River Restoration Toolbox
Practice Guide 4

Floodplain Restoration

Iowa Department of Natural Resources

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Executive Summary

Floodplain restoration provides floodwater storage during rain events, provides ecological and recreational benefits, helps regulate peak flows, helps recharge groundwater, and prevents erosion. The following techniques are detailed in this report:

1. Bank Shaping
2. Bankfull Bench
3. Floodplain Assemblages
4. Levee Setback or Removal
5. Multi-Stage channel
6. Oxbow

The *River Restoration Toolbox Practice Guide 4: Floodplain Restoration* (Practice Guide) has been developed to assist with the presentation of design and construction information for stream restoration in Iowa. It is intended to provide guidance to:

- Those responsible for reviewing and implementing stream restoration,
- Professionals responsible for the design of stream restoration projects,
- Others involved in stream restoration at various levels who may find the information useful as a technical reference to define and illustrate floodplain restoration techniques.

The Practice Guide includes a written assessment of the floodplain restoration practice and describes a variety of floodplain restoration techniques. Each technique includes design guidelines, a specifications list, photographs, and, when applicable, drawings.

The information in the Practice Guide is intended to inform practitioners and others, and define typical information required by the State of Iowa to be included with the use of floodplain restoration techniques. The information and drawings are not meant to represent a standard design method for any type of technique and shall not be used as such. The Practice Guide neither replaces the need for site-specific engineering and/or landscape designs, nor precludes the use of information not included herein.

The Practice Guide may be updated and revised to reflect up-to-date engineering, science, and other information applicable to Iowa streams and rivers.

1.0 INTRODUCTION

Floodplains are the area adjacent to the stream that is subject to flooding, they provide energy dissipation during times of high flows. In recent decades, many Iowa rivers and streams have become disconnected from their floodplains. Changes in land use within the watershed have contributed to channel degradation and incision. Manmade flood control structures have also disconnected rivers and streams from their natural floodplain. The unintended consequences of this process include loss of wildlife habitat, decreased water quality, increased erosion and threats to human safety. Floodplain restoration is the practice of reconnecting rivers and streams to their floodplains.

Reconnecting rivers and streams to their floodplains is an approach to flood control while addressing wildlife habitat and soil erosion concerns. Undeveloped floodplains allow floodwaters to dissipate energy naturally without damaging homes and businesses. Smaller rivers and streams that have been disconnected from the floodplain can be positively impacted by floodplain restoration techniques like bank shaping and providing a bankfull bench. Larger rivers may be reconnected to the floodplain through levee setback or removal. Wildlife and habitat restoration can be achieved in the floodplain with techniques like constructing oxbow lakes, oxbow channels, and floodplain assemblages.

The guidelines and specifications provided in this document are general and not a comprehensive design manual. It is the responsibility of the designer to understand the design approach and the feasibility of using floodplain restoration techniques on a case-by-case basis. The following criteria in no way replaces design discretion, experience, and training, and cannot incorporate every scenario. They are intended to flag common errors, promote empirically stable design ranges, assist designers and reviewers in communication, and adapt tested designs to Iowa conditions.

2.0 FLOODPLAIN RESTORATION TECHNIQUES

2.1 BANK SHAPING

2.1.1 Narrative Description

Bank shaping is the practice of grading the stream bank to an angle that can sustain vegetation growth and maintain lateral stability. Unstable stream banks occur as a result of bank erosion or bed instability. For discussion on channel bed stability see the Multi-Stage Channel technique or River Restoration Toolbox Practice Guide 1: Grade Control Practices. Bank shaping is an effective mitigation approach for bank erosion.

Bank shaping is often used with other stream bank stabilization techniques like toe protection (revetment, woody debris, etc.), multi-stage channel, and in-stream structures. Bank shaping is beneficial for stream bank stability, flood mitigation, and recreational access opportunities.

Proper vegetation of the newly shaped bank is essential to prevent erosion after construction. Analysis and design by a professional may be necessary to establish stable conditions in stream banks. See Vegetative Restoration Practice for more discussion.

2.1.2 Technique Information

- **Use:** Bank shaping mitigates stream bank erosion by grading banks to a stable slope
- **Other uses:** Bank shaping promotes ecological health by providing nutrient filtration through vegetation on the banks, and mitigates steep unsafe stream banks by providing flatter slopes.
- **Best applications:**
    - Channels experiencing erosion issue due to unstable banks
- **Variations:**
    - Providing stream bank stabilization (e.g. Rock Toe Protection, Root Wad, etc.) and temporary erosion control (e.g. Erosion Control Matting, etc.) for the lower banks. See Vegetative Restoration Practice for more information.
    - Combining bank shaping with grade control techniques (e.g. Cross Vane, W-Weir, etc.) See Grade Control Practice for more information.
    - Combining bank shaping with bankfull bench or multi-stage channels. See Bankfull Bench or Multi-Stage Channel techniques for more information.

- **Computations:** Typically, a slope of 3:1 or flatter is recommended for Iowa soils. Flatter slopes provide stability benefits when space and budget allow. Consult with a Geotechnical Engineer if a 3:1 slope or flatter cannot be achieved. For tall stream banks or sites with soft soil conditions, a slope stability analysis may be necessary.

  Establishing vegetation on the bank post-construction is essential to prevent erosion due to potential flood flows. Bank vegetation also aids in reducing nutrient pollution from storm water runoff. Techniques and procedures can be found in the Vegetative Restoration Practice section of this document.

  Hydrological and hydraulic modeling programs, such as HEC-HMS and HEC-RAS, can be used to evaluate shear stresses on the stream bank. Shear stress is a factor used to select vegetation and temporary erosion control techniques.

- **Key Feature:**
  - Shaping the bank to a stable slope that can support vegetation.
  - Erosion control and vegetation must be established quickly on the bare soils, see River Restoration Toolbox Practice Guide 2: Vegetative Restoration for more information.

2.1.3 Detail Drawings and Data Table

The following drawings and data table depict information that should be included in construction plans for bank shaping. The data table includes design guidelines and sources, where applicable.

Table 1. Required Design Data for Bank Shaping

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
A	Bankfull Width	Feet	Sized based on guidelines specified in computations section of Multi-Stage Channel technique	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain
B	Bankfull Elevation	Feet (NAVD)	Reference reach, regional curves, measured in field based on guidelines specified in computations section of Multi-Stage Channel technique	Maximum water level before flood water rises above the bankfull channel and begins to overflow onto a floodplain
C	Stream Bank Slope	N/A	2H:1V is the maximum for most Iowa projects, though toe protection influences the recommended toe slope	Grade of stream bank from the inner berm elevation to the bankfull bench elevation
D	Bankfull Bench	Feet	Bench Width should be greater than or equal to the bankfull width	Flat vegetated area at bankfull elevation where flood water can spread during flood events
E	Bankfull Channel Bottom Width	Feet	Reference reach	The bottom width of the bankfull channel

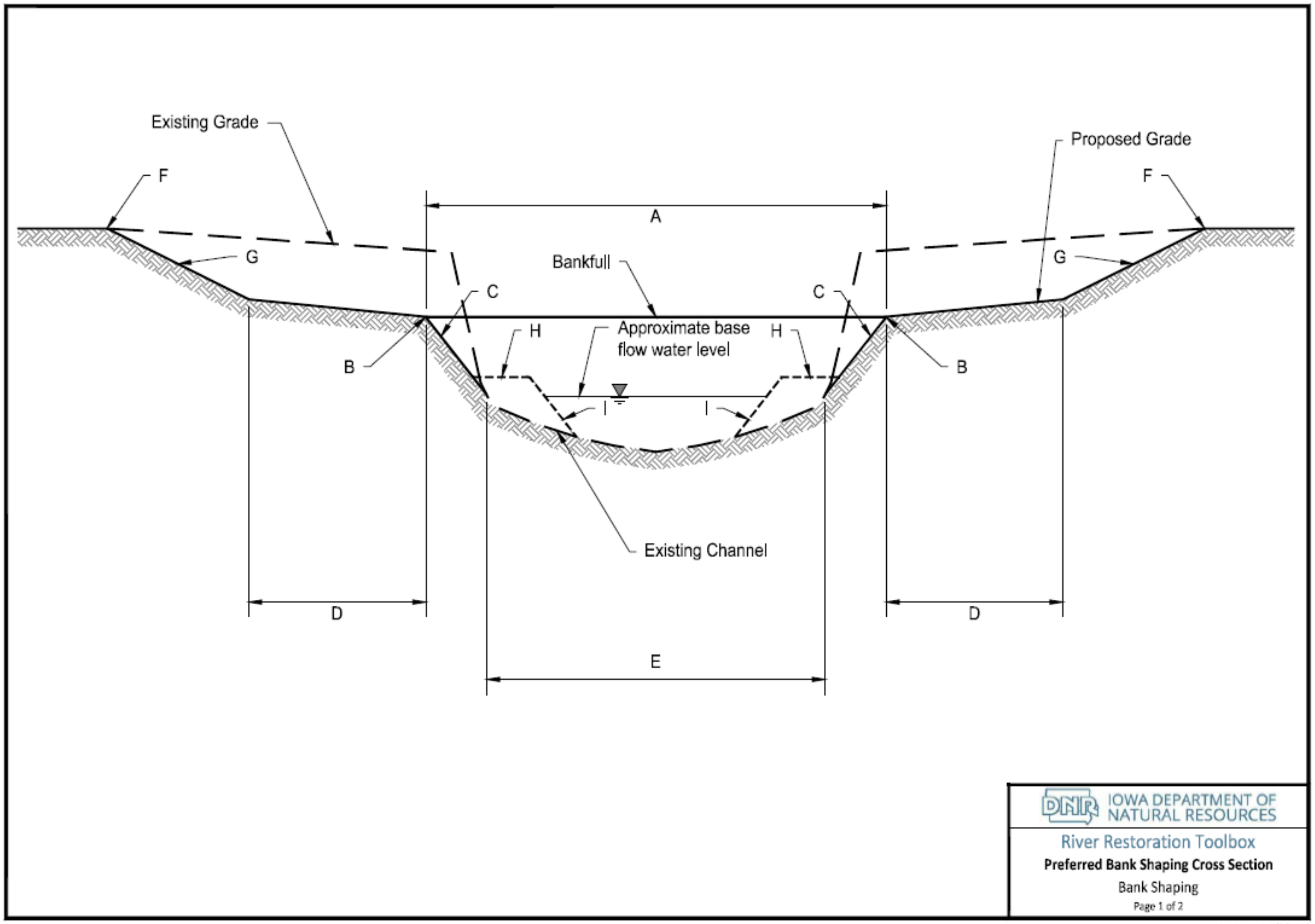
Table 1. Required Design Data for Bank Shaping

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
F	Floodplain Elevation	Feet (NAVD)	Reference reach, regional curves, regulatory flood maps, H&H modeling	Maximum water level above bankfull elevation that is prone to flood water
G	Upper Channel Bank Slope	N/A	2H:1V is the maximum for most Iowa projects	Grade of channel bank from the bankfull bench to the floodplain
H	Inner Berm Elevation	Feet (NAVD)	Typically located at ½ the bankfull elevation	Located slightly above the base/low flow water level and formed by sediment deposition
I	Inner Berm Channel Bank Slope	N/A	2H:1V is the maximum for most Iowa projects	Grade from the channel bottom to the inner berm elevation

Notes:

1. Some labels are referenced in the detail drawings.
2. Common guidance, values, or ranges are given unless they require computation using site-specific input.
3. NAVD-North American Vertical Datum or other, as appropriate.

