United States Department of Agriculture

NRCS

Natural Resources Conservation Service

May 2008

Technical Note No. 2

Stream Water Surface Profile Modification for Wetland Restoration

Issued May 2008

Cover: Enhanced hydrologic regime in RIVERINE wetland (*Photo by Richard Weber, NRCS*)

Stream Water Surface Profile Modification for Wetland Restoration

Introduction

Riverine wetlands in a natural setting are part of a dynamic self-sustaining stream corridor. The stream corridor consists of a stream channel, flood plain wetlands, flood plain nonwetlands, and flood plain vegetation which form a stable system in dynamic equilibrium. These riverine systems serve to reduce flood peak discharges, absorb and cycle nutrients, transport and/or cycle sediment, and provide habitat for wetland plant and animals. Vegetative plant communities change spatially and temporally in response to the inputs of water and sediment supplied by the stream system. While the active stream channel transports sediment through the reach, the flood plain and its wetlands capture and store sediment during flood flows for later release during periods of stable adjustment in channel and flood plain geometry. This dynamism provides the spatial and temporal changes in plant community and provides a system with multiple stages of succession which maximizes the available habitat niches for fish, herpetofauna, and mammals. Riverine wetlands have reduced their function because of multiple factors.

The scope of this technical note covers those stream systems where the wetland hydrology has been altered by the incision of the stream channel, general cases where this has occurred, and strategies for wetland restoration or enhancement by restoring the connectivity of the stream to its flood plain. It does not include those riverine wetland systems where connectivity cannot be restored due to cost, land rights, or other considerations. The approaches included provide for minimum maintenance on projects where there are no specific functions to manage for and dynamic shifts in conditions can be tolerated.

Frequent reference to the term geomorphic bankfull discharge is made in this technical note. Tools for determining this discharge are not included, but a complete description can be found in the National Engineering Handbook, Part 654, Stream Restoration Design (NEH654).

Wetland types—Hydrogeomorphic Classification System

The Hydrogeomorphic Classification System (HGM) (USACE 1995) provides a means of defining wetlands according to three parameters: geomorphic landscape setting, dominant water source, and hydrodynamics. This includes seven different HGM classes. They are:

- RIVERINE
- DEPRESSIONAL
- SLOPE
- MINERAL SOIL FLATS
- ORGANIC SOIL FLATS
- ESTUARINE FRINGE
- LACUSTRINE FRINGE

This subject of this technical note is the RIVERINE HGM class.

Landscape position

Since the HGM classification's first hierarchy is the broad landscape setting of a wetland, it includes everything in that landscape position. Thus, RIVERINE wetlands include all wetlands that have formed in landscapes formed and maintained by the stream. The active flood plain, as well as primary and secondary terraces, supports RIVERINE wetlands. This technical note will only consider those RIVERINE wetlands that are in the active flood plain or can be brought back into the active flood plain.

Figures 1 and 2 illustrate the relative landscape positions of RIVERINE wetlands.

Figure 1 The spatial relationships of streams, active flood plains, and uplands

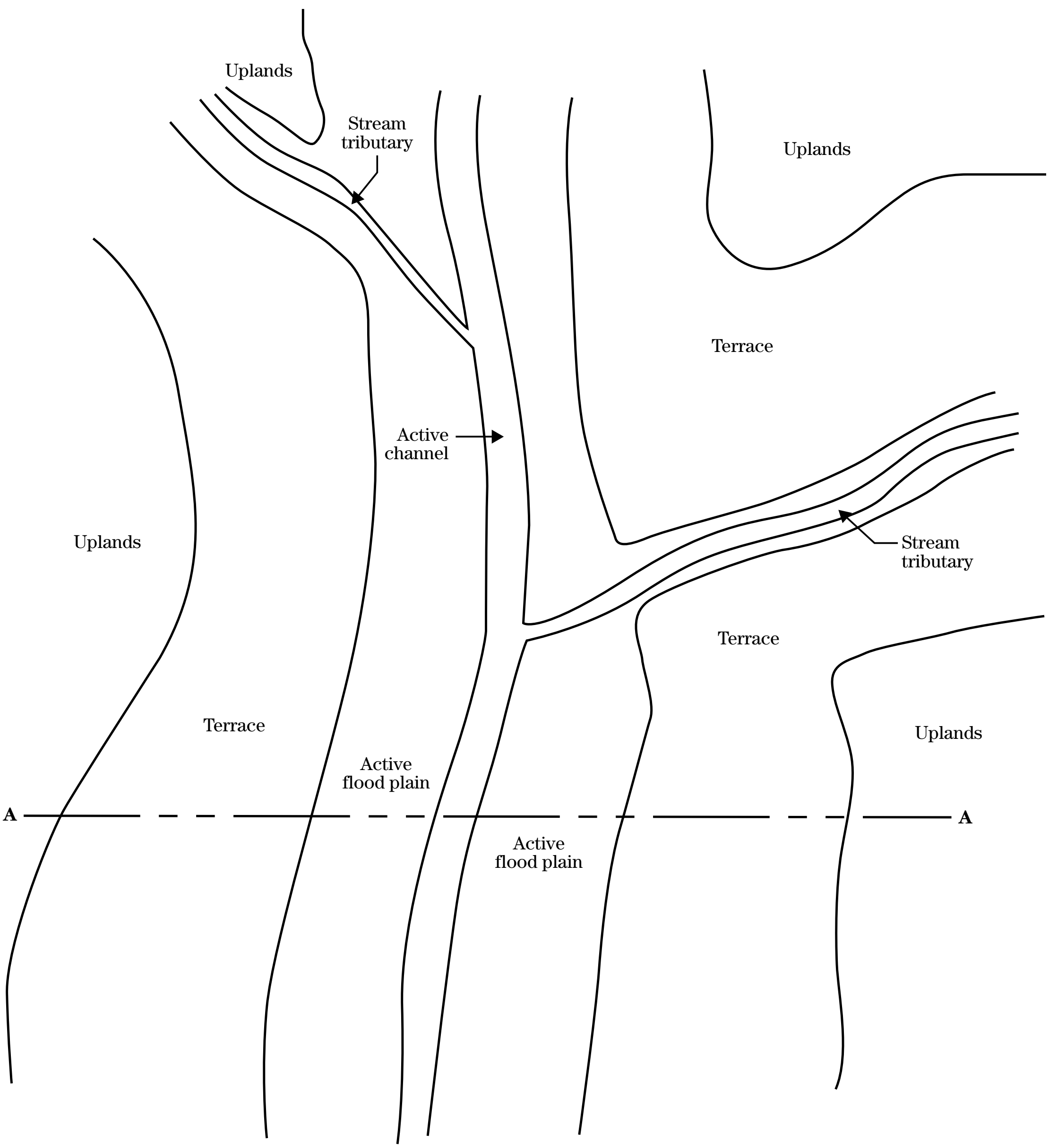
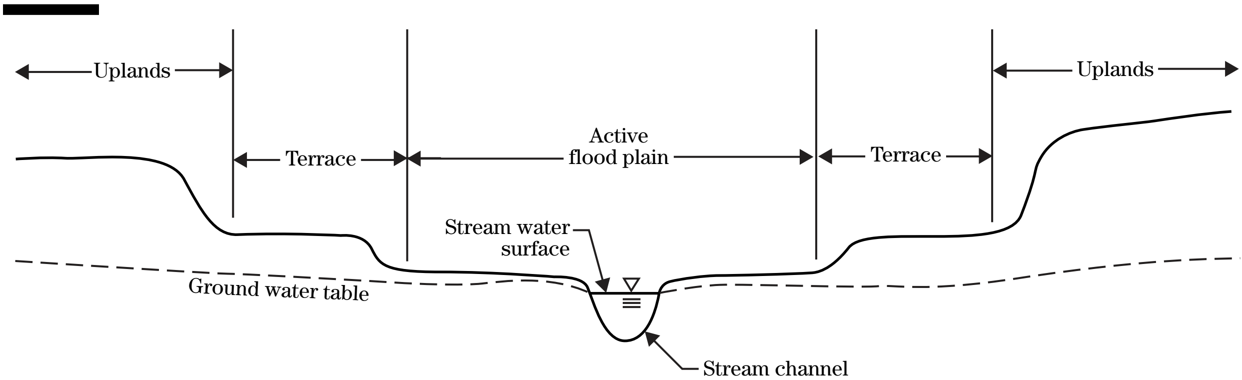


Figure 2 Cross section of stream corridor



Section A-A

Dominant water source and hydrodynamics

Dominant water source and hydrodynamics are the secondary parameters in the HGM classification hierarchy. In the case of RIVERINE wetland systems, they are considered together. RIVERINE wetland systems can be divided into three separate categories. These are epi- and endosaturated, episaturated only, and endosaturated only. These categories apply to the stable unaltered state.

RIVERINE wetlands have the stream as their dominant water source. This water is supplied as out-of-bank flows during flood events, as well as ground water inflows from the stream channel. Wetlands supplied with surface inflows during flood events are **episaturated**. Water supplied by ground water inflows from the streambank are **endosaturated**. RIVERINE wetlands may or may not be both episaturated and endosaturated, with one source dominating at different times of the wetland hydroperiod.

Wetland hydrology due to episaturation is defined as the presence of surface water for more than 15 days during the growing season. Wetland hydrology due to endosaturation is defined as the presence of ground water within 6 to 12 inches of the ground surface for more than 15 days during the growing season (USACE 1987).

RIVERINE wetlands are wetlands that are in dynamic hydraulic connectivity with the stream. This means that wetland conditions are maintained by water supplied by the stream, and the movement is bidirectional. Both ground and surface water may move from the stream into the wetland and from the wetland back into the stream. Stream conditions have a direct effect on the function of the wetland, and wetland conditions have a direct effect on stream functions.

