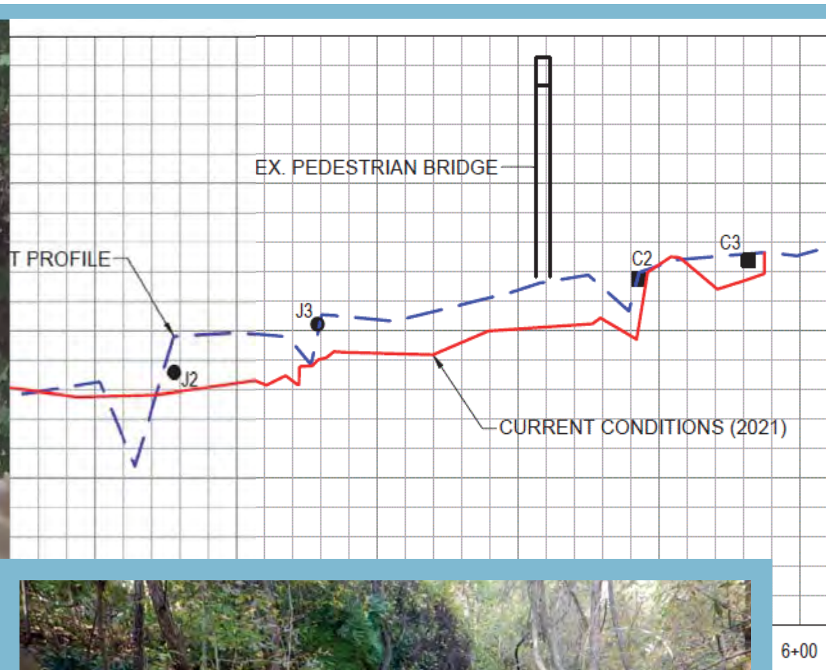
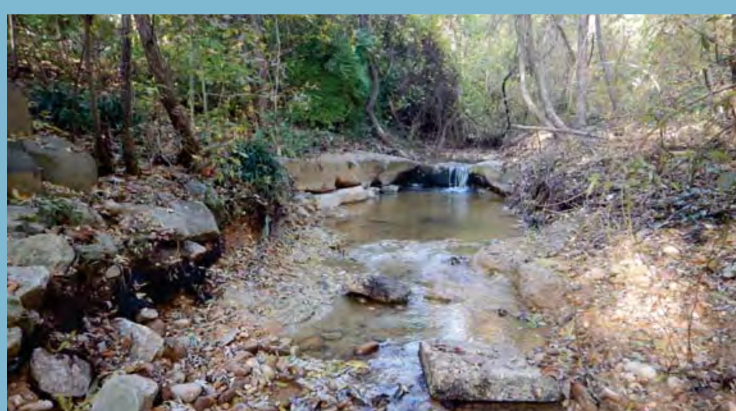
Strawberry Run Forensic Investigation

Prepared for:
Stormwater Management Division Transportation and Environmental Services

City of Alexandria

June 2022





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STRAWBERRY RUN DOWNSTREAM FORENSIC INVESTIGATION

PREPARED BY:

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FOR:

STORMWATER MANAGEMENT DIVISION

TRANSPORTATION AND ENVIRONMENTAL SERVICES

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ACKNOWLEDGEMENTS

The Strawberry Run Downstream Forensic Investigation represents a collaborative effort between staff from Wood Environment & Infrastructure Solutions, Inc. and the City of Alexandria's Stormwater Management Division, Department of Transportation and Environmental Services and Department of Project Implementation. The staff primarily involved in the project are listed below:

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SECTION 1 – INTRODUCTORY OVERVIEW

1. INTRODUCTORY OVERVIEW

A. EXECUTIVE SUMMARY

At the Alexandria City Council Legislative Meeting on April 27, 2021, Council instructed City staff to collaborate with the City's Environmental Policy Commission (EPC) to investigate stream restoration failures at the Strawberry Run site. This report describes findings of the forensic investigation to help the City understand the scope and causes of performance deficiencies, including excessive erosion and downstream sediment transport. Performance criteria protocols defined by the Chesapeake Bay Program were used to evaluate project conditions.

The report includes a physical characterization of current stream conditions and a description of likely failure mechanisms. The forensic investigation was comprised of the following components:

- Topographic field survey of the stream corridor to document current conditions and support analysis of failure mechanisms resulting in the departure from design and as-built conditions.
- Field assessment of the stream bed, banks, and rock structures to document stability, functions, and departure from design conditions.
- Geomorphic analysis of stream channel conditions and adjustments in relation to equilibrium conditions.
- Review of local rainfall data.
- Hydraulic analysis of predicted applied forces and resulting sediment transport competence.

Wood identified the major and minor factors leading to the current stream conditions. The previously restored reach of Strawberry Run meets the Chesapeake Bay Program criteria for project failure with more than 50% of the reach exhibiting bed or bank instability. The field data and hydraulic analysis support the conclusion that the undesirable vertical and lateral adjustments in the restored stream are attributable to applied hydraulic forces that exceeded the erosion resistance of the constructed channel boundaries. Some of the channel bed substrate has mobilized downstream, resulting in incision and headcutting at the upper end of the stream reach and accumulation of sediment at the downstream end. The dropping bed elevation has exacerbated problems by reducing floodplain access, thereby increasing applied shear stress during high flows, and causing the undermining and collapse of some rock vane grade control structures (Cross-Vanes and J-Hook Vanes). The erosion processes are worsening as the channel becomes more incised, as evidenced by the recent substantial headcut migration occurring between January and November of 2021.

Based on the forensic investigation of stream conditions and processes, Wood recommends short-term and long-term actions to stabilize the stream, restore optimal functions, and protect public infrastructure. The most urgent need for this reach is to protect the structural integrity of the pedestrian bridge abutment by preventing further stream bed and bank erosion. To resist the applied hydraulic forces during high flow events, large bed substrate and rock grade control structures should be installed near the bridge. In addition, the City should report the project failure in its next MS4 annual report and adjust planning for Chesapeake Bay TMDL compliance accordingly. To achieve long-term stability, Wood recommends the reconstruction of the channel using a design to achieve City and stakeholder objectives. Consideration should be given to the restoration of the upstream portion of Strawberry Run to ensure the long-term success and stability of the reconstructed channel.

B. BACKGROUND

The Strawberry Run stream restoration plan, approved in 2008, was completed in 2010 on 600 linear feet of channel in a public park upstream from its intersection with Duke Street. The stream restoration was implemented by a developer as mitigation for proposed permanent impacts to the Chesapeake Bay Resource Protection Area (RPA) and to meet stormwater quality requirements associated with the adjacent residential redevelopment project (Taft Avenue Subdivision). According to the Williamsburg Environmental Group (WEG) *Stream Restoration Plan 2008*, the pre-restored stream exhibited characteristics typical of degraded urban streams, citing "The upstream portion of the channel is severely incised, exhibiting vertical banks and minimal connectivity to the floodplain. Although the downstream portion of the stream is less incised, bank erosion and scour continue to demonstrate the overall instability of the channel."[1]

The stream restoration project included components of Natural Channel Design (NCD) and served to fulfill the requirements of the City's Environmental Management Ordinance (Alexandria Zoning Ordinance, Article XIII) for land disturbing activities. The requirements included mitigating proposed impacts to the RPA in accordance with a Water Quality Impact Assessment (Section 13-117) and meeting the water quality requirements of Section 13-109 for reductions of phosphorus for land disturbing activities. On-site stream restoration could not be used to meet minimum state water quality requirements under the current version of the ordinance.[2] However, the ordinance in effect at the time of the project allowed the Director of Transportation and Environmental Services (T&ES) to approve alternative water quality approaches if they were deemed consistent with good engineering practices (Section 13-109 (5) (b), 2006 version).

Wood recognizes that the primary technical objective of the Strawberry Run stream restoration was to reduce channel and bank erosion in the unstable urban stream, thereby reducing the downstream pollutant load. The *Taft Avenue Properties Water Quality Major Impact Assessment: Williamsburg Environmental Group (WEG 2006 WQIA)* estimated the restoration would result in an annual sediment reduction between 23,976 lbs/year and 44,410 lbs/year. The City ultimately claimed reductions of 40.80 lbs/year for total phosphorus (TP), 45.00 lbs/year for total nitrogen (TN), and 26,928.00 lbs/year for total suspended solids (TSS) in its *Chesapeake Bay Total Maximum Daily Load (TMDL) Action Plan for 5% Compliance* (2015) and subsequently in its *Phase 2 Chesapeake Bay Total Maximum Daily Load (TMDL) Action Plan for 40% Compliance* (2019).[3]

Credit was not taken as a stand-alone project. Rather, credit was taken in accordance with guidance from the Virginia Department of Environmental Quality (DEQ)[4], which allows the City to aggregate the impacts of land use changes and new BMPs (Best Management Practices) within a specified period to demonstrate that there was an overall reduction in pollutant loads (due to redevelopment, oversized BMPs, over treatment, etc.). According to the City's 5% compliance action plan, the 40.80 lbs/year TP removal was

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[1] Project narrative from the Williamsburg Environmental Group *Stream Restoration Plan* stamped 1/16/2008.

[2] Compliance with current state minimum water quality standards must be achieved using stormwater BMPs found on the Virginia BMP Clearinghouse website or through off-site compliance options in 9VAC25-870-69. Stream restoration is not currently an approved BMP on the Virginia BMP Clearinghouse website.

[3] BMP ID 2004-0038 01.