Drawing 1. Preferred Bank Shaping Cross Section



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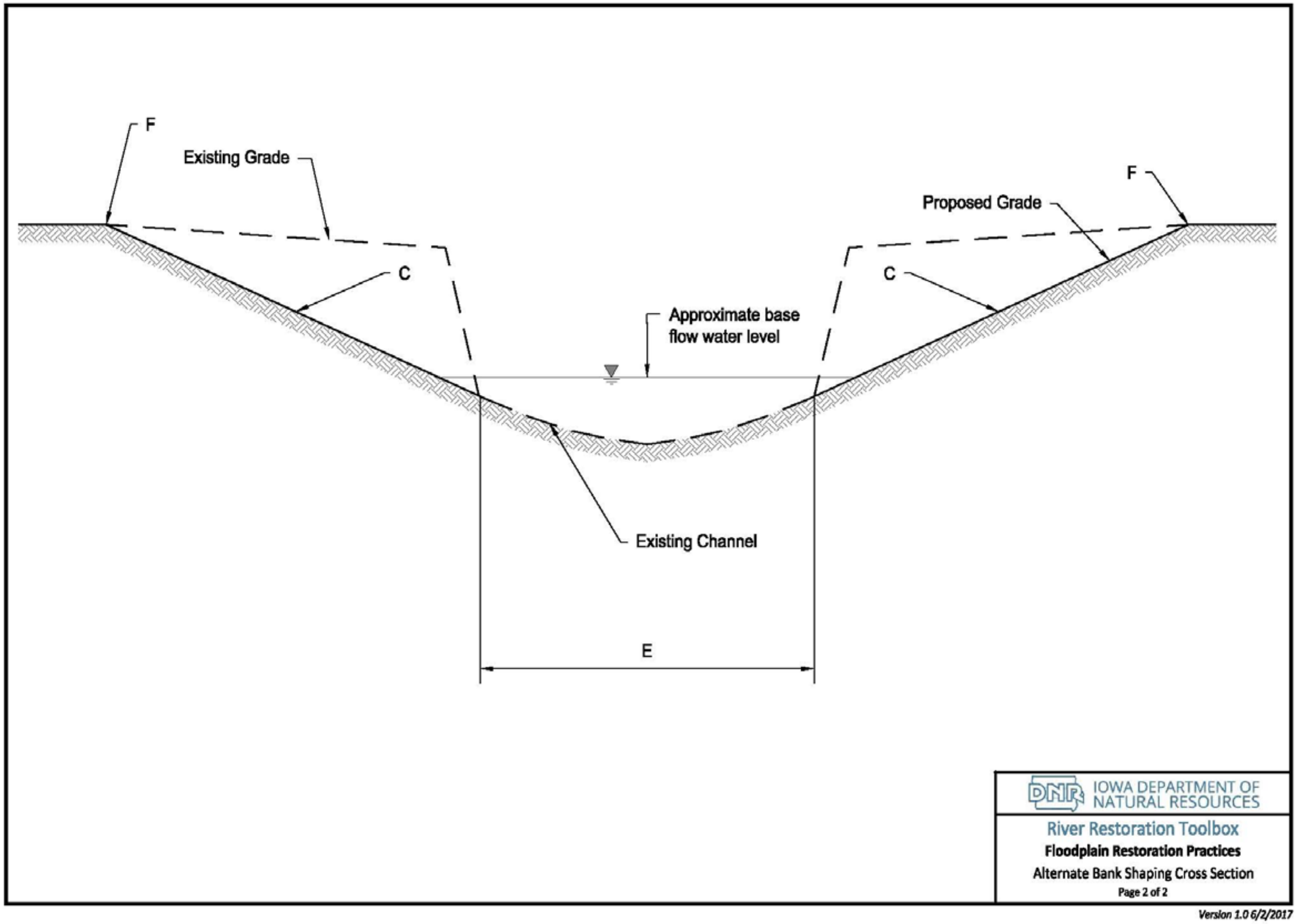
Drawing 2. Alternate Bank Shaping Cross Section (Preferred Method for Paleozoic Plateau Trout Streams)



2.1.4 Specifications

The following information should be developed into specifications to accompany the use of bank shaping:

- Materials:
    - Appropriate seed mix and/or vegetation. Refer to Vegetative Restoration Practice.
    - Engineered soil if existing soil is not adequate for stability or vegetative growth.
- Equipment/Tools:
    - Excavator
- Sequence:
    - Remove loose soil from face of slope.
    - Excavate banks.
    - Re-spread spoils in an approved location.
    - Seed and/or plant appropriate vegetation.
    - Protect slopes with temporary erosion control measures.
- Workmanship:
    - The finished surface of the banks should be generally in accordance with the lines, grades, cross sections and elevations of the design.
- Maintenance: During and immediately after construction, bank slopes are vulnerable to erosion. Establishing vegetation or other cover material as soon as possible will help reduce erosion. Maintenance will be needed as sediment settles within the channel. Dredging or grading may be required to maintain design flow capacity.

2.1.5 Photographs

Photo 1. Example 1 - Jordan Creek before bank shaping. Source: LT Leon Associates

Photo 2. Example 1 - Jordan Creek after bank shaping with rock toe protection. Source: LT Leon Associates

Photo 3. Example 2 - Eroded stream banks. Source: The Nature Conservancy & City of Charlottesville

Photo 4. Example 2 - Stream banks after reshaping and armoring. Source: The Nature Conservancy & City of Charlottesville

Photo 5. Example 2 - Reshaped stream bank after vegetative growth. Source: The Nature Conservancy & City of Charlottesville

Photo 6. Example 2 - Reshaped stream bank after vegetative growth. Source: The Nature Conservancy

2.2 BANKFULL BENCH

2.2.1 Narrative Description

A bankfull bench is a flat area adjacent to the stream at bankfull elevation constructed to both create an area for flows above bankfull to spread out and dissipate energy and to provide an area to catch erosion from the adjacent bank or mass bank failures. Bankfull benches are often used in combination with toe stabilizing techniques such as toe wood. A bankfull bench is effective for reducing high flow velocities, improving water quality, reducing stream bank erosion, and providing stream bed stability.

Bankfull benches are a common feature of a healthy stream system, and are often naturally occurring. The bankfull bench can be used to provide a stable bankfull channel section. The bankfull channel should be able to convey the 1-year to 2-year flood event (bankfull discharge) before flooding the bankfull bench (Leopold 1994). Constructing a bankfull bench can reduce shear stress on the stream banks from flood events and can allow vegetation to establish and stabilize the channel banks.

Analysis and design by a professional is necessary to determine the correct bankfull elevation and establish stable stream banks.

2.2.2 Technique Information

- **Use:** Bankfull benches provide flood conveyance and reduce shear stresses on the banks.

- **Other uses:** Bankfull benches promote ecological health by serving as a nutrient filter during flood events, reduce flow velocity during flood events and provide safe stable access to the water surface during base flow. Bankfull benches can help balance the sediment transport function of a stream.

- **Best applications:**

  - Channels experiencing erosion on unstable stream banks
  - Channels experiencing nutrient pollution due to storm water runoff
  - Channels with unbalanced sediment transport (aggradation, degradation)
  - In conjunction with any stream restoration activity

- **Variations:**
    - Providing stream bank stabilization (e.g. Rock Toe Protection, Root Wad, etc.) and temporary erosion control (e.g. Live Staking, Erosion Control Matting, etc.) for the low banks. See Vegetative Restoration Practice for more information.
    - Combining a bankfull bench with a grade control practice (e.g. Cross Vane, W-Weir, etc.) See Grade Control Practice for more information.
- **Computations:** The elevation of the bankfull bench is critical to providing stability to a stream. The elevation of an effective bankfull bench is directly related to the size and shape of the bankfull channel. The size and shape of the bankfull channel can be determined by using one of the following methods:
    - Natural Channel Design. See River Restoration Toolbox Practice Guide #5: Geomorphic Channel Design and the Multi-Stage Channel technique for more information.
        - Field-based indicators are useful for establishing bankfull channel elevation. Some common field-based indicators are sediment gradation, mineral marks on the stream bank from high flow, and the location of vegetation within the stream bank.
        - Regional curves are useful for sizing bankfull channels. Regional curves use the dimensions of stream systems from similar watersheds, and develop empirical relationships between measured dimensions and the drainage area of the stream system. With the developed relationship, the user may input the drainage area of the stream of interest to determine the dimensions of the bankfull channel.
    - The bankfull width may be directly measured through surveying techniques. For detailed procedures on surveying the bankfull width, see USDA's Stream Channel Reference Sites: An Illustrated Guide to Field Technique (Harrelson, 1994).
    - Effective discharge calculations. The effective discharge is the discharge that transports the most sediment over a period of years. Sizing the bankfull channel based on the effective discharge is often acceptable. Detailed procedure on effective discharge calculations is presented in USACE "Effective Discharge Calculation."

Once the size and shape of the bankfull channel have been established, the width of the bankfull bench can be determined. As a general rule, the width of the bankfull bench should be greater than or equal to the bankfull width. See Multi-Stage Channel technique for more discussion on sizing a bankfull bench.

- **Key Features:**
    - Determining bankfull elevation is essential in creating a bankfull bench.

2.2.3 Detail Drawings and Data Table

The following drawings and data table depict information that should be included in construction plans for bankfull benches. The data table includes design guidelines and sources, where applicable.

Table 2. Required Design Data for Bankfull Bench

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
A	Bankfull Width	Feet	Sized based on guidelines specified in computations section	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain
B	Bankfull Elevation	Feet (NAVD)	Reference reach, regional curves, measured in field based on guidelines specified in computations section	Maximum water level before flood water rises above the bankfull channel and begins to overflow onto a floodplain
C	Stream Bank Slope	N/A	2H:1V is the maximum for most Iowa projects, though toe protection influences the recommended toe slope	Grade of stream bank from the inner berm elevation to the bankfull bench elevation
D	Bankfull Bench	Feet	Bench Width should be greater than or equal to the bankfull width	Flat vegetated area at bankfull elevation where flood water can spread during flood events
E	Bankfull Channel Bottom Width	Feet	Reference reach	The bottom width of the bankfull channel

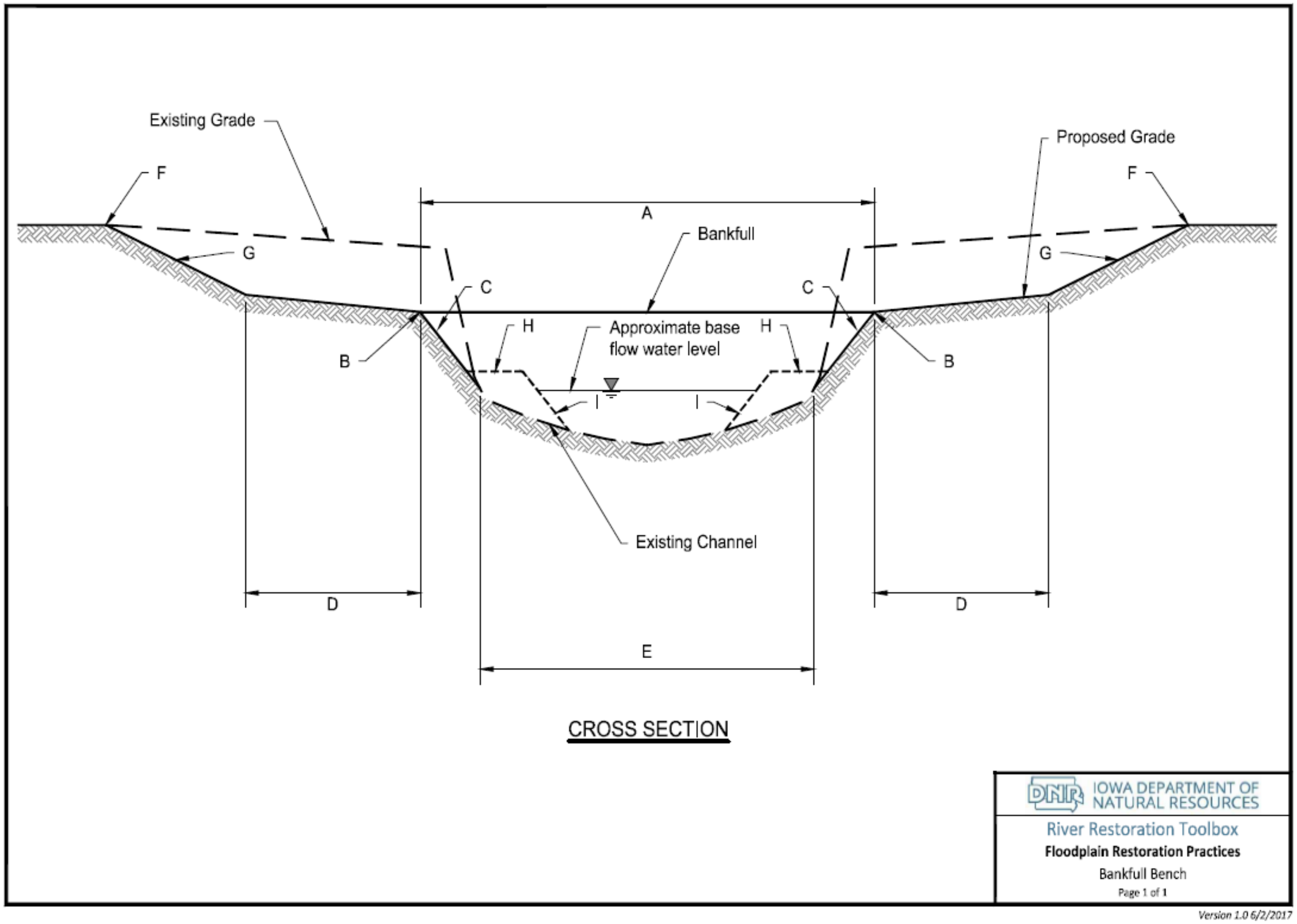
Table 2. Required Design Data for Bankfull Bench

