

EXECUTIVE SUMMARY

Root River Sediment-transport Planning Study

May 4, 2007
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INTRODUCTION

The Root River Sediment-transport Planning Study that is the subject of this report was prepared for the Milwaukee Metropolitan Sewerage District (MMSD) by Mussetter Engineering, Inc. (MEI) and our subconsultants DTM Consulting, TN & Associates, Inc., Mainstream Restoration and Cedarburg Science, LLC. The primary purposes of the study were to provide MMSD with: (1) a baseline analysis of existing channel stability conditions within the North Branch of the Root River and its principal tributaries, and (2) with hydrologic, hydraulic and sediment transport tools with which to predict the impacts of any future proposed work for flood management purposes on the vertical and lateral stability of stream channels within the District's jurisdiction (MMSD, 2005). Results of the study indicate that the North Branch and its principal tributaries are generally vertically and laterally stable and that they are somewhat insensitive to hydrologic changes in the watershed. Limited channel maintenance requirements were identified by the study, and it is highly recommended that MMSD continue its open lands protection policies. The MMSD project manager for this study was Mr. David Fowler, and MEI's project manager was Dr. Robert Mussetter, P.E.

The report is presented as a series of independent Technical Memoranda that were prepared during the course of the project, and include the following:

- Root River Sediment-transport Planning Study –Surveying (S)
- Root River Sediment-transport Planning Study- Hydrology (HY)
- Root River Sediment-transport Planning Study – Hydraulics (HA)
- Root River Sediment-transport Planning Study – Geomorphology (G)
- Root River Sediment-transport Planning Study - Sediment Transport (ST)
- Root River Sediment-transport Planning Study – Management Recommendations (MR)

Tables and figures cited in this Executive Summary are referenced to their respective Technical Memoranda. The sediment transport planning study was focused on the 17 miles of the North Branch Root River from the South 124th Street crossing to the confluence of the North and South Branches because of the availability of suitable scale topographic mapping and jurisdictional boundaries (Figure HY.1). A reconnaissance-level geomorphic assessment was conducted by MEI of the Root River in Milwaukee and Racine Counties between the North and South Branch (Root River Canal) confluence and the Crayfish Creek confluence (Figure G 1.1).

The study watershed is located in Milwaukee County, and includes a number of jurisdictional and non-jurisdictional tributaries that are within the MMSD planning area (Figure HY.1). Tributary drainages included in the study were: Hale Creek, Wildcat Creek, 104th Street Ditch, Whitnall Park Creek (including the North Branch and Northwest Branch), Tess Corners Creek, Dale Creek, East Branch Root River, Tuckaway Creek, Legend Creek, Ryan Creek and

Crayfish Creek. Existing conditions in the report refer to physical conditions that were observed and measured during the field work that was carried out by MEI between July 2005 and August 2006 and the year 2000 hydrology, and future conditions are referenced to the year 2020 hydrology (CDM, 2000).

1. SURVEYING (S)

Cross sections of the North Branch Root River (118) and five of the primary tributaries (two per tributary) that were required to develop one-dimensional hydraulic models (HEC-RAS) of the channels were surveyed by MMSD survey crews between September 2005 and August 2006 using control that was set by TN & Associates, Inc.. The surveyed cross sections were extended into the overbanks using the available SEWRPC 2-foot contour interval mapping of Milwaukee County that was developed from aerial photography taken on April 26, 1993, and March, 26, 1999.

2. HYDROLOGY (HY)

An evaluation of the hydrologic characteristics of the North Branch Root River was conducted by MEI using mean daily and peak flow data from the Root River near Franklin, Wisconsin stream gauge (USGS Gauge No. 04087220 with a 42-year period of record from 1964-2005) and an HSPF-based rainfall-runoff model that was initially developed by SEWRPC to evaluate high magnitude, low frequency events (CDM, 2000). The median discharge at the gauge during the period of record was about 17 cubic feet per second (cfs), and the discharge exceeded 4.3 cfs about 90 percent of the time and 93 cfs about 10 percent of the time. The 2-year peak flow at the Franklin gage is about 970 cfs, the 10-year peak flow is about 2,210 cfs, and the 100-year peak flow is about 4,660 cfs.