Episaturated and endosaturated

Simply put, the wetlands in these systems are supported by both ground water inflows from the stream and surface water inflows from stream flooding. The wetland hydroperiod due to episaturation may persist for much longer than the duration of flood stage if water is stored in the soil profile or in flood plain depressions. Water storage on flood plain surfaces is usually due to perched water table conditions caused by a slowly permeable soil horizon. The endosaturation hydroperiod coincides with the stream hydrograph. The rate of fall of the ground water table rise is typically slower than the rise, however, as the water table is augmented with the infiltration of water from surface flooding. Flood plain depressions that are lower than the water table will have open water fed by the ground water table (fig. 3).

Episaturated

These wetlands are common on lower gradient stream systems with fine-grained silt and clay-suspended loads, which form the alluvial flood plain. Ground water movement into the low permeability streambank material is slow. The flood plain soils typically support a perched water table condition. The dominant water source is surface water from stream flooding. In humid areas, direct precipitation can be a significant water source. The wetland hydroperiod may persist much longer than the duration of the flood hydrograph where water is stored in the soil profile or in flood plain macrotopographic or microtopographic features. The stream hydrograph is dominated by direct runoff from precipitation. The low hydraulic conductivity of the soils in the flood plain aquifer has limited ability to supply baseflow back into the stream. As a result, these streams often experience very low flow conditions between runoff events (fig. 4).

Endosaturated

The hydrology of these wetlands is supported mainly by the ground water surface in the alluvial aquifer. Although these streams may flood, the frequency of out-of-bank flows is greater than the 2-year return period required for wetland hydrology. The system is usually dominated by coarse-grained soils in the stream sediment load and flood plain. These high-permeability soils permit the ground water table to respond readily to changes in the stream water surface profile. The ground water surface is the local ground water table. During periods of high flow in the stream, the ground water gradient slopes into the flood plain, recharging the aquifer. As the stream hydrograph recedes, the gradient reverses, and stored ground water provides long-term baseflow for the stream (fig. 5).

Schumm Channel Evolution Model

In the resource inventory phase of planning, it is important to determine whether the stream wetland system is stable, moving away from stability, or moving toward stability. In regards to the stream channel, an effective tool for this determination is the Channel Evolution Model (CEM). This simple model applies to channel systems with movable beds, which respond to stresses in a predictable way. The simple model has five types (fig. 6) (Schumm, Harvey, and Watson 1984).

Figure 3 RIVERINE wetlands with both episaturation and endosaturation

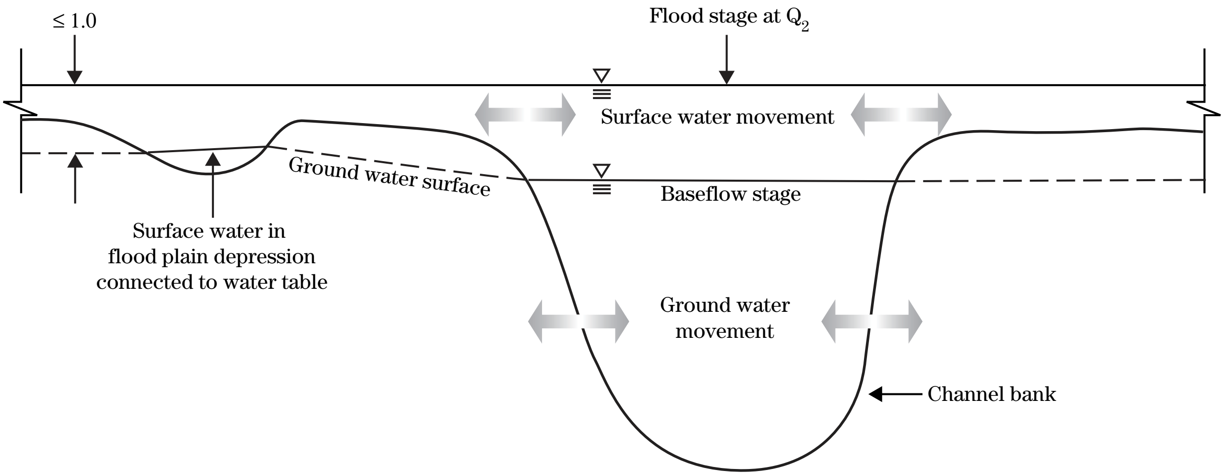


Figure 4 RIVERINE wetlands dominated by episaturation

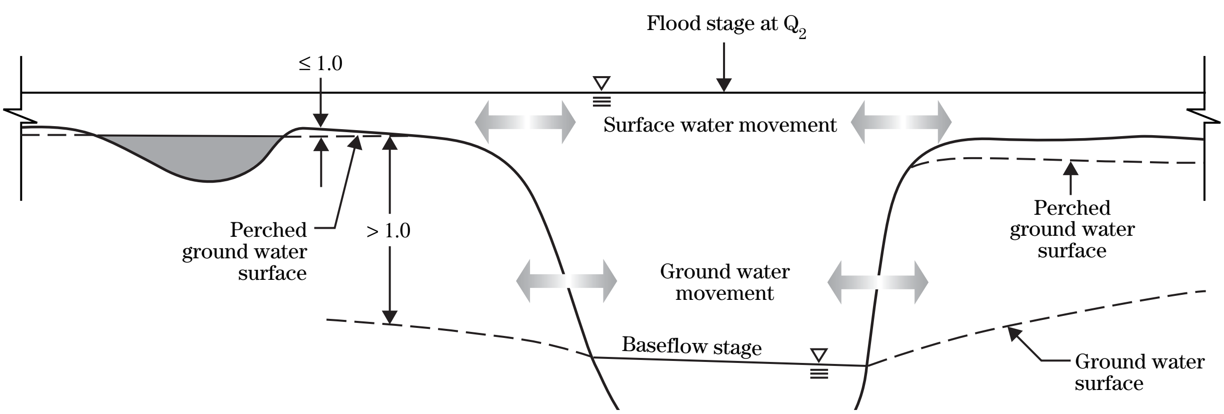


Figure 5 RIVERINE wetlands dominated by endosaturation

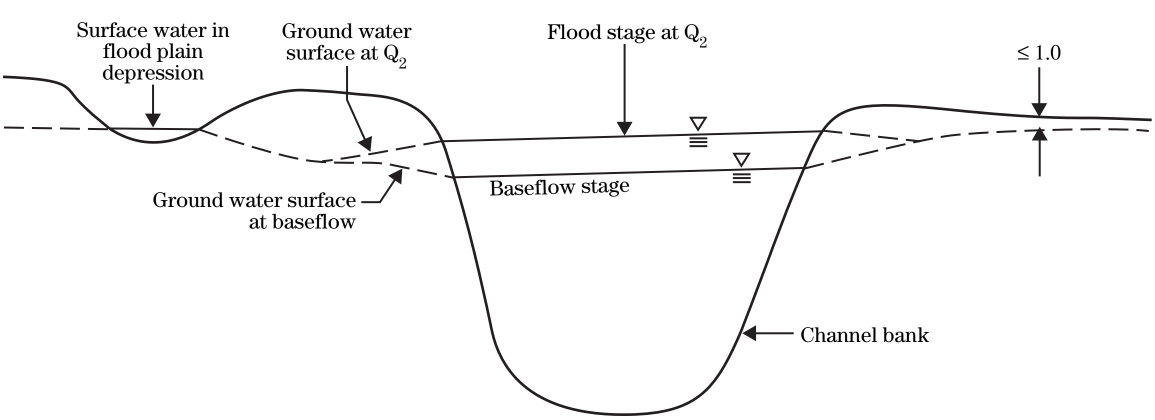
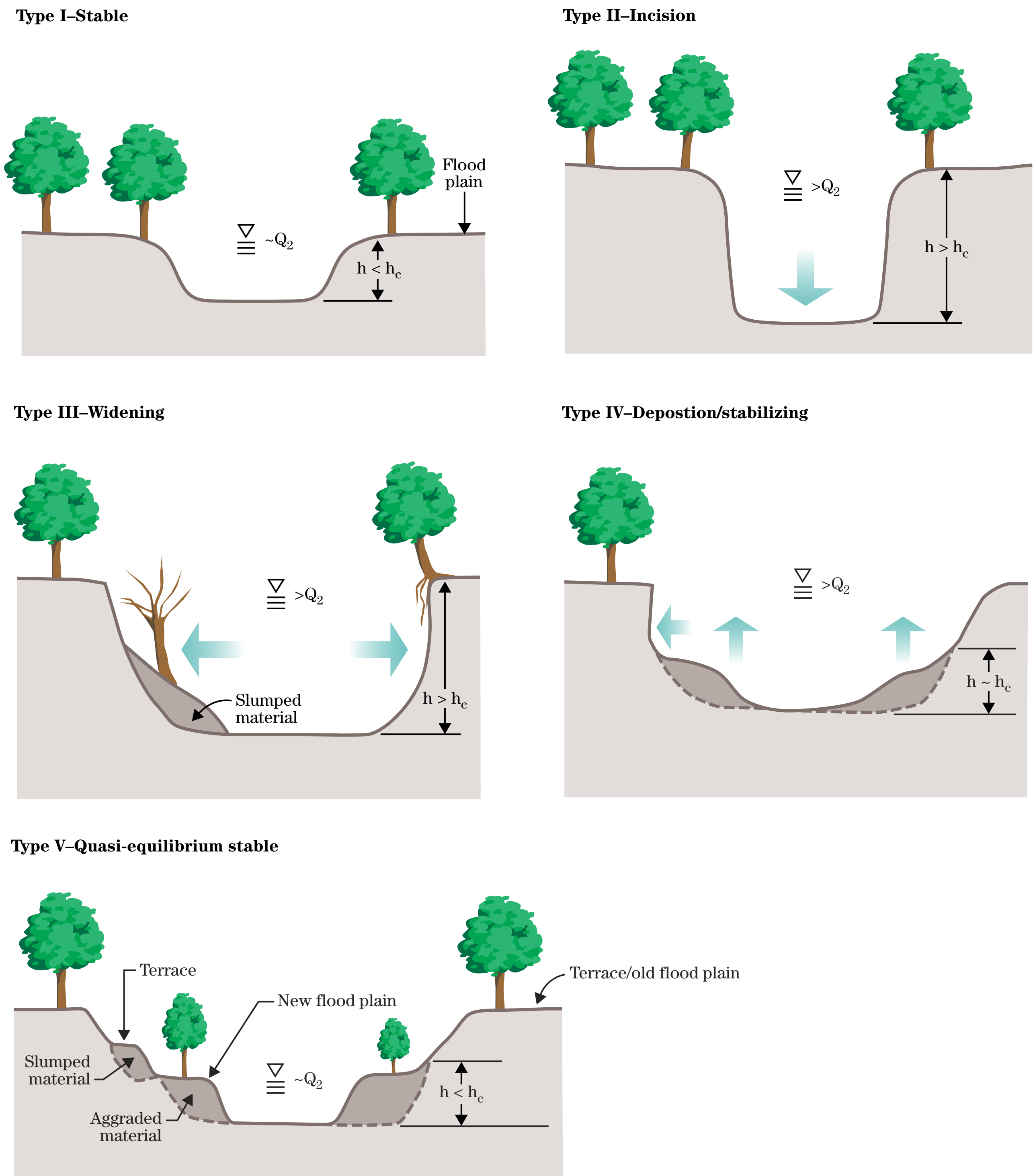


