Recommendations for River Restoration and Watershed Management in West Tennessee

submitted to

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Douglas P. Smith, Ph.D.

and

David L. Rosgen, P.H.

2004 author addresses

Douglas Smith
Science and Environmental Policy
California State University Monterey Bay
100 Campus Center, Seaside, CA 93955
Douglas_smith@csumb.edu

David Rosgen, Wildland Hydrology
11210 N. County Road 19
Fort Collins, CO 80524

1 Geology Department, Vanderbilt University, P.O. Box 115, Nashville, TN 37235
2 Wildland Hydrology, 157649 Highway 160, Pagosa Springs, CO 81147
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The following report is respectfully submitted to the Tennessee Environmental Policy Office of the Department of Environment and Conservation. The report serves to 1) evaluate the State Plan for restoring a natural meandering river within the Middle Fork Forked Deer (MFFD) valley bottom; 2) provide alternate guidelines for the MFFD project; and, 3) present restoration and management strategies for rivers throughout the west Tennessee region.

The basis for the analysis is chiefly the information provided in the Limited Reevaluation Report submitted by the U.S. Army Corps of Engineers, Memphis District, in June, 1996. Data for the alternative MFFD design comes from observations of the remnant natural meanders in the MFFD floodplain, and of numerous natural rivers in west Tennessee.

**REPORT SUMMARY**

- A dual-channel system is not recommended for the restoration of the Middle Fork Forked Deer River (MFFD) because it will not meet the objectives stated in the “Mission Plan” (Tennessee, 1994). A dual-channel system has no direct natural analogs in west Tennessee, so it is very difficult to predict its long-term stability. A fundamental problem is that the dual-channel system divides the energy of the flowing water, but does not proportionately divide the sediment load.

- The presence of berms (spoil piles resulting from channel construction) parallel to the State Plan channel will hinder the drainage of the floodplain following annual floods.

- The State Plan channel design has an appropriate width, but is too shallow when compared with streams of comparable drainage area. A shallow channel will not move water, sediment, or large woody debris as efficiently as a deeper channel, and will have a greater risk of premature failure from aggradation and debris jams.

- The appropriate channel shape and dimensions are best obtained by studying the well-functioning river reaches in west Tennessee, and scaling the data to the drainage area of the MFFD restoration reach (approximately 400 mi²).

- Sediment transport rates must be determined by field measurements, before confidence may be placed on the appropriate size and dredging intervals for the sediment retention basin, and on the long-term stability of the restored channel-floodplain system.

- The best approach for maximizing the chance of long-term stability in the restored reach is to mimic the geometry of natural western Tennessee channel reaches that are maintaining stability in the presence of similarly high sediment loads.

**GENERAL PHILOSOPHY REGARDING STREAM RESTORATION**

Most fully-functioning river reaches that exist today within western Tennessee watersheds have a single dominant channel. River system “restoration” should aim to mimic, as closely as possible, the dimension, pattern and profile of existing naturally-stable rivers. If this approach is embraced, it is likely that the resulting restored channel will be ecologically-sound, low-cost, and self-maintaining, like the rivers that form the design template. Given that philosophy, we recommend abandoning the dual-channel design because:

- construction of a single-channel system will cost far less than the proposed dual-channel system because it does not require the transport and placement of imported rock for weirs and revetment,
- a single-channel system will require less maintenance over the long run, and
a single-channel system will more accurately recreate and sustain the physical and biological functioning of a natural river system in this region.

Conveyance and Storage of Water, Large-Woody-Debris, and Sediment

The three main materials that move down the natural watersheds of western Tennessee are water, sediment, and large woody debris. Therefore, a “physically functioning” and “self-maintaining” restored river reach must transport, or store, water, sediment and large woody debris without aggrading or degrading over the time frame of many hydrologic cycles. The proposed project incorporates weirs, raised road beds, and spoil piles, all of which would impede the flow of water, sediment and woody debris down the channel/floodplain system. Raised topography on the banks and floodplain will hinder the exit and return flow of flood waters, thereby increasing the length of annual floodplain inundation and possibly creating artificially-ponded water. Therefore, the perception that the dual-channel system will reduce flood hazard is questionable. Lastly, raised topography on the banks or floodplain increases the risk of blockage by large woody debris. These shortcomings will dictate that frequent maintenance be performed after the proposed project is constructed, as is the case in most channelized systems today.

In contrast, a sinuous, deep, narrow, single channel running within a vegetated, broad floodplain, as is found in the region, will be far more effective than the proposed State Plan design at transporting the water, sediment and large woody debris produced in the watershed. This more natural channel will also best mimic the habitats of the other functioning lowland rivers. The characteristics that allow natural rivers to transport materials better than typical channelized reaches are described below.

Water

Unlike channelized streams that have spoil piles or constructed levees, natural lowland rivers have three “nested” channels: (1) a “low-flow” channel that maintains a reasonable depth during base flow for sediment movement and fisheries; (2) a “bankfull channel” that carries most of the sediment and water through the system over the long-term; and (3) a very wide floodplain that performs the environmental benefits of a wetland, and transports flows in excess of the bankfull capacity. In western Tennessee, the floodplain, or flood-prone area of the valley bottom, is commonly 50 to 80 times as wide as the low-flow channel. In natural systems, all three of these nested channels are required to convey the water produced in an annual hydrologic cycle. The absence of continuous spoil piles or other significant floodplain topography allows flood waters to more rapidly enter and leave the valley bottoms. Although this geometry leads to more frequent flooding, the duration of floods is reduced.

