Analysis of the Stream Restoration Design of Donaldson Run Tributary B in Arlington, VA

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EXECUTIVE SUMMARY

A stream restoration design based on the Natural Channel Design method has been developed for a 1,400-foot reach of Donaldson Run Tributary B to achieve several laudable goals: reduce bank erosion, improve water quality, enhance habitat, create a pleasing aesthetic, and decrease sediment transport downstream to Chesapeake Bay. Natural Channel Design is an appealing restoration approach in that it promises to stabilize the stream by simply reshaping and realigning the channel into a form expected to develop naturally over time in a largely unaltered or natural environment. The question addressed in this analysis is whether such an idealized “natural” channel can be sustainable within the context of the watershed’s physical setting and ongoing adjustments associated with urbanization. The basics of fluvial geomorphology (i.e., river science) and a fuller understanding of the current conditions along Tributary B are key to analyzing the stream restoration design and for conceptualizing a potential alternative design approach.

Fluvial geomorphology basics

All streams trend towards an equilibrium condition where the channel is linked in a delicate balance with the watershed conditions such that water and sediment delivered to the channel can pass through the system with no net change in the channel’s dimensions (e.g., width, depth, meander shape). Any changes in the watershed that effect the amount of water and sediment delivered to the channel often lead to adjustments along the stream that manifest as either excessive erosion (if runoff has increased) or deposition (if sediment loads from the watershed have increased). The response to these changes are sometimes hazardous and problematic but always reflect the tendency of the stream to achieve a new equilibrium channel dimension in balance with the altered watershed conditions, a process well illustrated by the current conditions on Donaldson Run Tributary B and its surrounding watershed.

Current conditions

Donaldson Run Tributary B flows at the bottom of an ancient narrow valley carved into a high river terrace on which the surrounding residential homes are built. The valley is confined by the steep valley side slopes upstream of a pedestrian bridge found part way down the proposed restoration reach. Prior to urbanization of the watershed, the stream in this confined valley flowed in multiple shallow flow paths as the natural flow from the heavily forested watershed was incapable of carving a well-defined channel into the cohesive clay-rich soils formed over millions of years. Further downstream where the valley is flatter and less confined, the stream has formed highly sinuous meanders as flood flows temporarily backwater (i.e., pond up) at the confluence with the larger Tributary A. The meanders have not changed their shape or position in more than 30 years (based on aerial photographs) despite urbanization and have likely retained this natural equilibrium configuration for hundreds of years with little change.

Unlike historically when no well-defined channel was present, the upper confined portion of Donaldson Run now flows in a deep channel incised by the increased energy generated from the excess urban runoff. The channel is also widening as a result of erosion along the unstable banks. Although threatening the nearby water main and sewer line, the incision and widening have the effect of reducing the energy of floodwaters by reducing the gradient (due to lowering of stream bed by incision) and spreading the flow out over a wider area (due to bank erosion), thus working to bring the stream into a new equilibrium condition in balance with the urbanized watershed. At the downstream end of the confined valley (around the pedestrian bridge), the incision and widening process is largely complete and the channel self-stabilizing. Where unconfined, the stream channel has remained resilient and largely unchanged for decades despite the increased runoff from urbanization.

Analysis of the stream restoration design

Arlington County's stream restoration design for Donaldson Run Tributary B if implemented would completely reform, realign, and fill the existing channel to form a new armored channel up to 5 feet above the existing streambed. The channel's design dimensions are based on measurements along streams in generally less altered watersheds yet similar in other ways (e.g., watershed size) to Tributary B. Although the design makes some adjustments in channel width to account for the urban setting, the complete alteration of the existing stream and associated changes in the channel's slope, width, and bank (also bed) resistance could result in serious problems developing along the restored reach in just a few years. The major features of the proposed Natural Channel Design project and the problems that may arise are best summarized with five rhetorical questions:

- *Why construct meanders unlike those present naturally*? The design proposes to create several nearly uniform low-sinuosity meanders along the entire length of the project where meanders have never existed (upstream of pedestrian bridge) or where the natural meanders have a much higher sinuosity (downstream of pedestrian bridge). The construction of the proposed uniform meander pattern will necessitate excavation into the steep valley side slopes and across a large meander, potentially destabilizing the channel with sediment from the valley side slopes, backwatering in the confluence area, or other unexpected events;

- *Why add sediment to reduce sediment*? The project design proposes to add imported fill to the design channel to elevate the stream bed and narrow the channel's width. By increasing the slope and constricting the flow, respectively, the project, even if functioning as intended, will have a greater capacity to transport sediment downstream. This outcome is in direct contradiction to the project's goal to reduce sediment delivery to Chesapeake Bay. The stream has spent the last several decades eroding a large gully in response to increased runoff from urbanization and now that sediment would be replaced and made available to wash downstream again, potentially doubling the damage to Chesapeake Bay;

- *Why create a floodplain where there never was a floodplain*? The existing channel is being filled to elevate the stream bed and allow floodwaters to regularly inundate the ancient valley bottom in order to limit the erosive energy in the design channel. By mistaking and misusing this ancient surface as a modern floodplain, the trees and plants adapted to an environment with little to no history of flooding will be stressed from the regular inundation of the surface by floodwaters. The numerous discussions regarding the saving of trees during construction will, unfortunately, be of only short-term consequence as a result;

- *Why add boulders where there are no boulders naturally*? The design channel will be armored on the bed and banks with rock, including small boulders, to prevent erosion in the channel up to a 10-year storm event. Once the armor layer is set in motion by a larger storm (with a 65 percent chance of occurring in 10 years), the stream, energized by the steepening and narrowing of the design channel, could rapidly erode and recreate a gully similar to the existing channel. Large boulders will also be used to create numerous step-like structures to dissipate energy and enhance aquatic habitat. Flows will aggressively scour the finer fill in contact with the boulders and allow bank erosion to outflank the boulder structures;

- *Why spend funds on restoration where no restoration is needed*? The lower unconfined portion of the proposed restoration reach (downstream of the pedestrian bridge) remains in a natural state or has largely restabilized after a long period of channel incision and bank erosion. The proposed restoration, by cutting off natural meanders and adding fill to the restabilized channel, will destabilize the stream and ultimately lead to worsening bank erosion. While some work may be necessary at the sewer lines 85 feet downstream of the pedestrian bridge, the County could save considerable funds by simply not undertaking any restoration further downstream where restoration, as proposed, is likely to do more harm than good.

An alternate restoration approach is warranted in lieu of the many problems described above that will prevent the proposed restoration from achieving the project's goals.

Alternative design approach

A restoration approach consistent with natural processes and utilizing natural materials is likely to be more sustainable than the "form-based" Natural Channel Design approach currently proposed for Donaldson Run Tributary B. The use of wood is commonly used nationwide in such "process-based" restoration projects (or process-based Natural Channel Design if you will). Wood structures including log jams and crib walls could be used on Tributary B to dissipate energy, stabilize eroding banks, encourage sediment storage (rather than sediment transport downstream), and enhance aquatic habitat. Wood helps build resilience in the stream by providing both energy dissipation (that reduces erosive forces when sediment inputs are low) and sediment storage capacity (that provides a buffer when sediment inputs are high).

In this way, the stream can withstand changing conditions with minimal disturbance and instability. In contrast, the armored "static" channel in the current restoration proposal would be unstable and sensitive to rapid adjustments during large floods, sudden sediment inputs, and other unexpected events (e.g., tree falling in channel). Consequently, the alternative process-based approach that can be implemented with minimal disturbance to the existing channel and surrounding forest will more effectively and sustainably achieve the project goals at a greatly reduced cost to Arlington County and the environment.