A comparison of the gage records with the results from the HSPF model at the gauge indicated that the HSPF model over-predicts the discharge for flows greater than the 90-percent exceedence level, with flows in the range between the 50- and 5-percent exceedence levels over-predicted by a factor of about two (Figure HY.5). The estimated peak flows from the HSPF model were also significantly higher than the measured peak flows and the flood-frequency curve at the gage that is based on the gage data, for recurrence frequencies less than about the 50-year event (Figure HY.7). However, since no other hydrologic model of the watershed exists, with the concurrence of SEWRPC, the HSPF model output volumes were adjusted by MEI to better reflect the gage data. Peak flows were developed from regional runoff relations (Walker and Krug, 2003).

The existing conditions (2000) runoff volumes from the HSPF models were adjusted to better match the measured data, and then were used to develop flow-duration curves for the North Branch Root River at the confluences with the primary tributaries and for the 10 major tributaries (Figures HY.11 and HY.12). Existing conditions (2000) peak flow estimates were developed by adjusting the USGS regional regression equations for rural streams to account for the urbanization of the North Branch Root River watershed (Walker and Krug, 2003). Based on the amount of urbanization, the 2-year peak flow has increased by a factor of about 1.6, the 5-year peak flow has increased by a factor of about 2.6, the 10-year peak flow event has increased by a factor of about 2.8 and the 100-year peak flow has increased by a factor of about 4 from undeveloped conditions. Future development (2020) is estimated to increase the runoff volumes by between 3 percent (Hale Creek) and nearly 50 percent (East Branch Root River), with an average increase over the entire basin of approximately 10 percent. Future (2020) peak

flows will increase by about 15 percent at the 2-year recurrence interval flow, and about 5 percent at the 100-year recurrence interval flow (Figure HY.16).

3. HYDRAULICS (HA)

A one-dimensional HEC-RAS model was developed by MEI to assess the channel capacity along the project reach and to develop hydraulic input for the sediment-transport analysis. Downstream boundary conditions for the model for flows less than the 1-percent exceedence flow (480 cfs) were established by assuming normal-depth with an energy slope of 0.0006. Because of backwater conditions caused by the floodplain constriction at the South 60th Street Bridge (Harza, 1966), the downstream boundary condition for flows greater than or equal to the 10-year event were taken from SEWRPC (1990, Figure 34). Based on geomorphic characteristics and the locations of tributaries, the project reach was subdivided into 10 subreaches (Subreach 1 is upstream and Subreach 10 is downstream) (Table HA.4).

The HEC-RAS model was run by MEI for a range of discharges from baseflows through the future conditions 100-year flood peak. The flow distribution along the project reach was established by adjusting the discharge to reflect tributary inflows. The model indicated that significant backwater occurs at discharges greater than the existing conditions 2-year peak flow upstream from the Root River Canal (Subreach 10), West Rawson Avenue (Subreach 6), South 76th Street (Subreach 5), West College Avenue (Subreach 4), and West Forest Home Avenue (Subreach 3) (Figure HA.5).

The HEC-RAS model output indicates that hydraulic conditions (i.e., velocities, depths, and main channel topwidths) vary considerably through the project reach due to variations in the local slope, channel geometry, hydraulic roughness conditions, and downstream hydraulic controls. The average main channel hydraulic depth at the 2-year flood peak ranges from about 2.1 feet in Subreach 1 at the upstream end of the study reach to about 6.5 feet in Subreach 10 (Figure HA.6). Main channel velocities are highest in Subreaches 1, 4 and 7 (Figure HA.7). Low main channel velocities (less than 1.2 fps) occur in Subreach 6, due to the low channel gradient and high hydraulic roughness that results from the presence of significant woody debris in this swamp-bound portion of the reach. Average main channel topwidth increases in the downstream direction from Subreach 1 (19 feet) to Subreach 3 (51 feet) at the 2-year peak discharge due to the increase in contributing drainage area (Figure HA.8). Channel capacity is relatively consistent, ranging from the 1-percent exceedence flow on the mean daily flow-duration curve to the existing conditions 2-year peak discharge.