[4] Virginia DEQ Chesapeake Bay TMDL Special Condition Guidance Memo 15-2005, dated May 18, 2015, and Memo 20-2003, dated February 6, 2021.

based on the revised interim removal rate of 0.068 TP per lbs/feet/year discussed in the *Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects, 2014*.

C. PURPOSE

At the April 27, 2021, Alexandria City Council Legislative Meeting, Council instructed City staff to collaborate with the City's EPC on several topics related to NCD. Specifically, City staff and the EPC were requested to investigate why NCD failed at this previously restored Strawberry Run site. In January 2021, Wood visited the site to document current conditions. Wood particularly noted performance deficiencies and issues observed with the project.

This Strawberry Run Downstream Forensic Investigation (investigation) has been developed to help the City understand the scope and causes of observed performance deficiencies. In addition, the investigation is designed to identify and evaluate problems with the stream restoration project, including areas of bed or bank instability that result in the project delivering more sediment downstream than designed.

The report includes condition assessments, photographic documentation, planform, profile, and cross-section comparisons, computations, hydraulic analyses, and other potential contributing factors. The report concludes with findings and high-level recommendations for potential solutions.

SECTION 2 – BASIS OF ANALYSIS

2. BASIS OF ANALYSIS

A. LIMITS OF ANALYSIS

The forensic investigation was limited to approximately 600 linear feet of Strawberry Run extending upstream from the culvert beneath Duke Street to the storm sewer confluence upstream of Cross-Vane #3. See Figure 1 and Figure 2. In November 2021, Bowman Consulting Group, Inc. (Bowman) surveyed the stream corridor, providing topographic survey of the channel, banks, and overbanks. As seen in Figure 2, the reach includes six in-stream rock vane structures (three Cross-Vanes and three J-Hook Vanes) and one section of rock toe. An assessment of the riparian vegetation was excluded from the scope of this analysis.

The City of Alexandria provided Wood with the *Stream Restoration Plan Taft Avenue Approved Plan DSP2007-00018; Williamsburg Environmental Group (WEG 2008 Design Plan)* along with the *Stream Restoration As-Built Taft Avenue Property; Williamsburg Environmental Group (WEG 2010 As-Built Stream Plan)*. Additionally, the City provided Wood with the following documents: *Taft Avenue Floodplain Alteration Study; Williamsburg Environmental Group (WEG 2005 Flood Study), Stream Restoration Maintenance and Monitoring Agreement; City of Alexandria 2008,* and *Taft Avenue Property Approved As-Built Site Plan DSP2004-0018; Williamsburg Environmental Group (WEG 2010 As-Built Site Plan).*

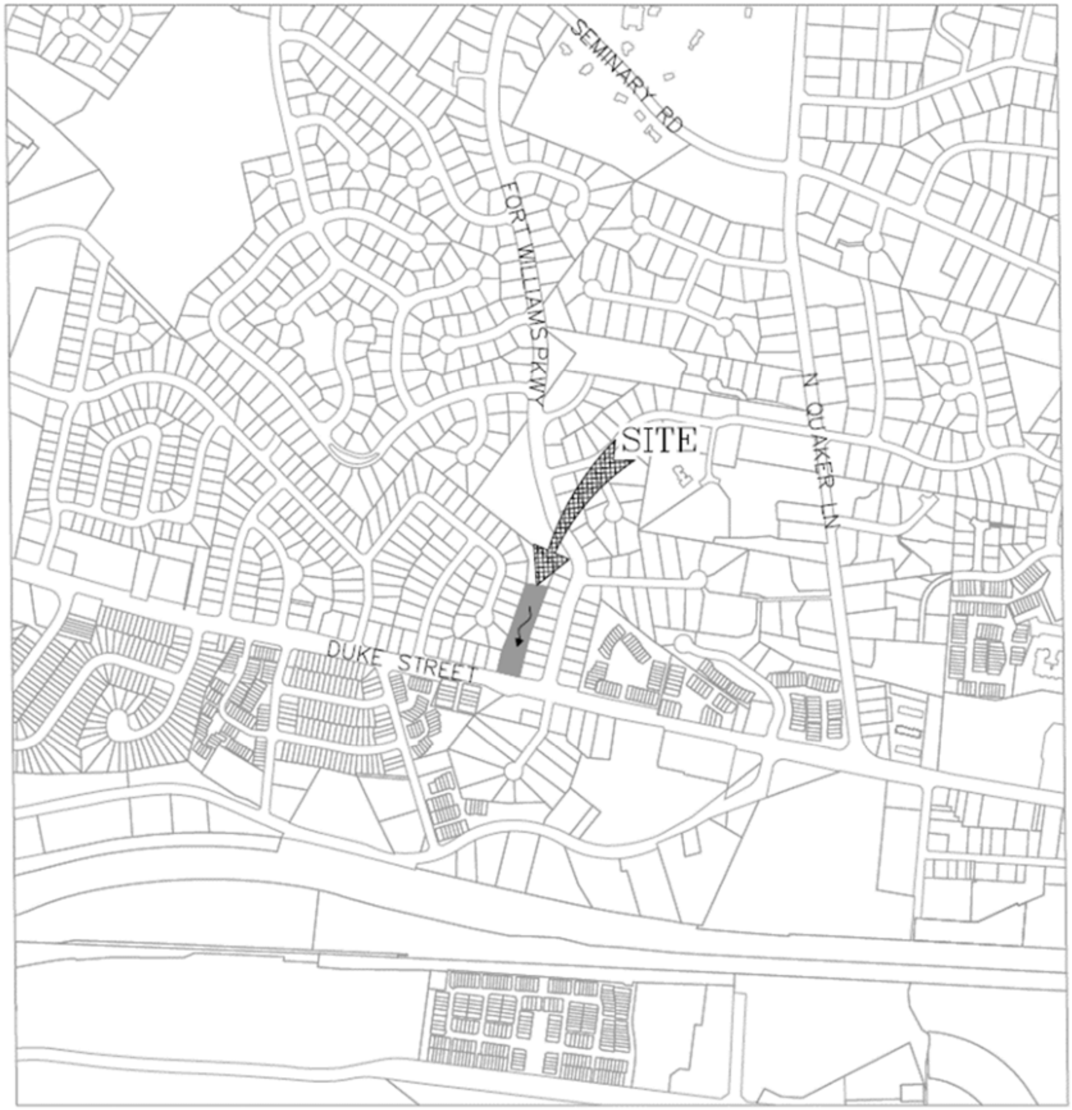


Figure 1. Site Location Map

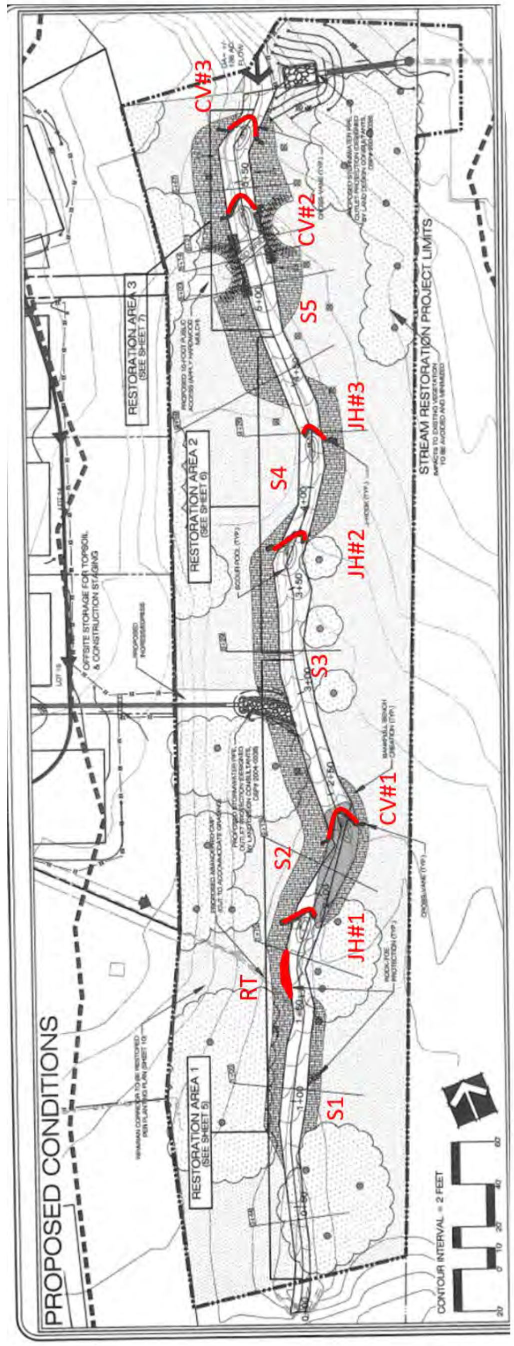


Figure 2. Design Plan View

** S=Stream Segment, CV=Cross-Vane, JH=J-Hook Vane, RT = Rock Toe*

B. PERFORMANCE CRITERIA

Virginia DEQ recognizes the *Consensus Recommendations for Improving the Application of the Prevented Sediment Protocol for Urban Stream Restoration Projects Build for Pollutant Removal Credit* (revised 2/27/2020) as the current performance criteria for stream restoration projects being designed and implemented pursuant to Bay Program protocols. Section 8, "Summary of Updated Reporting and Verification Requirements," establishes a two-stage inspection process and defines the criteria for loss of pollutant reduction function. The first stage involves a rapid inspection of the project reach to assess its condition, relying on key visual indicators to help the inspector determine whether there is a loss of function. The criteria for loss of function and key visual indicators are replicated in Table 1.[5]

Table 1: Defining Loss of Pollutant Reduction Function for Protocol 1

Criteria for Loss	Key Visual Indicators
Evidence of bank or bed instability such that the project delivers more sediment downstream than designed, as defined by exposed soils/fresh rootlets	• Bank erosion (e.g., exposed bare earth or undercutting bank) • Departure of more than 20% from average post- construction design bank height[1] • Incised channel, as indicated by loss of defined pools and riffles and/or presence of an active head cut • Flanking or scour of in-channel structures • Failure or collapse of allowable bank protection practices • Less than 80% ground or canopy cover in the restoration zone[2]
[1] As measured at riffles from the project as-built drawing, preferable from pre-designated control sections established at its most vulnerable locations [2] Depending on the long-term vegetative community objectives established for the project, may be expressed as a measure of exposed surface soil (>20%) or canopy cover (<80%)	

In January 2021, the City requested Wood to visit the site and obtain photographs of the site area. This site visit and subsequent discussion with the City constituted the rapid inspection for the first stage described above.