Large Woody Debris

Large woody debris forms a significant portion of the material transported in west Tennessee rivers (Diehl, 1994). Large woody debris commonly forms local temporary blockages, but it can also initiate valley-wide blockages that result in “valley plugs,” which in turn force major alterations in the position and evolution of the dominant river channel (Happ et al., 1940; Diehl, 1994, 1997a, 1997b).

Channelized streams tend to generate more large woody debris than natural channels because of accelerated bank erosion and resultant channel widening (Simon and Hupp, 1992). Once the woody debris is recruited from the banks, it is transported more efficiently in channelized streams. However, because of the resulting higher abundance of woody debris in
channelized streams relative to natural streams, catastrophic channel occlusions are more inclined to form when blockages do occur (Diehl, 1997b).

The dual-channel design will be exceptionally prone to accumulations of large woody debris. Large woody debris preferentially collects at points of “flow separation,” such as pier pilings, and central sand bars (Diehl, 1997b, 1997c). During floods, there is flow-separation at each cross-over point in the State Plan design. Large woody debris accumulations may lead to early failure of the dual-channel design.

In a natural channel-floodplain system with low banks and no constructed levees or spoil piles, logs and large branches are free to float out of the channel and onto the floodplain during annual flooding. Access to a broad floodplain reduces the incidence of channel occlusion by woody debris. In the natural setting, when a blockage occurs, the channel either (1) widens by lateral erosion until the stress is relieved, (2) forms a meander cut-off to bypass the occlusion, or (3) avulses to establish a new channel in a lower part of the floodplain (Diehl, 1997b). The portion of the channel that was blocked remains blocked, and is eventually filled with trapped sediment. The filled channel becomes part of the floodplain, and the new channel migrates around the obstruction. If dynamic channel adjustments are not desired, then a program using “SORG” guidelines (IAFWA, 1983) can foster the stability of a meandering stream.

Sediment

Sediment routing is perhaps the single most important design consideration for river restoration projects in west Tennessee. The Forked Deer River uplands are contributing a large quantity of sand that is shed from gullies in poorly consolidated, nearshore deposits of Tertiary and Cretaceous age (Fig. 1; Miller et al., 1966). Therefore, the restored channel will have to process (transport or store) abundant fine- to medium-grained sand (\(\Phi = 0.35 \text{ mm}\)) as bedload (Simon, 1989). The proper “competence” to move medium sand is easy to achieve, but designing the proper “capacity” to move great quantities of sand is more problematic.

The main concern in the restoration reach is that the channel will fill with sand because of the high rate of sand delivery from the upper watershed. If the sinuosity of the restored channel is at least that of the remnant channel, then long-term, net degradation (incision), such as seen at Cane Creek near Ripley, TN, should not be a problem. Three facts support that conclusion: 1) there is a high bedload supply, 2) the channel is very low gradient (~0.0002), and 3) the restored channel will be located far east of thick loess substrate, which is more prone to degradation (Fig. 1; Bryon et al., 1995).

Sediment is most efficiently transported when high shear stress conditions exist at the channel bottom. Given a fixed slope and channel cross-sectional area, a channel with high shear stress can be designed by means of a low width-to-depth ratio (w/d). A low w/d ratio channel has a relatively high hydraulic radius, which is proportional to average boundary shear stress and fluid transport efficiency. The typical reference reaches in west Tennessee have relatively low w/d ratios, ranging from 5 to 12, and relatively high hydraulic radii. The average w/d value of streams surveyed is 9.5 (unpublished data), typical of E stream types of the Rosgen (1994) classification.

In a natural channel with low w/d and high hydraulic radius, most of the sediment is transported down valley within the channel, but excess sediment is deposited on the floodplain. During floods, the channel scours its bed, carrying excess sand up and out of the channel and onto the flood plain where it is deposited in low natural levees or in backswamp areas away from
Figure 1: Geologic Context for the MFFD Restoration Project.

The project lies above thick Eocene sandstone formations, with the westernmost segment overlying thin loess deposits. Geologic map modified from Stearns (1975). NOTE: This is a revised figure, improved in 2004.
the main channel. The presence of ubiquitous, low, broad natural levees along the banks of natural streams of west Tennessee is evidence that this process can be expected to occur in the restored reach as well (Fig. 2). This process of floodplain sedimentation is greatly hindered where spoil piles or constructed berms restrict the lateral and down-valley flow of higher discharges. The natural levees are discontinuous. Therefore, the backswamp is hydrologically linked to the bankfull channel, and the ebb of floodplain flood waters is less impeded than with an infrequently breached berm.

Figure 2: Low natural levee and backswamp are areas of natural sediment storage. Axes are in feet. Location—Little Hatchie River above Powell Chapel Road.

