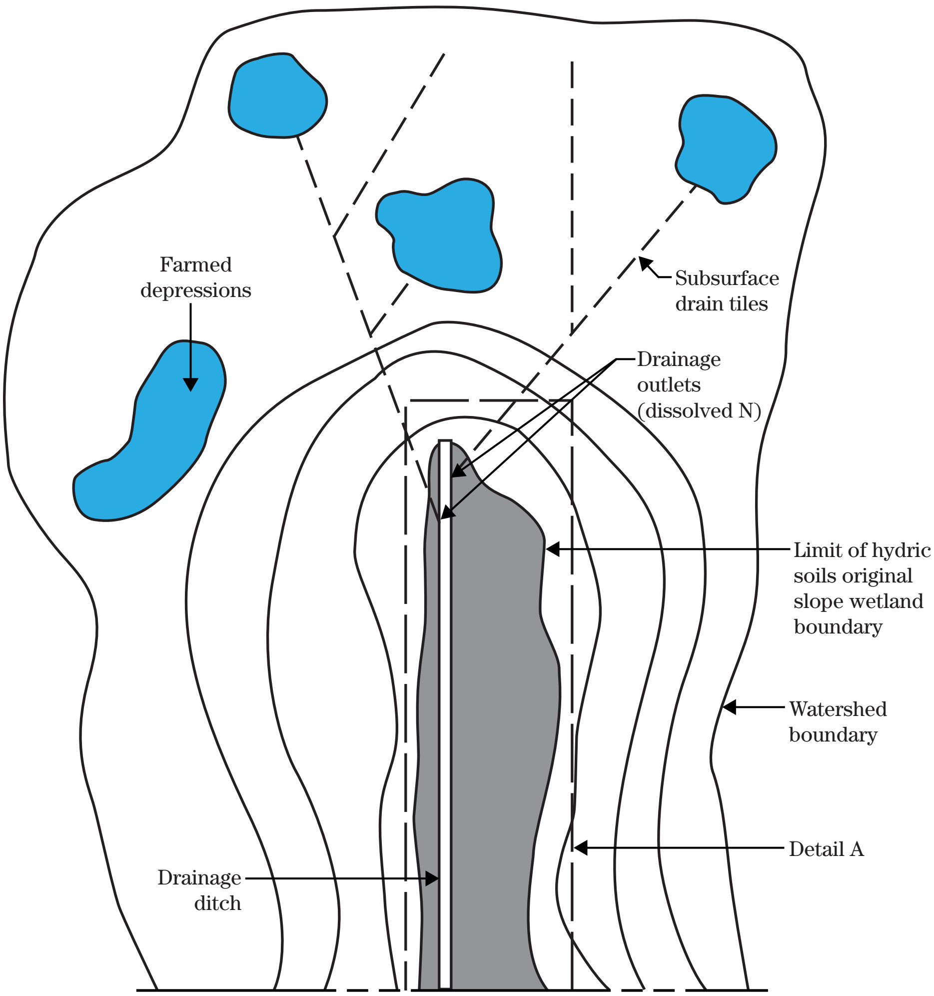
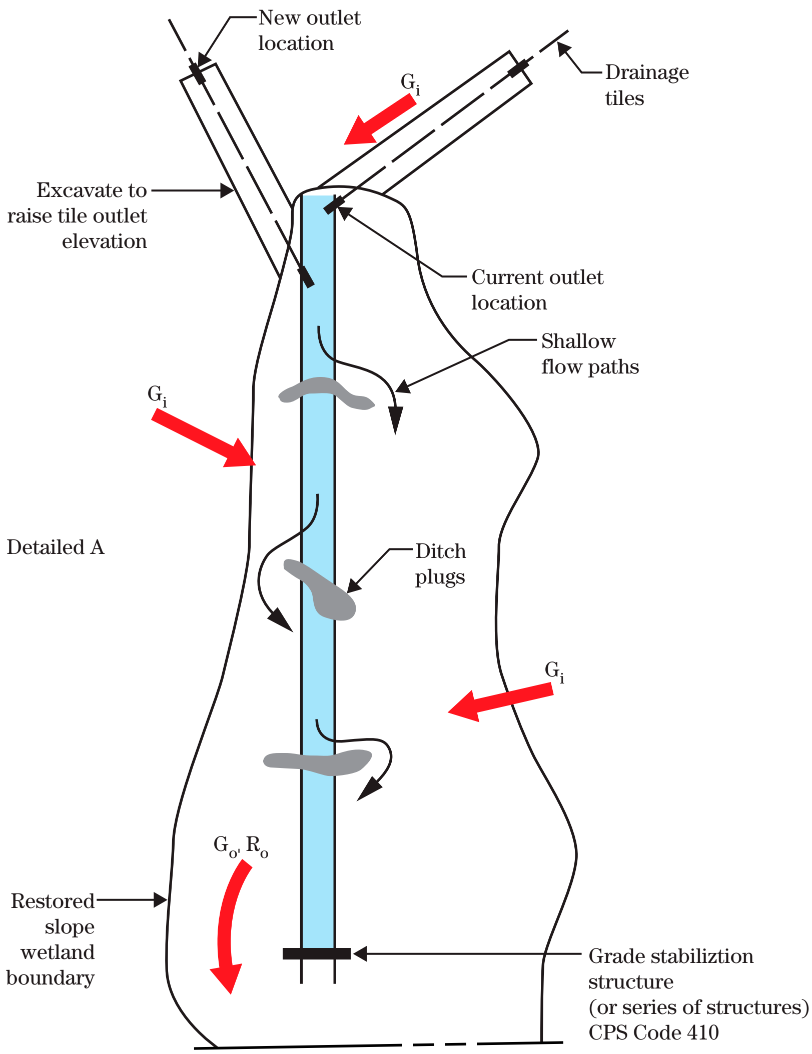


Figure 9 Plan view—continued

(b) After restoration



References

Brinson, M.M. 1993. Changes in the functioning of wetlands along environmental gradients. Wetlands 13(2):65–74.

Richardson, J.L., and M.J. Vepraskas (eds.). 2000. Wetland soils: genesis, hydrology, landscapes, and classification. Lewis Scientific Publ., Boca Raton, FL.

Smith, R.D., A. Ammann, C. Bartoldus, and M.M. Brinson. 1995. An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. Wetland Research Program Technical Report WRP—DE–9. U.S. Army Corps of Engineers Waterways Experiment Station. Vicksburg, MS.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2010. Understanding fluvial systems, wetlands, streams, and floodplains. Technical Note No. 4, Washington, DC.

U.S. Department of Agriculture, Natual Resources Conservation Service. 2008a. Hydrogeomorphic wetland classification system: an overview and modification to better meet the needs of the Natural Resources Conservation Service. Technical Note No. 190–8–76. Washington, DC.

U.S. Department of Agriculture Natural Resources Conservation Service. 2008b. National Engineering Handbook, Part 650, Chapter 13, Wetland Restoration, Creation, and Enhancement. Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service (formerly Soil Conservation Service). Soil Survey Staff. 1999. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Second ed. Agric. Handb. 436. U.S. Gov. Print. Office, Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service (formerly Soil Conservation Service). Soil Survey Staff. 1993. Soil Survey Manual. U.S. Department of Agriculture Handbook 18. Washington, DC.