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
F	Floodplain Elevation	Feet (NAVD)	Reference reach, regional curves, regulatory flood maps, H&H modeling	Maximum water level above bankfull elevation that is prone to flood water
G	Upper Channel Bank Slope	N/A	2H:1V is the maximum for most Iowa projects	Grade of channel bank from the bankfull bench to the floodplain
H	Inner Berm Elevation	Feet (NAVD)	Typically located at ½ the bankfull elevation	Located slightly above the base/low flow water level and formed by sediment deposition
I	Inner Berm Channel Bank Slope	N/A	2H:1V is the maximum for most Iowa projects	Grade from the channel bottom to the inner berm elevation

Notes:

1. Some labels are referenced in the detail drawings.
2. Common guidance, values, or ranges are given unless they require computation using site-specific input.
3. NAVD-North American Vertical Datum or other, as appropriate.

Drawing 3. Bankfull Bench



2.2.4 Specifications

The following information should be developed into specifications to accompany the use of bankfull benches:

- Materials:
  - Appropriate seed mix and/or vegetation. Refer to Vegetative Restoration Practices.
  - Engineered soil if existing soil is not adequate for stability or vegetative growth
- Equipment/Tools:
  - Excavator
- Sequence:
  - Remove loose soil from face of slope.
  - Excavate benches.
  - Re-spread spoils in an approved location.
  - Seed and/or plant appropriate vegetation.
  - Protect slopes with temporary erosion control measures.
- Workmanship:
  - The finished surface of the benches should be generally in accordance with the lines, grades, cross sections and elevations of the design.
- Maintenance: During and immediately after construction, benches are vulnerable to erosion. Establishing vegetation or other cover material as soon as possible will help reduce erosion. Maintenance will be needed as sediment settles within the bench. Dredging or grading may be required to maintain design flow capacity.

2.2.5 Photographs

Photo 7. Beaver Creek prior to bench construction. Source: Southern Ute Indian Tribe

Photo 8. Beaver Creek post construction with benches. Source: Southern Ute Indian Tribe

Photo 9. Big Cove Creek prior to bench construction. Source: Fulton County Conservation District

Photo 10. Big Cove Creek after bench construction. Source: Fulton County Conservation District

Photo 11. Benches covered with vegetative growth. Source: The Ohio State University

Photo 12. Bankfull benches after construction. Source: The Nature Conservancy

2.3 FLOODPLAIN ASSEMBLAGES

2.3.1 Narrative Description

Floodplain assemblages are structures in the floodplain designed to provide floodplain roughness and dissipate energy from flood flows. Floodplain assemblages are built from large woody debris and serve as habitat for terrestrial and aquatic species. Aquatic species utilize these structures during flooding events as cover from the high velocity flows in the main channel. Floodplain assemblages also encourage sediment deposition from floodwaters, enhancing riparian vegetative health.

The structural foundation of floodplain assemblages are carefully placed key members. Key members are partially buried logs in the floodplain designed to hold the structure in position during flooding events. Stacked members are strategically placed among the key members. Stacked members, held in place by key members, are responsible for creating floodplain roughness and encouraging sediment deposition.

Floodplain assemblage construction should not be undertaken by landowners. Poorly designed structures can be a safety hazard and can be harmful to stream systems. Floodplain assemblages require analysis and design by a professional.

2.3.2 Technique Information

- **Use:** Floodplain assemblages provide habitat for terrestrial and aquatic wildlife.
- **Other Uses:** Floodplain assemblages promote sediment deposition and provide hydraulic roughness in the floodplain during high flow events.
- **Best applications:**
    - Floodplains recently reconnected to the main stream system
    - Floodplains with a history of large woody debris removal resulting in habitat loss
    - Floodplains with setback levees where erosion during flood events is a concern
- **Computations:** Floodplain assemblages often influence hydraulic roughness, or the resistance to flow. High hydraulic roughness reduces erosive power of floods. An engineer should be consulted to evaluate the effect of hydraulic roughness on the floodplain.

  Floodplain assemblage design should account for forces exerted by floodwaters. Buoyancy, geotechnical stability, and gravity should be considered. Detailed analysis of each force is presented in the NRCS National Engineering Handbook Technical Supplement 14J.

- **Key Features:**
    - Anchoring these structures in place is important to prevent logs from washing downstream during high flows potentially cause logjams or clogging road crossings.

2.3.3 Detail Drawings and Data Table

The following drawings and data table depict information that should be included in construction plans for floodplain assemblages. The data table includes design guidelines and sources, where applicable.

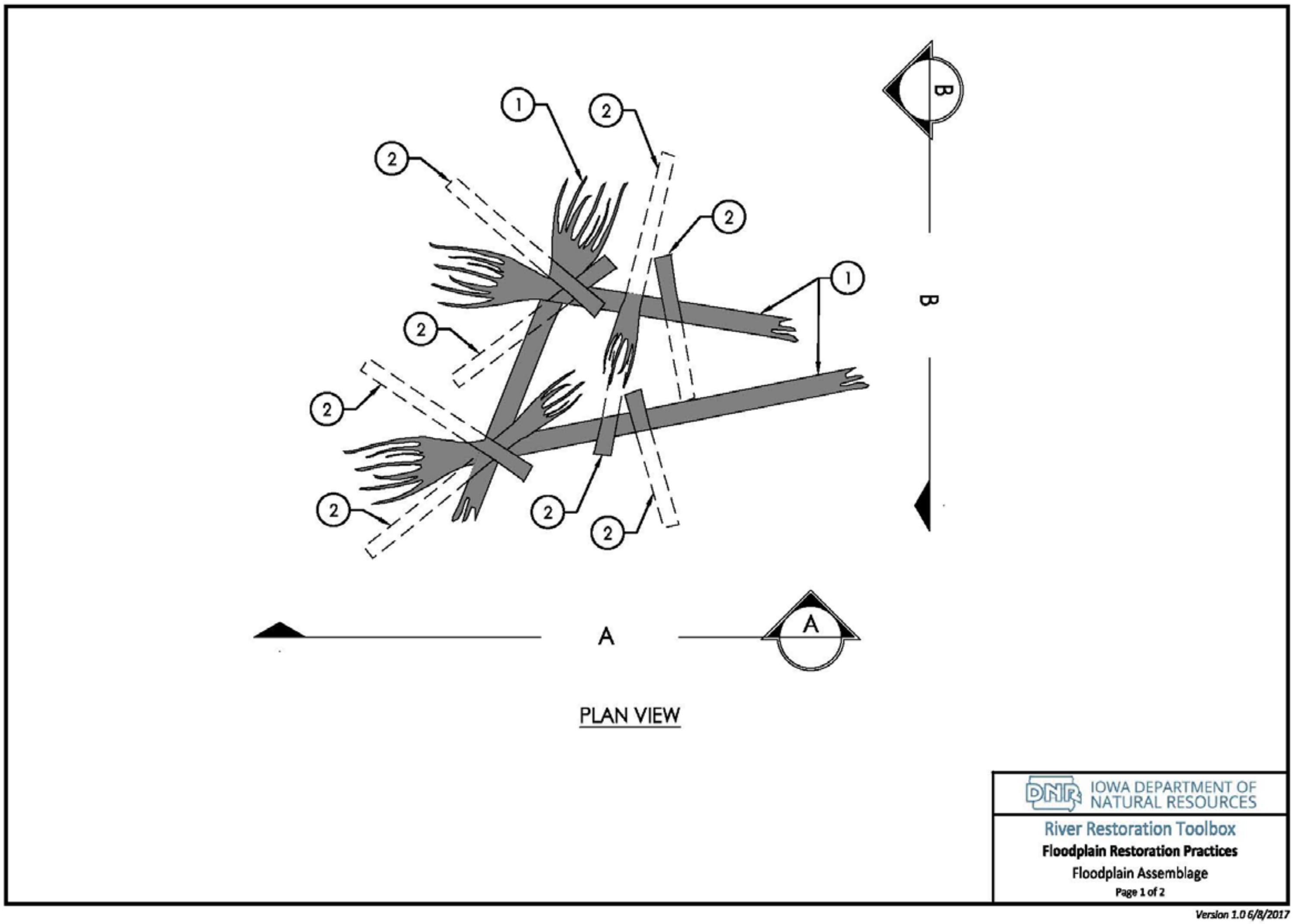
Table 3. Required Design Data for Floodplain Assemblages