1.0 INTRODUCTION

I am writing to comment on Arlington County's plan to undertake stream restoration along an approximately 1,400-foot reach of Donaldson Run Tributary B from the culvert outfall at North Upton Street downstream to its confluence with Tributary A. The objective of the restoration is to stabilize the currently incising and eroding stream in order to meet several project goals: 1) provide aquatic benefits and habitat; 2) provide grade control and energy dissipation; 3) improve water quality and aesthetics; 4) prevent further erosion; 5) protect adjacent infrastructure; and 6) provide an amenity within an active park setting (VHB, 2019, Drawing number D-1). Although not explicitly stated in the final restoration design plans, another goal of the project is to reduce sediment and pollutant loading to Chesapeake Bay as part of Arlington County's stormwater discharge permits (Web citation 1). While these are all laudable goals worth pursuing, the critical question is whether the proposed restoration project will sustainably achieve them.

I write this analysis with the authority that comes with 35 years of academic and consulting experience focused exclusively on streams and rivers (Appendix 1). I have analyzed, designed, constructed, and/or monitored well over a hundred stream restoration projects around the country and have completed numerous other river-related projects worldwide. Unfortunately, many stream restoration projects do not achieve their stated objectives and often completely unravel within a few years. This is not only my experience but is well documented in the scientific literature (Hawley, 2018; Miller and Kochel, 2010; Nagle, 2007; Simon et al., 2007). Of particular concern are Natural Channel Design projects, like proposed for Donaldson Run Tributary B, because they are often promulgated by "individuals with limited backgrounds in stream and watershed sciences" (Simon et al., 2007, p. 1118) and, thus, are completed without a full understanding of the stream processes that can undo the well-intentioned projects.

This is not to suggest all stream restoration projects are unsuccessful, but the mixed results of past efforts underscore the need for a critical analysis of all proposed restoration projects in order to: 1) ensure the proposed project aligns with the stated project objectives; 2) determine the resiliency (i.e., stability) of the project to large flows and unexpected events (e.g., trees falling into the restored channel); 3) determine if the project is consistent with the existing watershed conditions and ongoing adjustments along the stream; and 4) ascertain whether alternative restoration approaches may have greater success. After a short primer on fluvial geomorphology (i.e., river science) and description of the current conditions and setting along Donaldson Run Tributary B, below I provide an analysis of the proposed Donaldson Run Tributary B stream restoration design (VHB, 2019). I conclude this analysis by presenting an alternative restoration approach that will more effectively and sustainably achieve the stated project objectives, cause less disturbance to the existing landscape and ecosystem, and cost far less than the current restoration proposal.

2.0 FLUVIAL GEOMORPHOLOGY PRIMER

Flowing water can carry sediment. Lots of fast moving water, as during a flood, can carry great quantities of sediment compared to a small trickle that may barely be able to entrain a grain of sand. Streams trend towards an equilibrium condition which is achieved when the water AND sediment supplied to the stream from the surrounding watershed during a flood are able to pass through the channel without any change to the channel's dimensions (i.e., width and depth), pattern (i.e., the shape of meanders, if any), and profile (e.g., gradient/slope). A channel in equilibrium can be considered as geomorphically stable, but should not be confused with a static channel that is unable to move. A channel is able to maintain its dimensions while shifting its position by balancing the amount of erosion in one location with an equal amount of deposition in another such as on the outside and inside bends of a migrating meander bend (Figure 1). Over long periods of time, larger unconfined valley bottom streams build a floodplain adjacent to the channel that enable the stream to sustain the equilibrium channel dimensions even in the face of large floods, because the flood waters can spread out on the floodplain without exerting much additional force in the channel itself. In contrast, more confined upland streams tend to be more sensitive to large floods, sometimes dramatically changing their dimensions during large flow events.

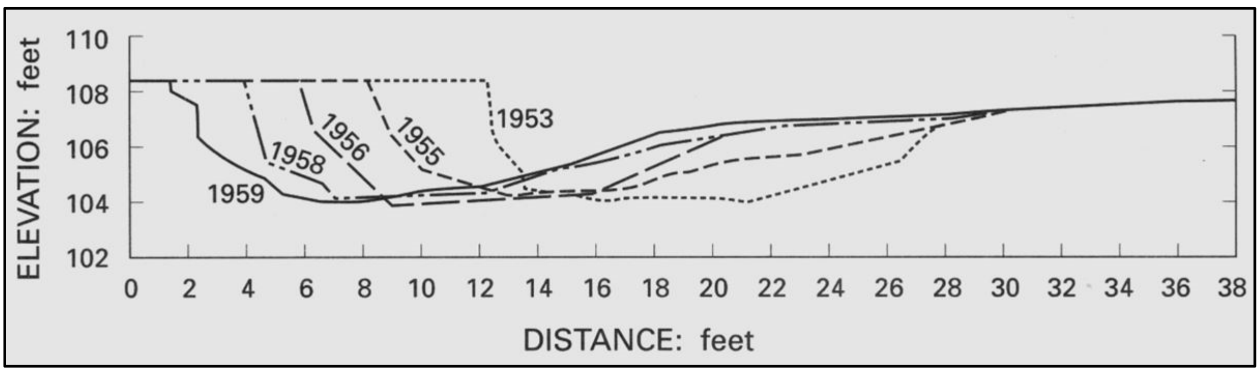

Figure 1. Repeated cross sections at the same location on Watts Branch, MD over a period of several years show how the channel maintained the same shape and dimension despite migrating over time. (From Leopold et al., 1964)

The dimension, pattern, and profile of a channel that has achieved an equilibrium condition will change, however, if the amount of the water or sediment delivered from the watershed changes (due to greater water runoff from impervious surfaces in an urbanized environment, for example) or alterations of the stream channel itself cause the water to flow faster or slower (due to the straightening of the channel, for example, or even as the result of a stream restoration project). The resulting adjustments along the channel continue until the stream has reached a new equilibrium dimension in balance with the new altered levels of water and sediment discharge. The existing conditions on Donaldson Run Tributary B illustrate this point well.

3.0 EXISTING CONDITIONS AND SETTING

The watershed draining to Donaldson Run Tributary B has impervious surfaces covering more than 26 percent of its area (VHB, 2019, Drawing number D-1). This has increased runoff to the stream compared to pre-development conditions while simultaneously reducing the amount of sediment available for transport. The resulting imbalance between the level of water and sediment entering Tributary B has engendered a channel response in the form of channel incision and bank erosion seen along the upper portion of the proposed restoration reach (Figure 2).

Figure 2. The upper portion of Tributary B has incised below the flat surface over which the stream once flowed.

A stream's response to alterations in the watershed or stream channel itself is always towards equilibrium. While the erosion on Tributary B is potentially putting some infrastructure at risk (a water main and sewer line parallel the channel on either side of the stream), the incision results in a slightly reduced slope that has the effect of slowing the water down, thus reducing the flows capacity to transport sediment. The incision, in turn, destabilizes the banks causing further erosion that widens the channel. As the flow spreads out and slows down over a wider area, the stream's capacity to transport sediment is further reduced. Eventually, once the widening has progressed sufficiently, the stream will achieve a new equilibrium by reducing its velocity (despite the greater runoff) to the point where only the low levels of sediment coming from the urbanized watershed can be transported such that no further incision and widening will occur. In this context, the observed erosion is a predictable natural channel response that will subside over time as a new equilibrium condition is reached with the surrounding urbanized watershed. While some bank stabilization may ultimately be required to protect the adjacent infrastructure, understanding the ongoing process of channel adjustment is critical to analyzing the existing stream restoration design (VHB, 2019) and developing alternative restoration approaches.

This incision and widening process, often observed on urbanized streams, will usually begin downstream and advance upstream. The uppermost end of Tributary B is still relatively narrow and actively widening, but will unlikely incise further as non-erodible bedrock has been exposed on the channel bottom in places. Downstream of the pedestrian bridge, the widening appears to be approaching its end as sediment is beginning to accumulate on the channel bottom, including large rock from past bank stabilization efforts (Figure 3). Trees falling into the stream during this latter phase of bank widening have the potential to stabilize the bank and enhance aquatic habitat. Consequently, the area of the channel below the pedestrian bridge, while still eroding in places, is nearing a stable (but not static) condition in equilibrium with the urbanized watershed.

Figure 3. Tributary B is self-stabilizing near the footbridge with sediment accumulating on the channel bottom.