4. GEOMORPHOLOGY (G)

The Root River watershed and channels have undergone significant changes as a result of agricultural development and use, removal of riparian corridors, urbanization, sand-and-gravel mining, construction of small dams and reservoirs, channelization for flood control purposes, and installation of structures for erosion control (bank protection) and transportation purposes (bridges and culverts). The earliest information available on the geomorphic conditions in the project area is provided on the 1906 and 1907 U.S. Geological Survey (USGS) maps (Figures G.1.3 and G.1.4). At the time of the mapping, the North Branch Root River and its larger tributaries, as well as the Root River, were low sinuosity streams ($P < 1.5$) that occupied the north-south trending valley bottoms between the hills that were formed by glacial moraines (Alden, 1906). Steeper portions of the tributaries flowed across the moraines. In general, the

ground moraine till in the valley bottom is more consolidated and erosion-resistant than the end moraine till on the hillsides (Figure G.2). Field observations by MEI in the North Branch Root River and its tributaries indicate that lateral erosion of the end moraines is currently the source of most of the coarser sediments (gravels) in the channels.

Aerial photography in 1950 and 1956, as well as the 1958 USGS map of the watershed that covered the North Branch to the Racine County line, clearly indicate that the North Branch Root River from about West Oklahoma Avenue to the abandoned MHL & T Railroad Bridge just downstream of West Layton Avenue had been channelized. Channelization was probably done with floating dredges in the early 1900s (Harza, 1966). The spoils were bermed on either side of the channel and along most of the channelized reach; they remain in place and act as levees. The lower reaches of Hale Creek, Wildcat Creek, 104th Street Ditch and Ryan Creek, and the upper reaches of the East Branch of the Root River north of West College Avenue were also channelized. The remainder of the North Branch Root River and the other tributaries were not channelized, and it appears that the current planform of the river is very similar to that mapped in 1958, which indicates that rates of lateral adjustment of the North Branch Root River have been low.

4.1. Channel Characteristics

In general, the bankfull capacity of the North Branch Root River between the Root River Canal confluence and West Layton Avenue (Subreach 10 to the upstream portion of Subreach 3) is about the 1-percent exceedence flow, which ranges from 578 cfs in Subreach 10 to 111 cfs in Subreach 3 (Figure G.3.13). The 1-percent exceedence flow under existing conditions is equivalent to the 2-year peak flow under rural and unregulated conditions in the watershed, which suggests that there has been very little channel response to the increased flows resulting from urbanization of the watershed. This is probably due to the combined effects of highly erosion-resistant bed and bank materials (consolidated and clay-rich ground moraines), wide floodplains, and generally low energy that make the North Branch Root River insensitive to hydrologic change (Schumm, 1991). In the channelized reach between West Layton Avenue and National/Oklahoma Avenue (Subreach 2), where the dredged berms are still in place, the bankfull capacity is the 2-year peak flow (200 to 400 cfs). Upstream of the Hale Creek confluence in the highly confined Subreach 1, the bankfull capacity ranges from the 5- to 100-year event (200 to 700 cfs). The bulk of the observed channel erosion, both lateral and vertical, occurred in Subreaches 1 and 2 and the upstream part of Subreach 3, where the relative magnitude of the in-bank flows are the highest and the channel was modified either directly by channelization (Subreaches 2 and 3) or by baselevel lowering (Subreach 1).