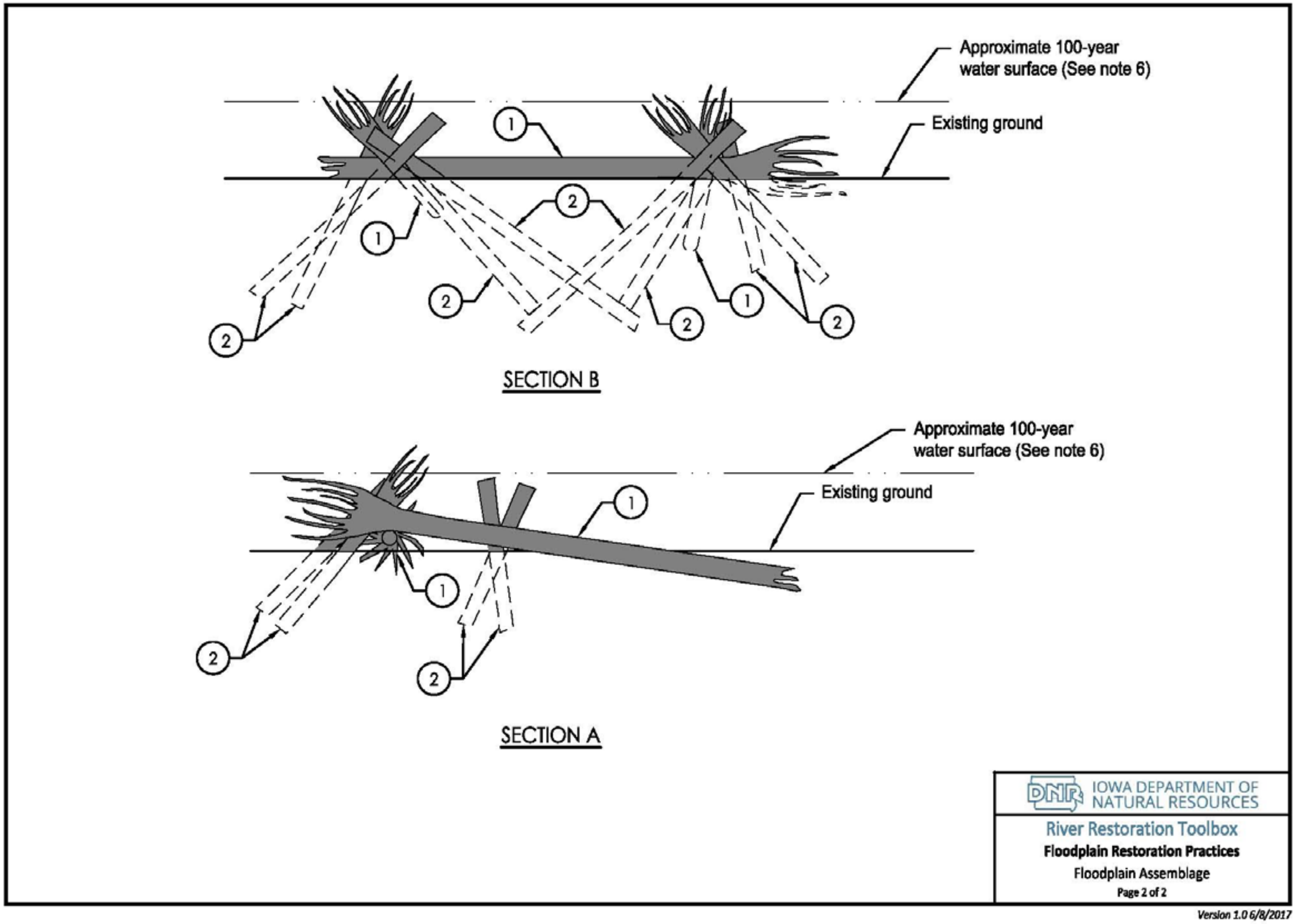
Log Number	Log Type	Quantity Per Structure	Log Size
1	Key	3	18-28” Dia. X 24-30’ long, with rootwad whenever possible.
2	Pile	8	12-18” Dia. X 24-30’ long, with rootwad whenever possible.

Notes:

1. All key logs shall be placed on the floodplain surface. No excavation or burial of logs shall be conducted.
2. Log piles shall be driven or pushed into the ground without excavation.
3. All exposed log ends shall have broken ends rather than saw cut ends.
4. Floodplain assemblage detail is typical and is intended to be configured in multiple orientations.

Drawing 4. Floodplain Assemblage




Approximate 100-year
water surface (See note 6)
Existing ground
1
2
1
2
2
1
2
2
SECTION B
Approximate 100-year
water surface (See note 6)
Existing ground
1
1
2
2
SECTION A
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Floodplain Restoration Practices
Floodplain Assemblage
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2.3.4 Specifications

The following information should be developed into specifications to accompany the use of floodplain assemblages:

- Materials:
    - Large woody debris with root wads that are decay resistant
- Equipment/Tools:
    - Machete, clippers, saw, come-along, rope, heavy chain, chainsaw, and/or loppers
    - Skid steer, small tractor, front-end loader, and/or dump truck
- Sequence:
    - All key logs shall be placed on the floodplain.
    - Piles shall be driven or pushed into the ground without excavation.
    - Final revegetation.
- Workmanship:
    - Piles shall be driven or pushed into the ground without excavation.
    - All exposed log ends shall have broken ends rather than saw cut ends.
- Maintenance: Floodplain assemblages may require maintenance to improve wildlife habitat, decrease upstream flooding, and remove excessive sedimentation.

2.3.5 Photographs

Photo 13. Large woody debris placement for floodplain restoration. Source: North West Fisheries Science Center

Photo 14. Floodplain assemblage structure during construction. Source: The Nature Conservancy

Photo 15. Floodplain assemblage structure during construction. Source: The Nature Conservancy

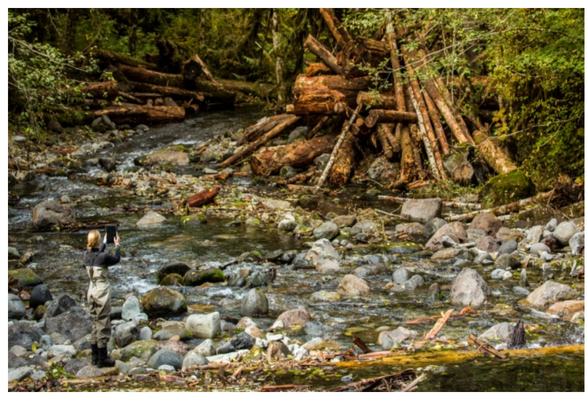


Photo 16. Floodplain assemblage structure. Source: The Freshwater Trust

2.4 LEVEE SETBACK OR REMOVAL

2.4.1 Narrative Description

Levees are walls built along the river banks of a channel or within the floodplain to protect flood-prone areas. They are typically constructed from soil. Though levees have the intended benefit of protecting real estate and farmland from floods, they are expensive to maintain and can promote risky land development in flood-prone areas. Levees disconnect the river system from floodplains, which can cause increased upstream water levels and can negatively impact overall river ecology.

Levee setback and levee removal are measures that can be used to improve negatively impacted river systems. Levee setback is the process of relocating a levee further back in the floodplain. Levee setback provides the river with more floodplain area to interact with and can result in lower flood elevations. Levee removal is the process of completely removing the levee, allowing the river to fully reconnect with the floodplain.

Floodplain reconnection, without any other form of floodplain restoration, is often sufficient for reviving riparian ecology. Decades after reconnection, floodplain ecosystems often closely resemble natural conditions. In the event that the restored floodplain was utilized for agriculture, revegetation of the floodplain with riparian plant species is recommended. For more information on vegetation of the floodplain, see River Restoration Toolbox Practice Guide 3: Riparian Buffer Practice.

The relocation or removal of levees should be conducted by a professional. Note: Levee adjustments will typically require coordination with FEMA, state and local agencies.

2.4.2 Technique Information

- **Use:** Levees are setback or removed to reconnect floodplains to river systems, reducing flood elevations and flow velocities.
- **Other uses:** Promotes improved river ecology by preventing erosion due to flood events, creates habitat in the floodplain, and improves water quality by increasing groundwater infiltration and nutrient sequestration on the floodplain. Removing levees reduces or eliminates maintenance costs due to erosion of levees.
- **Best applications:**
    - Overtopping of the levee occurs frequently, such as during a 2-year or a 5-year flood event
    - Areas with limited commercial or residential properties
    - Adequate floodplain area is available on the ‘dry’ side of the levee

- Poorly maintained or breached levees

- **Variations:**
  - In coordination with property buyouts on the floodplain
  - Can be used as a part of a wetlands restoration project

- **Computations:**

  Type of vegetation on the floodplain influences hydraulic roughness, or the resistance to flow. High hydraulic roughness reduces erosive power of floods. An engineer should be consulted to evaluate the effect of vegetation of the floodplain.

  Levees are useful structures for flood management, though they can be damaging to infrastructure and the local ecosystem if poorly implemented. A geotechnical engineer should be consulted for safe deconstruction and relocation of levees.

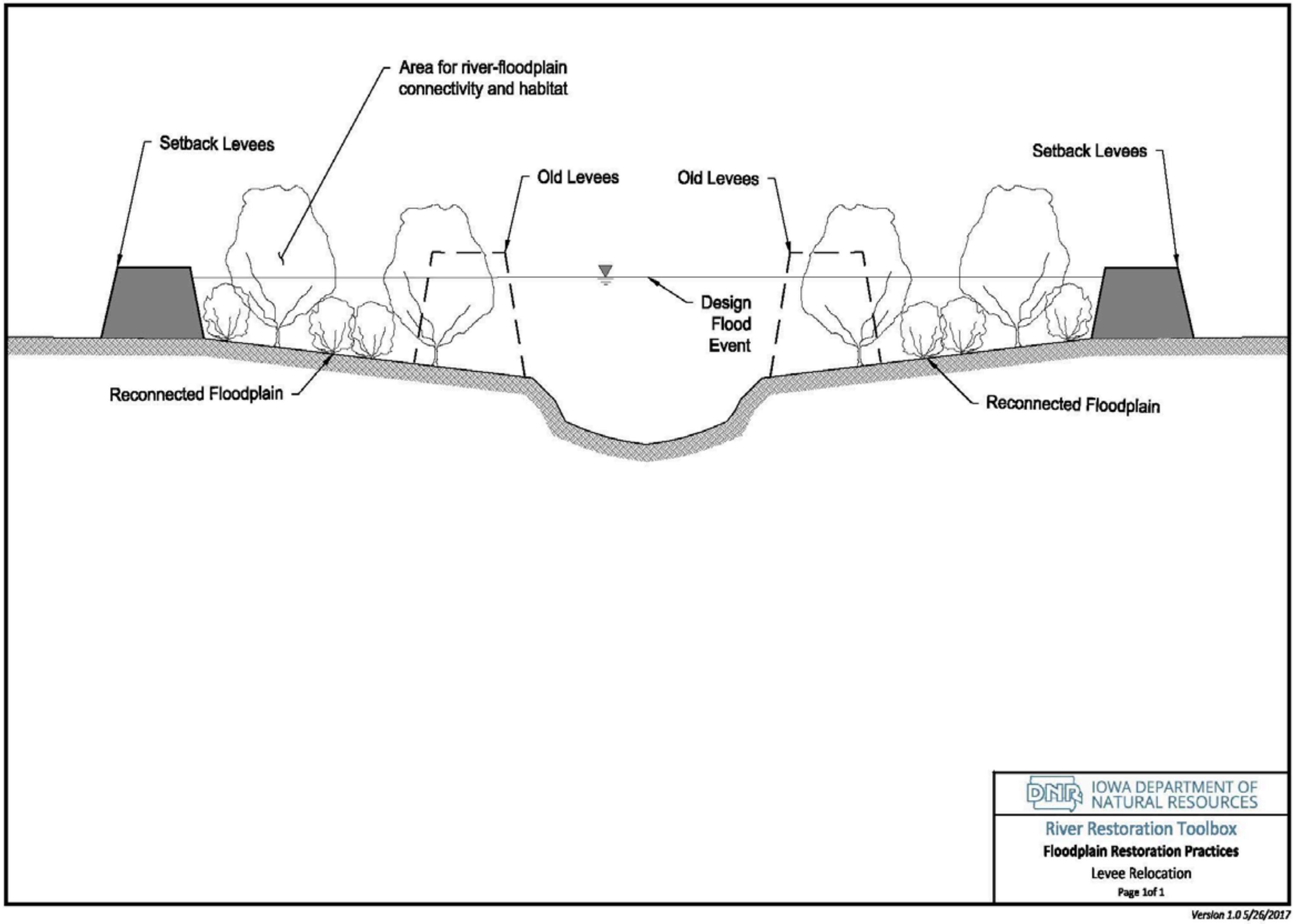
  Hydrologic and hydraulic computations aid in verifying the appropriate scenarios for levee relocation or removal. Hydrological and hydraulics modeling programs, such as HEC-HMS and HEC-RAS, are useful in determining flood behavior in response to levee removal or setback.

- **Key Features:**
  - Levee setback or removal involves relocating levees to reconnect the river system to floodplains
  - Relocating levees reduces maintenance costs

2.4.3 Detail Drawings

The following drawing depicts information that should be included in construction plans for levee setback or removal.