“Preferred Geometry” of the Restored Channel

The general procedure for stream “restoration” is to reconstruct, as closely as possible, the natural dimension, pattern, and profile of naturally-stable rivers in the region. Where one or more of the geometric parameters are not preserved in the remnant natural meanders, they are either (1) back calculated using well-established mathematical relations among the various geometric elements of rivers, or (2) estimated and scaled using data from other naturally-stable rivers in the same hydro-physiographic province (i.e. from “regional curves” of bankfull dimension). It is recommended that both approaches be used when possible to see if multiple approaches converge on the same design parameters. Below is a list of recommended geometry for the MFFD restoration project. The data for approach #2, above, come from recent, EPA-funded surveys performed in a collaborative project among Douglas Smith (Geology Department, Vanderbilt University), Leslie Turrini-Smith (Tennessee Department of Environment and Conservation), Timothy Diehl (U.S.G.S.), and several workers from U.S. EPA. The “preferred” geometry would be a single-channel project, in keeping with the typical rivers of west Tennessee. The geometry described below is for a single-channel system.
Method #1: Channel Dimensions Based Upon Remnant Meanders

Bankfull Channel Width = 70-75 feet

This parameter is based upon field measurements of remnant meanders (LRR). That figure can be verified by a back calculation from measured meander lengths (Lm) on a 1:10,000 scale aerial photograph. The aerial photograph is N10NAPPW09772130 taken February 1, 1997, which has very good reflections on about 2 miles of remnant meanders reaching from approximately R.M. 6 to R.M. 8 of the MFFD. One can count approximately 17 full meander waves within a down-valley distance of 12,330 feet. This provides an average Lm of 725 feet. Unpublished field data from west Tennessee suggests that the bankfull width (Wbkf) is roughly one-tenth the Lm, which yields a Wbkf of 72.5 feet, in good agreement with field measurements.

Mean Bankfull Channel Depth = 8 feet

This value is the average depth at a single cross-section, not the average maximum depth along the river. This value for the mean depth is based upon recent surveys, which indicate an average value of 9 for the ratio of bankfull width to mean depth (w/d) in stable channels of west Tennessee. Using w/d = 9, we calculate that \[\text{mean depth} = \frac{\text{Wbkf}}{1/(w/d)} = \frac{72.5}{1/9} = 8.\]

Maximum Channel Depth = 12 feet, but variable

The maximum channel depth should vary markedly along the length of the channel. It should be deeper at pools on the outsides of bends, and shallower along straight reaches between pools. The best design depths for these maximum channel depth values will come from further surveys of modern rivers. As an example, in one cross-section on a straight reach of a natural channel, the ratio of mean-depth to maximum depth is 1.5. It is valid to use that ratio as a design guideline in the following way. \[\text{maximum depth} = \text{mean depth} \times 1.5 = [8 \times 1.5] = 12.\]

Bankfull Channel Cross-sectional Area = 580 ft²

Cross-sectional area = mean-depth \times Wbkf = (8)\times(72.5) = 580 ft².

Method #2: Channel Dimensions Scaled From Naturally Stable Rivers in West Tennessee

It is prudent to compare the channel dimensions derived in “method #1” to those calculated from data representing naturally-stable west Tennessee Rivers. The “regional curve” mentioned above is based upon fourteen surveyed cross-sections (Smith, Turrini-Smith, and Diehl, in progress) and eleven cross-sections measured in 1911 and 1912 (Hidinger and Morgan, 1912). We use a drainage area of 400 mi² to scale the channel geometry.

Bankfull Channel Cross-sectional Area = 650 ft²

This value is scaled directly from the regional curve developed in west Tennessee.

Bankfull Channel Width = 72 feet

For this calculation we use a width-to-depth ratio (w/d) of 8, which is in the mid-range of values measured in the field, but below the average, so that the design channel will have a greater than average ability to process a high bedload rate. \[\text{Wbkf} = [\text{Area} \times (w/d)]^{0.5} = [650 \times 8]^{0.5} = 72 \text{ ft.} \quad \text{(method described in Rosgen (1996))}\]
Mean Bankfull Channel Depth = 9 feet
Same notes as in method #1, except,
\[\text{[Mean depth]} = \frac{\text{[A]}}{\text{[Wb kf]}} = \frac{650}{72} = 9 \text{ ft}\]

Maximum Channel Depth = 13.5, but variable
Same notes as in method #1, except
\[\text{[maximum depth]} = \text{[mean depth x 1.5]} = [9 \times 1.5] = 13.5 \text{ ft}\]

These two methods converge on a similar channel design, which qualitatively improves the confidence in the results. One could easily argue for using either set of dimensions for the restored channel; however, there are two reasons to embrace the results of “method #2.” First, the scaling is based largely upon naturally stable rivers that exist in the modern watershed conditions of west Tennessee. The remnant MFFD meander geometry may reflect watershed conditions and sediment supply that differ from those of today. Second, “method #2” maximizes the capacity to move sediment and water by maximizing the cross-sectional area and hydraulic radius, while minimizing the width-to-depth-ratio. A channel of this type might not need a sediment retention basin, thus eliminating the need for costly, frequent dredging.

Channel Cross-sectional Shape
The shape of the channel should mimic natural channels as closely as possible. A wide, flat-bottom trapezoid will be less effective at transporting sediment and water at low flow because of the relatively low hydraulic radius. Figure 3 provides an example of a natural cross-section measured in a straight reach of a stream in west Tennessee. It has been scaled-up slightly to better represent the proper dimensions for MFFD.

Figure 3: Little Hatchie River above Powell Chapel Road--dimensionally scaled to represent a channel that would be formed by 400 mi$^2$ drainage area
Channel Pattern

The pattern, including meander length, radius of curvature, meander belt width, and floodprone width should be based upon the existing remnant meanders. Where there is no remnant meander for a template, the design channel should follow a path generated by taking average values from existing meanders. For example, a meander length of 725 feet is appropriate, based upon measurements from aerial photography.