Figure 6 Channel evolution model



Type I

Type I channels are in a state of long-term dynamic equilibrium. The sediment transport of the system is in balance with the sediment supply from the watershed. The channel has dynamic connectivity with its flood plain. The capacity of the channel is the geomorphic bankfull flow, which the model arbitrarily assumes is the 2-year return period discharge (typical ranges are from 1 to 3 years). Flood flows supply water to the RIVERINE wetland. Endosaturated conditions may or may not exist, depending on the nature of the flood plain soils and the distance from the baseflow elevation to the flood plain surface.

Type II

Type II channels are actively incising. The causes of this are many, but the most common are described. Straightening of the channel within the reach or downstream causes an increase in stream grade. This grade increase induces a higher tractive stress on the channel bed and allows it to move material downstream at a rate greater than its sediment supply. In beds of cohesive silts and clays, an observable headcut will form and advance upstream to the point where the tractive stress forces are in balance with the soil's resistive forces. In some cases, successive headcuts advance up the channel. Headcut advance causes a decrease in stream grade, as well as an increase in sediment from the eroding bed and banks. When the grade is low enough to preclude any further bed erosion, the type II process is complete.

The downcutting may also be driven by changes in watershed conditions which provide a higher peak in the discharge hydrograph. Urbanization or other changes in land use that convert surface infiltration to runoff will cause shorter duration, higher peak hydrographs (flashy hydrographs). Construction of reservoirs or irrigation diversions can interrupt the sediment delivery and alter the discharge hydrograph, inducing downcutting.

The channel is now deep enough to carry significantly more than the 2-year peak discharge. The RIVERINE wetland no longer receives surface flooding to support wetland hydrology. In addition, any previous endosaturated conditions no longer exist, as the flood plain ground water surface profile is much lower than needed to maintain water within 6 to 12 inches of the flood plain surface.

Type III

The stream system reacts by attempting to build a new active flood plain at the new lower level. Tractive stress forces begin to attack the channel banks as the active channel widens. Cohesive banks experience slip or block failures when the height of the bank exceeds the ability of the soil resistive forces to maintain stability. The alluvial ground water table in cohesive flood plain soils frequently intercepts the channel bank well above the stream baseflow level, causing abnormally high saturated bank conditions. This further exacerbates the bank instability condition. Bank failure provides a high supply of sediment for the stream to move, and the active channel may exhibit a braided or multiple-channel condition as the stream struggles to move the extra sediment. This is probably the worst condition for water quality and instream habitat as pools, riffles, and bank vegetation are removed from the system. This is usually the stage where damage to flood plain farmland, property, and infrastructure becomes apparent due to bank failure, undermining of bridge abutments, and loss of other infrastructure. The increase in flood capacity during type II may, in fact, encourage an increase in human activity as historic flooding is reduced by the increased ability of the channel to carry flood discharges. Type III ends when the channel widens sufficiently to allow the stream to begin building a new flood plain.

Type IV

Type IV is a period of flood plain development. It usually occurs in conjunction with more channel widening, but the stream is trending back to a single-thread channel and utilizing the sediment from bank erosion to form channel bars, pools, and riffles. This type is potentially the longest term portion of the channel evolution process. At the end, the channel will have an active flood plain to which it supplies flood flows at the original 2-year frequency. Flood plain widening is continuing due to bank failure, as well as natural lateral migration of the channel into banks at the edge of the growing flood plain. The former flood plain is now the first terrace.

Type V

Type V is the same as type I, except the entire stream flood plain cross section is now at a lower landscape position, and the former flood plain is now the first terrace. This former riparian RIVERINE wetland setting has lost its riparian hydraulic connectivity. Wetlands in this landscape position must now rely upon direct precipitation, ground water from uplands, and upland surface runoff for their water source.

The Rosgen Stream Classification System

Many systems for classification of streams have been developed. The Rosgen classification system will be used in this technical note because of the broad acceptance of its use among many disciplines, its relative ease of use, and the repeatability of its results. It may not necessarily be the most applicable for the geologic discipline of fluvial geomorphology. However, the system is readily understood by many disciplines including engineering, biology, landscape architecture, and geology. A complete dissertation on the use of the Rosgen system is beyond the scope of this technical note. For a complete description of the use of the Rosgen classification system, refer to NEH654. The key to the Rosgen system is illustrated in figure 7 (Rosgen 1996).

Using CEM with the Rosgen Level II classification system

The Rosgen classification system provides a stream classification (A through F) for a natural channel. A RIVERINE wetland system which has lost its hydrology is typically associated with an unstable channel that is not type I or V. The Rosgen Level II classification system applied by itself will not give an indication of stability or instability. The challenges for the planner and designer are threefold:

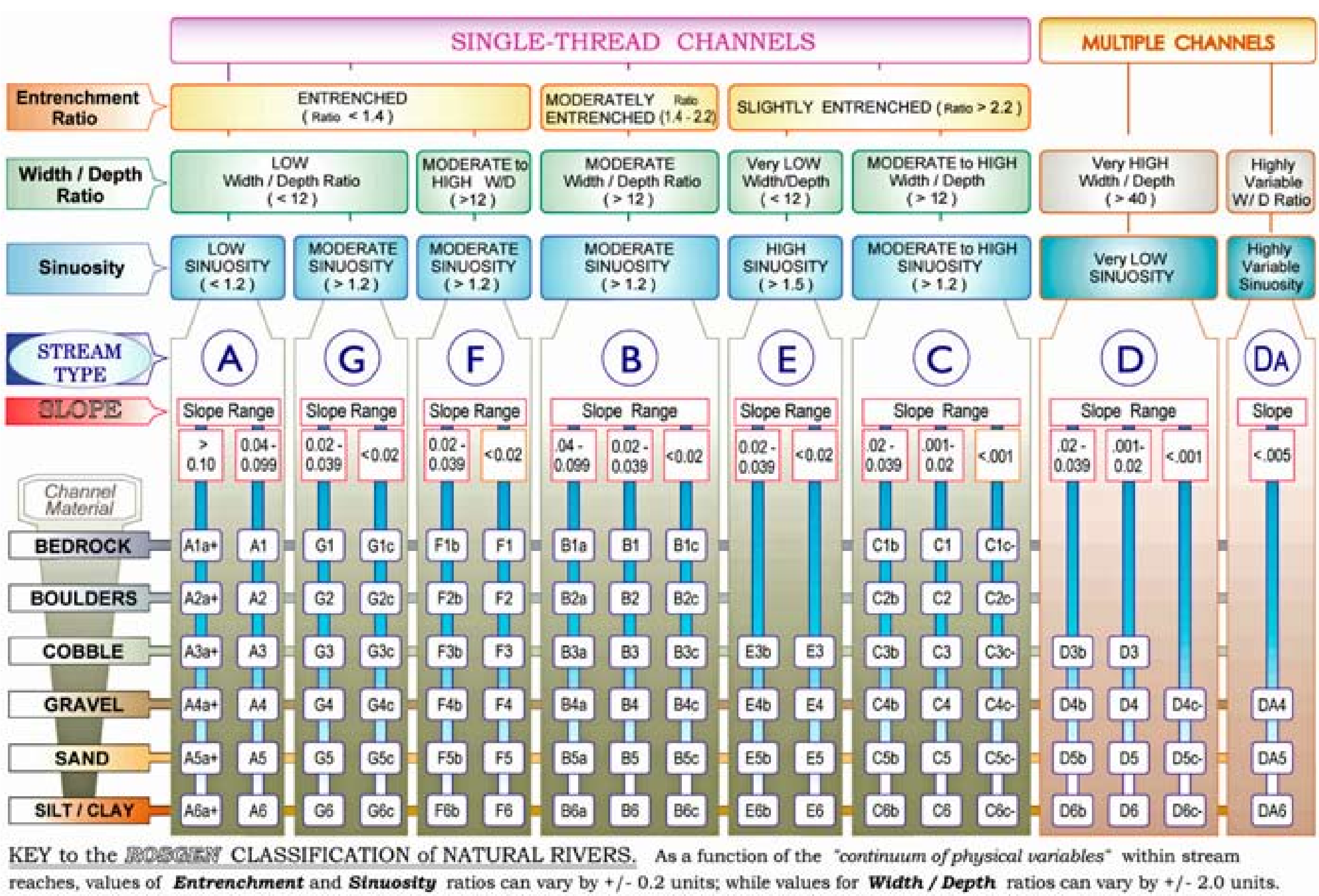
- determining if the channel is stable
- determining the stable channel geometry for a restoration template
- determining the degree of restoration possible with site constraints of land ownership, and cost

The Rosgen classification system can be applied (with care) to unstable channels to gain information about its CEM type.

Stability determination

As mentioned, the CEM types I and V are in a state of stability. Types II, III, and IV are unstable. Listed are some parameters that can be observed in the field, an associated Rosgen stream class (or classes), and the possible CEM type associated with each parameter.