The second stage, should a project appear to fail, "is a forensic inspection to diagnose the nature and cause(s) of the problem, and whether project functions can be recovered by additional work." The guiding rule is that "inspectors are looking for departures from the original design that could possibly compromise

[5] Table 6, *Consensus Recommendations for Improving the Application of the Prevented Sediment Protocol for Urban Stream Restoration Projects Build for Pollutant Removal Credit,* 2/27/2020.

pollutant reduction functions." Follow up action is then governed by the degree of change relative to the original design. Table 2 shows possible management categories based on the severeness of the reach failure.[6]

Table 2: Framework for Relating Reach Conditions to Management Decisions

Status	**% Failing**	**Inspections**	**Management Actions**
Functioning or Showing Minor Compromise	0 to 10% of project reach	Re-inspect in 5 years	Non needed. Credit renewed for 5 years
Showing Major Compromise	20 to 40% of project reach	Conduct immediate forensic investigation to identify cause(s)	Do project repairs and maintenance, as warranted
Project Failure	50% or more of reach	Lose credit and abandon the project or reconstruct a new stable channel	

Using the *WEG 2010 As-Built Stream Plan* and the recently collected topographic channel survey information, profile comparisons can be made to analyze and determine the relative change to the original design/as-built. Additionally, field investigations and condition assessment allow for determining if the key visual indicators defined in Table 1 are present. The field condition assessment and field survey comparisons to the original design are discussed in Section 3.

[6] Table 7, *Consensus Recommendations for Improving the Application of the Prevented Sediment Protocol for Urban Stream Restoration Projects Build for Pollutant Removal Credit,* 2/27/2020.

SECTION 3 – FINDINGS

3. FINDINGS

A. CONDITION ASSESSMENT

Wood visited the site on November 11 and 22, 2021, to document and observe field conditions for the second stage of the forensic investigation. The previously restored reach was visually assessed and photographed (Figure 3 – Figure 28). During site visits, staff collected and measured select samples of bed and point bar materials to better understand the ongoing fluvial processes. The assessment included the conditions noted from the field observations for the original six rock vane structures, one rock toe structure, and the five separate stream reaches. Personnel walked the project site from Duke Street to approximately 80 feet upstream of the pedestrian bridge.

All references to direction of left and right bank areas are facing in the downstream direction. References to approximate stream stationing are based on the design/as-built alignment unless noted otherwise. A map key is provided for each structure, with the red box indicating the approximate area of the photographs.

i. Structures

a. J-Hook Vane #1

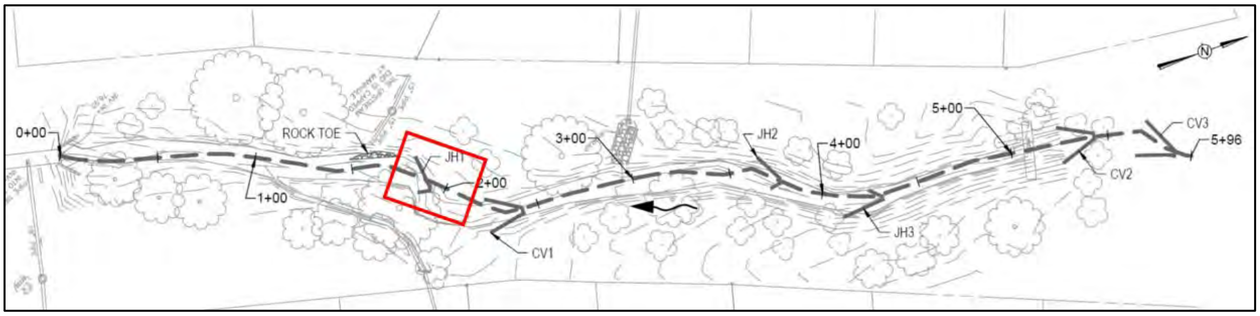


	
Figure 3. J-Hook Vane #1 – Looking Upstream (Station 1+70)	**Figure 4**. J-Hook Vane #1 – Looking Downstream (Station 2+20)

Conditions noted from field observation:

- Sediment filled in scour hole below structure
- Header rocks not visible/displaced
- Flanking around left of structure
- Parts of the structure are gone, no longer in function; right vane arm appears to be intact

b. Rock Toe Revetment

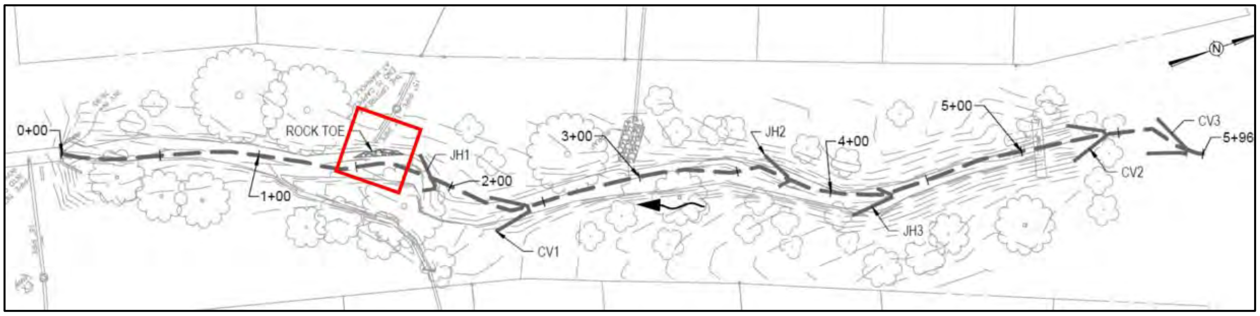


	
Figure 5. Rock Toe Looking Downstream (Station 1+60)	**Figure 6**. Displaced Rock Toe Material (Station 1+60)

<u>Conditions noted from field observation:</u>

- Rock toe has minor gaps in revetment
- Some of the rocks have moved from the bank

c. Cross-Vane #1

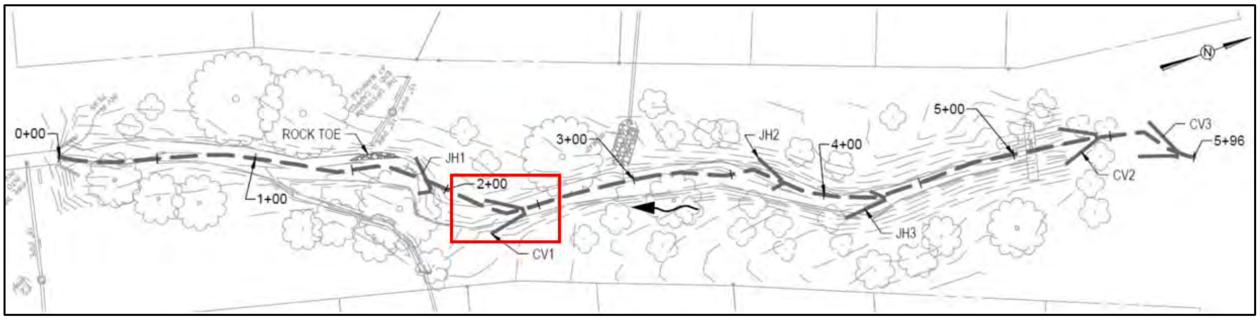


Figure 7. Cross-Vane #1 – Looking Upstream (January 2021, Station 2+40)

Figure 8. Cross-Vane #1 – Looking Upstream (November 2021, Station 2+40)

<u>Conditions noted from field observation:</u>

- Stream bed has aggraded and deposited material over the structure (approximately 4 inches of material on top of header boulders)
- Structure is still in-place
- Sediment has filled the scour hole

d. J-Hook Vane #2

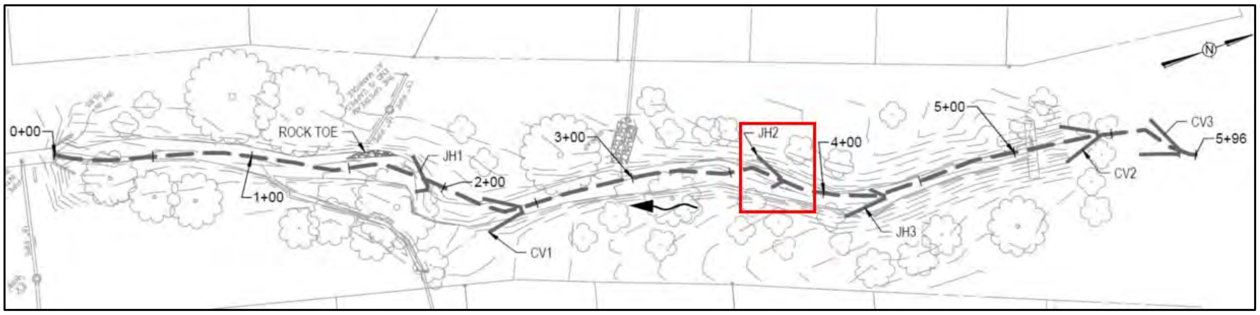


	
Figure 9. J-Hook Vane #2 – Looking Upstream (Station 3+70)	**Figure 10**. J-Hook Vane #2 – Looking Downstream (Station 3+80)