4.2. Large Woody Debris

A high frequency of large woody debris jams (9-18/mile) is present in the middle subreaches of the North Branch Root River (Subreaches 4 to 6), due to the presence of a higher density of woody riparian vegetation along the channel margins within the Parkway (Table G.2.1). Reduced agricultural use of the floodplain has increased the density and extent of the riparian forest since the 1950s, and therefore, it can be expected that a high frequency of woody debris jams will continue to be present in the channel. This is in contrast to the conditions reported in the 1960s by Harza (1966) who commented on the low incidence of woody debris in the North Branch channel.

4.3. Tributary Controls

In general, where the tributaries deliver gravels to the North Branch Root River, the channel bed immediately downstream of the confluence is composed of coarse gravels that are mobilized very infrequently by the North Branch. As a result, the tributaries create local hydraulic and geomorphic controls in the North Branch. Downstream of the local gravel accumulations, the bed material rapidly fines to sand. Because of the local tributary contributions of coarse sediments, the North Branch does not show an expected downstream-fining trend in the bed material that is common in most rivers (Table G.4.1), and this significantly complicates modeling of sediment transport through the North Branch.

4.4. Bank Erosion and Protection

The extent of the observed bank erosion on the North Branch Root River and the primary sediment producing tributaries was mapped by MEI during the field reconnaissance (Table G.4.2; Appendix G.C). The bulk of the observed bank erosion was observed in Subreaches 1, 2 and 3 of the North Fork Root River where the lengths of the eroding banks were 16, 20, and 18 percent of the total bank lengths, respectively. Very little bank erosion was observed in Subreaches 4, 5, 6 and 7. In the more sinuous Subreaches 8, 9, and 10, the amount of bank erosion ranges from 3 to 9.5 percent of the total bank length. In the mapped reaches of Hale Creek, Whitnall Park Creek and 104th St. Ditch, the amount of eroding bank was between 2 and 3 percent of the total bank length. The East Branch Root River has the highest percentage of eroding banks (11 percent of the total bank length).

The extent of the observed bank protection along the North Branch Root River and the primary tributaries was also mapped by MEI (Table G.4.3; Appendix MR.B). The majority of the bank protection is located in Subreaches 1 and 2 of the North Branch where 14 and 28 percent, respectively, of the total bank lengths have been protected. The amount of bank protection in Subreaches 4, 5, 6, 8 and 9 of the North Branch is relatively small. About 7 percent of the total bankline has been protected in Subreaches 7 and 10. Hale Creek has the highest amount of protection of the tributaries that were evaluated (11 percent), while the amount of protection in the other tributaries varies from 2 to 5 percent.

4.5. Bed Erosion and Control

Field observations indicate that Subreach 1 is vertically stable. Subreach 10 on the North Branch may be vertically unstable, but the rate of bed degradation appears to be relatively low, primarily because of the erosion-resistance of the ground moraine tills that underlie the valley floor and form the bed of the channel over much of its length. Comparative thalweg elevation data are available for the North Branch Root River from 1966 (Harza, 1966), the 1993/1999 SEWRPC mapping and from the 2006 MMSD channel surveys (Figure G.4.3). Within the resolution of the data, it appears that there has been 2 to 4 feet of degradation since 1966 in the lower part of Subreach 1, which corresponds with the field observations of on-going degradation. The degradation rate in Subreach 1 was in the range of 0.05 and 0.1 ft/yr during the period encompassed by the data. There appears to have been about 4 feet of degradation in Subreach 4, but this probably reflects removal of woody debris jams. Subreach 10 experienced 2 to 5 feet of degradation during the period, with average degradation rates between 0.05 and 0.13 ft/yr. Whether the degradation in Subreach 10 is ongoing is not clear, but the results from the sediment-continuity modeling suggest that the subreach is net degradational at a rate about 0.1 ft/yr.

5. SEDIMENT TRANSPORT (ST)

A sediment-transport analysis of the North Branch Root River was carried out by MEI to evaluate tendencies for erosion and sedimentation under existing conditions, and to determine the potential effects of future development within the watershed on channel stability. Because of the geomorphic complexity of the North Branch Root River, the project reach was subdivided into 28 subreaches for purposes of the sediment transport analysis (Figure ST.1.1).