Drawing 5. Levee Relocation



2.4.4 Specifications

The following information should be developed into specifications to accompany the use of levee setback or removal:

- Materials:
    - Soil and subgrade material with proper graduation and soil type in accordance to local levee standards.
- Equipment/Tools:
    - Heavy machinery for removal, placement and transportation of soil and subgrade material.
    - Compaction equipment, such as vibratory rollers.
- Sequence:
    - Clear vegetation on existing levee prior to excavation.
    - Identify reuse opportunities for existing soil, especially for levee setback. Store reusable soil.
    - Excavate existing levee while actively implementing erosion control measures to prevent river bank instability during construction.
    - Levee footprint area will have compacted soil. Rip levee footprint to reduce soil density to allow for vegetative growth.
    - Vegetate disturbed locations after excavation of existing levee.
    - Place and compact setback levee material.
    - For a completely removed levee, haul removed levee material to an approved offsite spoil area.
    - Implement erosion control measures such as vegetation and erosion control matting for setback levee.
- Workmanship:
    - All levee material should be sufficiently compacted to prevent erosion during flooding events.

- Maintenance:
    - Setback levee should be maintained in accordance to the applicable levee safety program.
    - Visual inspections should occur annually. Comprehensive inspections including data collection, field inspections, and report development occur every 5 years.

2.4.5 Photographs

Photo 17. Levee breach near Hamberg, Iowa. Source: CBS News

Photo 18. Levee overtopping. Source: USACE

Photo 19. Levee removal. Source: National Park Service

Photo 20. Levee maintenance. Source: USACE

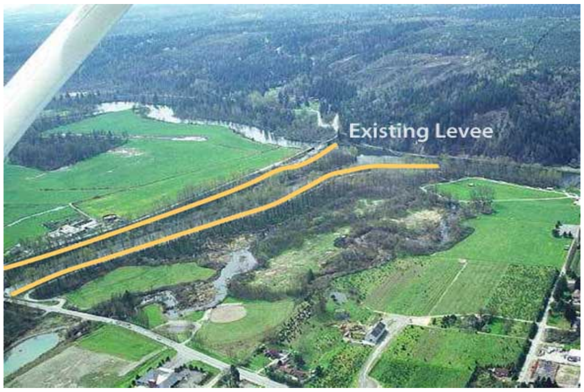


Photo 21. Levee location prior to relocation. Source: King County, WA

Photo 22. Proposed levee location after setback. Source: King County, WA

2.5 MULTI-STAGE CHANNEL

2.5.1 Narrative Description

A multi-stage channel is designed to accommodate a range of flows while maintaining sediment transport capacity. The most common form of multi-stage channel is the two-stage channel, though three and four-stage channels are options for larger channels and watersheds. Multi-stage channels provide flood conveyance, balanced sediment transport, and opportunity for nutrient filtration. The multi-stage channel also provides a stable stream system, reduced maintenance costs, and increased ecological benefits for landowners.

Multi-stage channel design includes a bankfull channel, floodplain benches, and often an inner berm. The bankfull channel functions as an alluvial channel, responsible for transporting sediment downstream. The floodplain benches convey floodwater while significantly reducing stream bank erosion risks. Constructing a bankfull bench can reduce shear stress on the stream banks during flood events by allowing floodwater to spread out onto the bankfull bench. This reduction in shear stress reduces erosion potential and allows vegetation to establish and stabilize the stream banks.

The bankfull bench can be used to provide a stable bankfull channel section. The bankfull channel should be able to convey the 1-year to 2-year flood event (bankfull discharge) before flooding the bankfull bench (Leopold 1994). A stable channel carries a balanced amount of sediment. An unstable channel can carry too much sediment, resulting in channel degradation, or not enough sediment, resulting in channel aggradation.

The multi-stage channel design may also include an inner berm that provides a low flow channel for aquatic organisms and maintains sediment transport capacity. An inner berm, a depositional feature in alluvial channels, is located within the bankfull channel and typically is located slightly above the base flow elevation. Grass growing on the inner berm can offer shade to aquatic species, improving ecological health.

Correct sizing of a multi-stage channel is necessary to ensure the effective transport of sediment, minimize stream bank erosion, and maintain flood conveyance capacity. The analysis and design of a professional may be required to ensure the channel will function as intended.

2.5.2 Technique Information

- **Use:** Multi-stage channels provide flood conveyance with reduced shear stresses on the banks.
- **Other uses:** In addition to flood conveyance and sediment transport capacity, multi-stage channels mitigate steep unsafe stream banks by providing a flat area above the base flow water surface and promote ecological health by serving as aquatic habitat

and a nutrient filter during flood events. Multi-stage channels can also provide safe stable access to the water surface during base flow.

- **Best applications:**
    - Channels experiencing erosion on unstable stream banks
    - Channels requiring frequent maintenance due to sedimentation or bank instability
    - Channels experiencing nutrient pollution due to storm water runoff.
    - Channels with unbalanced sediment transport (aggradation, degradation)
    - Channels with limited habitat for aquatic species
- **Variations:**
    - Adding benches above the bankfull bench to convey larger flood events.
    - Providing temporary erosion control (e.g. live staking, erosion control matting, etc.) for the low banks.
- **Computations:** The size and shape of the bankfull channel is critical to designing a multi-stage channel. The size and shape of the bankfull channel can be determined by using one of the following methods:
    - Natural Channel Design – A stable reference reach, with similar hydrologic watershed characteristics, and the bankfull discharge should be used as part of the natural channel design process to size the bankfull channel. See Geomorphic Channel Design Practice for more information on reference reaches. Bankfull discharge can be obtained through the following methods:
        - Hydrological calculations/models
        - Gage data analysis
    - The bankfull width may be directly measured through surveying techniques. For detailed procedures on surveying the bankfull width, see USDA's Stream Channel Reference Sites: An Illustrated Guide to Field Technique (Harrelson1994).

Once the size and shape of the bankfull channel have been established, the width of the bankfull bench can be determined. As a general rule the width of the bankfull bench should be greater than or equal to the bankfull width.

Floodplain benches above the bankfull elevation can be designed for larger frequent and infrequent flood events. They can be designed to protect critical areas from large flood events.

2.5.3 Detail Drawings and Data Table

The following drawings and data table depict information that should be included in construction plans for multi-stage channels. The data table includes design guidelines and sources, where applicable.

Table 4. Required Design Data for Multi-Stage Channel

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
A	Bankfull Width	Feet	Sized based on guidelines specified in computations section	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain
B	Bankfull Elevation	Feet (NAVD)	Reference reach, regional curves, measured in field based on guidelines specified in computations section	Maximum water level before flood water rises above the bankfull channel and begins to overflow onto a floodplain
C	Stream Bank Slope	N/A	2H:1V is the maximum for most Iowa projects, though toe protection influences the recommended toe slope	Grade of stream bank from the inner berm elevation to the bankfull bench elevation
D	Bankfull Bench	Feet	Bench Width should be greater than or equal to the bankfull width	Flat vegetated area at bankfull elevation where flood water can spread during flood events
E	Bankfull Channel Bottom Width	Feet	Reference reach	The bottom width of the bankfull channel
F	Floodplain Elevation	Feet	Reference reach, regional curves,	Maximum water level above bankfull

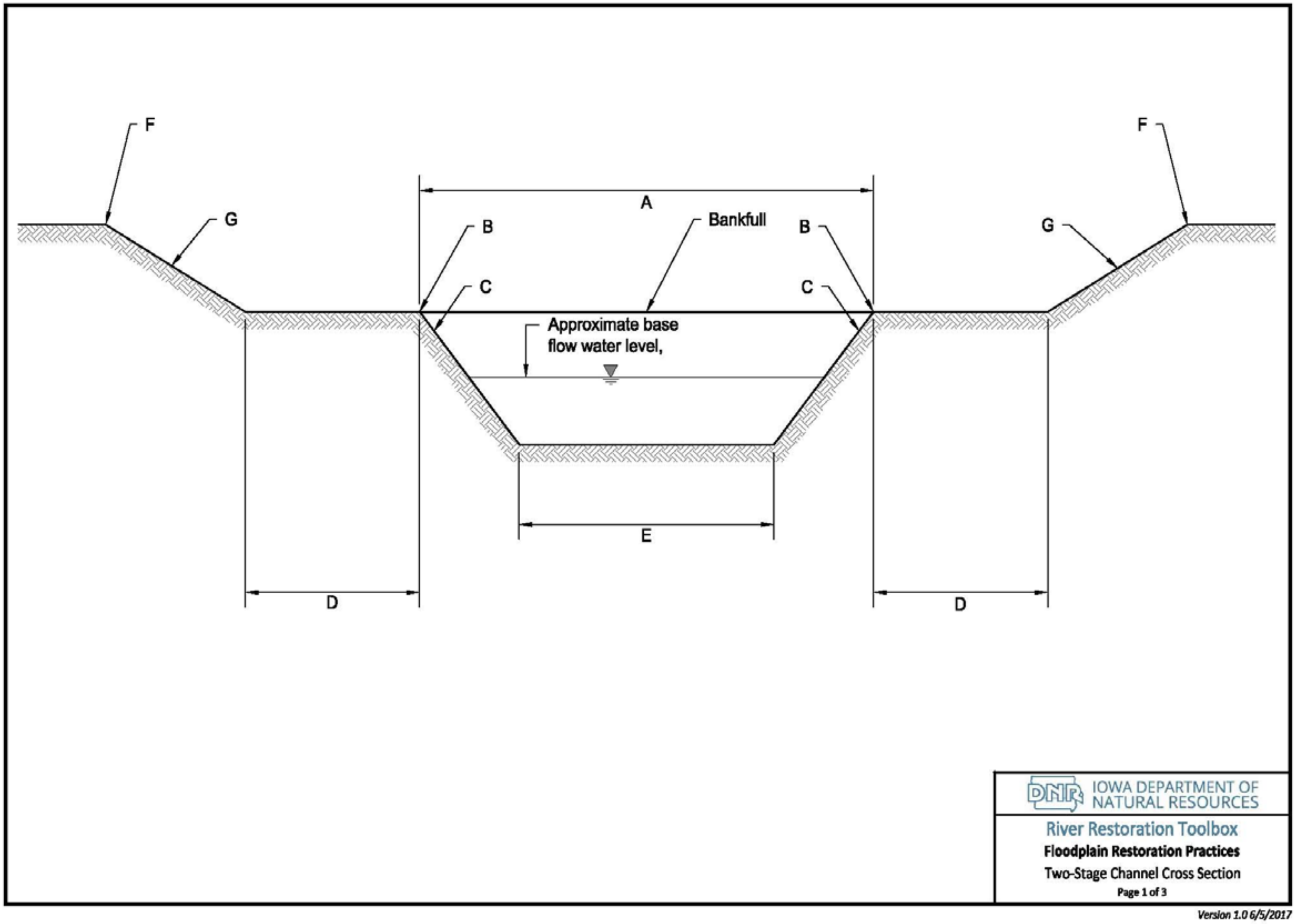
Table 4. Required Design Data for Multi-Stage Channel

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
		(NAVD)	regulatory flood maps, H&H modeling	elevation that is prone to flood water
G	Upper Channel Bank Slope	N/A	2H:1V is the maximum for most Iowa projects	Grade of channel bank from the bankfull bench to the floodplain
H	Inner Berm Elevation	Feet (NAVD)	Typically located at ½ the bankfull elevation	Located slightly above the base/low flow water level and formed by sediment deposition
I	Inner Berm Channel Bank Slope	N/A	2H:1V is the maximum for most Iowa projects	Grade from the channel bottom to the inner berm elevation
J	Inner Berm Width	Feet	Reference reach	The width of the inner berm
K	Floodplain Bench	N/A	Can be sized to convey larger flood events and protect critical areas	Width of the floodplain bench
L	Upper Floodplain Elevation	Feet	Reference reach, regional curves, regulatory flood maps, H&H modeling	Maximum water level above the floodplain elevation that is prone to infrequent flooding
M	Floodplain Slope	N/A	2H:1V is the maximum for most Iowa projects	Grade from the floodplain bench to the upper floodplain