<u>Conditions noted from field observation:</u>

- Structure flanking around left side of vane arm
- Structure is compromised and no longer functions
- Right vane arm collapsing; boulders starting to fall in
- Footer boulders remains at center of structure
- Erosion immediately downstream of structure along left bank

e. J-Hook Vane #3

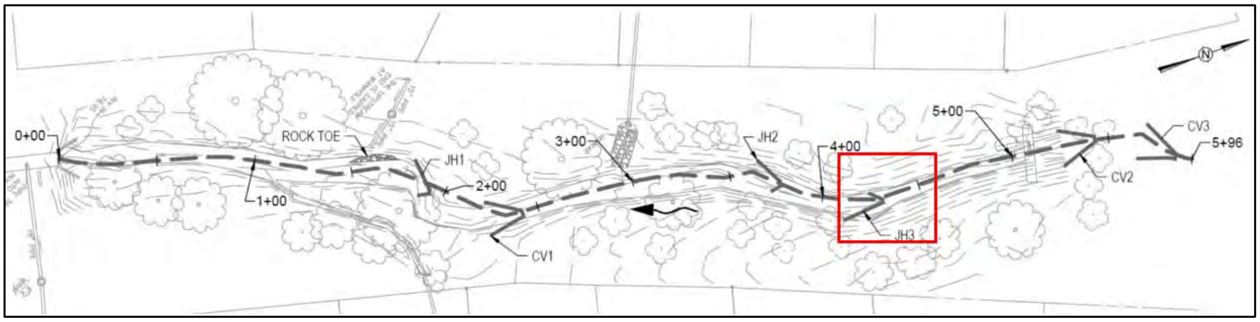


	
Figure 11. J-Hook Vane #3 – Looking Upstream (Station 4+20)	**Figure 12**. J-Hook Vane #3 – Looking Downstream (Station 4+30)

Conditions noted from field observation:

- Structure has collapsed and no longer functions
- Evidence of flanking along left side of structure

f. Wooden Pedestrian Bridge

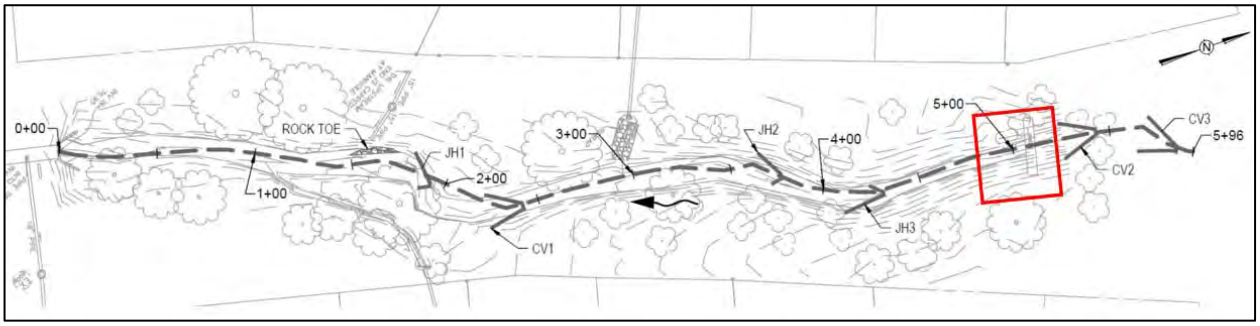


	
Figure 13. Right Bridge Abutment – Looking Upstream (April 2018, Station 5+00)	**Figure 14**. Right Bridge Abutment – Looking Upstream (November 2021, Station 5+00)

<u>Conditions noted from field observation:</u>

- Headcut has migrated upstream of bridge
- Pedestrian bridge abutments at risk of continual erosion and potential undermining

g. Cross-Vane #2

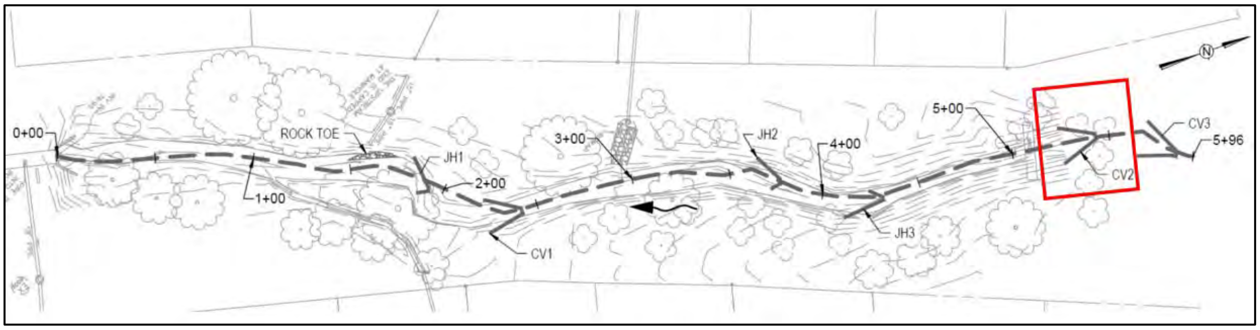


	
Figure 15. Cross-Vane #2 – Looking Upstream from Underneath Bridge (Station 5+20)	**Figure 16**. Cross-Vane #2 – Looking Downstream Towards Bridge (Station 5+50)

Conditions noted from field observation:

- Headcut has advanced to structure
- Footer rocks are exposed
- Structure at risk of collapse
- Minor signs of flanking around header boulders along right side

h. Cross-Vane #3

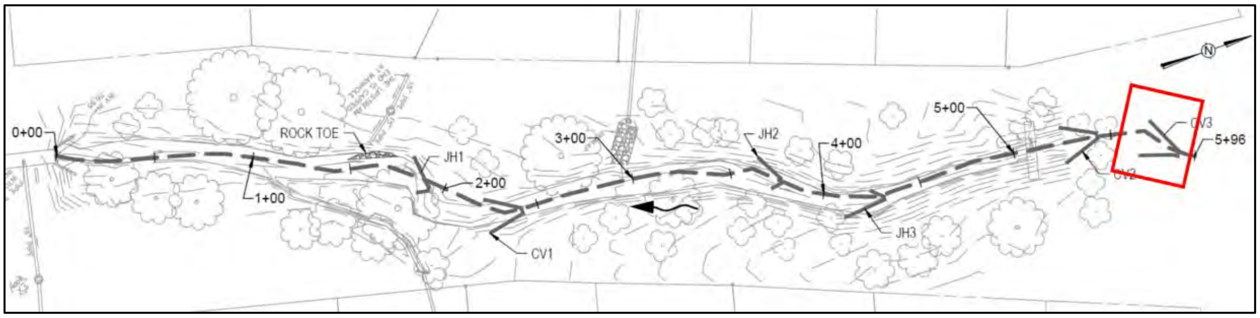


	
Figure 17. Cross-Vane #3 – Looking Upstream (Station 5+60)	**Figure 18**. Cross-Vane #3 – Looking Downstream (Station 5+80)

Conditions noted from field observation:

- Mid-channel bar development in center of channel just upstream of structure
- Flow predominately through the throat
- Structure flanking starting to occur along left vane arm

ii. Stream Reaches

a. Stream Reach #1 (S1) – Between Duke St. Culvert and J-Hook Vane #1

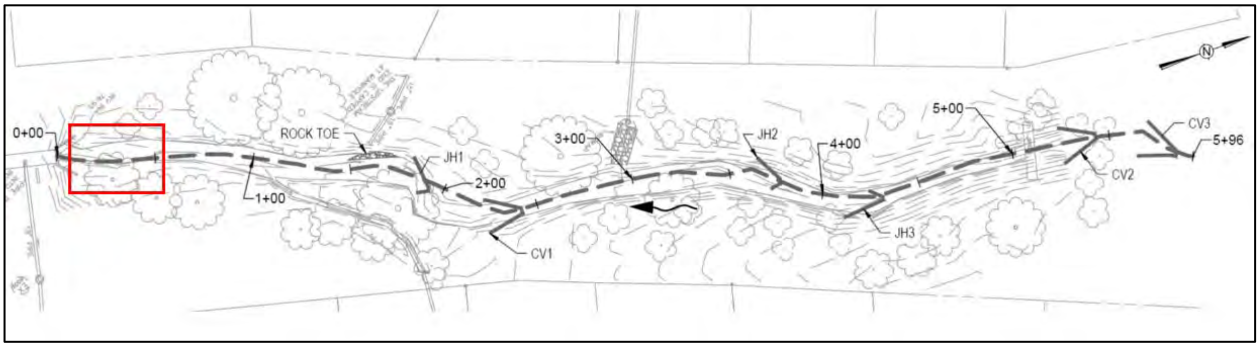


	
Figure 19. Stream Reach #1 – Looking Upstream (Station 0+10)	**Figure 20**. Stream Reach #1 – Looking Downstream (Station 0+50)

Conditions noted from field observation:

- Channel appears more stable towards culvert
- More floodplain access compared to other stream reaches
- Low bank heights, approximately 2 – 2.5 feet
- Concrete debris observed in channel
- Stream meanders with signs of deposition – cobble
- Likely a backwater area from downstream culvert control

b. Stream Reach #2 (S2) – Between J-Hook Vane #1 and Cross-Vane #1

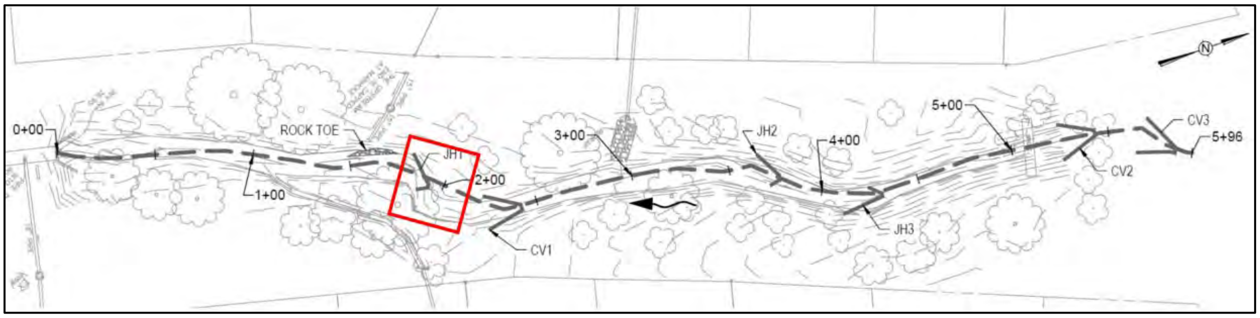


	
Figure 21. Stream Reach #2 – Looking Upstream (Station 1+90)	**Figure 22**. Stream Reach #2 – Looking Downstream (Station 2+20)

<u>Conditions noted from field observation:</u>

- Large point bar on right overbank
- Low radius meanders
- Left bank – raw, vertical
- Cobble/gravel banks
- Channel banks 4 feet plus

c. Stream Reach #3 (S3) – Between Cross-Vane #1 and J-Hook Vane #2

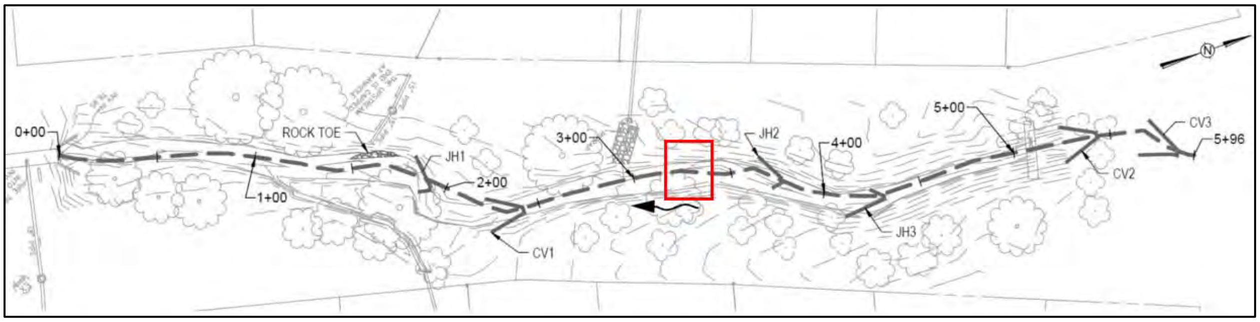


	
Figure 23. Stream Reach #3 – Looking Upstream Right Streambank (Station 3+30)	**Figure 24**. Stream Reach #3 – Looking Downstream (Station 3+40)

<u>Conditions noted from field observation:</u>

- Deposition of cobble throughout
- Vertical banks
- Stratified non-cohesive banks – cobble, gravel, and sand
- Multiple transverse bars

d. Stream Reach #4 (S4) – Between J-Hook Vane #2 and J-Hook Vane #3

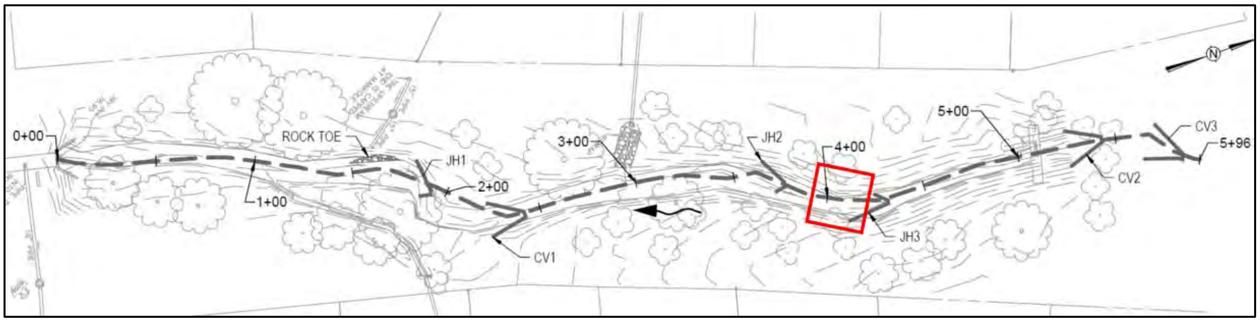


	
Figure 25. Stream Reach #4 – Looking Upstream (Station 4+10)	**Figure 26**. Stream Reach #4 – Looking Upstream Left Streambank (Station 4+00)

Conditions noted from field observation:

- Near vertical banks
- Banks are 4 feet high
- Clayey banks with cobble and gravel material
- Limited deposition along bed, plane bed feature
- Headcut has proceeded through this segment

e. Stream Reach #5 (S5) – Between J-Hook Vane #3 and Cross-Vane #2

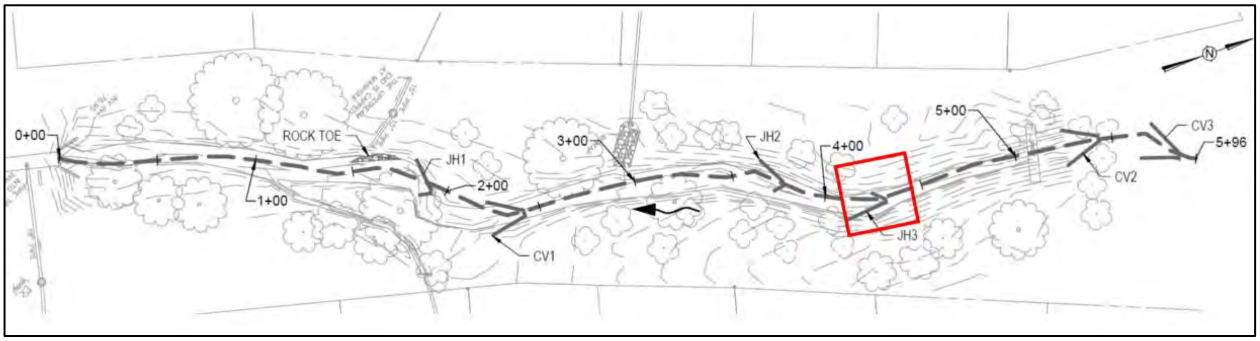


	
Figure 27. Stream Reach #5 – Looking Upstream (Station 4+40)	**Figure 28**. Stream Reach #5 – Looking Upstream (Station 4+20)

Conditions noted from field observation:

- Channel appears to have dropped approximately 24 inches under the bridge since January
- Channel has cut down to a compacted clay (hardpan layer)
- Limited deposition – plane bed feature
- Undercut banks and vertical banks
- Stratified bank material
- Headcut has proceeded through this segment

iii. Planform and Profile

Profiles of the *WEG 2010 As-Built Stream Plan* and the survey by Bowman Consulting (11/29/2021) were compared. To account for changes in stream length, Bowman survey's elevations along the thalweg (lowest point in cross section) were projected along the as-built thalweg alignment. Further, to account for differences between the vertical datums used to record the *WEG 2010 As-Built Stream Plan* and Bowman survey data, the existing 88-inch culvert invert on the north side of Duke Street was used as a local benchmark. As-built elevations were translated vertically to match the surveyed elevation at the culvert invert, which enabled the comparison of channel elevations in a common datum.

According to Rosgen (1996), river stability (equilibrium or quasi-equilibrium) is defined as "the ability of a river, over time, in the present climate to transport the flows and sediment produced by its watershed in such a manner that the stream maintains its dimension, pattern, and profile without either aggrading or degrading"[7] As seen by the comparison profile (Figure 29), the system is in disequilibrium with signs of degradation and aggradation. Visual inspection of the profile reveals a headcut has proceeded approximately 200 feet along the upper end of the project from Station 3+30 to Station 5+43, where the knickpoint has reached Cross-Vane #2. Two structures have been undermined in this section (J-Hook Vane #2 and J-Hook Vane #3) and the base level has dropped approximately two feet under the pedestrian bridge since January 2021. The lower end of the project area has aggraded and led to a shift in the planform of the stream. As shown in the planform comparison (Figure 30), this has led to lateral instability and a change in the watercourse. As visible in Figure 31 and Figure 32, the stream has shifted laterally as much as 16 feet as point bar growth has forced water against the opposite bank causing erosion through a process known as downward valley meander migration.