Average Channel Profile

The average slope of the restored channel should be based upon the geometry of the remnant meanders. The slope may be calculated by dividing the valley slope (Sv) by the remnant channel sinuosity (k) (e.g., Leopold and Wolman, 1957). The valley slope is 0.00035 based upon the spacing of 10 foot contours along the MFFD canal on the “Friendship” U.S.G.S. 1:24,000 Quadrangle. The sinuosity is 1.8 based upon the ratio of channel length to valley length on a 1:10,000-scale aerial photograph (N10NAPPW09772130). So, channel slope = Sv/k = 0.00035/1.8 = 0.0002. This average channel slope approximates the surface water slope at bankfull discharge. In pools and straight reaches the channel bottom slope should markedly deviate from the average channel slope value. The values for pool slopes and straight-reach slopes will come from detailed surveys on existing natural channels. The average slope value given above may change somewhat as surveys obtain a more precise estimate of the valley slope.

Construction Procedures

Construction procedures should use in-channel excavators, barges, and dredges. In-channel excavators are low-impact, tracked vehicles that can work from within the channel, and barges will carry and stockpile spoil and woody debris from the excavation work. The great advantage of that approach, as compared with the existing plan, is that the riparian vegetation along the newly excavated banks will remain intact, or at least, less impacted. The preservation of undisturbed vegetation along a new, steep-sided channel margin is one key to ensuring channel stability. The proposed State Plan would result in the removal of bank vegetation, and the channel banks are to be laid back at a 2-to-1 slope. Under these conditions, the banks will be extremely vulnerable to liquefaction and slope failure. If the banks are allowed to slough into the channel bottom, a low w/d channel will not be achieved, thus compromising the sediment transport capacity. Revegetation of newly-graded banks is more expensive and riskier than leaving existing vegetation in place.

In general, there will be two sources of spoil—(1) the newly dug or cleaned out natural channel, and (2) removal of old levees, dikes, and spoil piles that currently exist on the floodplain. Most of the spoil should be used to fill in long reaches of the existing canal. The project should use very low impact tracked excavators to clean out the old channel and construct new channel where necessary. The spoil material, carried by barges or dredge slurry pipes, will incrementally fill the canal. In reaches where spoil cannot be carried to a barge or siphoned by dredge, the material should be spread evenly about the adjacent floodplain by throwing it sideways from the excavator bucket.

Not all of the ditch will be filled in with new spoil. Fairly long reaches of the old ditch will be left as floodplain ponds that simulate the physical and biological function of natural oxbow lakes. These lakes can be excellent habitat for waterfowl and fisheries. Small sinuous channels can be excavated to connect these “oxbow” lakes with each other and with the new
channel to maintain fresh water flow. This hydrologic connectivity will keep the lakes from stagnating, and will provide access routes for juvenile fish.

Stockpiled large woody debris (including entire trees with crowns) and sediment should be firmly packed in the canal adjacent to the cross-over points. This blockage will eliminate hydraulic connectivity between the new channel and blocked canal. Elsewhere in west Tennessee, there are canals that are totally occluded by woody debris and sediment--these locations are the natural model for occluding the MFFD canal at the cross-over points.

If the sediment excavated from the natural channel is water saturated, then a suction dredge can be employed to transport the excavated material directly to the canal, thereby limiting the need for sediment barges. A sediment-water slurry can be moved through slurry pipes laid across the floodplain. Some combination of suction dredge and sediment barge may be employed to facilitate construction.

**Evaluation of State Plan Restoration**

The contract requests an evaluation of the State Plan design as rendered in the LRR. This section, provides a general assessment of the potential outcomes of the proposed WTT project, paying particular attention to design features such as the weir placement, weir height, levee removal, sediment retention basin and channel design.

**Summary**

- HEC hydrologic models are not appropriate for modeling natural rivers that have erodible banks and relatively high loads of large woody debris.
- The design capacity of 300 cfs is much smaller than a natural channel in a watershed ranging from 369 mi$^2$ to 485 mi$^2$. A deeper channel will accommodate higher discharge, and will be able to transport a higher sediment load, thus reducing the risk of premature failure from sand aggradation.
- The sediment retention basin will require dredging on average ten times per year, based upon the information in the LRR. The bedload sediment transport rate in the MFFD canal directly upstream from the proposed sediment retention basin has not been measured. Without that data, a more precise estimate of the frequency of dredging is not available.
- If the sediment basin is not dredged during severe storms, when much of the sediment will be transported, then the in-channel basin will be in danger of filling with sediment. The result may be channel avulsion at the point of blockage in the retention basin, or aggradation of the restored channel.
- The bedload sediment transport rate has not been measured in significant tributaries, such as Cypress Creek, Epperson-Buck Creek, and Buck-Davis Creek. Assuming that the sediment trap captures much of the excess sediment coming from above the restoration reach, there is still abundant sediment contributed by Cypress Creek and other tributaries downstream from the retention basin.
- Values of Manning’s “n” should be derived from analogous, natural channels in west Tennessee. Field-derived values will provide more confidence in evaluating this and future restoration designs.
Computer Models

The primary basis for the LRR evaluation of the long-term stability of the proposed State Plan design has been through computer simulations using the HEC computer models. Computer models are fundamentally based upon physical data and physical constraints. One assumption in any computer model is that the system being modeled is very similar to the system on which the computer model is based. That assumption is not validated for the dual-channel design. Three particularly important shortfalls in the numerical analysis are: 1) the HEC models do not accommodate bank erosion or deposition, 2) natural channels in west Tennessee transport or store substantial quantities of large woody debris, which has not been modeled, and 3) natural channels migrate, sometimes great distances, in 50 years. The local channel geometry is constantly changing. If the HEC models do not consider those physical realities of natural rivers, then there will be unexpected results when the design is implemented in the field. Lastly, no small-scale physical models, or full-scale examples exist. Without a physical analog for design guidance, there is great uncertainty (low confidence) in the meaning of numerical simulations.