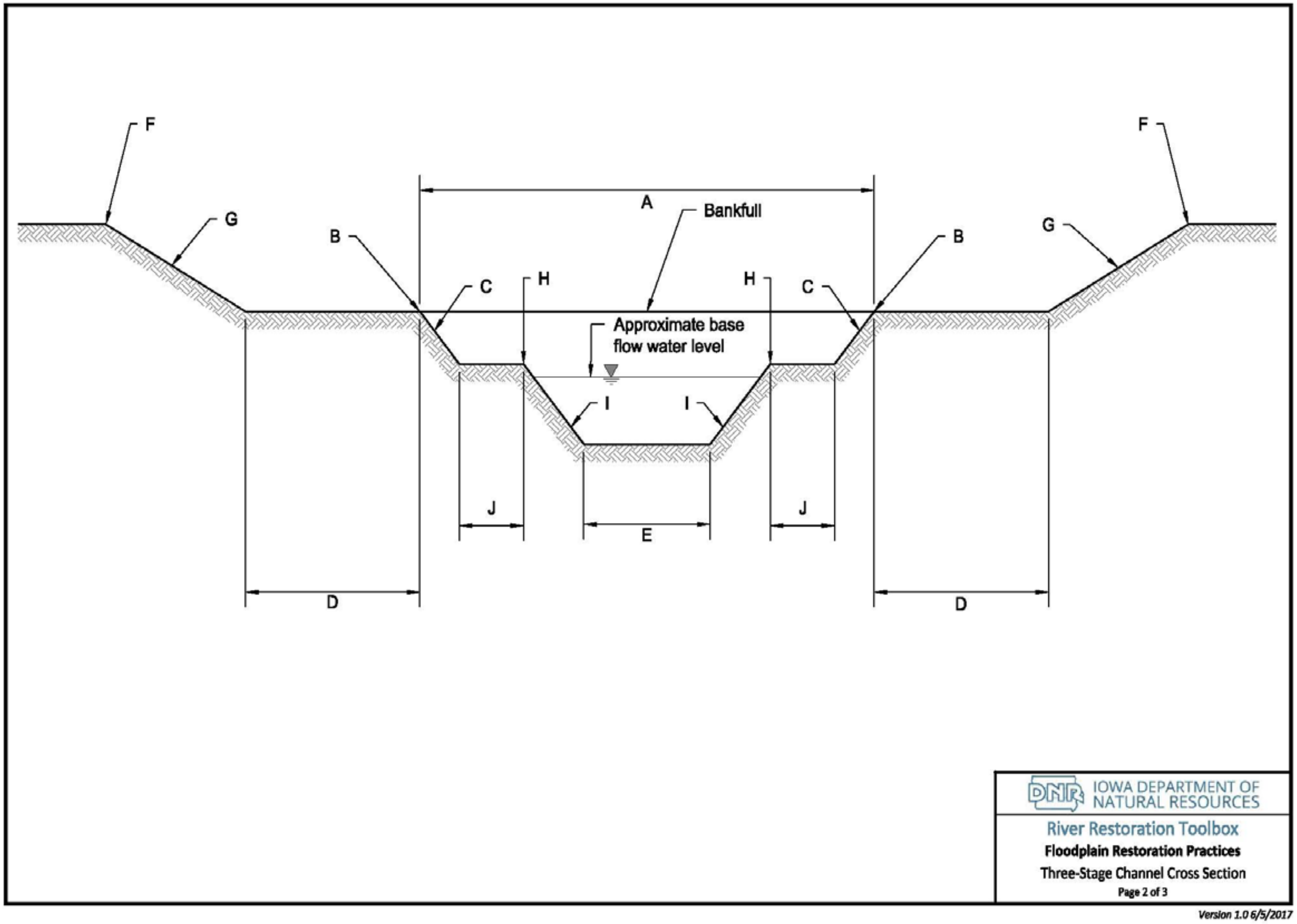
Notes:

1. Some labels are referenced in the detail drawings.
2. Common guidance, values, or ranges are given unless they require computation using site-specific input.
3. NAVD-North American Vertical Datum or other, as appropriate.

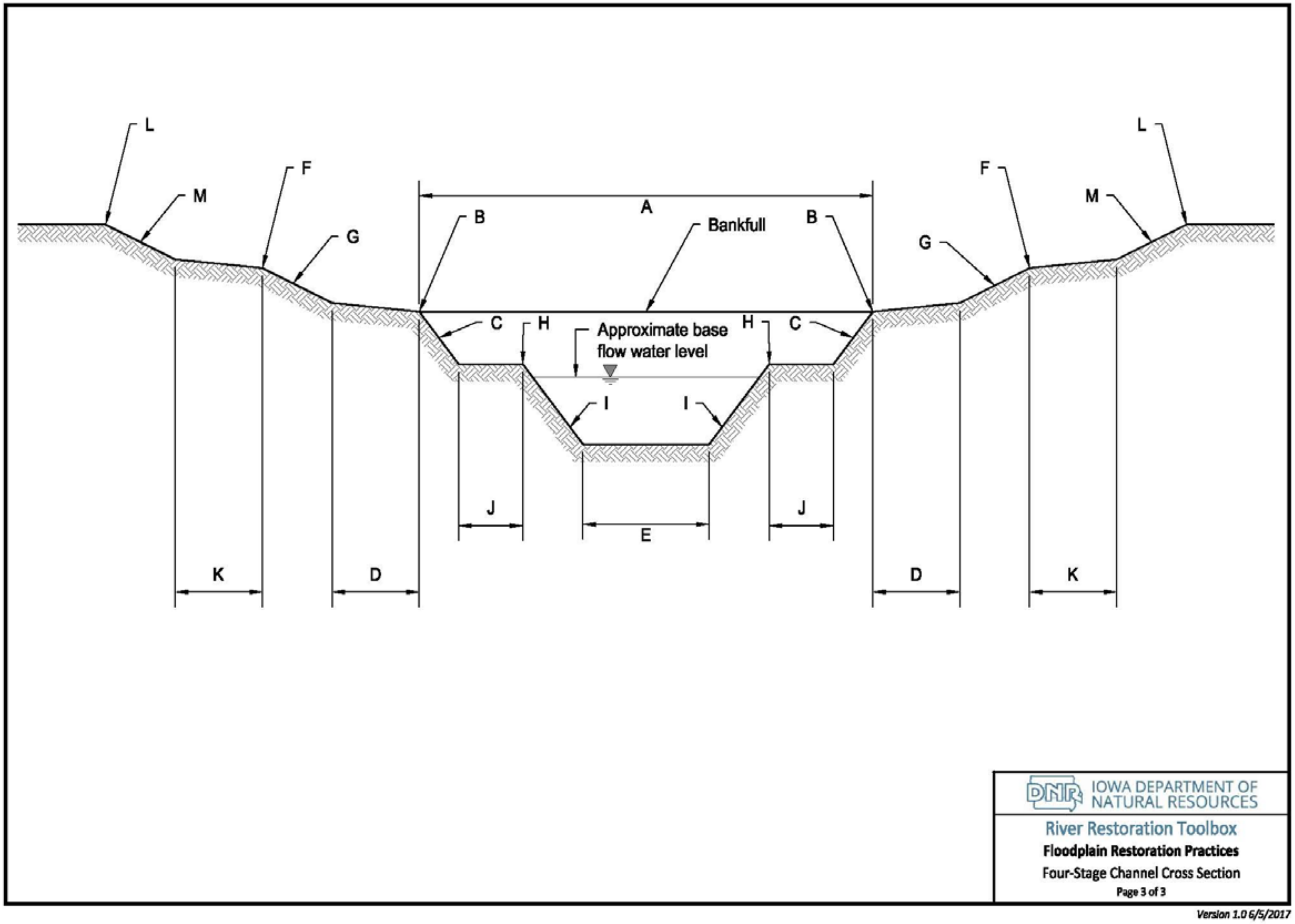
Drawing 6. Two-Stage Channel Cross Section



Drawing 7. Three-Stage Channel Cross Section



Drawing 8. Four-Stage Channel Cross Section



2.5.4 Specifications

The following information should be developed into specifications to accompany the use of multi-stage channels:

- Materials:
  - Appropriate seed mix and/or vegetation. Refer to Vegetative Restoration Practices.
  - Engineered soil if existing soil is not adequate for stability or vegetative growth.
- Equipment/Tools:
  - Excavator
- Sequence:
  - Remove loose soil from face of slope.
  - Excavate benches.
  - Re-spread spoils in an approved location.
  - Seed and/or plant appropriate vegetation.
  - Protect slopes with temporary erosion control measures.
- Workmanship:
  - The finished surface of the multi-stage channel should be generally in accordance with the lines, grades, cross sections and elevations of the design.
- Maintenance: During and immediately after construction, multi-stage channels are vulnerable to erosion. Establishing vegetation or other cover material as soon as possible will help reduce erosion. Maintenance will be needed as sediment settles within the bench. Dredging or grading may be required to maintain design flow capacity.

2.5.5 Photographs

Photo 23. Example 1 – Pre-construction aggrading channel with trapezoidal geometry. Source: University of Minnesota

Photo 24. Example 1 – Post construction 2-stage channel. Source: University of Minnesota

Photo 14. Example 2 - Two-stage channel during construction. Source: The Nature Conservancy

Photo 26. Example 2 - Two-stage channel during final restoration. Source: The Nature Conservancy

Photo 27. Example 2 - Two-stage channel during a flood event. Source: The Nature Conservancy

Photo 28. Example 2 - Two-stage channel after vegetative establishment. Source: The Nature Conservancy

2.6 OXBOW

2.6.1 Narrative Description

An oxbow is a historical river meander which is cut off from the main channel during the natural process of channel migration, or through man-made channelization. Water levels are maintained through larger flooding events overflowing into the oxbow and groundwater seepage. When the oxbow is cut off, it no longer receives water from the main channel and can eventually fill in with sediment. As the oxbow fills in with sediment it loses ecological benefits. Potential oxbows can be located based on historic imagery, which can be found on the Iowa Geographic Map Server.

Restoring an existing oxbow, which can include excavating the sediment down to the historic riverbed depth to allow groundwater to flow into the oxbow, provides numerous ecological benefits. Historic stream locations can be determined through analysis of historic maps and photos. Historic riverbed depth can often be determined by probing the historic stream location and looking for alluvium that may be similar to that of the current streambed. These benefits include improved water quality, such as nitrogen reduction, and habitat restoration. Oxbows also provide storage during flooding events, which can reduce channel bank erosion. Recreational benefits such as fishing can also be provided, groundwater elevations can prevent oxbow water levels from freezing solid in the winter, allowing fish and wildlife a year-round habitat, and providing recreational benefits such as fishing. Additionally, if the oxbows are in a pasture, they can offer a constant water source for livestock, keeping livestock out streams. Restored oxbows can either be oxbow channels or oxbow lakes depending on restoration goals.

Oxbows can also be created during the construction of a new channel. Filling in the old channel can require a large amount of fill, to offset this quantity off channel wetlands or ponds can be created that function as natural oxbows would.

Oxbow channels are reconnected to the main channel with inlet and outlet structures. Inlet and outlet structures, such as weirs or grade control structures, are used to allow water from the main channel to flow into and out of the oxbow channel. The inlet structure is designed to a specific elevation to allow water into the oxbow channel during certain flood events. The outlet structure backs water up and regulates the water elevation in the oxbow before it overflows back into the main channel. However, oxbow lakes require no inlet or outlet structures, and naturally connect to the main channel during high flows.

Excavation projects within floodplains, when handled poorly, can promote erosion and bank destabilization. For this reason, analysis and design by a professional is recommended to create a stable oxbow system.