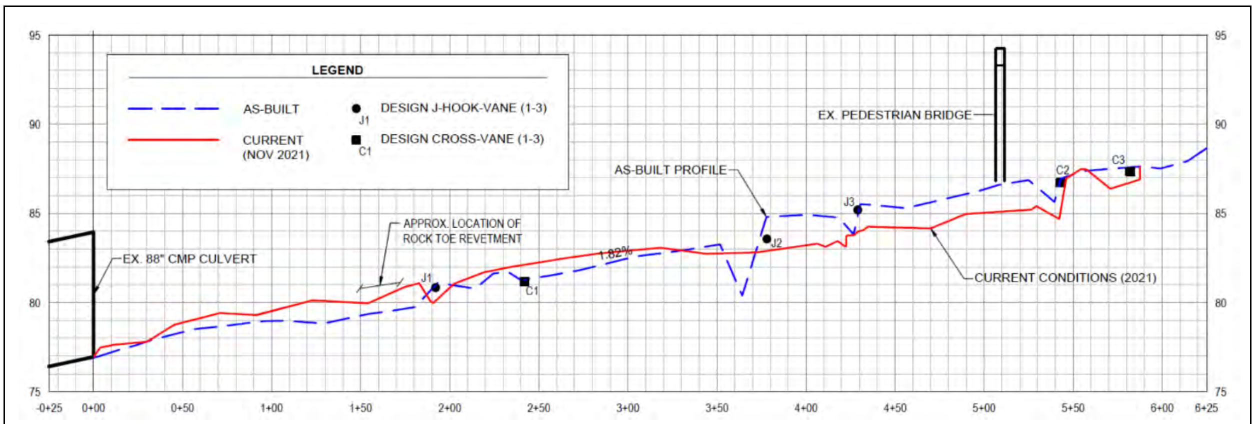


Figure 29. Profile Comparison

[7] Rosgen, D. (1996) Applied River Morphology. Wildland Hydrology, Pagosa Springs.

The lateral and vertical adjustments are symptoms of disequilibrium. The headcutting represents the vertical disequilibrium and the change in stream planform represents the lateral disequilibrium. Figures 33 through 36 document the progression of headcut and subsequent structure failure from March of 2018 to November of 2021. In general, the hydraulic forces exerted on the stream bed and banks during high flows exceed the ability of the channel boundaries to resist erosion in many areas of the restored stream reach.

The primary purpose of the six rock grade control structures is to maintain the as-built vertical position of the stream bed by preventing channel incision. In a typical stream restoration project, the boulders are sized and placed with the intent that structures will withstand extreme shear stresses during high flow conditions. In urban streams with repeated high flows and narrow floodplains, these structures are often supplemented with rock substrate mix placed in riffles and pools to resist erosion (i.e., threshold stream bed design approach).

The lateral adjustments result in part from sediment accumulation in the lower channel that causes stream flow to move around rapidly growing sediment bars. Typically, in urban settings, the channel bed will downcut (vertical instability) and start to widen (lateral instability) as described by the Channel Evolution Model (CEM).[8] See Figure 37.

[8] Channel Evolution Model (Simon 1989, USACE 1990).

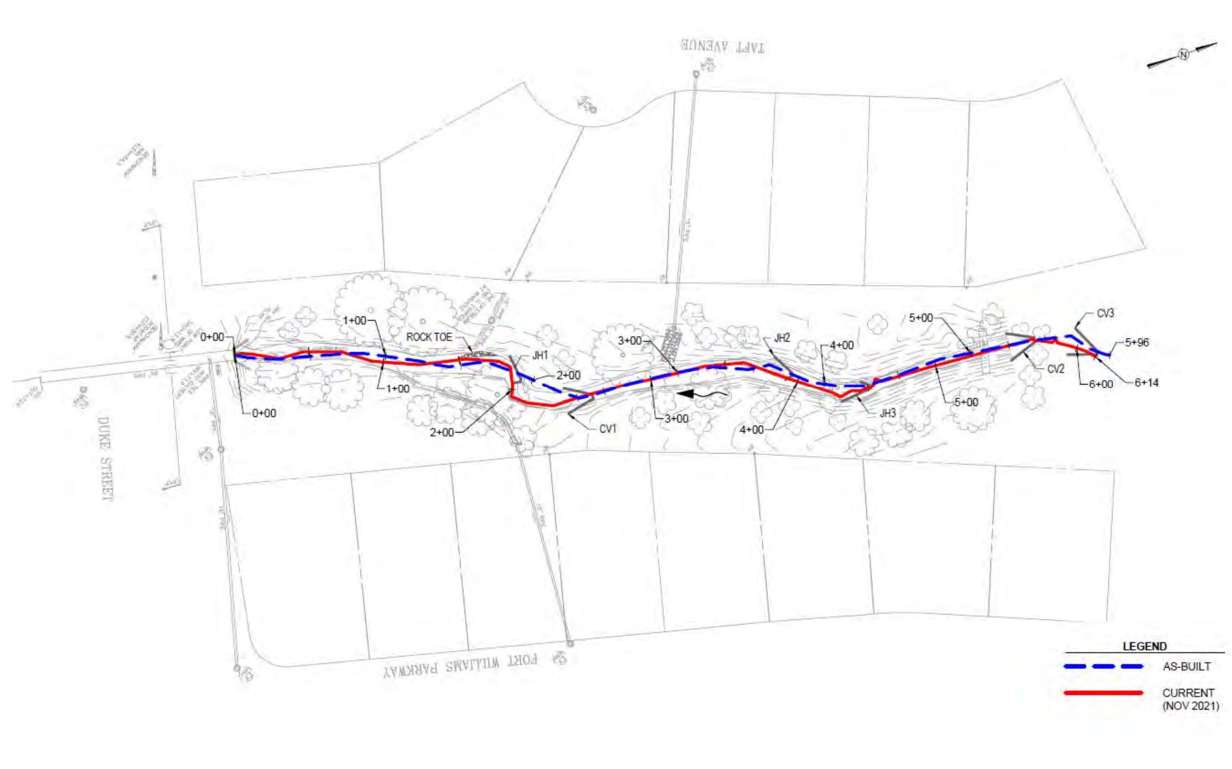


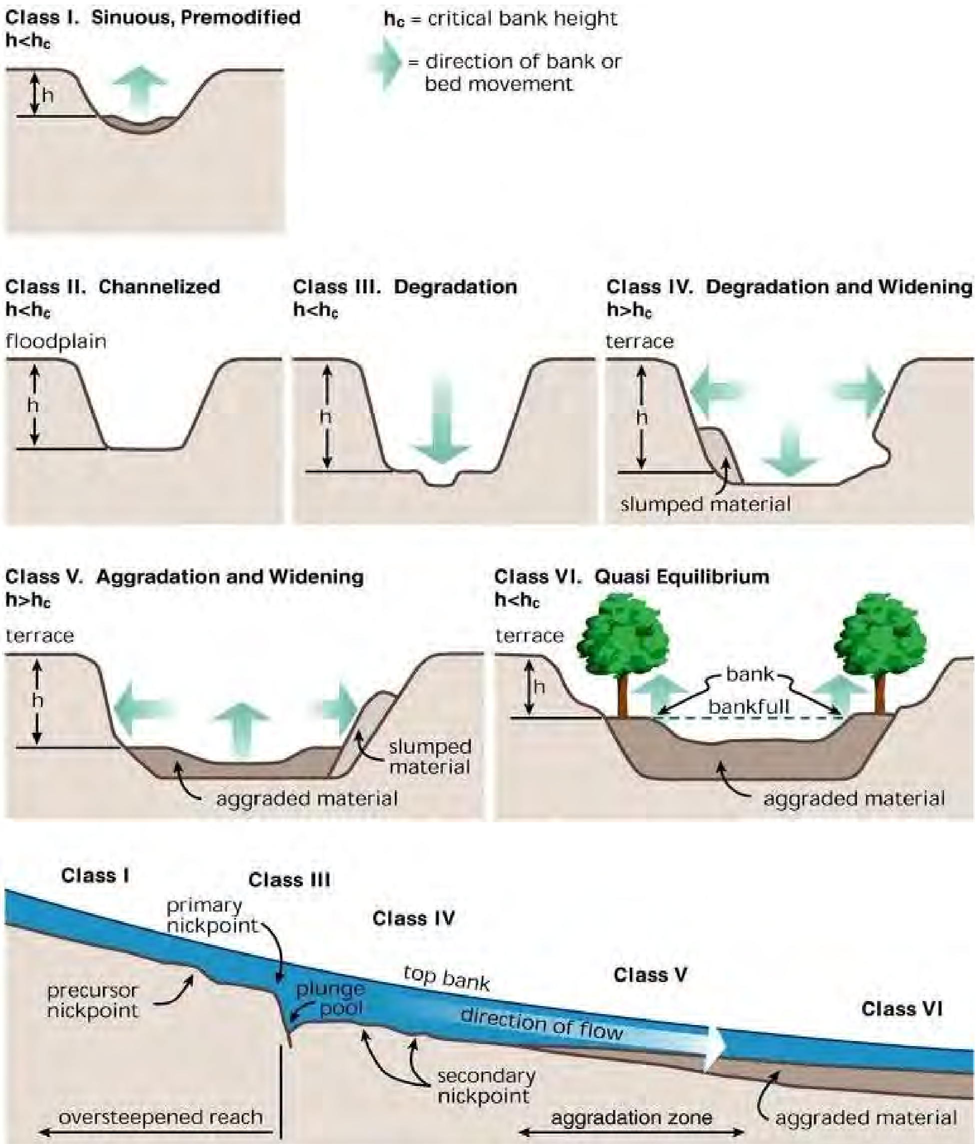
Figure 30. Planform Comparison

Figure 31. J-Hook Vane #1 As-Built Looking Upstream (Station 1+90, 2010)