5.1. Incipient Motion Analysis

An incipient motion analysis was carried out by MEI to determine the minimum flows required to mobilize the bed material in the various subreaches (Figure ST.3.1). In general, incipient conditions for bed material mobilization (i.e., the point where bed mobilization just begins) occur at about the 1-percent exceedence discharge in subreaches with bed material that has a median (D_{50}) size of coarse sand to very fine gravel ($D_{50} < 4$ mm); in subreaches where the median bed-material size is greater than very fine gravel ($D_{50} > 4$ mm), incipient conditions occur very infrequently. However, in Subreach 6.1, the hydraulic energy is insufficient to mobilize the relatively fine sediment over the range of modeled flows due to the high frequency of large woody debris jams. Flows on the order of the 10-percent exceedence discharge mobilize sediments in Subreach 10.2, but downstream backwater affects the reach at higher flows, and therefore, the bed material is no longer mobile. Above Hale Creek (Subreaches 1.1 through 1.3), incipient conditions occur at about the 10-percent exceedence discharge. Except in Subreaches 6.1, 6.2, and 10.2, significant bed mobilization and sediment transport occur in the subreaches with a median grain size of less than 4 mm at flows above the 1-percent exceedence discharge. Significant bed material transport rarely occurs in the coarser-grained subreaches where the median grain size is greater than 4 mm.

5.2. Sediment-continuity Analysis

To compute annual bed-material transport volumes for existing and future (2020) conditions, sediment-transport capacity rating curves were developed by MEI for each of the subreaches using appropriate bed-material transport equations with the subreach-averaged hydraulics, and representative subreach bed-material gradations. The Yang sand and gravel equation (Yang, 1972) was used for Subreaches 2.1 through 10.2 where the bed material is relatively fine, and the Wilcock and Crowe (2003) equation was used for the coarser-grained Subreaches 1.1 to 1.3. (Figure ST.4.5). Sediment-rating curves were also developed for the primary tributaries that contribute significant amounts of sediment to the North Branch Root River. The average annual bed-material transport capacities for each subreach were then estimated by integrating the mean daily duration curve over each respective rating curve, and the results were used to perform a sediment-continuity analysis by comparing the annual bed-material transport capacity of each subreach to the supply from the upstream river and local tributaries within the subreach. Where the transport capacity of a particular subreach exceeds the supply, the channel will respond by either degrading (i.e., channel downcutting) or coarsening its bed material, and where the supply exceeds the capacity, the channel will respond by aggrading or fining its bed material.

The computed average annual aggradation/degradation volumes were converted into annual changes in mean bed elevation using the average width and length of each subreach (Figure ST.5.2). Seven (7) of the subreaches were identified as throughput reaches because their

transport capacity exceeds the upstream supply, but their bed material is coarse and essentially immobile for the entire range of flows that was analyzed (Subreaches 1.1, 3.1, 3.2, 4, 5.1, 7 and 9.4). With the exception of Subreach 5.1, little or no aggradation or degradation is indicated in these subreaches. In Subreach 5.1, the upstream supply is passed through the subreach, but slight aggradation occurs due to deposition of coarse sediments that are delivered from Whitnall Park Creek. In the remainder of the subreaches, the average annual change in bed elevation indicated by the sediment-continuity analysis is less than about 0.1 feet. The most strongly aggradational subreaches (about 0.1 ft/yr) are Subreach 2.1, due to significant sediment loads from both the upstream North Branch Root River and Hale Creek, Subreach 5.2, due to the sediment-trapping effects of the numerous large woody debris jams, and Subreaches 8.4 and 9.1, due to large tributary loads from the East Branch Root River that consist of moderately coarse material. The largest degradation depths are indicated in Subreach 1.2, due to the steep channel gradient, and in Subreaches 3.4 and 10.2, due to the relatively fine-grained and highly erodible finer sediments present in the bed. Moderate degradation (about 0.04 ft/yr) is also indicated in Subreaches 8.2 and 9.3. Comparison of the computed aggradation/degradation trends with field observations indicates that the results from the sediment-continuity analysis are reasonable. The predicted aggradation/degradation trends under future (2020) conditions are slightly higher than those under existing conditions, but the rates are still relatively small (Figure ST.5.2).