2.6.2 Technique Information

- **Use:** Oxbows promote ecological health by providing habitat for wildlife, aquatic species, floodwater storage, and filtering excess nutrients from watersheds.

- **Other uses:** If designed and planned properly a constructed oxbow can serve as wetland mitigation. Sediment excavated from oxbows is often productive topsoil. The soil may be applied to local farming fields to increase productivity. Oxbows can also provide recreational benefits such as fishing.

- **Best applications:**

    - Oxbows located on land not well suited for farming

    - Watersheds prone to erosion during flooding events

    - Watersheds with water quality issues

    - Watersheds with habitat needs for endangered species

- **Variations:**

    - Step-pools can be used to provide additional grade control for oxbow channels.

    - Additional recreational amenities such as trails can be designed to provide access to oxbows.

- **Computations:** Computations are necessary to determine acceptable oxbow side slopes. Additionally, computations are recommended to ensure the oxbow is able to maintain its structural integrity in response to runoff and flooding events.

    Hydrologic and hydraulic modeling programs, such as HEC-HMS and HEC-RAS, are useful for predicting channel behavior in response to the reconnection of oxbows.

- **Key Features:**

    - Determine goals for oxbow restoration (habitat, water quality, flood control, and/or recreation, etc.) Design will vary depending on goals.

    - Oxbow channel maximum side slopes should be determined based on vegetation cover and existing soil types so that additional erosion is not created.

    - Based on habitat proposed, inlet and outlet structures should be set to regulate the inflow and outflow of water for the oxbow.

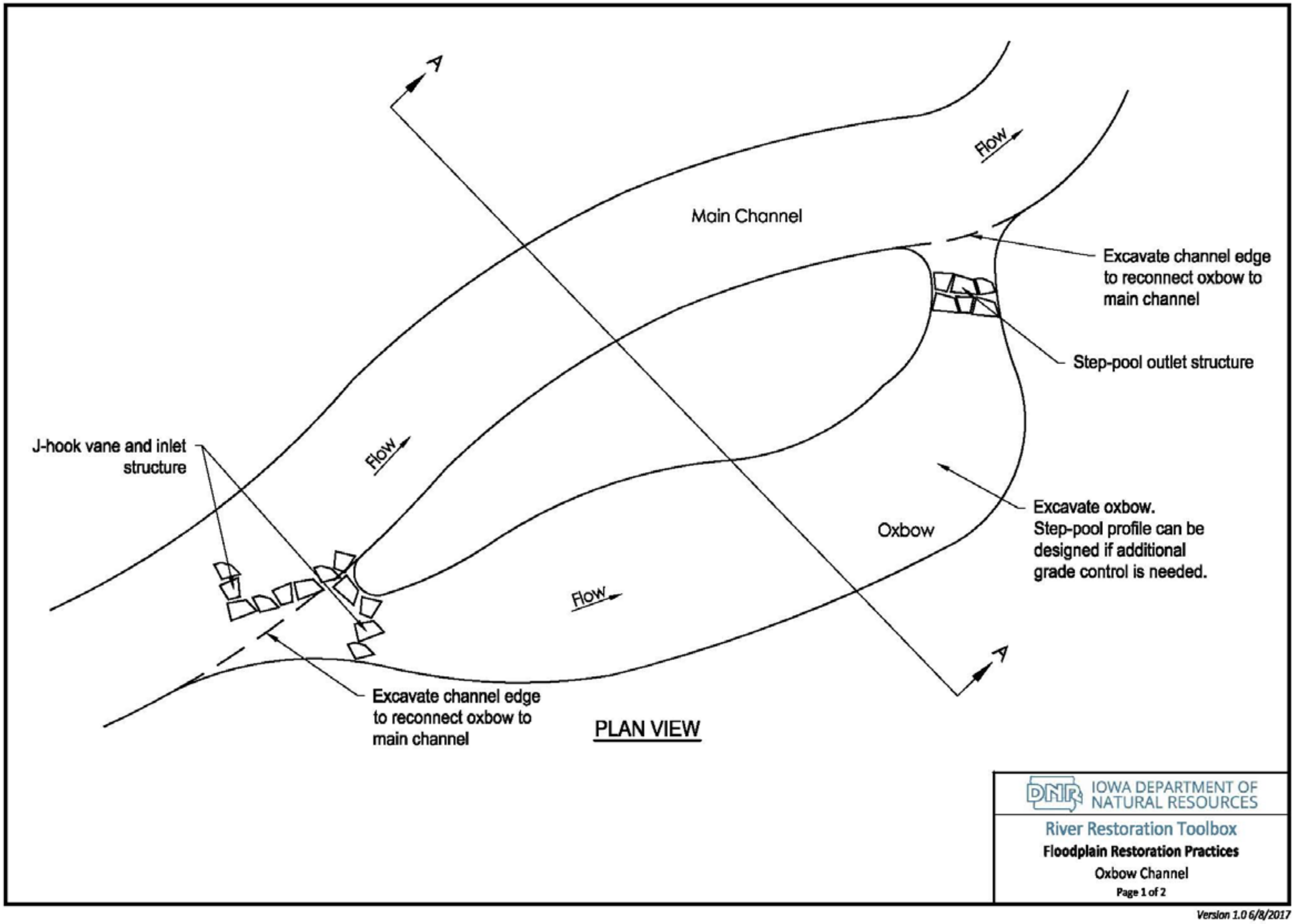
- For oxbow lakes, groundwater levels and frequency of floodwater to flow into the oxbow should be determined to make sure the oxbow does not dry up.
- Determine storage volume to be provided within oxbow if flood storage is a proposed benefit.

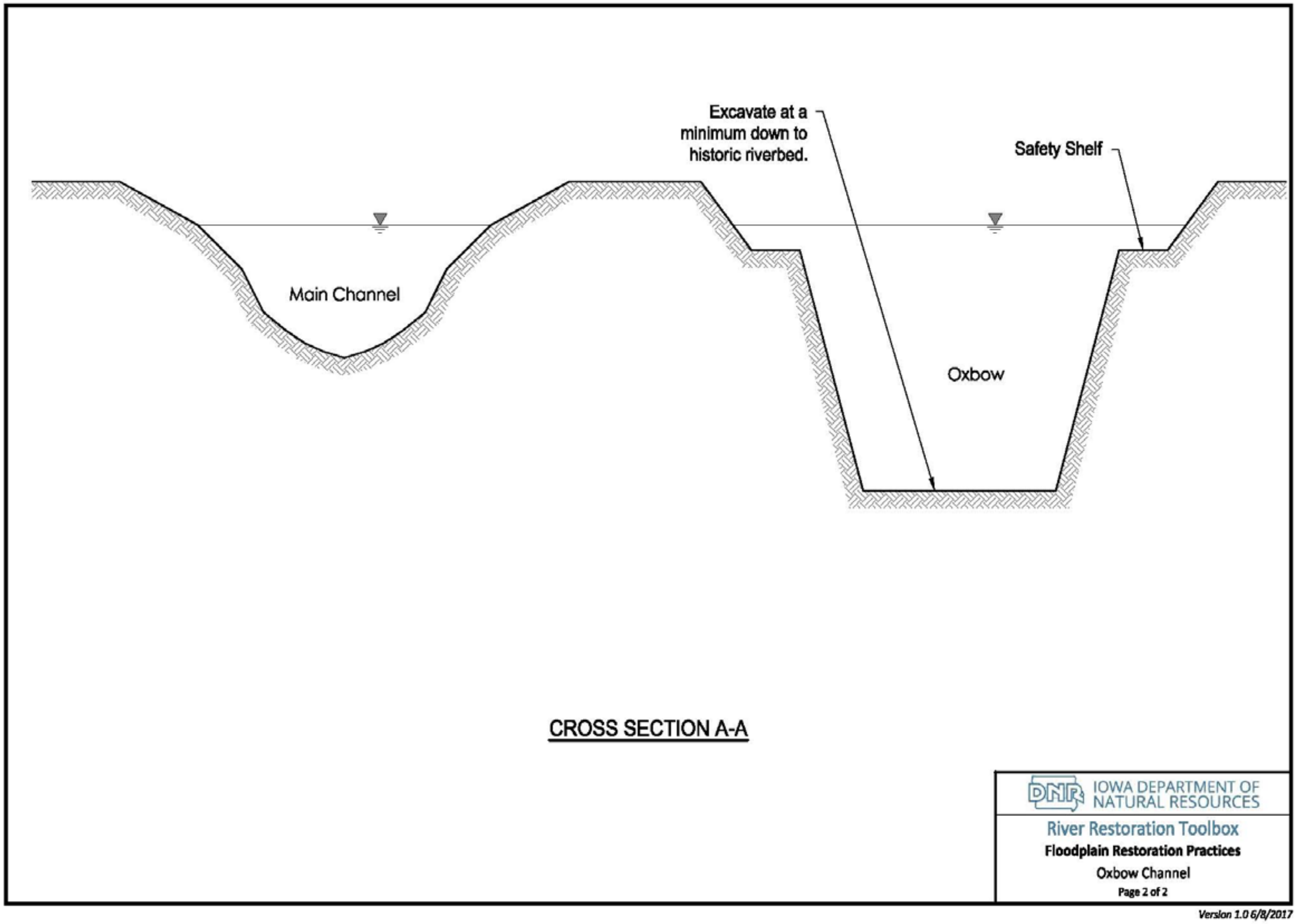
- **Cautions:**
  - Digging below the historic riverbed depth may pose a risk to cultural resources.

2.6.3 Detail Drawings

The following drawings depict information that should be included in construction plans for oxbows.