Figure 32. J-Hook Vane #1 Looking Upstream (Station 1+90, January 2021)

	
Figure 33. J-Hook Vane #3 (Station 4+20, March 2018)	**Figure 34**. J-Hook Vane #3 (January 2021)

	
Figure 35. J-Hook Vane #3 (January 2021); Duplicate Image for Reference	**Figure 36**. J-Hook Vane #3 (November 2021)



Simon 1989, USACE 1990

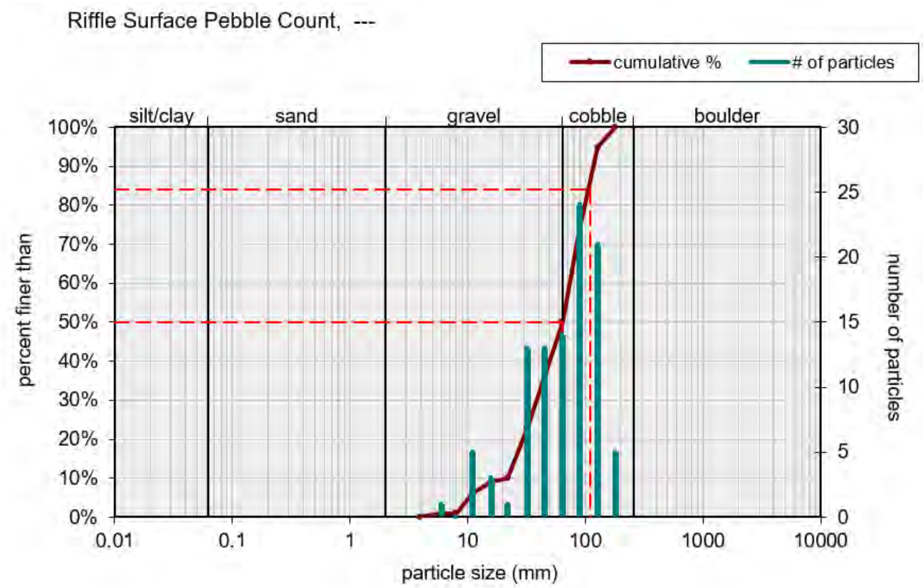
Figure 37. Channel Evolution Model

B. COMPUTATIONS/ANALYSIS

i. Substrate Analysis

Analysis of the stream substrate was performed to characterize the sediment material comprising the channel and moving through the system. A reach-wide composite pebble count was undertaken to classify the dominant bed material along the previously restored reach. Pebble counts were taken along each of five representative sections with 20 particles (stones) collected along each transect (Figure 38). The calculated D_{50} (median particle size; 50% of streambed substrate is smaller, and 50% of streambed substrate is larger) for the representative sections was 64 mm and the D_{95} (95% of streambed substrate is finer) was determined to be 130 mm. The restored reach is comprised of equal parts cobbles and gravels. Results of the pebble count are summarized in Figure 39. The largest natural particles observed during the investigation were approximately 305 mm (Figure 41).

Figure 38. Pebble Count and Sieve Location Map



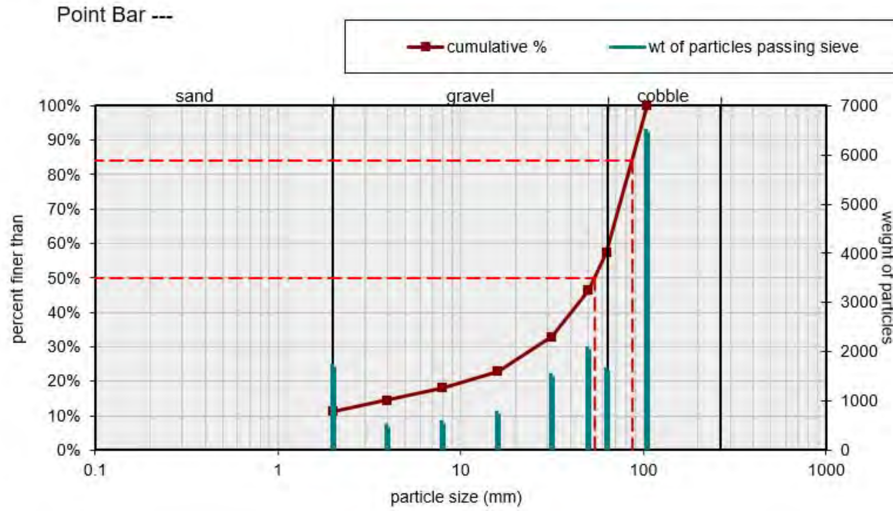
Size (mm)	
D16	26
D35	44
D50	64
D65	79
D84	110
D95	130

Size Distribution	
mean	53.5
dispersion	2.1
skewness	-0.10

Type	
silt/clay	0%
sand	0%
gravel	50%
cobble	50%
boulder	0%

Figure 39. Pebble Count Along Bed Surface

Additionally, a bar sample was collected along a point bar in the lower section (S1) of the project reach(Figure 38). Point bar material was collected (Figure 43) and wet-sieved to determine the material size-class distribution (Figure 44 - Figure 52). The material size-class distribution represents the range of channel materials subject to transport as “bedload” sediment materials. The point bar material distribution shows that 11% of the sample was finer than the 2 mm sieve (Figure 40). This material passed into the catch bucket and is made up of sands, silts, and clays (Figure 45). The largest particles found on the point bar were 100 mm and 105 mm (Figure 42). The samples were classified as 43% cobble, 46% gravel, and 11% sand (Figure 40).



Size (mm)				Type	
D16	5.4	D65	69	sand	11%
D35	34	D84	87	gravel	46%
D50	54	D95	99	cobble	43%
				boulder	---

Figure 40. Sieve Analysis at Point Bar

Figure 41. Typical Largest Particle (305 mm) Observed Along the Streambed

Figure 42. Weighing Largest Point Bar Sample Particle (105 mm)

	
Figure 43. Bar Sample Location/Collection (Station 1+40)	**Figure 44**. Sieved Material

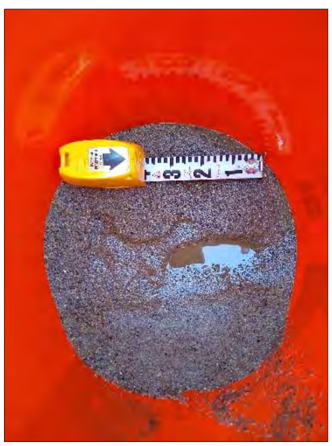


Figure 45. Catch Bucket	**Figure 46**. 2mm Sieve

Figure 47. 4mm Sieve

Figure 48. 8mm Sieve

Figure 49. 16mm Sieve

Figure 50. 31.5mm Sieve

	
Figure 51. 50mm Sieve	**Figure 52**. 63mm Sieve

ii. Rosgen Classification

The Rosgen Classification involves the field measurement of channel and valley physical characteristics to classify the stream based on dimension, pattern, profile, and substrate composition. The parameters determined during the field work are based on practices outlined in *Applied River Morphology*.[9]

The restored reach of Strawberry Run is not currently in dynamic equilibrium, meaning the natural erosion and deposition balance is compromised. Due to the high degree of instability, there is not a consistent bankfull stage representing the incipient point of flooding throughout the project stream reach. The "top of banks" elevation for this stream corridor is much greater than the expected, stable bankfull stage, which indicates deep vertical incision and substantial horizontal floodplain entrenchment.

The portion of Strawberry Run subject to this investigation drains approximately 0.3 square miles at its point of intersection with Duke Street. The land use is predominantly urban and suburban, including residential and small amounts of commercial areas. Urban systems such as Strawberry Run are generally supply-limited systems. Ephemeral streams have been replaced with impervious surfaces and storm sewers and the sediment supply has been reduced. This man-made landscape typically delivers smaller gravel, sands, and salts from road operations and construction (Valley Type VI, moderately steep, fault-controlled valleys). The primary source of bedload in these systems comes from localized bank erosion and not the valley itself.

Due to the flashy, high energy storm events that can typically be found in urban settings, there were limited prominent physical indicators present to establish bankfull stage for the project reach. Therefore, Wood used the Bankfull Regional Curves for Streams in the Non-Urban, Non-Tidal Coastal Plain Physiographic Province, Virginia, and Maryland (2007) to determine the expected mean bankfull depth from the drainage area. The non-urban curve was used because an urban curve would not reflect the equilibrium condition and channel adjustment due to incision and widening. In the absence of compelling field indicators for bankfull stage, the mean depth of 0.91 feet was used as the bankfull mean depth for Rosgen classification

[9] Rosgen, D. (1996) Applied River Morphology. Wildland Hydrology, Pagosa Springs.

purposes. Wood analyzed four cross sections (Figure 53) and set the bankfull depth to achieve a mean depth of 0.91 feet. The width/depth and entrenchment were subsequently calculated for each cross section based on this assumption. This data, used in conjunction with reach-wide material classification, channel slope, and sinuosity were used to classify the stream according to the Rosgen classification at each section (Figure 54-Figure 61)