There have been no measurements of bedload transport rate in the MFFD canal or tributaries feeding the proposed restoration reach. It is shown below that the State Plan channel will have the hydraulic radius required to easily move the .35 mm diameter sand (Bryan et al., 1995) typical of the watershed. On the other hand, there is little confidence that the channel will be able to move the volume of sediment required for long-term stability. The calculated annual sediment yield from the sediment retention basin will have more credibility if the sediment transport rate is known. The rate of sand transported from the tributaries located downstream from the retention basin is also unknown. Field-based sediment discharge data are essential for thorough design evaluation.

Natural Analogs

Although naturally braided and anastomosing river systems have “multiple” channels, the “dual” channel system departs from those natural analogs in several ways. The most important departure is the ability to adjust the relative capacity and number of active channels in response to changing inputs of discharge and sediment. This constraint will prevent the two channels from adjusting cross-sectional dimensions to changes in sediment load and discharge. Natural rivers adjust in a variety of ways to maintain equilibrium during and following changes in discharge and sediment supply through time (Hey, 1978).

Weir Placement

According to the LRR, seven weirs are to be constructed where the natural channel and canal intersect. Their purpose is to partially block the upstream end of each canal reach so that approximately 300 cfs is routed to the restored channel. The weir placements will serve their intended purpose. (Note: the first paragraph on page 22 of the LRR makes reference to Plate 9, which should be changed to Plate 10.)
Weir Height

The weir spillway heights provided in the LRR (Table 1) range from 2.1 feet to 6.2 feet above “existing ground,” which is assumed to be the design elevation of the State Plan channel bottom. If this assumption is true, then the weir heights in Table 1 must represent the estimated stage at 300 cfs. As the channel design has a flat bottom (LRR, p. 22), the weir height (Table 1) is also the maximum channel depth in the restored channel. A trapezoid with a 2.1 foot maximum depth, and a 300 cfs capacity will have a very large width-to-depth ratio. The channel will have a very low capacity to move sediment. Several of the channel depths (Table 1) are too low (3.7 ft. average depth) for efficient water and sediment transport.

Table 1: Weir Spillway Heights (from LRR Table VI-3, Appendix 1)

<table>
<thead>
<tr>
<th>MFFD Cross-section Number</th>
<th>Weir Spillway Height (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.29</td>
<td>2.1</td>
</tr>
<tr>
<td>8.15</td>
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<td>6.2</td>
</tr>
<tr>
<td>15.23</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Levee Removal

It is difficult to evaluate the planned levee removal without a knowledge of the existing levees. In general, it would be prudent to remove all existing levees that impede either the lateral or down-valley flow of at least the 50-year flood.

Sediment Retention Basin

The State Plan design will rapidly fail without frequent maintenance of a sediment retention basin (LRR, p. 20, Appendix 1). The LRR (p. 20, Appendix 1) calls for “frequent maintenance” on the retention basin, but there is no stated frequency. Although we can estimate the clean-out frequency based on the available data, the estimate does not carry much confidence until the bedload transport rate is measured on the MFFD canal above, but near, the MFFD restoration reach. Below is an estimate of the frequency of clean-outs.

The HEC-6 model described in the LRR (p. 20, Appendix 1) has indicated that the State Plan channel will be at risk when the retention basin fills to more than 20% of its cross-sectional area. The LRR (p. 27, Appendix 1) also reports that the annual excess sediment will be 20,000 cubic yards. Using the calculated volume of the retention basin with the above data allows an estimate the frequency of clean-outs. Figure 4 (from LRR Figure VII-3, Appendix 1) depicts the State Plan retention basin as being only 400 feet long, but the text describes a 1000 foot long basin (LRR, p. 23). For a conservative estimate of clean-out frequency, assume a 1000-ft long basin that has the largest cross-section depicted in Figure 4. The largest transverse cross-sectional area of the basin is 260 ft$^2$, which gives an estimate of 260,000 ft$^3$ of total volume, when multiplied by the 1000 ft basin length. Twenty percent of that volume is 52,000 ft$^3$. That volume represents the functional “capacity” of the basin. 52,000 ft$^3$ is equal to 1,926 yd$^3$. Therefore the clean-out frequency will be 20,000 yd$^3$/yr. divided by 1,926 yd$^3$/clean-out, or an
average of 10 clean-outs each year.
Figure 4: Design for Sedimentation Retention Basin from LRR Figure VIII-3, Appendix 1.

Original report had a photocopy of LRR Figure VIII-3. This figure was not available in digital format for this pdf file.
The ten clean-out times will not be evenly distributed through the year because sediment transport is seasonal. The times of greatest sediment transport, and therefore greatest need for dredging will be during high water. The cost and technique for performing regular clean-outs during flood conditions is difficult to estimate, especially if there is concern about introducing excess fine sediment into the water column during each dredging. Conversely, if sediment is not dredged as needed, the sediment retention basin and restored channel will be at risk of aggradation, blockage, and avulsion.