Figure 7 Key to Rosgen classification system



Type II—Active incision

- Channel bottom is on hard, consolidated clay, shale, or bedrock, with no visible bars
- Channel banks are steep, and may be relatively stable
- Upper levels of the bank consist of stratified alluvial material
- Flooding occurs with a frequency of 5 years or more
- Active headcuts and overfalls can be detected within the reach
- Rosgen channel geometry indicates A or G channel type

Types III and IV—Active bank widening or recovery

- Channel bottom has multiple channel threads formed in unconsolidated sediment
- Channel bank is actively eroding with slip and block failures
- Flooding occurs with a frequency of greater than 10 years
- Rosgen channel geometry indicates B, D, or F channel type

Types I and V—Stable channels

- Channel bottom shows single-thread channel with well-defined bars
- Channel banks are stable
- Channel bed is stable
- Flooding occurs with a frequency of less than 5 years
- Rosgen channel geometry fits with the bounds for all Rosgen types
- Rosgen channel type C or E is usually a CEM type I or V

RIVERINE wetland restoration or enhancement

The remainder of this technical note will focus on increase of hydrologic function of RIVERINE corridors on CEM types II and III channels, which means that they have suffered channel incision. Wetlands adjacent to type I channels will still receive water from the stream with sufficient frequency and duration to support wetland hydrology. Type V channels provide wetland hydrology to their new flood plains. Types IV and V channels generally are at a point where reconnecting the stream water surface profile to the old flood plain is not practical. Exceptions are systems on first- and second-order streams with small drainage areas where the cost and land rights needed are not great.

Restoration of the RIVERINE wetland system is now a twofold process. First, the stream channel must be returned to a state of stability. Secondly, the stream must supply water through flooding and ground water inflow adequate to support wetland hydrology. Fortunately, these two objectives are, for the most part, coincident with each other. The planning and design of stream channel restorations are covered extensively in NEH654. The remaining descriptions are on considerations for RIVERINE wetlands, with references to NEH654, when appropriate.

General cases of wetland alteration due to channel incision

There are two general cases of channel degradation for types II and III channels which alter wetland hydrology.

Case 1—Incision in place

The first case is one where the stream channel planform is relatively unchanged, but the channel has incised in place. The cause of the degradation is external. Upstream dams or reservoirs may have interrupted the sediment supply to the degraded reach, and the new sediment supply and hydrographs are not in equilibrium. The stream has responded by channel incision. Watershed changes may have resulted in a change to the stream's hydrograph, with increased peak discharges and a consequent increase in the tractive stress on the channel bottom, or downstream channel modifications have caused a headcut to move through the stream reach. Downstream channel straightening projects commonly cause this to happen. The RIVERINE wetland may or not be physically altered, but the lowering of the stream's water surface profile decreases the water available to support wetland conditions from flood flows or ground water supply.

Case 2—Incision with channel straightening

The second general case is a channel straightening on the stream reach. The original channel is typically filled in with material excavated from the new, straightened channel. The increase in slope provides an increase in tractive stress on the channel bottom, and a wave of channel incision moves through the reach and advances upstream. As in case 1, the water available to the RIVERINE wetland is decreased. In addition, the remnant flood plain features which provide valuable macro- and microtopography are commonly obliterated by leveling and filling as part of the straightening activity.

Hydrology restoration strategies

The restoration of the wetland is accomplished by restoring the channel geometry to a condition where flows in excess of geomorphic bankfull (NEH654, Stream Restoration Design) will again have access to the flood plain. It is not appropriate to provide less than geomorphic bankfull capacity. Doing so will initiate a series of channel adjustments which may endanger the long-term stability of the entire stream corridor. This is caused when the flood events occur with a frequency greater than tolerated by the conditions of dynamic equilibrium between the stream channel geometry, sediment supply, and flood plain interactions.

Before any RIVERINE wetland restoration is planned that requires the raising of the water surface profile, the adequacy of land rights must be evaluated. The scope of the project must include the entire stream corridor width that is affected by increased water surface, as a minimum. This is usually defined as the extent of the 100-year flood plain. The appropriate state permitting agency should be contacted for minimum land rights needs. In addition, the upstream affect on the water surface profile must be determined and land rights obtained.

Case 1

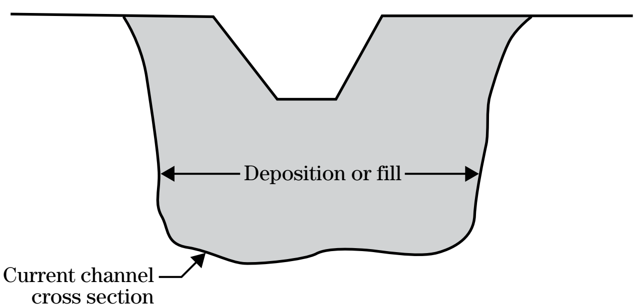
In cases where the channel planform still exists, it is appropriate to focus on raising the stream's water surface profile by installing structures. Refer to NEH654, Technical Supplement 14G, Grade Stabilization Techniques for information on the planning and design of structures. The objectives for wetland restoration place the additional demand on structures that the water surface profile be increased, often significantly. This is in addition to the objective of channel stabilization by the decrease or absorption of tractive stress from streamflow. In addition, the geomorphic bankfull flows must enter the flood plain. For this reason, the following considerations are added to those in NEH654.

- Install multiple structures with minimum head drop between structures. Treat the structures as full-flow open structures meeting the criteria of Conservation Practice Standard 410—Grade Stabilization Structure, under island structures. An island structure is one where the capacity is the same as the downstream channel capacity. This criterion is effectively met when the water surface profile drop is a minimum (generally less than 1 ft) during flows which exceed the capacity of the stream channel. As stated, these structures provide not only grade stabilization, but are designed to force flows onto the flood plain. Because of these requirements and practice standard criteria, multiple structures must be installed, such that the backwater effects of a downstream structure raise the water surface of the upstream structure's discharge pool. The system, when complete, should provide a uniform water surface profile throughout the stream reach with little or no water surface profile drop across an individual structure during the bankfull discharge. In this way, out-of-bank, or auxiliary spillway, discharges do not have a profile drop when re-entering the channel. The use of water surface profile modeling with the HEC–RAS computer program is recommended.
- Use the stable channel geometry as a guide to the width and depth of the structures. The determination of the appropriate width/depth ratio for the restored channel system is beyond the scope of this technical note, but can be found in NEH654. Once these dimensions are determined, the width and depth can be matched to the vertical projection of the structure. If the current channel width is wider than the structure, use a straight structure extension to tie it into the existing bank. Providing this structure geometry will allow the stream cross section to adjust to its stable cross section as sediment is deposited in the project reach (fig. 8).
- Place the structures in the appropriate locations in the meander pattern of the existing channel. Grade stabilization structures act as riffles in the channel profile. In natural channels, the riffle sections occur at a predictable location between meander bends. As pools typically occur just downstream of meander bends, riffles and pools are matched to meanders and straight sections in a repeatable pattern. Structures introduce complexity in this scenario because they force the creation of a scour pool immediately downstream of the structure. Thus, the location of structures is a compromise between installing them at natural riffle locations near points of inflection between meanders and installing them at natural pool locations at the bends. It is recommended that they be installed at a point midway between riffles and bends. The crest of the weir can still support the maintenance of a riffle extending upstream to its natural location. If placed sufficiently downstream of this natural

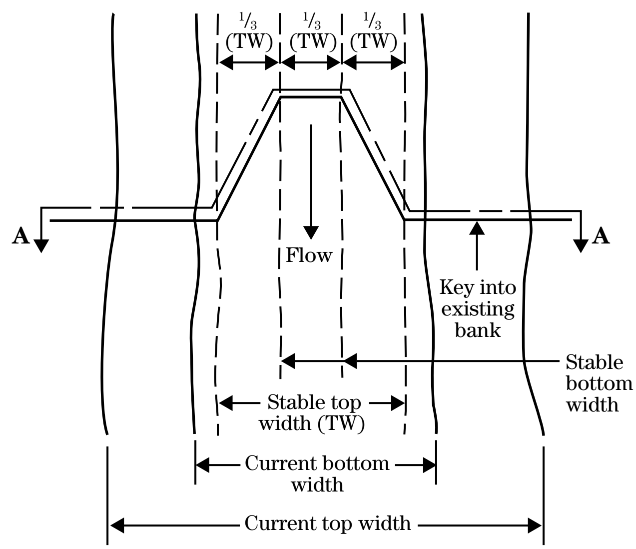
riffle point, it may have the opportunity to transition into the natural meander bend pool. The recommended layout is shown in figure 9.