6. MANAGEMENT RECOMMENDATIONS (MR)

During the course of the field investigation by MEI of the North Branch Root River and the primary tributaries, observations were made of vertical and lateral channel instability, the presence of large woody debris obstructions in the channels, the presence and performance of bank protection and grade-control measures, and the presence and performance of various infrastructure elements (bridges, stormwater outfalls, utility crossings). These observations and the results of the quantitative analyses (hydrology, hydraulics, and sediment transport) were used to develop a set of management recommendations for the ten identified subreaches of the North Branch and primary tributaries.

In general, the North Branch is relatively insensitive to changes in water and sediment supply. The primary tributaries to the North Branch tend to exhibit more lateral erosion because the slopes are steeper as they traverse the end moraines, the tills that comprise the moraines are more heterogeneous, and for some of the tributaries, the floodplain has been encroached. The coarser bed materials derived from the end moraines tend to armor the bed of the tributary channels, but a number of boulder grade-control structures have been constructed, primarily in the East Branch Root River, to counter the effects of channelization and straightening. The lower reaches of Whitnall Park Creek, Tess Corners Creek, Tuckaway Creek and Legend Creek are laterally eroding their relatively coarse-grained alluvial fans due to clear-water scour in response to the upstream presence of ponds and other small detention structures that effectively trap the upstream-supplied bed material.

6.1. Bank Instability

A total of 26,182 lineal feet of bank erosion was mapped on the North Branch Root River (19,933 feet) and its primary tributaries (6,249 feet) (Figures MR A.1 through A.13). Based on the historical behavior of the river and tributaries, it is apparent that both lateral and vertical erosion rates are low, and therefore, neither forms of channel instability are likely to cause catastrophic problems during a single flood event. Based on the historic system behavior,

algorithms for assessing erosion risk and prioritizing sites for remediation were developed. The risk of lateral erosion affecting infrastructure (roads, bridges, houses) was assessed based on the distance between the eroding bank and the infrastructure element, expressed as multiples of the channel width. If the distance from the eroding bank is less than or equal to 1 channel width, the Proximity Rating (PR) is 1. If the distance is between 1 and 2 channel widths, the PR is 2, and if the distance is greater than 2 channel widths, the PR is 3. Sites with PR of 1 are considered to have high enough erosion risk to warrant action, sites with PR of 2 have lower erosion risk but should be carefully monitored, and at sites with PR of 3, the risk is low enough to warrant no action. PR 1 sites were further ranked based on the nature of the bank materials, with a higher rating being assigned to noncohesive soils and a lower rating being assigned to the cohesive soils.

Based on the risk assessment, about 2,800 lineal feet of bank erosion at 16 locations on the North Branch Root River are rated as Category 1 (highest risk) and of this, about 1,100 lineal feet has the higher priority rating based on the potential erodibility of the bank materials. All of the Category 1 sites are located in Subreaches 1, 2, 3 and 10, with the 4 highest priority locations in Subreaches 2 and 3. Approximately 2,150 lineal feet of eroding bank were rated as Category 2 (moderate risk), and because of the lower level of risk, they should be monitored. The remainder of the observed erosion (14,945 lineal feet) is rated as Category 3 (lowest risk), and as such, appears to pose little risk to infrastructure.

Approximately 6,250 lineal feet of eroding bank was observed in the tributary channels, but only 2 locations (80 lineal feet) in the East Branch Root River were rated as Category 1 risks (Figure MR A.12). Category 2 risks were assessed at three locations (2 in the East Branch Root River and 1 in Whitnall Park Creek), and these have a combined length of 170 lineal feet (Figures MR A.12 and A.13, and Figure MR A.9, respectively). Monitoring of the Category 2 locations is recommended. The remainder of the observed erosion in the tributaries (6,000 lineal feet) is rated as Category 3, and as such, appears to pose so little risk to infrastructure that no action is required.