The upper part of Tributary B was likely much different prior to urbanization. No well-defined channel was present as the limited discharge from the small forested watershed likely spread out across the flat valley bottom (i.e., level of the walking trail) in multiple shallow flow paths (Figure 4). This flat narrow surface is not a modern floodplain, but rather the bottom of a large ancient gully carved into the high river terrace on which the adjacent residential homes are now built. The soils on this ancient gully bottom are millions of years old and support a forest community and ecosystem distinct from an active modern floodplain. Only with urbanization, did the discharge increase sufficiently to carve a channel into the ancient cohesive soils.

Figure 4. A small shallow channel flowing on an ancient valley bottom in the Hollin Hills neighborhood of Alexandria, VA is similar to how Tributary B likely looked prior to urbanization.

The lower portion of Tributary B becomes less confined and has likely changed very little since urbanization of the watershed. The loss of confinement is key in terms of the stream's ability to maintain the tight highly sinuous meanders in this section of stream (Figure 5) despite the increasing runoff from urbanization, because the flow can spread out over a wide area and limit the forces exerted on the channel's bed and banks. Although some minor changes are likely resulting from urbanization, the tight meanders have remained essentially unchanged since 1988 (oldest aerial photograph available on Google Earth) and likely much longer. These tight bends, therefore, are not an indication of inherent instability or evidence of rapid erosion, but are rather an expression of the natural equilibrium form for the setting.

Figure 5. A highly sinuous meander on Tributary B near its confluence has remained relatively unchanged for decades as evidenced by the two large trees growing near the banks on both sides of the channel.

The formation of these tight meanders is not unexpected given the natural low-gradient setting. Sinuosity (i.e., a measure of how much winding the channel is doing) typically increases as the slope of the valley decreases – flowing water is more easily deflected off of a straight course on a flatter surface. Tight meanders are also quite common as tributaries approach a confluence with a larger stream because flows in the tributary can be backwatered – and again more easily deflected from a straighter course – by high flows along the primary stream (Tributary A in this case). Finally, despite the lack of confinement, the bank soils at the lower end of Tributary B, like upstream, are ancient cohesive soils that do not easily erode. Consequently, the soils do not "give way" as might less cohesive floodplain soils and thus the flow for a third reason is more easily deflected off of a straighter course, further encouraging the formation of the tight sinuous meanders. The meanders, then, like the forest that surrounds them are a relict of past conditions threatened by the urbanization of the watershed and potentially, as discussed below, the proposed stream restoration project based on Natural Channel Design principles.

4.0 ANALYSIS OF THE PROPOSED STREAM RESTORATION DESIGN

"Natural Channel Design" is the stated design methodology used in developing the stream restoration plans for Donaldson Run Tributary B (VHB, 2019). Natural Channel Design attempts to recreate the dimension, pattern, and profile of a stream channel expected to form at a given site under natural conditions or, in other words, in an unaltered watershed. The expectation is that a channel created in this way would be in equilibrium such that for any sediment moving into the restoration reach at the upstream end an equal amount of sediment will exit the reach downstream. To be truly in equilibrium, Natural Channel Design projects should not "fix" the channel in place or harden (i.e., armor) its bed and banks (Rosgen, 2011).

The process for determining what the dimensions of the restored channel should be is based on multiple sources of information such as "regional curves", "reference reaches", and the "Rosgen channel classification" system (Rosgen, 2011). Very little detail is provided by VHB (2019) regarding how the various channel parameters (e.g., width, depth, meander dimensions, slope, spacing of rock structures) for the Donaldson Run Tributary B design were derived from these sources. Consequently, I will simply discuss below three primary techniques proposed for use in VHB's (2019) design, present VHB's stated justification (or presumed justification) for proposing their use, explain why the proposed technique is inappropriate for Tributary B given the setting, and describe the potential problems that are likely to arise if the techniques are implemented as proposed.

4.1 Creating meanders of a uniform dimension

Implementing the design channel as presented in VHB (2019) will necessitate a massive and costly earth-moving operation that will result in a significant realignment and alteration of the current channel and adjacent portions of the valley bottom. Numerous uniformly shaped meanders will be constructed in the upper portion of Tributary B (Figure 6). The justification for this is based on the fact that "alluvial" streams (those streams that are capable of self-forming a channel across a floodplain) tend to form meanders to achieve an equilibrium condition. However, as stated above, Tributary B never had a floodplain and was never able to self-form a channel prior to urbanization. As a consequence, the design channel does not truly represent the natural stable configuration for this setting and, as a consequence, instabilities will likely result.

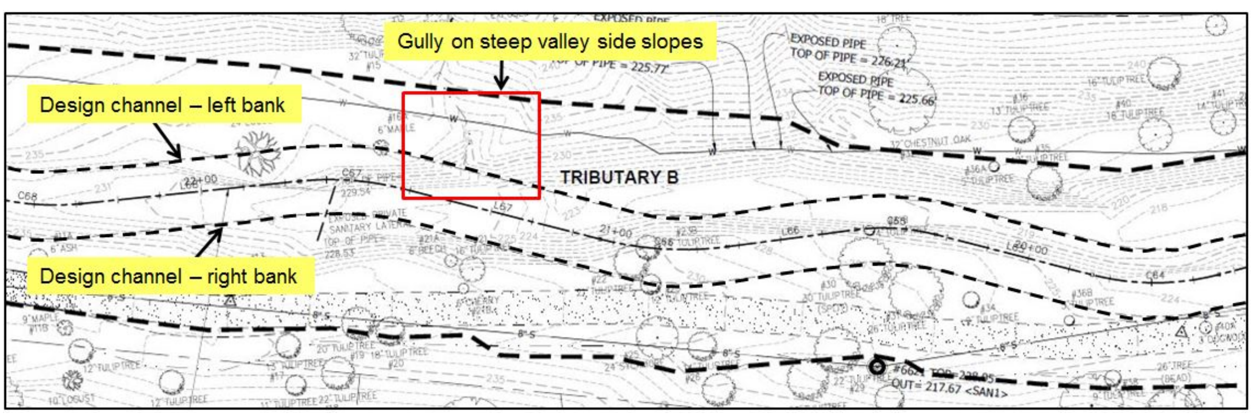

Figure 6. A portion of Drawing C-1 (VHB, 2019) showing proposed uniform meanders. Right and left bank are based on a downstream view with flow from left to right. The area highlighted by the red box is discussed in text.

The red box in Figure 6 highlights one of many locations where the design channel approaches the steep valley side slopes due to the lateral space needed to create the proposed meandering planform. At the highlighted location, a steep gully on the side slope will drain directly into the proposed channel and, as a result, could rapidly deposit large amounts of sediment. Such rapid inputs of sediment are unlikely along alluvial rivers that flow across a low floodplain, so the design (that essentially assumes Tributary B is alluvial) does not plan for such "outside" inputs of sediment and the proposed channel will be destabilized as a result.

Figure 7 is a cross section showing one location where the design channel will actually be excavated into the base of the steep valley side slope. This could destabilize the slope and trigger a landslide – a threat that will increase over time as flow in the design channel continues to impinge on and eat away at the slope. No evidence is provided in the design package (VHB, 2019) that documents a geotechnical analysis has been completed to determine the risk of such a landslide. The potential consequences of a landslide (or rapid inputs of sediment from the gully highlighted in Figure 6) would be to completely infill the design channel, allowing the flow to escape the design channel, reform a new channel elsewhere on the valley bottom, and cause the abandonment of the entire design channel downstream. This begs the question "Why does the design propose to form meanders in the upper confined section of Tributary B where no meanders ever existed before?" and also demonstrates that the primary project objective to stabilize the stream will not be achieved.