It is highly recommended that data on the volume of bedload transport near the location of the proposed sediment retention basin be collected before designs are finalized. These data will reduce the risk of premature project failure, will provide a more realistic basis for estimating dredging costs and frequency, and will provide a basis for monitoring the success of BMPs and channel stabilization measures in the upper watershed of MFFD.

It is also recommended that if a sediment basin is ultimately deemed necessary, an “off-channel” basin be evaluated. An off-channel basin has two important advantages over an in-channel basin. First, there is no disruption of the physical integrity of the main channel or impairment of water quality during dredging. Second, a larger basin can be used, greatly reducing the frequency of dredging, or perhaps eliminating the need for dredging.

Sediment

In addition to determining the bedload transport rate in the main canal of the MFFD, it is recommended that bedload sediment studies be completed on the main tributaries entering the restoration reach. These tributaries include Buck-Davis, Epperson-Buck, and Cypress Creeks. It is important to determine their potential impact on the restored channel system prior to final project design.

Channel Design

There are two fundamental problems with the proposed State Plan channel design as it is presented in the LRR.

- The State Plan channel is undersized for its drainage area. The initial premise in the design of the State Plan channel is that the remnant meanders reflect a bankfull discharge of 300 cfs, which is an underestimation of the original capacity.
- The State Plan channel shape is not typical of naturally-functioning streams in west Tennessee. As discussed previously, a wide, shallow trapezoid is not an efficient shape for transporting the high volume of bedload that is present.

These points are underscored by comparing a sketch of the proposed State Plan channel to modern and historical natural channels (Fig. 5; Tables 2, 3 and 4). The sketch of the “State Plan” channel (Fig. 5) is based upon the available dimensions (LRR, p. 22): 75 ft. top width, 2-to-1 side slope, and a depth of 5 feet. A depth of 5 feet is greater than the typical maximum depth of 3.7 feet at the cross-over points (Table 1), but it is a dimension that is commonly referred to in discussions of the State Plan design.
Figure 5: Channel cross-sections of the proposed State Plan, and a scaled-up depiction of the Little Hatchie River.
Table 2: Hydraulic parameters for State Plan channel (Stream Type C5)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>cross-sectional area</td>
<td>303 ft²</td>
</tr>
<tr>
<td>width</td>
<td>75 ft.</td>
</tr>
<tr>
<td>depth (maximum)</td>
<td>5.0 ft.</td>
</tr>
<tr>
<td>depth (average)</td>
<td>4.0 ft.</td>
</tr>
<tr>
<td>width-to-depth ratio</td>
<td>18.6</td>
</tr>
<tr>
<td>hydraulic radius (R)</td>
<td>3.9 ft.</td>
</tr>
<tr>
<td>channel slope (S)</td>
<td>0.0002</td>
</tr>
<tr>
<td>average shear stress (τ)</td>
<td>0.049 ft. lb. (R x S x specific weight of water)</td>
</tr>
<tr>
<td>critical diameter</td>
<td>4 mm (Shields criteria, which is not for natural mixtures of river sediment)</td>
</tr>
<tr>
<td>velocity</td>
<td>1.0 (assuming Manning’s roughness = 0.05 as in LRR)</td>
</tr>
<tr>
<td>discharge</td>
<td>316 (V x A)</td>
</tr>
<tr>
<td>excess τ</td>
<td>0.044 (after moving 0.35 mm sand (ignoring bedform drag))</td>
</tr>
</tbody>
</table>

Table 3: Hydraulic parameters for scaled Little Hatchie River channel (Stream Type E5).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>cross-sectional area</td>
<td>653 ft²</td>
</tr>
<tr>
<td>width</td>
<td>72 ft.</td>
</tr>
<tr>
<td>depth (maximum)</td>
<td>13.7 ft.</td>
</tr>
<tr>
<td>depth (average)</td>
<td>9 ft.</td>
</tr>
<tr>
<td>width-to-depth ratio</td>
<td>8</td>
</tr>
<tr>
<td>hydraulic radius (R)</td>
<td>7.8 ft.</td>
</tr>
<tr>
<td>channel slope (S)</td>
<td>0.0002</td>
</tr>
<tr>
<td>average shear stress (τ)</td>
<td>0.097 ft. lb. (R x S x specific weight of water)</td>
</tr>
<tr>
<td>critical diameter</td>
<td>7 mm (Shields criteria, which is not for natural mixtures of river sediment)</td>
</tr>
<tr>
<td>velocity</td>
<td>1.6 (assuming Manning’s roughness = 0.05 as in LRR)</td>
</tr>
<tr>
<td>bankfull discharge</td>
<td>1077 (V x A)</td>
</tr>
<tr>
<td>excess τ</td>
<td>0.093 (after moving 0.35 mm sand (ignoring bedform drag))</td>
</tr>
</tbody>
</table>

Historical surveys conducted in 1911 and 1912 provide an estimate of the dimensions of the rivers in the Forked Deer basin at that time. According to surveys by Hidinger and Morgan (1912), the following stream dimensions existed near the end of the nineteenth century (Table 4).