Bank protection is the appropriate course of action at the Category 1 locations in both the North Branch Root River and the primary tributaries. Composite forms of bank protection that have an armored toe with bio-technical upper bank protection will provide bank stabilization while also improving the aesthetics and habitat values of the sites. Where site conditions permit, a rock toe and a fully bio-technical upper bank treatment can be used (Figure MR.2.1). If site conditions are more limited, the mid-bank region can be protected with backfilled and planted geocells that permit a steeper mid-slope segment between the armored toe and the planted upper bank (Figure MR.2.2).

6.2. Bed Instability

The bed of the North Branch Root River has degraded into the till deposits that comprise the bed of the channel in Subreach 1, most probably due to downstream channelization in Subreach 2 and 3 that caused baselevel lowering for Subreach 1,. Headcuts (2) and knickzones (2) with about 2- to 3-foot of drop across them were observed in the bed of the channel between West Oklahoma Avenue and West Lincoln Avenue. Cumulatively, these knickpoints and headcuts could lower the bed of the channel by up to 7 feet. Degradation of this magnitude would most likely cause the bank height to exceed the critical height (Harvey and Watson, 1986), thereby leading to mass failure of the banks and general destabilization of the channel (Schumm et al., 1984). Where the channel is located adjacent to South 124th Street, degradation-induced mass failure is likely to have an adverse impact on road stability, and thus,

public safety. Additionally, the integrity of the historic WPA wall located on the east bank of the channel between Sta 1303+20 and Sta1305+60 is threatened by a 3-ft high knickzone at the downstream end of the wall. Stabilization of the knickpoints and headcuts can be accomplished with suitably designed constructed riffles that have the advantage of being adjustable and more aesthetically pleasing (Figure MR.2.3).

Based on comparative thalweg profiles (Figure G.4.3), field observations, and the results of the sediment transport modeling, it appears that Subreach 10 of the North Branch Root River is also degradational. However, since the West Oakwood Road culverts are likely to be replaced with a span bridge and recent bridge replacements have included riprap placement on the bed and banks, it is unlikely that further grade control will be required in the subreach.

6.3. Existing Bank and Bed Protection

Field inspections identified the status of existing locations of bank-protection and grade-control structures in the North Branch Root River and primary tributaries. Two levels of assessment were applied to the existing bank protection structures. First, an assessment was made as to whether or not the existing structure is functioning, or has been damaged but is still functioning. Second, the proximity to other infrastructure elements was assessed with a channel width-based metric. Risk was evaluated as a combination of existing damage and proximity to other infrastructure elements. If the failed or damaged structure is less than one channel width away from an adjacent infrastructure element (e.g., road, bike path or bridge), it was placed in Category 1. If the failed or damaged structure is between one and two channel widths away from an infrastructure element, it was placed in Category 2, and if the distance is greater than two channel widths it was placed in Category 3. Category 1 sites require replacement or rehabilitation, Category 2 sites should be monitored, and no action is required at Category 3 sites.

About 3,685 lineal feet of bank protection has been installed along the North Branch, mainly in Subreaches 1, 2 and 3. Based on the risk assessment, none of these sites were rated in Categories 1 or 2. About 4,440 lineal feet of bank protection has been installed along the primary tributaries. Based on the risk assessment, one Category 1 site (about 50 lineal feet) that requires replacement or rehabilitation was identified on Whitnall Park Creek, and a further 57 lineal feet at one Category 2 site requires monitoring on Tess Corners Creek.