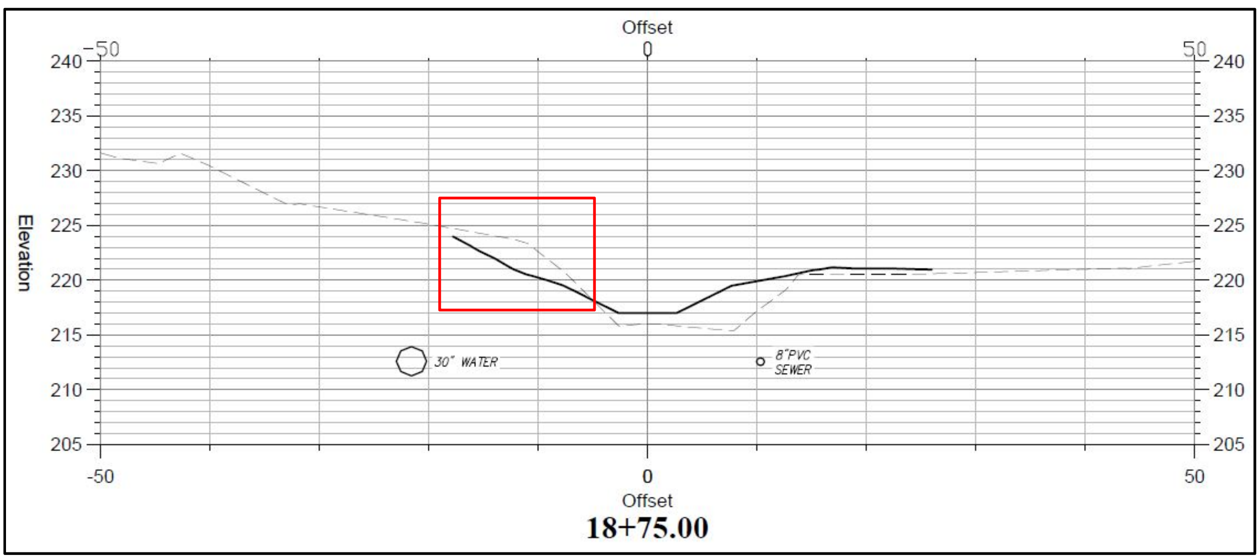

Figure 7. Cross section showing the proposed design channel (solid black line) will be excavated into the base of the high valley side slope (highlighted in red box). Note that the valley slope rises at least another 15 feet in elevation beyond the limits of the cross section. (From VHB, 2019, Drawing C-12)

By maintaining essentially the same uniform meander shape throughout the project, problems at the downstream unconfined end of the project are also possible. The proposed design will cutoff one of the existing highly sinuous meanders (Figure 8) that, as described in Section 3.0 above, is the natural stable meander form for this setting. The proposed less sinuous meander, then, will be an unstable feature that will eventually be undone over time as the more sinuous meander dimension is reestablished. This process would most likely be initiated when backwatering caused by high water in Tributary A leads to deposition and infilling of the design channel.

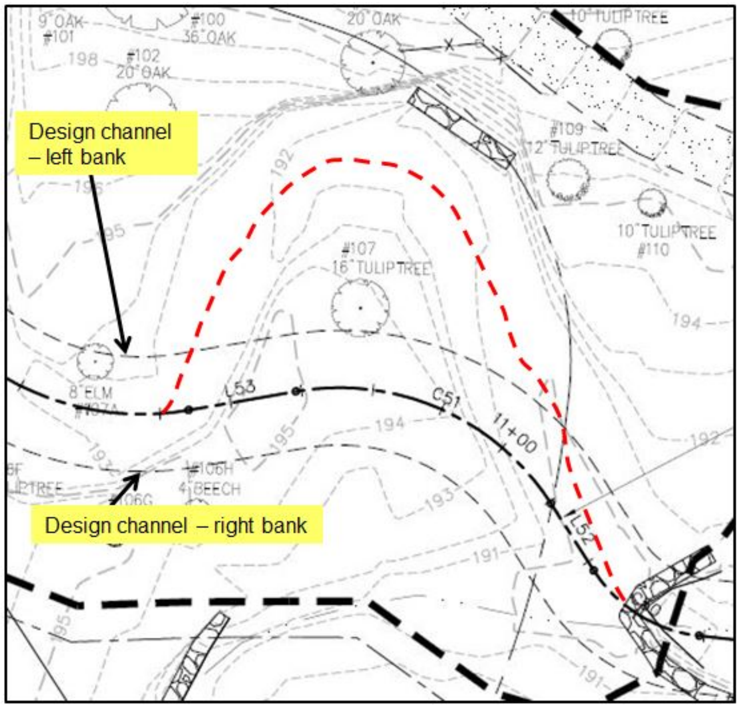

Figure 8. The lower sinuosity design channel proposes to cutoff the existing high sinuosity meander (centerline shown with dashed red line). (From VHB, 2019, Drawing C-2)

4.2 Filling of the existing channel

VHB's (2019) restoration design proposes to fill, at least partially, the existing incised channel with what will presumably be a mixture of sand, silt, and clay (Figure 9). The amount of fill to be added is generally greater in the upper part of the proposed project with much less needed downstream where the existing stream is less incised. However, some fill is proposed for nearly the entire project's length. The cross section in Figure 9 is typical for the upper portion of the project with the depth of fill ranging from 5 to 7 feet depending on the position of the "thalweg" (i.e., deepest portion) and banks of the proposed channel. No details are provided in the design plans regarding the total volume, character, or origin of the fill to be used. The design justification for filling the existing channel with more than a thousand cubic yards of presumably imported fill is twofold: 1) to elevate the steam bed so that flows can more easily escape the channel and spread over the flat valley bottom in order to limit the stream power exerted in the design channel; and 2) to narrow the channel to approximate the expected width of an equilibrium channel in an undisturbed setting (with an adjustment factor added in recognition of urbanization as described in VHB, 2019, Drawing D-1).

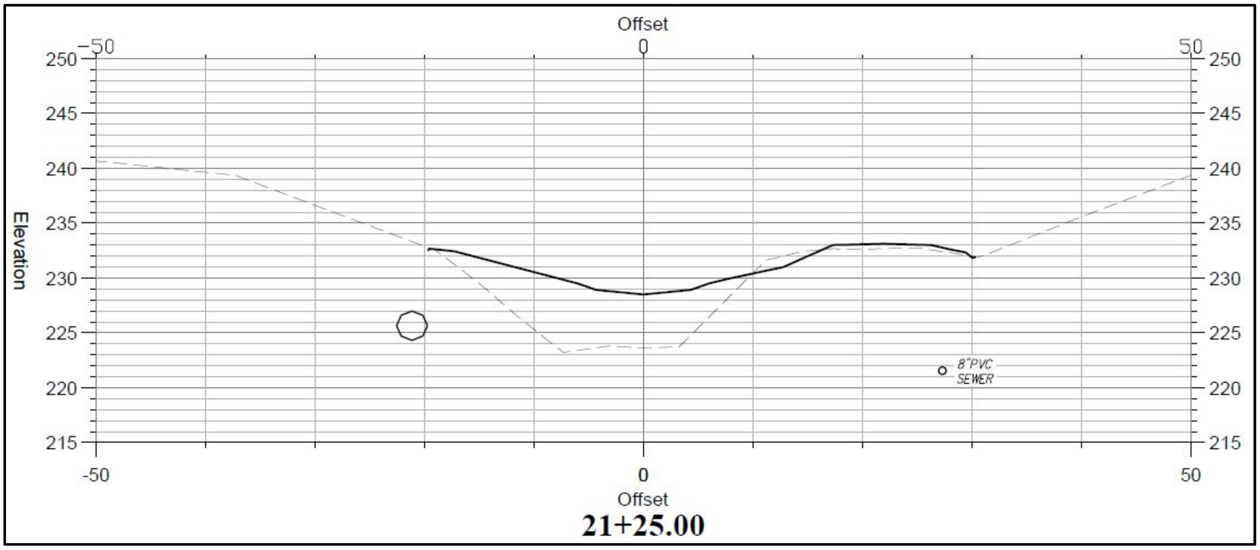

Figure 9. A typical cross section in the upper part of the restoration reach illustrating the difference in elevation between the existing channel (dashed line) and the proposed design channel (solid line). Fill will be needed where the solid line is above the dashed line. (From VHB, 2019, Drawing C-11)

Elevating the stream bed by adding fill in the channel increases the stream's gradient and, in turn, increases the stream's capacity to carry sediment. The stream's length in the project area is being shortened from 1,404 feet to 1,331 feet (VHB, 2019, Drawing C-3) due to planform changes like that shown in Figure 8, leading to additional slope increases. (Perhaps imperceptible to the human eye, streams trending towards an equilibrium condition are sensitive to even minor slope changes.) The fill is also being added to the existing channel to narrow its width (Figure 10). Squeezing the flow through a narrower channel, like putting a finger over the end of a garden hose, will further increase the flow's velocity and ability to carry sediment.