- Provide a downstream structure capable of transitioning the water surface profile from the project reach to the downstream reach. In many cases, this will involve the installation of a traditional grade stabilization structure with an auxiliary spillway. In other cases, the project geometry will allow a stable transition to the downstream water surface profile. If this is the case, it is still recommended that a final structure be installed as a safety structure even if there is no profile drop.
- Carefully analyze the flood plain topography to determine flow areas that have the potential to carry flood flows downstream past the last structure and flank the project. The use of flood plain excavations can be utilized to route these flow channels back into the project reach. The

Figure 8 Plan and cross section of structure to raise water surface profile

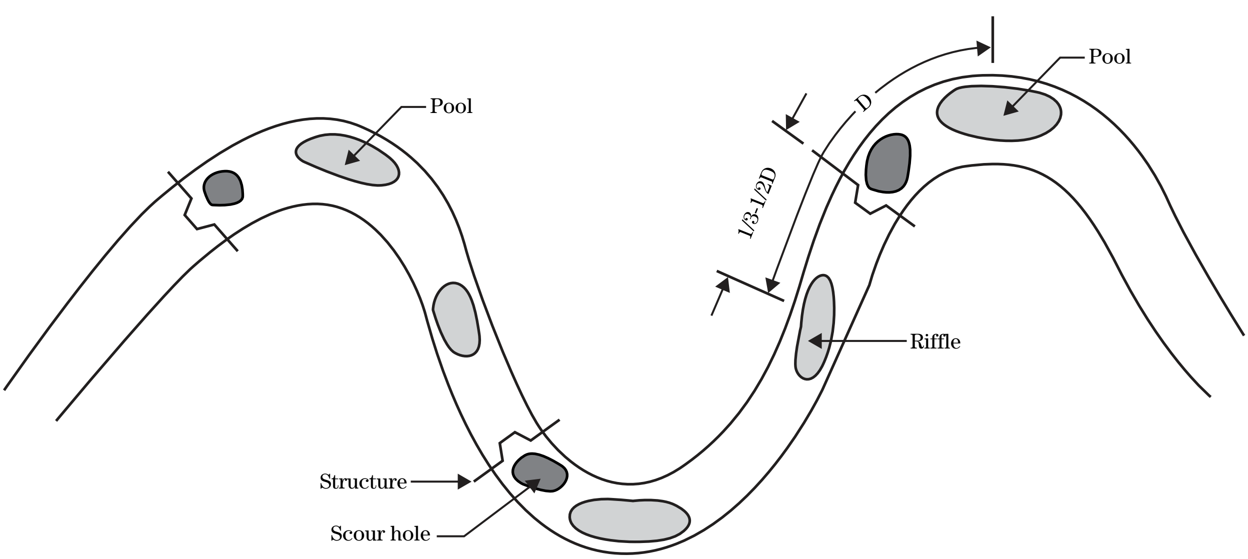


Section A-A



Plan view of structure

Figure 9 Structure locations



use of internal dikes should be avoided, as they will have limited ability to dynamically adjust to flood plain processes such as scour and sediment deposition. Select fill placement can be used to create natural levees and other depositional features; however, they must be able to survive frequent inundation, and the anticipated flow velocities.

- If the original macro- and microtopography have been altered by leveling and filling, consider replacing these features. In a dynamic restoration, these features should be located with careful consideration of their effect on flood flows and sediment deposition. The size, shape, location, and hydraulic functioning of these features can be determined by careful examination of similar features in a stable reference stream corridor.
- Consider physically filling the stream up to the structure crests with alluvial material, especially in high bedload streams with mobile beds. This will maintain sediment transport, preventing any grade loss downstream of the last structure. It will also serve to reduce the channel capacity, which will decrease the water surface profile drop across structures (see Measuring success).

The sheet pile cross vane

The need to restore wetland hydrology often requires structure heights in excess of those typically used for the grade stabilization structures shown. In addition, streams of sand, silt, and clay often cause problems with the functioning of structures made of rock or logs. Steel sheet piling has been used extensively for high head structures in these conditions. However, a series of straight weirs of sheet piling will cause high velocities in the near-bank zone of the channel and do not lend themselves to the restoration of stable channel cross sections through the structure locations. That is why the cross vane structure orientation works well in channel restoration situations.

The sheet pile cross vane shown in figure 10 is appropriate for bed materials of sand or finer material and can be used for water surface rises up to 4 feet. It is based on the standard geometry associated with cross vanes or J-hook vanes. The structure is sized to handle the geomorphic bankfull discharge. Discharges greater than this will enter the flood plain. These structures must be installed in series.

Measuring success

The project is considered a success when flows in excess of geomorphic bankfull access their flood plain with the planned frequency and/or if the flood plain ground water surface supports wetland hydrology.

Changes in flood plain structure, such as formation of natural levees, scour channels, and even meander bend cutoffs, should be anticipated. The channel can be expected to narrow to match the cross section of the structures as sediment deposits at the structure locations and deposition moves upstream. As this occurs, the channel capacity decreases, forcing lower flows onto the flood plain and reducing the water surface profile drop across the structures.

The loss of a structure, especially the downstream safety structure, which results in a drop of the restored water surface profile, is considered a failure. However, the flanking of an individual structure within the project reach may occur and can even be anticipated in the long term as the channel location makes dynamic adjustments such as the cutoff of a meander bend or the creation of a new meander.

Case 2

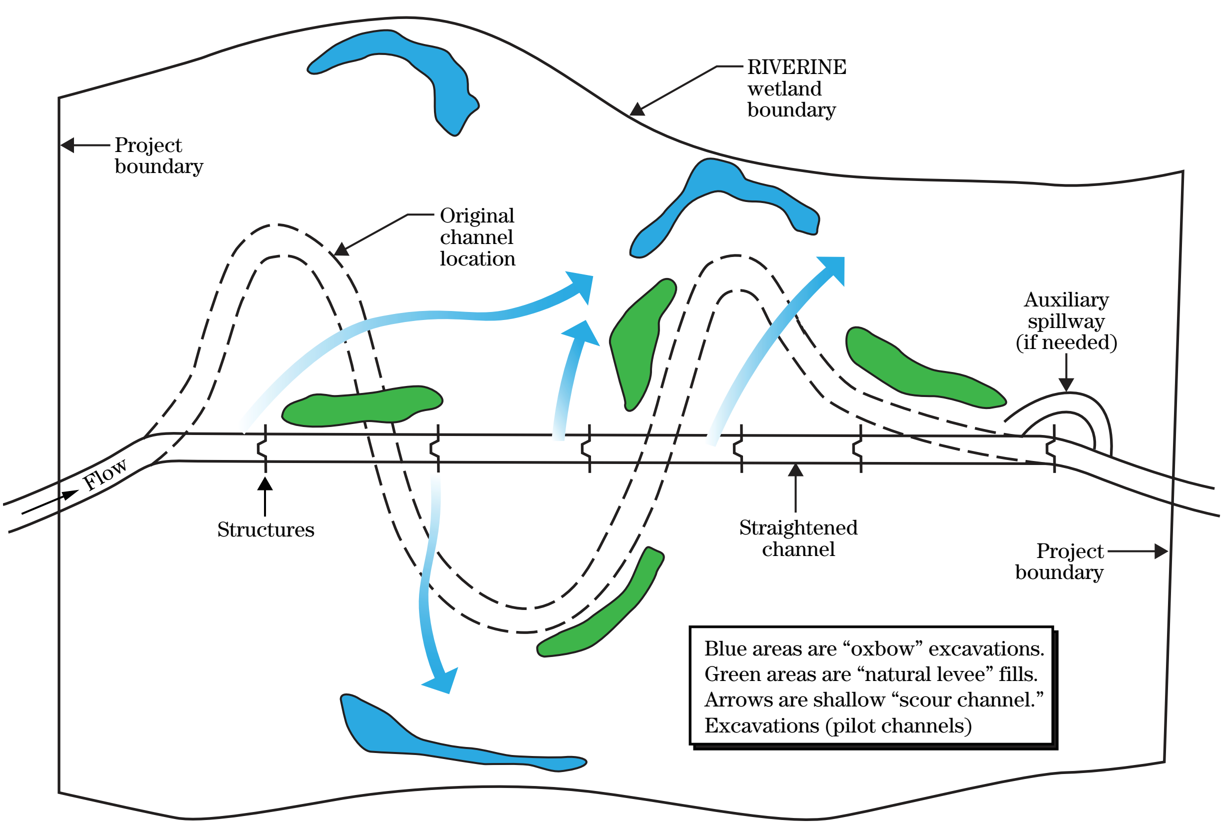
In case 2, the channel plan and cross section have both been altered, usually in a channel straightening project. The original channel is usually filled, and flood plain macro- and microtopography is filled and leveled. The two options available are to completely restore the stream with a meander reconstruction or to raise

Figure 10 Sheet pile cross vane structure

the water surface profile of the existing straightened channel. The design of a stable meander reconstruction is described at length in NEH654. The considerations for raising the water surface in the existing straightened channel are the same as those listed above for channels incised in place with the following additions:

- Anticipate the channel's readjustment to a new alignment. The insertion of structures into the stream profile will cause a series of adjustments to take place. In high bedload streams, deposition of sediment will occur quickly, beginning at the upper end of the weir pools created by the structures and also at the banks immediately adjacent to the structures. As the channel capacity is reduced, flood flows will access the flood plain with greater frequency, and channel realignments can occur. Reducing the profile drop by spacing structures more frequently will decrease the hazard from structure flanking. In channels of fine-grained cohesive soil with little or no bedload, the straightened channel may remain in its current location throughout the design life of the project.
- Any flood plain excavations should be conducted in a manner that safely directs flood flows from direct re-entry back into the channel. Fills can be placed to protect the current channel from re-entry of flood flows. Shallow pilot channels can be excavated to direct flow. The invert elevation of these pilot channels should be at or below the crest elevation of the next downstream weir. In this way, if one structure is lost, the flood flows will be at least partially diverted to return safely back to the channel without dropping over a vertical bank. They will also provide a template for any eventual channel geometry adjustments. Excavations and fills should be sized and shaped to match existing flood plain features in a reference reach. These features include abandoned oxbows, natural levees, scour channels, and backwater areas. Figure 11 shows a layout plan for case 2.

Figure 11 Layout plan for straightened and incised restoration



Hydrology

RIVERINE flood plain restoration introduces additional hydrology criteria to the hydrology of stream restoration design. Water from the stream must be supplied with sufficient frequency and duration to support wetland hydrology. To the stream restoration planner and designer, the focus is on the geomorphic bankfull discharge, which is a single flow rate governing the channel's geometry and sediment transport analysis. Wetland hydrology adds the need to determine the stream's flow duration characteristics. In general, the stream will need to provide a flow rate sufficient to support wetland hydrology for 15 days in an average year. The water supplied by this flow enters the RIVERINE wetland through surface flooding (episaturation) or through ground water supported by the stream's water surface profile (endosaturation).

Flow duration

If the hydrology criterion is 15 days, it is necessary to determine the 50 percent chance 15 day-low flow, usually during the growing season. To begin the analysis, daily data for mean flows must be obtained. Daily mean flow data for a period of record are available at the U.S. Geological Survey (USGS) Web site:

http://waterdata.usgs.gov/nwis/sw

Figure 12 shows an example of a portion of a mean daily flow file.