Drawing 9. Oxbow Channel




Excavate at a minimum down to historic riverbed.
Safety Shelf
Main Channel
Oxbow
CROSS SECTION A-A
IOWA DEPARTMENT OF NATURAL RESOURCES
River Restoration Toolbox
Floodplain Restoration Practices
Oxbow Channel
Page 2 of 2
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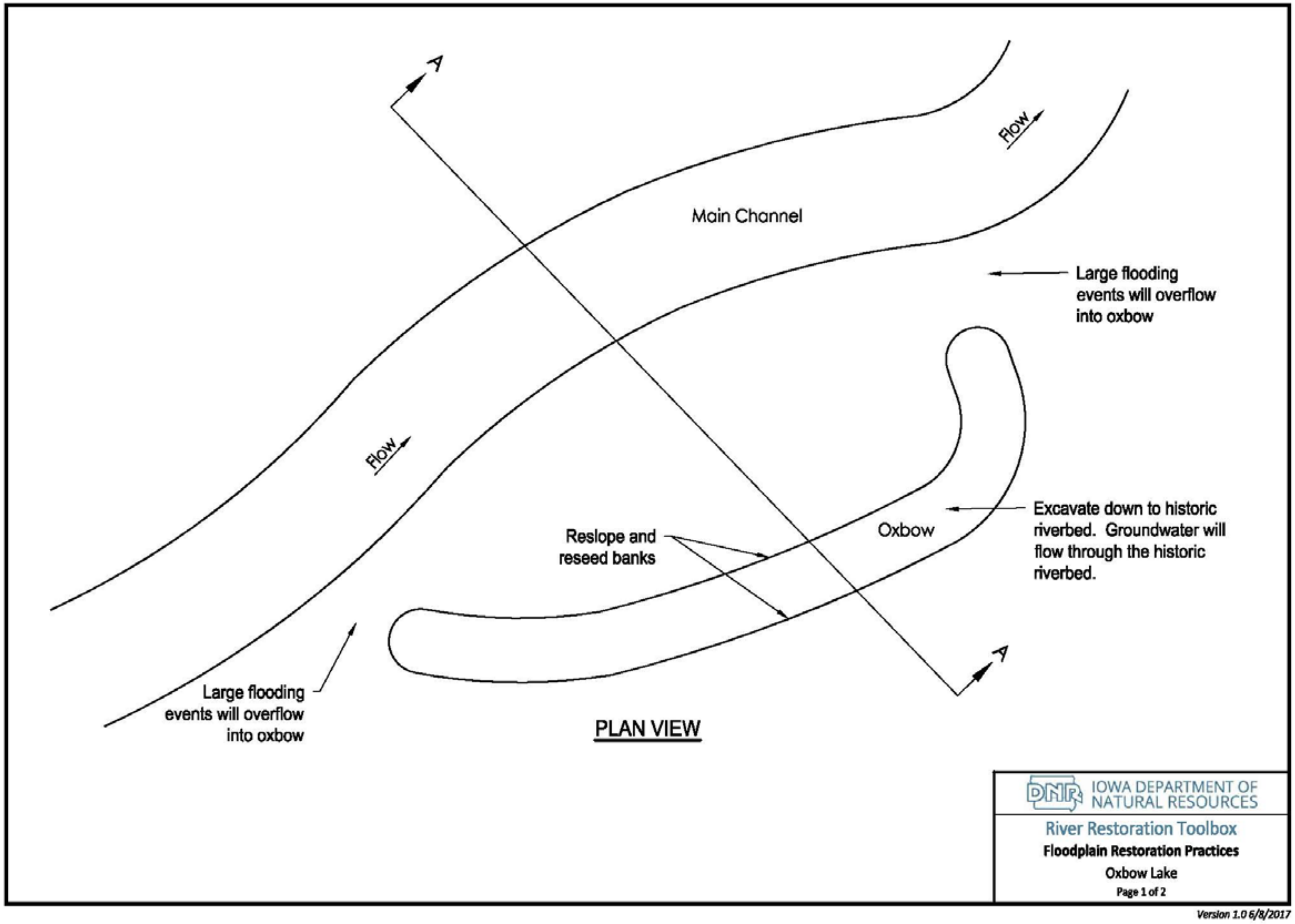
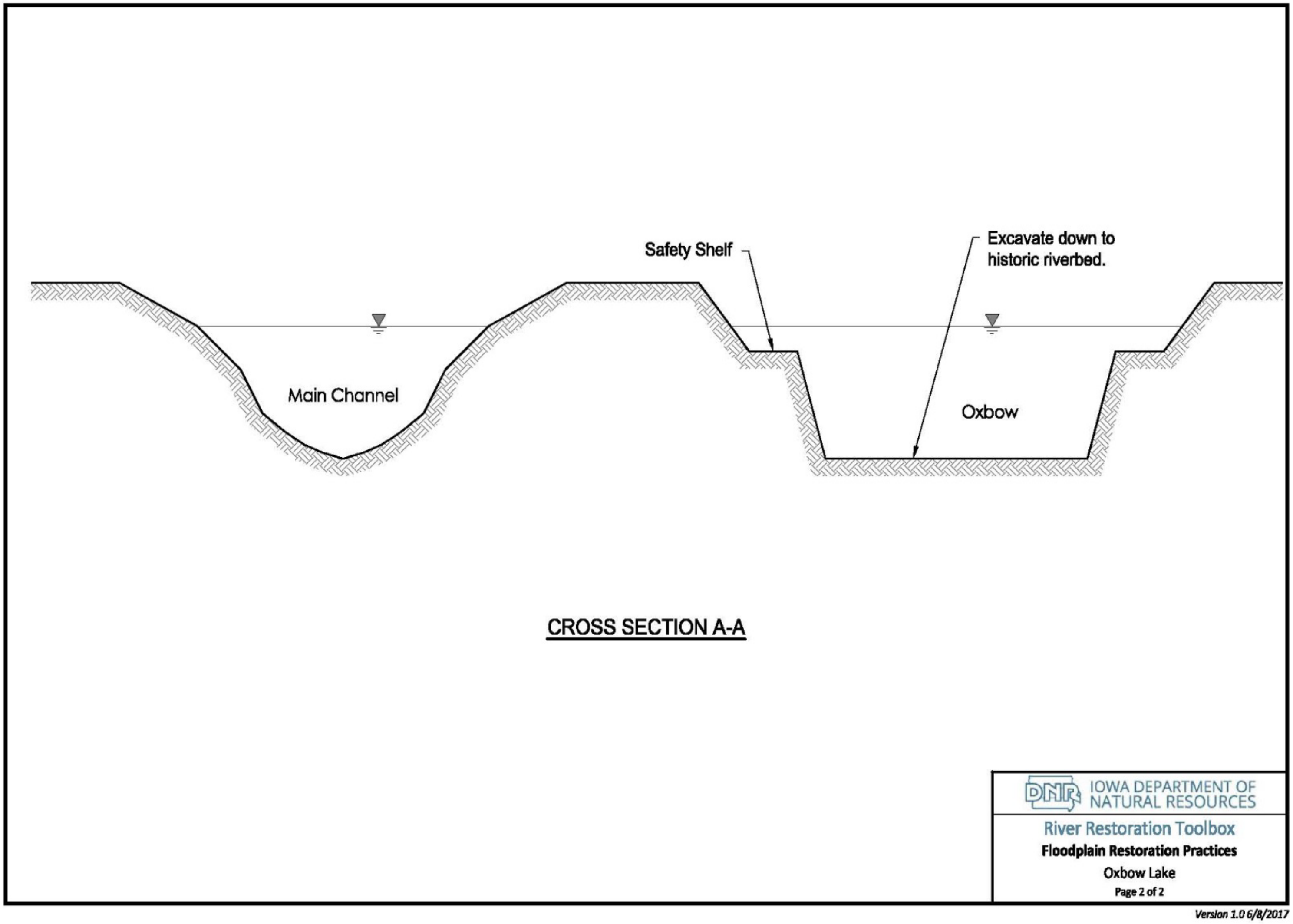
Drawing 10. Oxbow Lake




Safety Shelf
Excavate down to
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Main Channel
Oxbow
CROSS SECTION A-A
IOWA DEPARTMENT OF
NATURAL RESOURCES
River Restoration Toolbox
Floodplain Restoration Practices
Oxbow Lake
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2.6.4 Specifications

The following information should be developed into specifications to accompany the use of oxbow restoration:

- Materials:
  - Appropriate seed mix and/or vegetation. Refer to Vegetative Restoration Practice.
  - Engineered soil if existing soil is not adequate for stability or vegetative growth.
- Equipment/Tools:
  - Excavator
- Sequence:
  - Applicable permits must be obtained prior to excavation in the floodplain.
  - Excavate sediment from oxbow to historic riverbed depth or to elevations indicated on plans.
  - Stockpile or re-spread spoils in an approved location. Excavated spoil must be placed outside of the regulatory floodplain or spread less than six inches thick within the floodplain.
  - Build inlet and/or outlet structures if proposed.
  - Seed and/or plant appropriate vegetation.
  - Re-route subsurface tile to oxbow, if applicable.
- Workmanship:
  - The finished surface of the oxbow should be generally in accordance with the lines, grades, cross sections and elevations of the design.
- Maintenance: During and immediately after construction, oxbows are vulnerable to erosion. Establishing vegetation or other cover material as soon as possible will help reduce erosion. Maintenance will be needed as sediment settles within the oxbow. Dredging or grading may be required to maintain design capacity.

2.6.5 Photographs

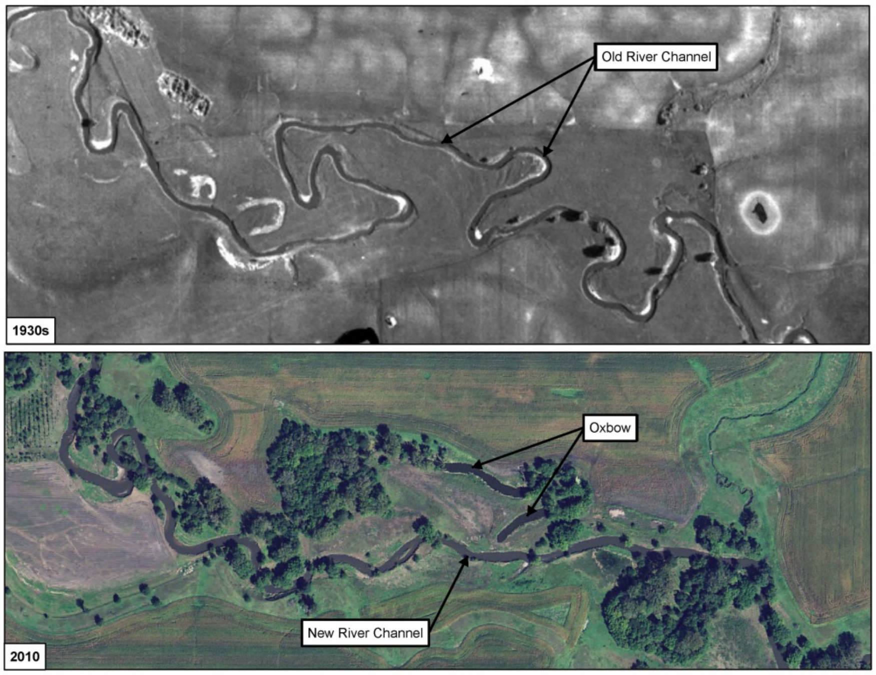

Photo 29. Oxbow along West Buttrick Creek in Greene County, IA. Source: National Agriculture Imagery Program (NAIP)

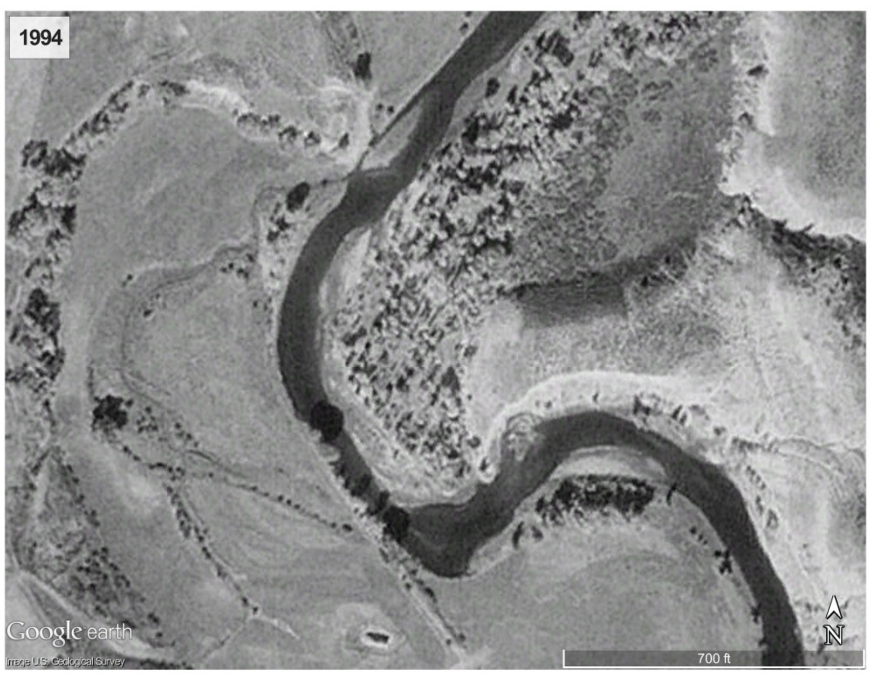

Photo 30. Blue River oxbow before restoration in Grand County, CO. Source: Google Earth

Photo 31. Blue River oxbow channel in Grand County, CO. Source: Google Earth

Photo 32. Boone River Watershed oxbow before restoration. Source: The Nature Conservancy

Photo 33. Boone River Watershed oxbow during construction. Source: The Nature Conservancy

Photo 34. Boone River Watershed oxbow after restoration. Source: The Nature Conservancy

Photo 35. Morgan Creek oxbow before restoration. Source: The University of Iowa IIHR – Hydroscience & Engineering

Photo 15. Morgan Creek oxbow after restoration. Source: The University of Iowa IIHR – Hydroscience & Engineering

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