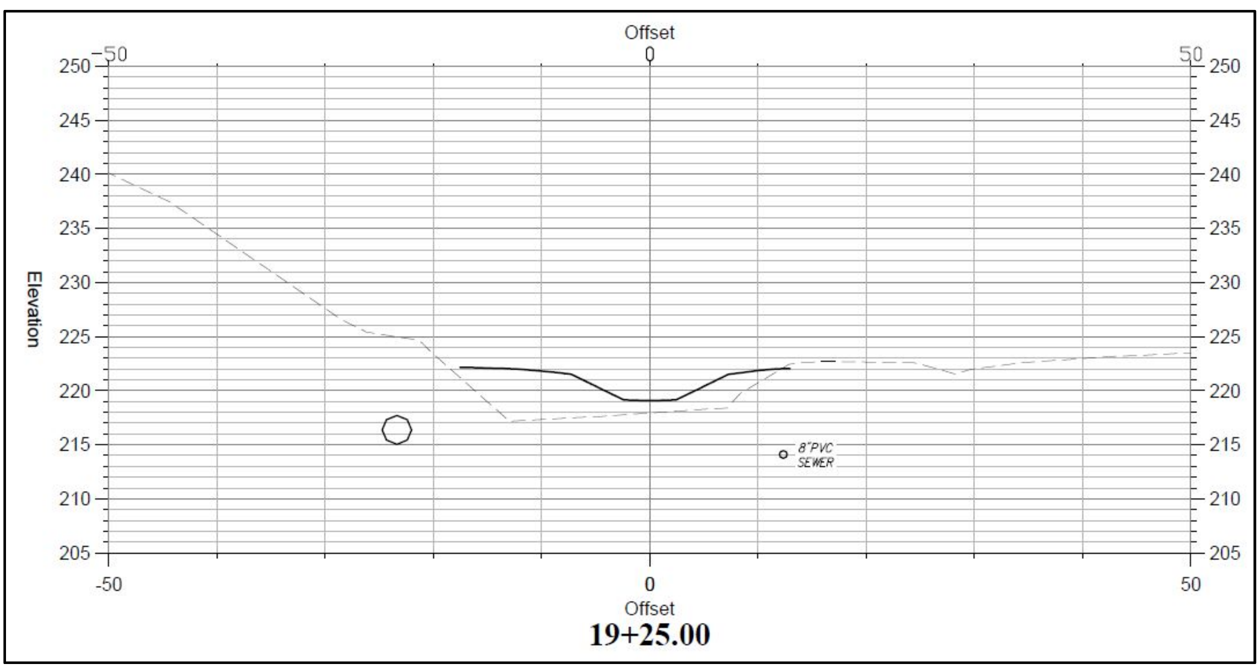

Figure 10. Cross section showing particularly well how fill placed in existing channel (dashed line) will create a narrower design channel (solid line) through most of the project's length. (From VHB, 2019, Drawing C-12)

What may appear as only subtle changes resulting from adding fill to the existing channel could actually cause significant problems. Please note that elevating the stream bottom and narrowing the channel by adding fill stands in stark contrast to the stream's natural channel response of incision and widening that has been ongoing for several decades. As described above in Section 3.0, this has been occurring to achieve a new equilibrium condition in balance with the urbanized watershed. Why, then, is the sediment that has taken decades to wash downstream now being replaced with imported fill? The long-term fate of the fill will invariably be similar to previous soils eroded away given that implementation of the project will have no effect on the high volume of runoff emanating from the urbanized watershed. Simply changing the form (i.e., width, slope, and sinuosity) of the channel as proposed in the restoration design does not change the process at the root of the problem.

The addition of fill, therefore, achieves exactly the opposite result of the project's goal to reduce downstream sediment transport towards Chesapeake Bay. The intent of the restoration design is to more efficiently transport sediment downstream by increasing the channel's gradient and decreasing its width, so even when functioning properly, the project will have a greater capacity to transport sediment towards Chesapeake Bay despite the project's goal to do the opposite. In addition, the fill added to the existing channel will be far more erodible compared to the cohesive native soil, so is more likely to be removed in years rather than decades as the steeper and narrower energized stream begins to erode the design channel. Lots of sediment being moved in a shorter period of time can harm aquatic habitat more significantly than if the same volume of sediment passes through the channel over a longer time frame, indicating the project's goal to enhance aquatic habitat could also be jeopardized by the addition of fill in the existing channel. Put simply, why add sediment to reduce sediment, especially if the project goals are less likely to be achieved?

The use of fill to raise the bed elevation in order to regularly flood the valley bottom is also problematic. The project design narrative refers this valley bottom surface as an "historic floodplain" (VHB, 2019, Drawing D-1) but as described in Section 3.0 above that is inaccurate. The vegetation growing on the valley bottom is adapted to an upland environment with clay-rich soils that are rarely inundated by floodwaters. Many of the large trees growing on this surface are to be removed to realign the channel and to accommodate haul roads for carrying fill and other materials. Those trees saved near the channel and others growing beyond the limits of disturbance will not, however, be saved from the frequent overbank flooding that will ensue if the project is implemented as designed. Not adapted to frequent inundation, the trees and other plants growing on the valley bottom will become stressed and ultimately die. A view of numerous unhealthy and dying trees while walking down the walking trail is inconsistent with the project goal to improve aesthetics and provide an amenity within an active park setting.

The increased flooding of the valley bottom surface could have even more serious consequences as well. Where the design channel extends beyond the limits of the existing channel, the existing channel will be filled to the level of the valley bottom, but existing low spots on the valley bottom beyond the limits of disturbance will remain (such as the drainage swale along the walking path) (Figure 11). These low spots near the downstream end of the project are at times even lower than the bottom of the design channel itself (see VHB, 2019, Drawing C-16, Section 11+25.00).

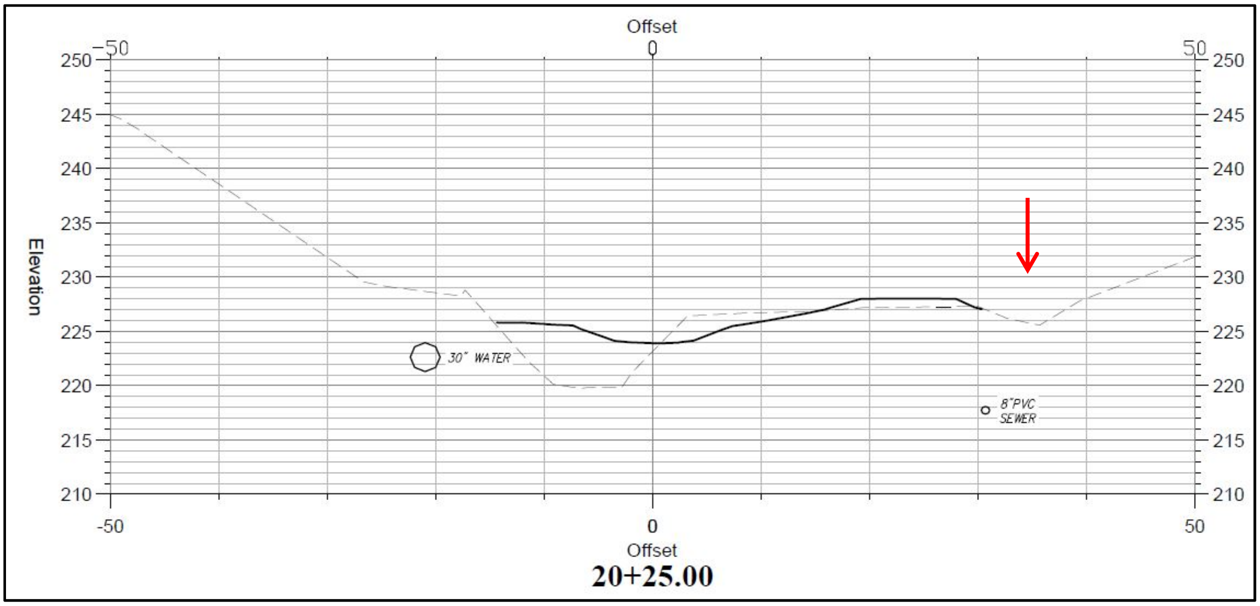

Figure 11. Cross section showing existing channel (dashed line) filled in to accommodate design channel (solid line), but leaving a low spot on the valley bottom (highlighted by red arrow) beyond the limit of disturbance. (From VHB, 2019, Drawing C-11)