The extraction of the 50 percent chance 15-day duration annual flow can be done with spreadsheet methods. An example spreadsheet is shown in figure 13. This spreadsheet is available from the wetland hydraulic engineer, Wetland Team, CNTSC.

The procedure for using daily mean flow data to determine the 50 percent chance 15-day low flow using the example spreadsheet is:

Step 1 Obtain daily mean flow file for a period of record of at least the last 10 years of record available from the source given above, in ASCII text format.

Step 2 Open this file in a Microsoft® Excel spreadsheet, and manipulate the data to place date and flow in the first two columns. Delete remaining data, and headings.

Step 3 The third column is optional and is used to convert gage data to the estimated values at the project. In the example spreadsheet, the flows were assumed to be directly proportional to the drainage area. The example drainage area was 80 percent of that at the gage, and this ratio was applied.

Step 4 In the fourth column, compute the running 15-day low flow for the period of record. The first value is computed on the 15th day of record and continues to the end. The cell formula for the first value is MIN(C16:C30). Copying this value downward to the end of the record will populate this column.

Step 5 In the fifth column, a formula is placed corresponding with December 31 of each year of record and computes the maximum flow from the 15-day low flow columns. Use the cell formula MAX(XX:XX). This must be inserted for each year of record, and the cell addresses carefully entered to cover the values. In this example, the statistical analysis is done on a calendar year basis (January 1 to December 31). The user may also perform the statistics based on the more traditional water year (October 1 to September 30). Stream statistics available from the U.S.Geological Survey (USGS) and most State agencies are based on the water year. However, statistical analysis using spreadsheets may be easier to perform using a calendar year basis. The results will not be significantly different if a period of record of at least 10 years is used.

Step 6 At the top of the example spreadsheet, the values from column 5 are listed by year in the first two columns of the ranking. In the next columns, the yearly maximums are sorted descending by using the data sort spreadsheet tool. The next column is the rank assigned to each value beginning with 1 and ending with 20, which is the number of years of record. Note that 1987 was included as a year of record, even though it is not a complete year of record. It was included because for this stream, the maximum 15-day low flows typically occur after the May 2 beginning of the record.

Step 7 The last column is the Weibull plotting position. The value is computed by dividing each year's rank by the number of years of record plus one. The cell formula for the first cell in the column is H16/21*100.

The values for the maximum 15-day low flows are plotted against the Weibull plotting position on the example graph (fig. 14) from the spreadsheet. The spreadsheet also computes the regression equation for the "best fit" curve selected. The 50 percent chance flow can be read from the graph, and can be seen to be approximately 450 cubic feet per second. It is known that the stream water surface profile at 450 cubic feet

Figure 12 Portion of a mean daily flow file

```
                   Tongue River nr. Dayton - Daily Peaks, Text.txt
# ----------------------------------- WARNING
-----------------------------------------
# The data you have obtained from this automated U.S. Geological Survey database
# have not received Director's approval and as such are provisional and subject to
# revision.  The data are released on the condition that neither the USGS nor the
# United States Government may be held liable for any damages resulting from its
use.
# Additional info: http://waterdata.usgs.gov/nwis/help/?provisional
#
# File-format description:
http://waterdata.usgs.gov/nwis/?tab_delimited_format_info
# Automated-retrieval info: http://waterdata.usgs.gov/nwis/?automated_retrieval_info
#
# Contact:   gs-w_support_nwisweb@usgs.gov
# retrieved: 2007-05-03 10:36:36 EDT
#
# Data for the following site(s) are contained in this file
#    USGS 06298000 TONGUE RIVER NEAR DAYTON, WY
#
-----------------------------------------------------------------------------------
#
# Data provided for site 06298000
#    DD parameter statistic   Description
#    03   00060     00003     Discharge, cubic feet per second (Mean)
#
# Data-value qualification codes included in this output:
#     A  Approved for publication -- Processing and review completed.
#     P  Provisional data subject to revision.
#     e  Value has been estimated.
#
agency_cd       site_no datetime        03_00060_00003  03_00060_00003_cd
5s      15s     16s     14s     14s
USGS    06298000        1987-05-02      590     A
USGS    06298000        1987-05-03      402     A
USGS    06298000        1987-05-04      360     A
USGS    06298000        1987-05-05      357     A
USGS    06298000        1987-05-06      381     A
USGS    06298000        1987-05-07      385     A
USGS    06298000        1987-05-08      390     A
USGS    06298000        1987-05-09      380     A
USGS    06298000        1987-05-10      374     A
USGS    06298000        1987-05-11      337     A
USGS    06298000        1987-05-12      334     A
USGS    06298000        1987-05-13      333     A
USGS    06298000        1987-05-14      312     A
USGS    06298000        1987-05-15      303     A
USGS    06298000        1987-05-16      319     A
USGS    06298000        1987-05-17      497     A
USGS    06298000        1987-05-18      357     A
USGS    06298000        1987-05-19      323     A
USGS    06298000        1987-05-20      319     A
USGS    06298000        1987-05-21      309     A
USGS    06298000        1987-05-22      282     A
USGS    06298000        1987-05-23      255     A
USGS    06298000        1987-05-24      243     A
USGS    06298000        1987-05-25      270     A
USGS    06298000        1987-05-26      251     A
USGS    06298000        1987-05-27      355     A
USGS    06298000        1987-05-28      352     A
USGS    06298000        1987-05-29      383     A
USGS    06298000        1987-05-30      353     A
USGS    06298000        1987-05-31      330     A
USGS    06298000        1987-06-01      326     A
                                       Page 1
```

Figure 13 Example spreadsheet

50% Chance 15-Day Flow Exceedence

Drainage Area Proportion, % 80

Discharge At Wetland Hydrology, CFS
(From Channel Rating) 40

Date	Flow at Gage	Flow @ Project	15 Day Duration Flows		Max by Year	Sorted Descending	Rank	% Chance Exceedence (Weibull Plot)
5/2/1987	590	472		**1987**	**242.4**	**750.4**	**1**	**4.8**
5/3/1987	402	321.6		**1988**	**578.4**	**679.2**	**2**	**9.5**
5/4/1987	360	288		**1989**	**245.6**	**666.4**	**3**	**14.3**
5/5/1987	357	285.6		**1990**	**666.4**	**632.8**	**4**	**19.0**
5/6/1987	381	304.8		**1991**	**617.6**	**628**	**5**	**23.8**
5/7/1987	385	308		**1992**	**324.8**	**617.6**	**6**	**28.6**
5/8/1987	390	312		**1993**	**435.2**	**592**	**7**	**33.3**
5/9/1987	380	304		**1994**	**545.6**	**578.4**	**8**	**38.1**
5/10/1987	374	299.2		**1995**	**679.2**	**545.6**	**9**	**42.9**
5/11/1987	337	269.6		**1996**	**592**	**467.2**	**10**	**47.6**
5/12/1987	334	267.2		**1997**	**628**	**435.2**	**11**	**52.4**
5/13/1987	333	266.4		**1998**	**354.4**	**430.4**	**12**	**57.1**
5/14/1987	312	249.6		**1999**	**750.4**	**354.4**	**13**	**61.9**
5/15/1987	303	242.4		**2000**	**632.8**	**324.8**	**14**	**66.7**
5/16/1987	319	255.2	242.4	**2001**	**159.2**	**292.8**	**15**	**71.4**
5/17/1987	497	397.6	242.4	**2002**	**247.2**	**247.2**	**16**	**76.2**
5/18/1987	357	285.6	242.4	**2003**	**467.2**	**245.6**	**17**	**81.0**
5/19/1987	323	258.4	242.4	**2004**	**125.6**	**242.4**	**18**	**85.7**
5/20/1987	319	255.2	242.4	**2005**	**430.4**	**159.2**	**19**	**90.5**
5/21/1987	309	247.2	242.4	**2006**	**292.8**	**125.6**	**20**	**95.2**
5/22/1987	282	225.6	225.6					
5/23/1987	255	204	204					
5/24/1987	243	194.4	194.4					
5/25/1987	270	216	194.4					
5/26/1987	251	200.8	194.4					
5/27/1987	355	284	194.4					
5/28/1987	352	281.6	194.4					
5/29/1987	383	306.4	194.4					
5/30/1987	353	282.4	194.4					
5/31/1987	330	264	194.4					
6/1/1987	326	260.8	194.4					
6/2/1987	295	236	194.4					
6/3/1987	278	222.4	194.4					
6/4/1987	266	212.8	194.4					
6/5/1987	254	203.2	194.4					
6/6/1987	248	198.4	194.4					
6/7/1987	253	202.4	194.4					

per second must be raised enough to inundate the RIVERINE wetland area or else support a water table high enough to maintain wetland hydrology. For this stream system, the flood plain is composed of highly permeable sands and gravels, and the water table is directly connected to the stream water surface profile. Maintaining the ground water table within 6 to 12 inches of the wetland surface will provide wetland hydrology.

Ground water modeling

In cases where the wetland hydrology is dominated by ground water, it is worthwhile to investigate the current ground water levels and directions of movement so that predictions of the ground water table's response to stream water surface rise can be made. The USACE publication Installing Monitoring Wells/Piezometers in Wetlands (USACE 2000) is available at the USACE Web site:

http://el.erdc.usace.army.mil/elpubs/pdf/tnwrap00-2.pdf

A simple ground water monitoring effort can be carried out using the following steps:

Step 1 Select one or more cross sections across the flood plain.

Step 2 Locate at least two monitoring wells on each side of the stream channel on the cross sections.

Step 3 Survey the cross sections with the well locations, and plot.

Step 4 Record the ground water level at various stream stages along with the stream stage and flow through the stream hydrograph period.

Step 5 Make a separate plot of each well location's ground water level against stream stage.