Table 4: Channel dimensions typical of the South Fork Forked Deer River in 1911-1912

<table>
<thead>
<tr>
<th>R.M.</th>
<th>Notes</th>
<th>Drainage Area (sq. mi.)</th>
<th>Channel Width (ft.)</th>
<th>Channel Depth (ft.)</th>
<th>Channel Area (sq. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>road</td>
<td>1120</td>
<td>95</td>
<td>12</td>
<td>1140</td>
</tr>
<tr>
<td>20</td>
<td>ferry</td>
<td>1070</td>
<td>85</td>
<td>12</td>
<td>1020</td>
</tr>
<tr>
<td>30</td>
<td>L.&amp; N. R.R.</td>
<td>860</td>
<td>85</td>
<td>15</td>
<td>1275</td>
</tr>
<tr>
<td>33</td>
<td>-</td>
<td>-</td>
<td>80</td>
<td>15</td>
<td>1200</td>
</tr>
<tr>
<td>37</td>
<td>680 road</td>
<td>680</td>
<td>70</td>
<td>14</td>
<td>980</td>
</tr>
<tr>
<td>42</td>
<td>-</td>
<td>-</td>
<td>70</td>
<td>14</td>
<td>980</td>
</tr>
<tr>
<td>47</td>
<td>540 Chester @ levee of Jackson</td>
<td>540</td>
<td>100</td>
<td>12</td>
<td>1200</td>
</tr>
</tbody>
</table>

These historical data indicate that the restored MFFD channel should have a much deeper channel and greater cross-sectional area than called for in the State Plan. The State Plan channel
width (75 ft.) is commensurate with the widths measured in 1911-1912. The agreement between widths, but not depths, is to be expected, because the State Plan design is based on paleo-channel data, and channel widths are better preserved than depths. Borings or shallow geophysical work could be performed to better estimate the true original depths and geometry of the MFFD natural meanders.

It is also instructive to compare the State Plan channel design with modern, naturally-formed channels of west Tennessee (Fig. 5, Table 2, and Table 3). The recommended channel design (see above), which is derived from both geomorphic principles and a recent study of modern rivers, strongly suggests that the State Plan channel is undersized. The chief difference is that natural channels are deeper, but do not have a flat bottom. Both of those points are important for effective sediment transport.

In summary, based upon these lines of geomorphic evidence, the restored channel capacity should be far above 300 cfs to satisfy the State Plan goals of improving and restoring “natural drainage patterns” by recreating the prehistoric conditions (LRR, p. 22).

Channel Hydraulics

The State Plan channel cross-sections typically have a cross-sectional area of about 300 ft\(^2\). If the design discharge is 300 cfs, then the average design velocity is about 1 ft/s (Table 2). This velocity is underestimated based upon measurements at USGS and ACOE gage sites and field observations at the MFFD canal during channel-full conditions. Observations of natural channels of the same approximate slope and dimension should be used to better predict the design velocity.

As noted in this report, the most important parameters for creating a geomorphically stable river, given high bedload conditions, is to minimize the width-to-depth ratio while maximizing the hydraulic radius, within the limits found elsewhere in the physiographic province. A comparison of width-to-depth ratios and hydraulic radius values in Table 2 and Table 3 indicate that State Plan channel design can be improved.

It is unclear how the value of Manning’s “n” was derived for use with the HEC models. The value of "n" used in the HEC models ranges from 0.05 to 0.055 (LRR, p. 14, Appendix 1). This range may be too high. According to Rosgen (1994), E5 and E6 stream types typically have an “n” value of about 0.034. On the other hand, the value published by Rosgen (1994) may be too low because it was not derived from west Tennessee streams where large woody debris can significantly increase the hydraulic roughness (Shields and Gippel, 1995). It is strongly advised that an average value of “n” be empirically-derived for E5 streams in west Tennessee. A field-verified value will help calibrate future HEC modeling for channel design.

“Strategy Report”

The contract requests a “strategy report” for rivers of west Tennessee. The report includes a summary of stream types, advice for restoration and maintenance, recommendations for demonstration sites, and recommendations for long-term management strategies.

Stream Types (Rosgen, 1994 classification)

Relatively undisturbed, or recovering, stream reaches of the Obion and Forked Deer basins have the following physical characteristics. They are sinuous, low gradient, single-channel streams. They have low-to-moderate width-to-depth ratios (3-20) and easy access to a very
broad floodprone area (entrenchment ratio >20). They all carry fine- to medium-grained sand, or have muddy bottoms. These features are remarkably uniform in streams of all sizes, ranging in drainage area from a few square miles to thousands of square miles. The above features place the relatively pristine streams in the C5, C6, E5, and E6 categories. Some B5 streams and G5 gullies occur in higher-gradient headwater catchments. F5 and F6 streams are pervasive throughout west Tennessee where head-cutting or ditching has caused incision, resulting in channels that are out of equilibrium.

Many of the dug canals in west Tennessee, including the Middle Fork of the Forked Deer canal, have a low width-to-depth ratio value, but little or no sinuosity. Thus, the channelized reaches commonly have some, but not all, of the qualities of an E stream type.

Restoration Strategies

The appropriate techniques for restoring the disturbed rivers of west Tennessee are highly variable, depending upon site-specific details. The streams perched upon highly-erodible loess soils will have different, site-specific strategies than the sand-choked rivers east of Jackson. Although there is no “one-size-fits-all” advice for restoration, an approach utilizing the general methodology that is outlined in the “Preferred Channel Geometry” section above is recommended. The most important consideration when attempting restoration projects is to match the geometry of stable streams that exist in the same watershed conditions as the disturbed stream. Caution is advised in the use of computer models for design work, unless the input parameters are based upon actual field data from the river or region and important materials, such as large woody debris, are included in the analysis.