The overbank flow emanating from the design channel will preferentially concentrate in these low spots on the valley bottom and could initiate channel incision to a depth lower than the design channel itself. In such an event, the design channel would be abandoned and the entire flow of the stream diverted to the newly incised channel. The potential damages from a new channel being carved on the valley bottom are significant as most of the existing low spots on the valley bottom are immediately adjacent to the sewer line. While the likelihood of such an event is low, dismissing a low risk event would be unwise given the potential high cost of repairs. By adding fill in the existing channel but leaving low spots on the valley bottom, the project could fail to meet its primary objective of stabilizing the stream and the project's explicit goal to protect adjacent infrastructure.

4.3 Placing large rock in the design channel

Large rock is to be placed in the design channel in the form of an 18-inch thick bed layer across the entire channel bottom (and banks) throughout the length of the project (Figure 12). The "D_{84}"rock size to be used will have a diameter of 15 inches (i.e., a small boulder), which means that 84 percent of the rock will be smaller (including at least 10 percent sand) and 16 percent larger than that value (VHB, 2019, Drawing D-1). Much larger more rectangular boulders (with an intermediate axis diameter up to 5 feet) will be used to build a variety of step-like rock structures (VHB, 2019, Drawing C-4 and C-5) throughout the project's length (Figure 13). The justification for the coarse bed layer is to keep the stream bed and banks from eroding given that the sediment supply from the urbanized watershed is lower than in a more natural environment. The numerous boulder step structures are justified as "grade controls" (i.e., to prevent downcutting of the channel) and habitat features.

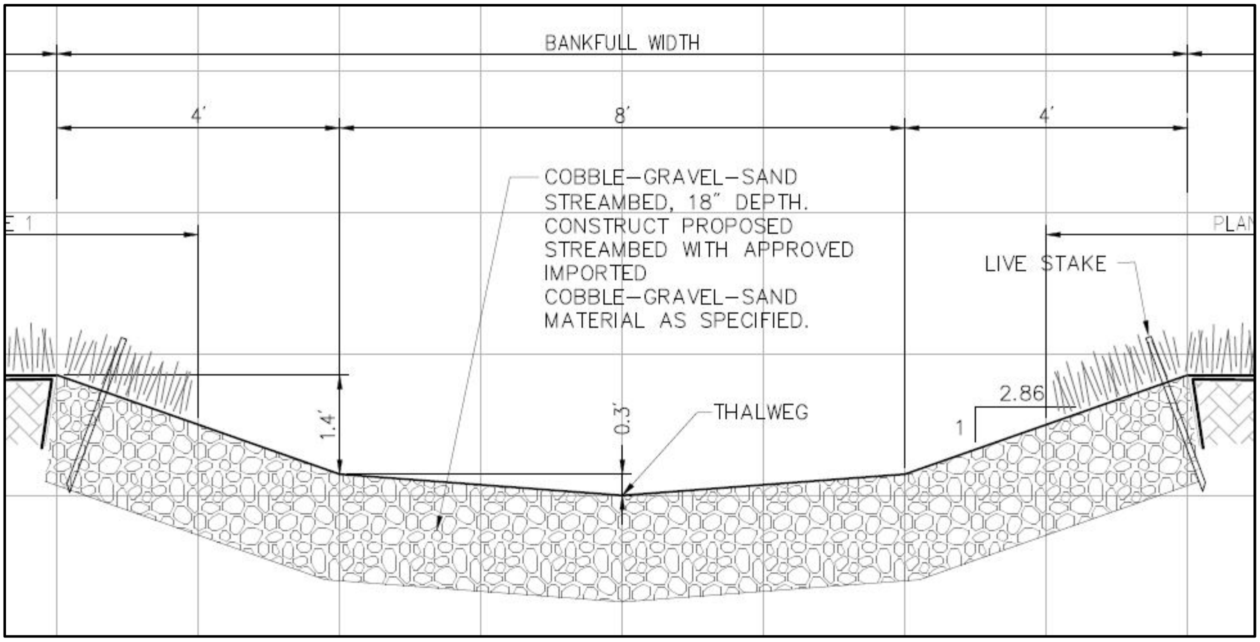

Figure 12. Portion of typical cross section showing 18-inch rock bed layer to be added to design channel along the length of the restoration project (From VHB, 2019, Drawing C-6)

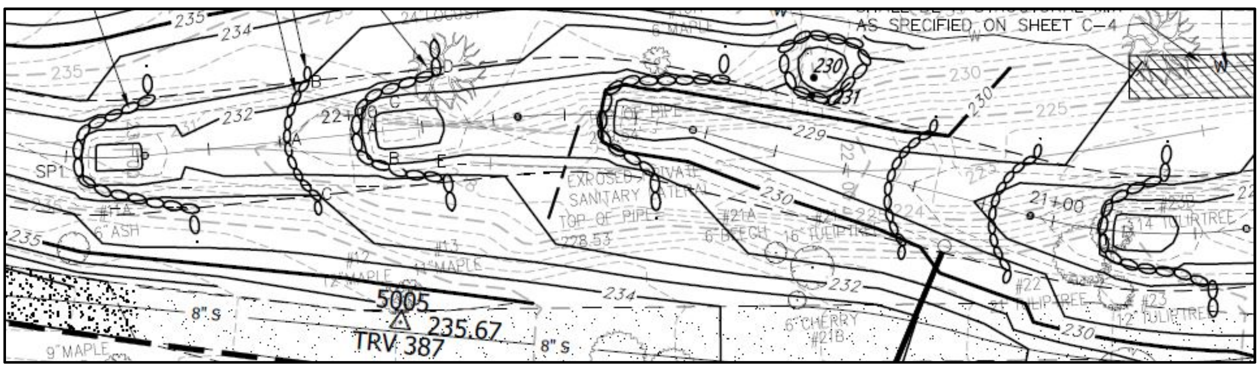

Figure 12. Portion of design plan showing several of the boulder step structures to be built across the proposed channel along its entire length. (From VHB, 2019, Drawing C-7)

The large rock, although not explicitly stated, is essentially being used to armor or lock the proposed design channel in place in direct contradiction to the basic tenets of Natural Channel Design (Rosgen, 2011). As a result, the use of large rock in the design is a tacit acknowledgement that the proposed project cannot function as a geomorphically "stable" channel (see Section 2.0 above). By creating a static rather than a stable channel with the freedom to adjust its position over time, several potential problems are likely to arise if the project is implemented as designed.

The rock size used in the 18-inch thick bed layer has been carefully selected to remain immobile up to a 10-year flood event (VHB, 2019, Drawing D-1). What will happen, however, during an even larger flood when the bed layer is able to move? With only finer-grained fill underneath the coarse bed layer (see Section 4.2 above), the implication, perhaps expectation, is that the design channel could be enlarged through bed and bank erosion with the currently existing gully eventually reestablished. By designing for a 10-year flood, a 10 percent chance exists that the project could unravel within the first year of completion and a greater than 65 percent chance within 10 years (Web citation 2). With the potential ramifications of increased sediment delivery downstream to Chesapeake Bay and a return to eroding banks that threaten adjacent infrastructure, should nearly $2.5 million dollars (Web citation 3) be invested in a project with a better than even chance of beginning to unravel in the first 10 years? This is not hyperbole but simply the implications of the design parameters.