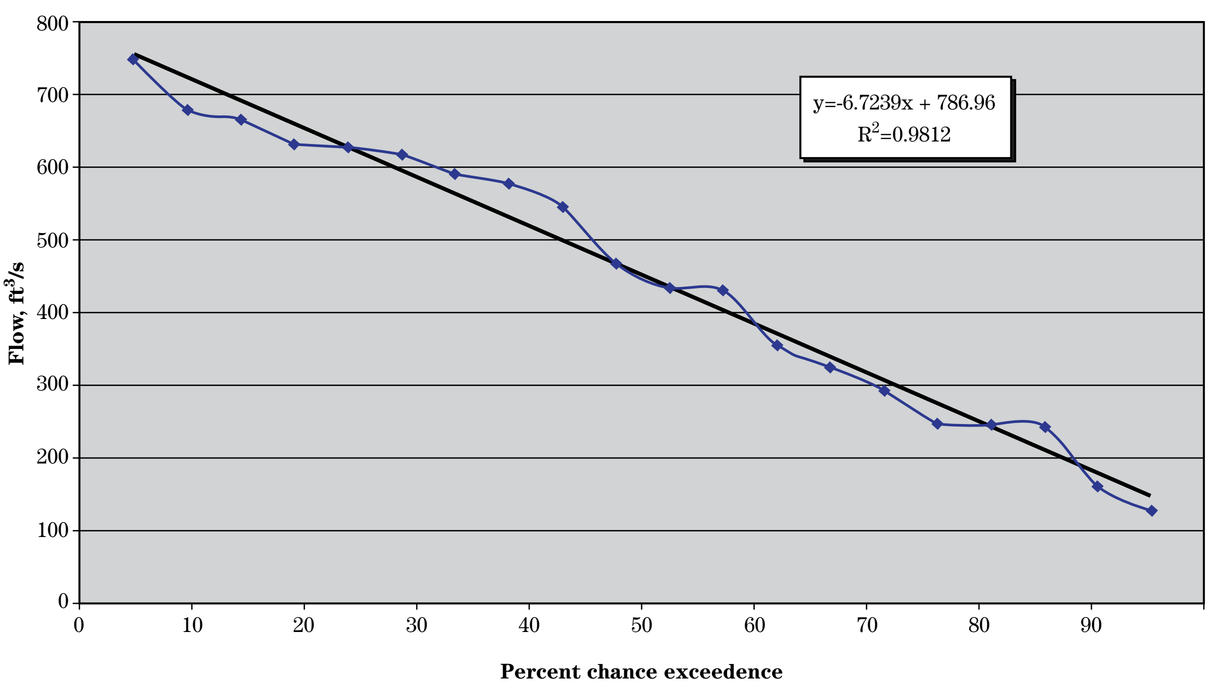
Step 6 Determine the best fit curve for the plot and use to predict ground water level for stream bankfull stage and each desired duration probability stage.

Step 7 Use the results to plot maximum ground water levels, water level durations, and other results.

Step 8 If topography is available, the data can be transferred to plan view maps to delineate areas of depth and/or duration for use in vegetative plans and habitat feature locations.

More complex models can be developed using flow nets. These models require the collection of saturated horizontal and vertical conductivity for all the differ-

Figure 14 Flow vs. probability chart



ent strata down to at least the stream channel bed, as well as boundary water table conditions at the edge of the flood plain to account for ground water gain or loss from the uplands. This level of analysis should not be needed for most projects.

Figures 15 and 16 show example layouts of a simple ground water monitoring plan.

Figure 17 is an example of data collection and analysis for monitoring wells. The spreadsheet tool can be used to perform a temporal and spatial interpolation of observed ground water levels to provide the actual hydroperiod at each well location. Accuracy is increased be adding more wells and increasing the frequency of reading. The user inputs the maximum depth of the water table below the ground surface for wetland hydrology. In the example, the depth is set at 6 inches. This is in line with the criteria in the Corps of Engineers 1987 Wetlands Delineation Manual, which states that sands and gravels will provide saturation to the surface due to capillarity from a 6-inch depth. The hydroperiod (within 6 in) column in figure 17 is simply a linear interpolation to 0.5-foot depth from the depth to GW column multiplied by the value in the time (days) column.

Figure 18 shows the relationship between the stream stage and ground water level in well number 1.

Figure 19 shows the rating curves for the original stream channel and the planned channel geometry. This relationship establishes the new stream stage, which is used to predict the new ground water level in the wells.

Finally, figure 20 shows the analysis sheet of the spreadsheet, which provides the predicted ground water levels. The user provides the channel rating data and the flows to use for the analysis. The example shows the geomorphic bankfull, and the 15-day, 50 percent chance flows. This duration flow is a rational value to choose for wetland hydrology. As stated earlier, the design and analysis of wetland hydrology for restoration does not necessarily require the use of criteria for wetland determination. The durations should be chosen to meet the needs of the wetland based on the goals of the project. They should consider the durations which approximate the original wetland before alteration and also consider the hydrology needed to increase wetland function based on a functional assessment.