Two riprap grade-control structures are located in Subreach 1 between West Cleveland Avenue and West Lincoln Avenue. Both of the structures show some signs of rock loss and rock displacement, but they are still functional. Addition of constructed riffles in Subreach 1 will provide the required level of bed stabilization, and therefore, there is no need to replace or rehabilitate the existing riprap structures. Existing grade-control in the remainder of the subreaches in the North Branch does not require monitoring, replacement or rehabilitation. Because of the generally coarser nature of the bed material derived from the end moraines, and the presence of a number of existing rock riprap grade-control structures and concrete bridge sills, no requirements were identified for additional grade control in the primary tributaries.

6.4. Large Woody Debris

The riparian corridor along the Root River has expanded over the last several decades as adjacent land use has shifted from agriculture to parkland. This expansion will likely continue over time given the regulatory objectives of watercourse protection. As a consequence, the size and quantity of LWD that enters the river will likely increase, as will the number of woody debris

obstructions in the channel. These obstructions may increase the frequency of overbank flooding and the rate of channel shifting adjacent to debris jams. In general, however, the obstructions will continue to contribute to the functional geomorphic character and biologic health of the river and floodplain.

Most bridges on the North Branch Root River (with the exception of West Drexel Avenue and West Oakwood Road) are capable of passing wood transported by the river. Large trees that do collect on bridges should be removed as needed. Where not located immediately upstream of a bridge, it is recommended that trees leaning toward the river, and LWD obstructions in the channel, be left intact. It is further recommended that mowing to the edge of the river banks cease and an unmanaged, approximately one channel topwidth wide, vegetation buffer be maintained. Development and maintenance of a woody riparian strip will increase root reinforcement of the channel bank materials, thereby reducing the risk of lateral erosion.

6.5. Water Impoundments

Water impoundments are present in the lower reaches of a number of the primary tributaries to the North Branch Root River, including Whitnall Park Creek, Tess Corners Creek, Legend Creek and Tuckaway Creek. In general, the ponds and dams have high trap efficiencies for the bed material sediments supplied from the upstream watershed and channels, and consequently the channels downstream of the structures exhibit bank erosion due to clear-water scour. Most of the downstream bank erosion takes place as the tributary channels traverse their relatively coarse-grained alluvial fans, but there is no evidence of vertical instability because of the coarseness of the bed material. Since the fans are undeveloped, there is little point in preventing the bank erosion which compensates to some extent for the sediment trapped in the impoundments. Removal of the impoundments and restoration of the channels is unlikely to be successful because the upstream watersheds have been, or are in the process of being, developed; thus the sediment-water ratios have already changed, or will change, to the point where channel equilibrium is unlikely to be achieved. Consequently, the water impoundments, which provide recreational and other benefits, can be maintained, with little additional adverse impact to downstream channel stability. Mechanical removal of deposited sediments from the impoundments may, however, be periodically required.

6.6. Subreach-specific Management Recommendations

Subreach-specific summary data sheets with management recommendations were prepared for the 10 subreaches of the North Branch Root River and the primary tributaries. These sheets are provided in Appendix MR.C (Figures MR.C.1 to MR.C.10 [North Branch] and Figures MR.C.11 to MR.C.21 [tributaries]).

In summary, in the North Branch 3 grade-control structures are recommended in Subreach 1 and bank protection is recommended at four locations. In Subreach 2, bank protection is recommended at two locations, and it is also recommended at 1 location in Subreach 3. Bank protection is recommended at one location in Subreach 8 and at three locations in Subreach 10. No immediate action is recommended in the remainder of the North Branch subreaches.

No immediate action is recommended for Hale Creek, 104th Street Ditch, Wildcat Creek, Tess Corners Creek, Legend Creek and Ryan Creek. Failed gabions should be replaced in the Northwest Fork of Whitnall Park Creek upstream from Janesville Road. A grade-control structure is recommended to prevent upstream incision in Dale Creek. Replacement of a

partially failed rock wall that is protecting South 35th Street is recommended on the East Branch, and bank protection is recommended to protect private residences at two locations. Because of the potential for failure, the outlet works for the pond at the Milwaukee County House of corrections should be monitored.