The use of the large boulders to form the rock step structures also presents problems. Boulder steps are natural features found on confined and steep mountain streams. While the upper portion of the restoration reach on Donaldson Run Tributary B is confined and fairly steep, the soils are largely composed of fine-grained material with no boulders occurring naturally. When stream flows encounter a contact between large immobile boulders and fine erodible sediment, the stream will preferentially and aggressively scour the fine sediments on the bed or banks of the channel. Since the boulder steps will be set below the coarse bed layer (VHB, 2019, Drawing C-5), undermining of the structures seems less likely than the "outflanking" of the structures (i.e., lateral erosion around the steps) due to bank erosion. Similar outflanking of boulder structures occurred as a result of bank erosion along the design channel constructed as part of the nearby Donaldson Run Tributary A restoration completed in 2006 (Figure 13).

Figure 13. Outflanked boulder structure installed as part of Donaldson Run Tributary A restoration. Dashed yellow line approximates position of bank at completion of construction but is now well within the channel limits such that the boulder structure is not functioning as intended – note gravel bar against the boulders where a pool should be.

Again, this is not hyperbole but exactly what has happened along the immediately adjacent restoration project on Tributary A (Figure 13) and other projects in the mid-Atlantic region (Miller and Kochel, 2010). Why are so many large boulders being used in a Natural Channel Design project at a site where no boulders exist naturally? The ability to sustainably achieve the project goals on Tributary B will be greatly compromised, not enhanced, by the use of boulders to create step-like structures.

5.0 ALTERNATIVE RESTORATION APPROACH

Given the numerous issues with the Donaldson Run Tributary B restoration design (VHB, 2019) identified in Section 4.0 above, an alternative restoration design approach is warranted. A restoration approach consistent with natural processes and utilizing materials natural to the site is likely to: 1) better achieve the project goals; 2) function properly for a longer time period; and 3) be more cost effective. The use of wood in restoration projects is gaining favor nationally (USBR and ERDC, 2016; Reich et al., 2003), has been used to address urban impairments such as channel incision (Field and Carney, 2020), and may serve as an effective alternative for restoring Tributary B.

Wood could serve at least four different functions as part of Tributary B restoration: 1) energy dissipation; 2) bank stabilization; 3) sediment storage; and 4) habitat enhancement. Just downstream of the upstream culvert outlet where the current restoration design envisions a series of rock plunge-pool structures to dissipate the energy of the runoff exiting the culvert (VHB, 2019, Drawing C-7), low log jam structures (Figure 14) spanning the channel could more effectively dissipate energy while providing greater habitat function. In addition, the log jams would be more porous, so pools of water during low flow conditions would not persist as potential mosquito breeding areas. The banks of the channel around these log jams could be stabilized with some form of log crib wall (Figure 15) that would better resist scour and undermining than the currently proposed rock walls if vertical log piles are used to anchor the log cribbing.

Figure 14. Low log jam structure built for an urban stream restoration project in South Portland, ME. Such log jams on Tributary B would extend only partially up the high banks and could be used to dissipate the high energy flows emerging from the culvert outlet at the upstream end of the project.

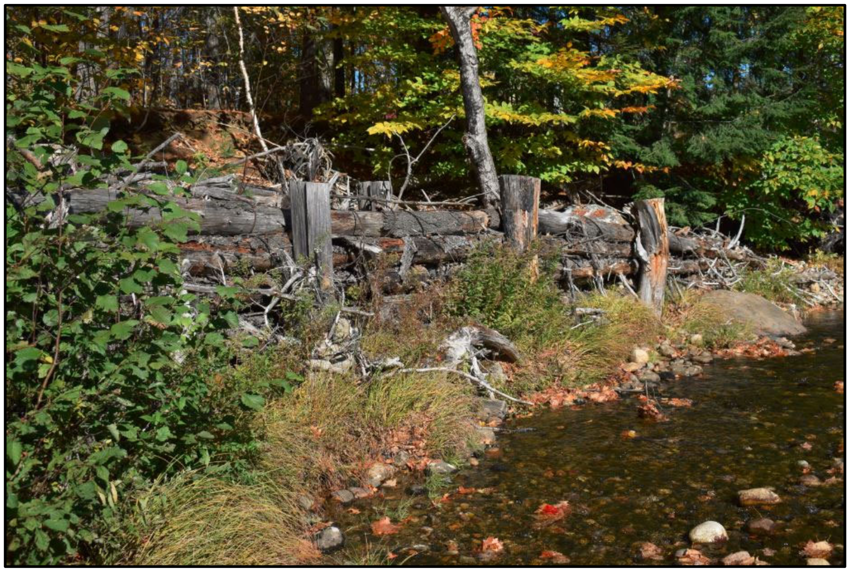

Figure 15. Log crib wall constructed for bank stabilization on Sunday River in Newry, ME. Photo was taken 14 years after construction and is unchanged since completion and remains solid. Rot resistant hemlock used.

Log crib walls could also be used for bank stabilization elsewhere along the stream. However, the entire length of the stream does not need to be stabilized. Bank stabilization should be reserved for only where critical infrastructure is most threatened. Only by allowing the channel to finalize its natural widening process (see Section 2.0 above) will the stream be able to reach an equilibrium condition in balance with the urbanized watershed. However, given the proximity of critical infrastructure, most of the restoration reach upstream of the pedestrian bridge may require bank stabilization. Log crib walls with roots protruding slightly out from the bank would further dissipate the energy driving the erosion in contrast to the current restoration proposal with stream-lined meanders and smoothed rock banks on a slope steepened by the addition of fill. Downstream of the pedestrian bridge, very little need for bank stabilization exists as the stream has essentially completed the widening process (Figure 3), the highly sinuous meanders near the confluence (Figure 5) have changed little in more than 30 years, and the critical infrastructure is not as proximal to the existing stream banks.

One motivation for completing restoration on Tributary B is to earn "credits" for reducing sediment loading downstream to Chesapeake Bay. The method used to justify the credits for the current design is by calculating the amount of sediment prevented from entering the stream by stabilizing the banks. While this should still apply for bank stabilization using log crib walls, additional credits could be earned using wood to encourage sediment storage along the stream bottom. Wood placed across the channel can store a considerable volume of sediment and help narrow the stream channel (Figure 16). Skalak and Pizzuto (2010) demonstrated that fine sediment and organic matter can remain in storage for decades behind large wood in rivers, significantly reducing the annual sediment load moving downstream. Wood placed periodically along the existing stream channel helps to build resilience against large floods and rapid sediment inputs by providing both energy dissipation (that reduces erosive forces when flows are high) and sediment storage capacity (that provides a buffer to downstream sediment transport when sediment inputs are high).

Figure 16. Wood addition projects on two small streams in the Green Mountain National Forest, VT. Photos taken a) one year after completion and b) 20 years after completion (arrows at edge of channel prior to wood addition). Note considerable sediment accumulation following one year and how after 20 years a revegetated floodplain developed as the channel narrowed as a result of the sediment storage.

Wood added to the channel for the purpose of sediment storage along Tributary B could take the form of low log jams (Figure 14) or random placements of large logs to appear like natural tree fall. Sediment would be stored upstream of the log structures and when filled to the top of the logs could create step-like structures with plunge pools forming downstream as envisioned for the boulder steps in the current design plan (VHB, 2019). Furthermore, the sediment storage, over time, leads to channel narrowing in a sustainable manner (Figure 16b) as opposed to the Natural Channel Design proposal (VHB, 2016) that is unlikely to maintain the constructed narrow channel (see Section 4.2 above). Wood would be best placed where bedrock has been exposed, since a stream bed composed of gravel and cobble would be better for macroinvertebrate colonization than sheer rock. However, wood structures promoting sediment storage and energy dissipation would be beneficial throughout the length of the project.