A specific restoration strategy that will work well in west Tennessee is to foster the recovery of rivers reaches that are naturally recovering from channelization. There are several examples of naturally-recovering streams in west Tennessee. The philosophy would be to observe how the river is naturally recovering, and to accelerate those same processes using the appropriate scale of technology (hand saws, track-hoe, dynamite charges, etc.). A policy that encourages the augmentation of natural stream recovery offers the lowest-cost, lowest-risk restoration opportunities because natural processes are harnessed to do much of the work and maintenance. The best opportunities will be found where the dug canal is partially or completely occluded by sediment or woody debris. Occluded ditches provide the opportunity to naturally redirect low flows into the floodplain (avulsion) where the water naturally seeks the old meanders (Fig. 5). The old meanders can be cleared of woody debris, and enlarged, if necessary, to improve the hydraulics. Specific sites for this low-risk, low-cost approach are numerous, including Cypress Creek below Ramer, the South Fork of the Obion near Jarrell Bottoms, the MFFD at the “Old River Run,” and the MFFD at O’Brien/Law Road.

For restoration of deeply incised systems, Rosgen (1997) offers a four-priority strategy.

Long-Term Management Strategies

West Tennessee represents a challenge for long-term management for a variety of social, economic, and physical reasons. It is a region with some unique problems that might require unique solutions. For this reason, the most important suggestion for a long-term management policy is a diligent program of physical monitoring, for both natural and restored rivers. Physical monitoring of restoration projects will reveal trouble spots before they become failures,
Figure 5: Block Diagram Illustrating the Processes of Sedimentation and Avulsion in Certain Channelized Streams of West Tennessee. (Note: This figure is modified from the original report, improved in 2004)

The diagram below was published by Happ et al. (1940). It was meant to represent typical conditions in a region of Mississippi, but it is directly analogous to conditions in some west Tennessee valley bottoms where excess sediment and large woody debris have naturally occluded the canal. At sites where this process is not yet complete, the natural recovery process can be augmented as a low-risk, low-cost strategy for stream restoration.
and will reduce the long-term cost of restoration efforts. Physical monitoring of natural rivers will provide a basis for understanding how much erosion and channel migration is expected of healthy rivers. Physical monitoring of the bedload of natural channels will also provide a basis for defining when “excess” sediment may lead to physical or biological damage in a river. Physical monitoring includes quantifying changes in channel dimension, pattern, and profile, and sediment load. Specific further recommendations are divided into tributary management and bottomland management.

**Tributary management** is needed to reduce the sediment supply entering the bottomland rivers. Specific issues include:
- continue implementing BMP’s for agricultural lands throughout the region
- more stringent BMP guidelines on erosion control from construction sites
- the use of multiple stream culverts beneath roadways—a great majority of road culverts in west Tennessee concentrate flow, thereby greatly accelerating erosion on the downstream side of each culvert. This erosion is mitigated by constructing separate culverts for channel and floodplain flow.
- revegetating and stabilizing the numerous gullies that feed a large volume of sand from the Sand Hills geomorphic province to the Forked Deer, Obion, and Hatchie rivers. In some of the badlands that are riddled with gullies, the landscape must be graded before revegetation efforts will be successful. There are regions in west Tennessee with “healed” gullies that can be used as models for grading and revegetating active gullies. In some areas, the techniques described in Rosgen (1997) can be used to restore incised and gullied streams to a more stable geometry.

**Bottomland management** should be geared toward fostering the health of natural meandering channels within the context of broad, unobstructed floodplains. This management direction would discourage land use on the valley bottoms that would (1) inhibit the flow and ebb of flood waters, or (2) result in monetary loss or hardship to the land owners as a result of frequent natural flooding. This policy includes prohibiting the construction of levees or berms, and discouraging the maintenance of channelized streams. Once meandering channels become established, a program of “SORG” (IAFWA, 1983) practices will reduce the risk of channel shifts initiated by large woody debris. In localities where high bedload discharge from tributaries is threatening the stability of natural channels, a sediment retention basin can be placed along the tributary, above the confluence with the bottomland channel.

A long-term management plan for west Tennessee will require an understanding of “valley plugs” (Happ et al., 1940; Diehl, 1994, 1997a, 1997b). Valley plugs are reaches of river blocked by large woody debris and sediment. The blockages impede the flow of water. Valley bottoms aggrade as sediment settles from the slowly moving backwater located upstream from the blockage. The valley plug produces backwater effects until sediment and aquatic vegetation fill in the valley bottom up to the level of the standing water. Eventually, the valley plug and floodplain reach an equilibrium elevation, or graded condition, and a newly-formed natural channel system again drains the floodplain. Thus, valley plugs are “temporary” features in a sense. Valley plugs are prevalent in the modified bottoms of west Tennessee (Diehl, 1994, 1997a) and Mississippi (Happ et al., 1940), and they may have been important in pre-European times as well. The negative consequence of a valley plug is that there is greater than normal flooding of the valley.
bottom above the blockage, which may result in timber kills and agricultural land loss. The benefit of a valley plug is that it forms a natural sediment retention basin that has great capacity and that never requires maintenance. The water emanating from the front of a valley plug typically carries less suspended sediment and bedload, leaving downstream reaches with a reduced risk of damage from excess sediment.

The questions that remain unanswered include:

- Are valley plugs a part of the natural long-term geometry of west Tennessee river valleys?
- How do the environmental and social benefits of valley plugs compare to the costs?
- Do valley plugs serve an important biological or ecological function? Are the various valley plug environments key to the healthy biodiversity of low-gradient, meandering rivers of west Tennessee?

**REFERENCES CITED**