Figure 15 Cross section of ground water monitoring plan

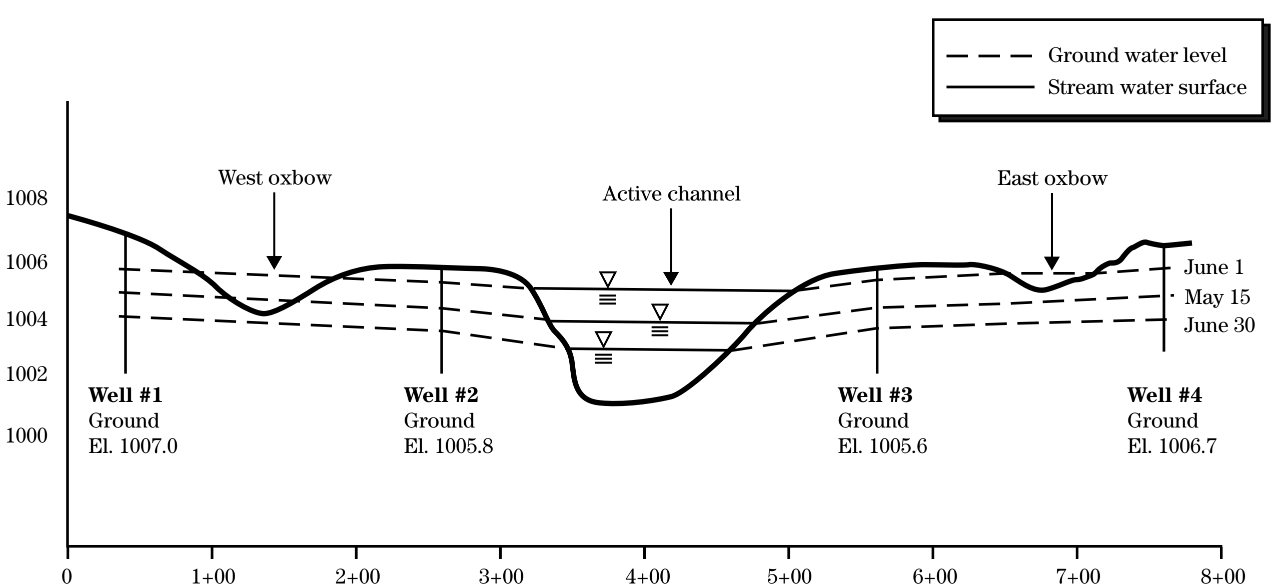


Figure 16 Plan view of ground water monitoring plan

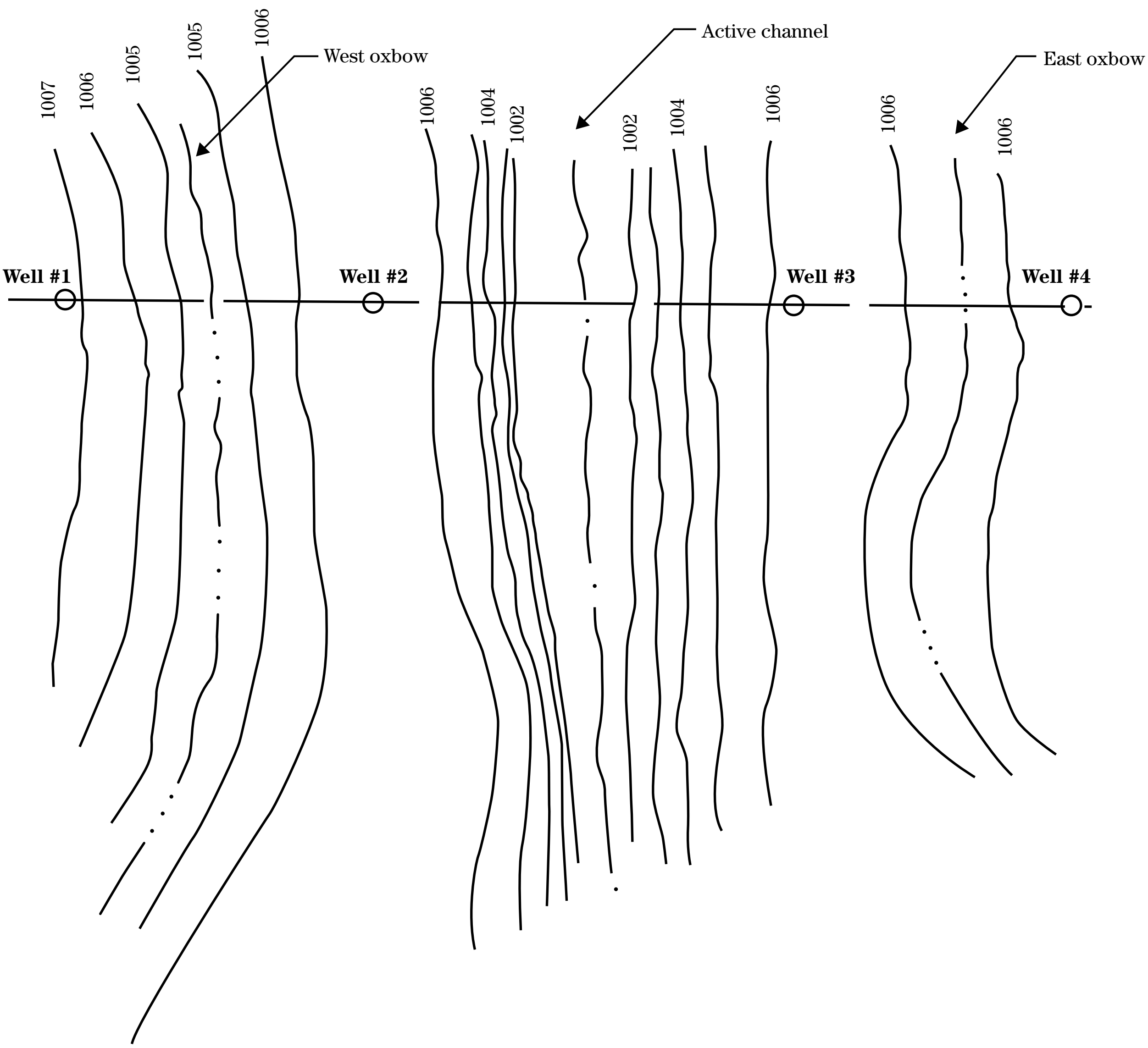


Figure 17 Monitoring well data from spreadsheet

Observed Well Data - Original Conditions

Well #1

		Stream Stage	Date	Depth Reading	Depth to GW	GW Elev	Time (Days)	Hydroperiod (Within 6")
Ground El.	1007							
Top Casing	1007.5							
		1003.9	5/15/07	2.6	2.1	1004.9		
							17	0.0
		1004.9	6/1/07	1.7	1.2	1005.8		
							29	0.0
		1003.1	6/30/07	3.5	3	1004.0		
								Total Hydroperiod 0

Well #2

		Stream Stage	Date	Depth Reading	Depth to GW	GW Elev	Time (Days)	Hydroperiod (Within 6")
Ground El.	1005.8							
Top Casing	1007.1							
		1003.9	5/15/07	2.6	1.3	1004.5		
							17	1.9
		1004.9	6/1/07	1.7	0.4	1005.4		
							29	1.6
		1003.1	6/30/07	3.5	2.2	1003.6		
								Total Hydroperiod 3.5

Well #3

		Stream Stage	Date	Depth Reading	Depth to GW	GW Elev	Time (Days)	Hydroperiod (Within 6")
Ground El.	1005.6							
Top Casing	1006.9							
		1003.9	5/15/07	2.5	1.2	1004.4		
							17	3.8
		1004.9	6/1/07	1.6	0.3	1005.3		
							29	3.4
		1003.1	6/30/07	3.3	2	1003.6		
								Total Hydroperiod 7.2

Well #4

		Stream Stage	Date	Depth Reading	Depth to GW	GW Elev	Time (Days)	Hydroperiod (Within 6")
Ground El.	1006.7							
Top Casing	1007.5							
		1003.9	5/15/07	2.7	1.9	1004.8		
							17	0.0
		1004.9	6/1/07	1.7	0.9	1005.8		
							29	0.0
		1003.1	6/30/07	3.6	2.8	1003.9		
								Total Hydroperiod 0.0

Figure 18 Stream type vs. ground water level

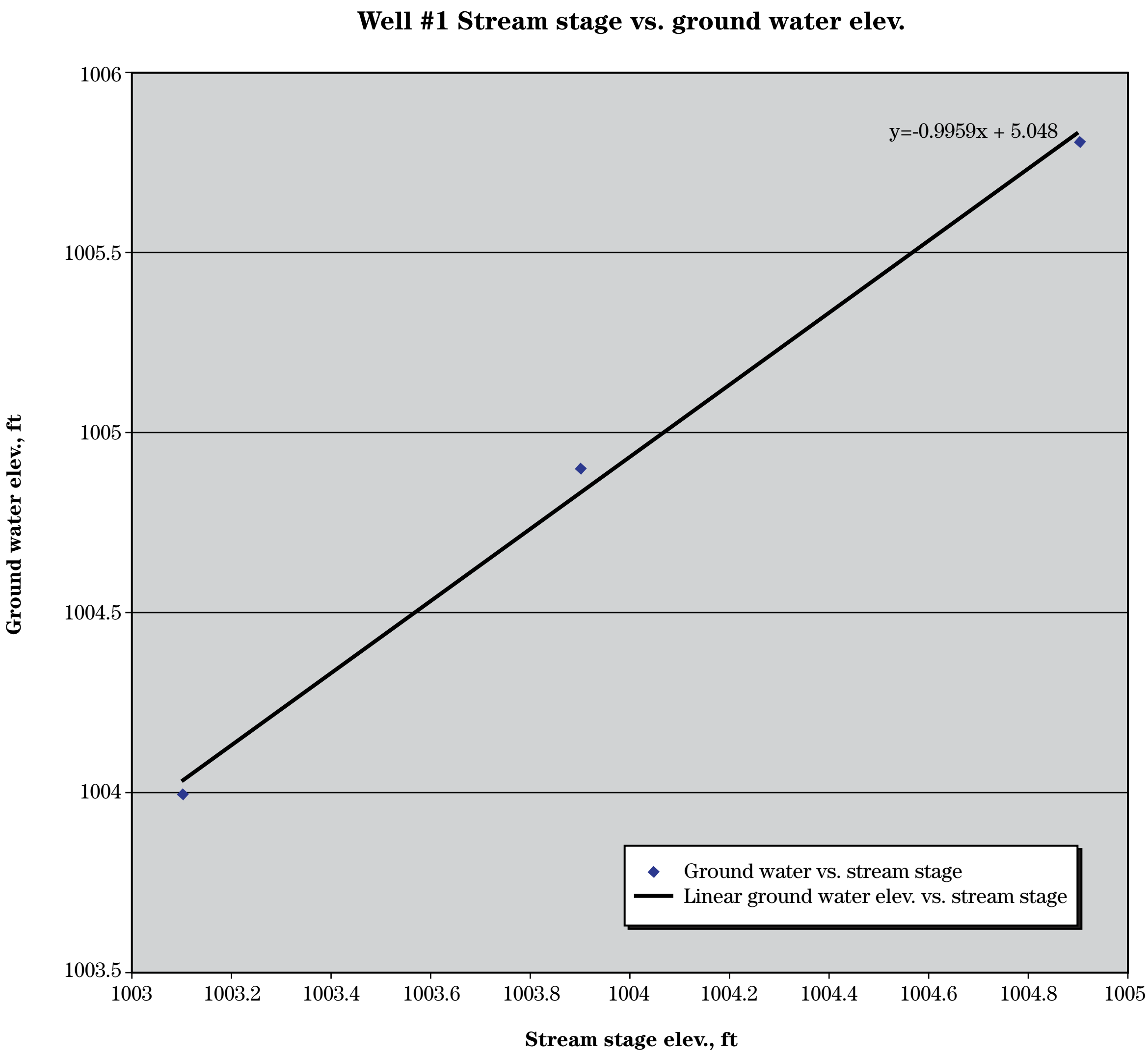


Figure 19 Channel ratings for current and planned stream geometry

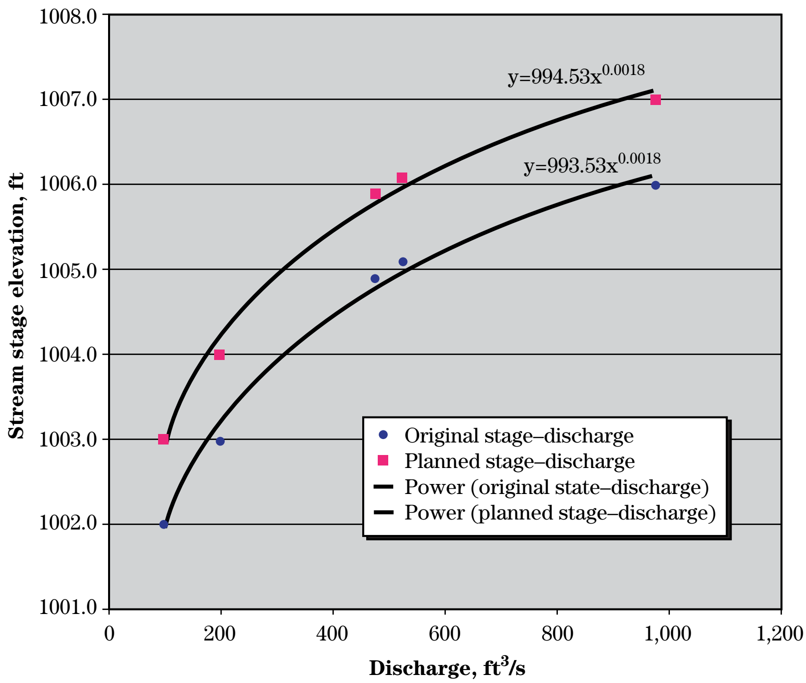


Figure 20 Analysis of wetland hydrology based on predicted ground water response to increase in stream water surface profile

Geomorphic Bankfull, CFS	475
15-day, 50% Chance Flow, CFS	450

Original Stage	Discharge	Planned Stage
1002.0	100	1003
1003.0	200	1004
1004.9	475	1005.9
1005.1	525	1006.1
1006.0	975	1007.0

l #1 Response to Stream Modification

Well #1

Qbkf eam Stage	15-day, 50% Chance Stage	Qbkf GW Elev.	15-day, 50% Chance GW Elev.
1005.6	1005.5	1006.5	1006.5

Well #2

Qbkf GW Elev.	15-day, 50% Chance GW Elev.
1006.0	1005.9

Well #3

Qbkf GW Elev.	15-day, 50% Chance GW Elev.
1006.0	1005.9

Well #4

Qbkf GW Elev.	15-day, 50% Chance GW Elev.
1006.6	1006.5

Discussion

A discharge now exists that will provide wetland hydrology on the RIVERINE flood plain. This does not mean that this discharge is the appropriate geomorphic bankfull discharge. The user is again referred to NEH654 for determination of this discharge. The geomorphic bankfull discharge, if significantly different, can be used to determine the ground water response in the wetland and decisions made. In most stream systems, there should not be a significant difference between the 50 percent chance duration discharge and the geomorphic bankfull discharge.

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