The habitat benefits of using wood in streams are documented thoroughly in the scientific literature. Wood in stream channels results in higher fish populations (Flebbe, 1999), a greater abundance and richness of macroinvertebrates (Bond et al., 2006), and more complex physical habitat (Benke and Wallace, 2003). A separate wood structure for enhancing habitat is not needed as the structures described above for energy dissipation, bank stabilization, and sediment storage all simultaneously improve habitat as well. Compared with the current Natural Channel Design proposal (VHB, 2019) that proposes to completely bury the existing stream bottom with fill and then add boulders to create habitat elements in a sterile environment, the alternative described here to add a variety of wood structures on the existing stream bottom represents a far superior approach for achieving the project's goal of providing aquatic benefits and habitat.

The use of wood in restoration is often dismissed as ineffective because of the inevitable decay of wood that will ultimately lead to the loss of the functional benefits. Wood-based restoration projects, especially when rot-resistant tree species such as White oak (*Quercus alba*) are used, can typically have a functional life of more than 20 years (Figure 15 and 16b). That duration can be extended even longer where the wood remains submerged in water or encased by sediment deposited around the log structures. While the individual boulders used in rock structures will obviously persist for millions of years, they are more easily dislodged from a structure than individual logs in interlocking wood structures. As a result, the loss of structural function for boulder structures often occurs in less than 20 years as is evidenced by the numerous isolated boulders found on the bed of Tributary B derived from past bank stabilization efforts (Figure 3).

Another concern expressed regarding the use of wood in restoration projects is that the wood, due to its buoyancy, will too easily wash downstream. Several methods are available to anchor the wood in place, although the exact anchoring approach to use on Tributary B would need to be addressed in the development of a final design. Vertical log piles driven into the stream bed serve as solid anchor points and should work well on the lower end of Tributary B, but will be difficult upstream where bedrock is locally exposed. Steel eye bolts could be drilled into the rock in these locations with steel cable wrapped around the logs and fastened to the bolts – all easily concealed to not detract from the natural aesthetic of the structures. Tributary B is small enough where the use of large diameter logs may be sufficient enough to prevent the flow from dislodging them, especially where the logs could be wedged between large standing trees growing near the edge of the channel.

A detailed cost estimate for a wood-based restoration project is not possible based simply on the conceptual ideas presented above. However, the costs can easily be understood to be much lower than the current final design (VHB, 2019) cost estimate of nearly $2.5 million (Web citation 3), even after accounting for additional engineering and permitting costs that might be required to develop a final wood-based design. The concept described above will not require a major realignment of the channel nor will the significant earth moving that entails be needed. Earth fill, rock, and boulders would no longer need to be used, so that in itself represents a huge cost savings on materials. Trees could presumably be sourced much closer to the site than these other materials and some trees that have already fallen into the channel could be salvaged for reuse. Far less material would be needed, in general, for a wood-based project as very little, if any, wood is needed below the pedestrian bridge where the channel already is largely stable and displays excellent habitat. The construction timeline and need for heavy machinery would also be greatly reduced such that the often uncalculated costs of noise pollution, air pollution, and CO_2 emissions would represent additional savings in the form of improved health and well-being of the environment and for those living closest to the site. Strategic placement of wood structures along the channel could greatly reduce the number of large trees that would be removed as part of the restoration, although some small trees would inevitably be impacted.

Natural Channel Design is often perceived as the only approach to restoration that will meet with the approval of state and federal environmental regulators. Natural Channel Design, however, embodies several techniques and does not exclusively require the major realignment of the channel and its dimensions. A wood-based restoration project using natural materials and enhancing the ongoing natural processes along the stream is more consistent with the intent of Natural Channel Design than those projects requiring a significant alteration of the existing channel and surrounding ecosystem. While the wood-based approach may be novel for the DC metropolitan region, state and federal environmental regulators are often seeking, perhaps required to approve, what is referred to as the Least Environmentally Damaging Practicable Alternative. Given the two alternatives discussed in this report, the wood-based alternative is both less environmentally damaging and far more practicable from both a technical and financial perspective.

6.0 CONCLUSION

Natural Channel Design is an appealing approach to stream restoration as it promises to put an end to bank erosion, poor water quality, and degraded habitat by simply creating a channel that mimics the size and pattern of a channel expected to form in a similarly-sized unaltered watershed. However, such projects do not address the ongoing processes, such as excess runoff, that have led to the instabilities being addressed by the restoration. As a result, the channels created by Natural Channel Design are often, unfortunately and perhaps counterintuitively, unstable and unsustainable.

The proposed design channel for Donaldson Run Tributary B, when functioning as designed, will more efficiently transport sediment downstream towards Chesapeake Bay counter to the project's intent due to an increase in the design channel's slope and narrowing of its width (see Section 4.1 and 4.2 above). By misunderstanding the setting within which the idealized channel form is being constructed, the project design intends to frequently inundate a surface that has never regularly flooded before (see Section 4.2 above), causing undo stress to the natural ecosystem not adapted to regular floodwater inundation. Note that both of these negative outcomes will result when the project is functioning as designed and represent a further destabilization of the local environment and, more broadly, Chesapeake Bay itself.

Increasing the slope and narrowing the width of the channel will make the design channel unstable relative to the urbanized watershed experiencing increased runoff. Over time (more than likely within the first 10 years of construction based on the design parameters – see Section 4.3 above), the design channel will begin to unravel during a large flood or unexpected event that clogs the channel (e.g., sediment from the valley side slopes, tree falling into stream). Once the armor layer of rock and boulders in the design channel is weakened, outflanked, or bypassed entirely, the channel will adjust relatively rapidly to reestablish a channel more closely approximating the existing condition that is already nearing an equilibrium condition in balance with the urbanized watershed (see Section 3.0 above). Consequently, any short-term improvements in bank stability, water quality, and aquatic habitat will prove unsustainable.

A process-based restoration approach using wood (representing an alternative form of Natural Channel Design if you will) can avoid many of the pitfalls of the traditional Natural Channel Design approach. By adding wood within the existing channel in a variety of ways (see Section 5.0 above) rather than completing realigning the channel, the project can achieve its goals with less of a short-term and long-term impact to the existing park aesthetic and at a greatly reduced cost. Modifications to the Tributary B restoration design plan that embrace a wood-based solution can put Arlington County at the vanguard of developing new eco-friendly cost-effective approaches to stream restoration in the DC metro region that will more effectively address the goals of these restoration efforts.

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APPENDIX 1

(Resume for Dr. John Field)

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EDUCATION

University of Arizona, Tucson, Arizona, August 1990 - May 1994.
Ph.D. in Geosciences (Minor-Hydrology).

University of Arizona, Tucson, Arizona, Jan. 1984 - Dec. 1985.
M.S. in Geosciences.

Virginia Tech, Blacksburg, Virginia, Sept. 1979 - June 1983.
B.S. in Geology with Honors.

EMPLOYMENT

2002-present, President, Field Geology Services
- Independent consulting firm specializing in fluvial geomorphology
- Projects completed in 15 states and 11 countries worldwide
- Restoration of over 30 miles of stream and geomorphic assessments of more than 500 miles

2002-present, Faculty Associate, Colby College and University of Maine at Farmington
- River management and watershed education projects
- Taught college courses in "River Management: Past and Present" and "Introduction to Geology"

1999-2002, Associate Professor, Green Mountain College
- Development of geology and environmental education program

1994-1999, Assistant Professor, Western Washington University
- Taught courses in Geomorphology and Science Education
- Research and monitoring of stream restoration and habitat enhancement projects

1990-1993, Geomorphologist, Arizona Geological Survey
- Geomorphic and flood hazard mapping on alluvial fans and river floodplains

AWARDS AND HONORS

U.S. Environmental Protection Agency Environmental Merit Award for Long Creek Restoration Project
Geological Society of America's 1998 Biggs Teaching Award
Western Washington University's 1997 Excellence in Teaching Award

SELECTED PUBLICATIONS AND PRESENTATIONS

Field, J., and Carney, P., 2020, A national model for urban stream restoration from South Portland, Maine: River Management Society Journal, v. 33, 3 p. (Cover article).