Figure 53. Rosgen Classification Cross Section Locations

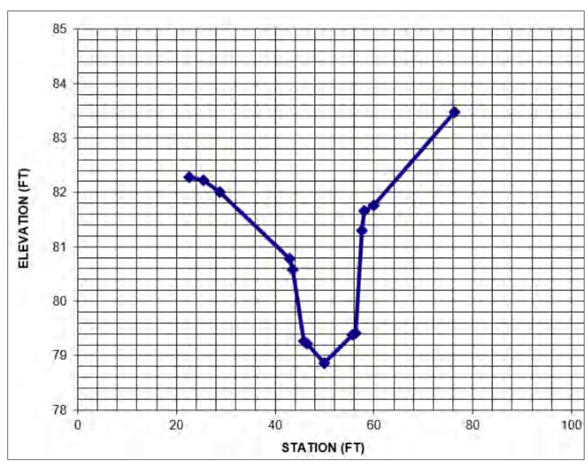
	
Figure 54. Cross Section 0+50 (B3/4c) Looking Upstream	**Figure 55**. Cross Section 0+50

Figure 56. Cross Section 3+00 (F3/4) Looking Upstream

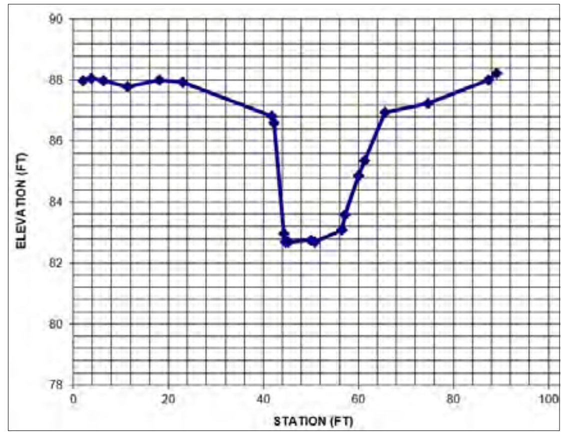


Figure 57. Cross Section 3+00

Figure 58. Cross Section 4+00 (F3/4) Looking Upstream

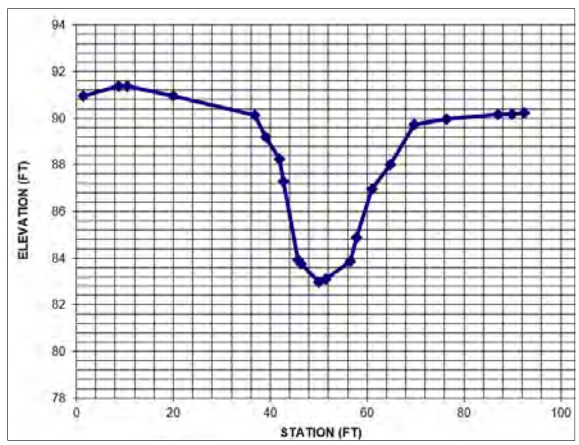
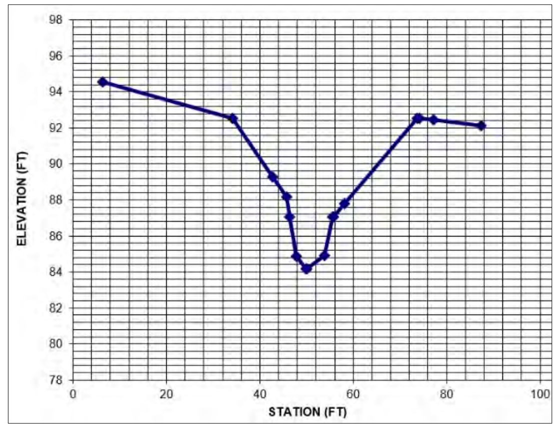


Figure 59. Cross Section 4+00

	
Figure 60. Cross Section 4+90 (G1*c) Looking Upstream	**Figure 61**. Cross Section 4+90

Representative reaches were classified in accordance with Rosgen's Classification of Natural Rivers. The upstream section (4+90) is classified as a G stream type (narrow and deep), whereas the downstream sections are wider and classified as F and B stream types. The G stream type is narrow and deeply incised in depositional material primarily comprised of an unconsolidated, heterogeneous mixture of gravel, some small cobble, and sand. The F stream type is entrenched, wide, meandering channel, deeply incised in gentle terrain. The B stream type is typical of moderate to gently sloped, narrow valley, moderately entrenched, and generally low streambank erosion rates.[10] For the Rosgen classification, the number next to the letter represents the dominant bed material (1= bedrock, 2 = boulders, 3 = cobble, 4= gravel, 5 = sand, and 6 = silt/clay). For example, Cross Section 4+00 is an F stream type consisting of approximately equal parts gravel and cobble (F3/4). The lowercase letter next to the number representing dominant bed material indicates classification between stream types based on slope ranges. For example, Cross Section 0+50 is denoted as a B3/4c because the slope is less than 2%. Stream classification variables are summarized in Table 3.

[10] Rosgen, D. (1996) Applied River Morphology. Wildland Hydrology, Pagosa Springs.

Table 3: Rosgen Classification Summary Table

Parameter	0+50	3+00	4+00	4+90
Channel	Single-Thread	Single-Thread	Single-Thread	Single-Thread
Entrenchment Ratio (ft/ft)	1.7	1.2	1.3	1.3
Width/Depth Ratio (ft/ft)	13.6	15.0	13.2	7.7
Sinuosity (ft/ft)	1.06			
Slope (ft/ft)	0.0151			
Dominant Channel Material	Gravel / Cobble	Gravel / Cobble	Gravel / Cobble	Clay Hardpan
Stream Type	B3/4c	F3/4	F3/4	G1*c

** Dominant bed material at section 4+90 differed from that typical of the reach. The stream in this location has down cut to a friable, weathered layer and was largely absent the cobble and gravel typical of the remainder of the reach.*

iii. Local Rainfall Gauge Data

Wood reviewed local rainfall gauge data of storm events which have occurred since the project was constructed in 2010. Rainfall data from Washington/Reagan National Airport, DC (Reagan Gauge), USGS (United States Geological Survey) 01652500 Four Mile Run at Alexandria, VA (Four Mile Run Gauge), and the City of Alexandria operated rain gauge at Francis Hammond Middle School (Francis Hammond Gauge) were reviewed as part of this effort. It should be noted that considerable variability was observed among these gauge locations (Figure 62) as well as other gauges installed throughout the City.

According to the City of Alexandria Rainfall Intensity-Duration-Frequency Curves (IDF Curves) shown in Figure 63, the 1-year, 24-hour rainfall is approximately 2.40 inches (0.1 inches/hour). Rainfall data from the Reagan Gauge and the Four Mile Run Gauge shows that from September 2010 through December 2021, the 1-year, 24-hour rainfall was equaled or exceeded 20 times at each gauge. Actual runoff from rainfall events can vary depending on the antecedent soil moisture, which is a measure of the water content of the upper soil layer in a catchment prior to a storm event. In 2018, there were three consecutive months (July, August, and September) that experienced at least one day with rainfall totals exceeding the 1-year, 24-hour storm. However, according to the *WEG 2008 Design Plan*, shear stresses were computed for the 1- and 2-year return intervals, which were based on 2.7 and 3.2 inches of rainfall over a 24-hour period, respectively, using an SCS (Source Control System) Type II Distribution. Since the completion of the project, there have been a total of six events at both the Reagan Gauge and Four Mile Run Gauge that have exceeded the 2-

year, 24-hour design storm of 3.2 inches. At these gauges, the 24-hour totals ranged from 3.31 to 4.68 inches.

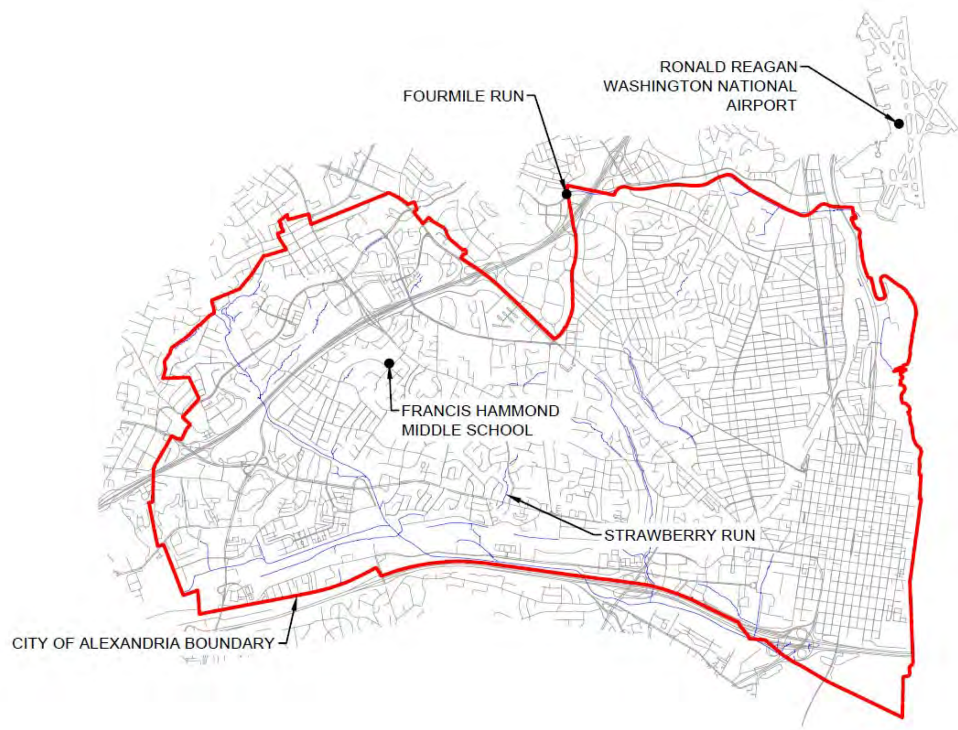


Figure 62. Rainfall Gauge Locations In Relation to Strawberry Run

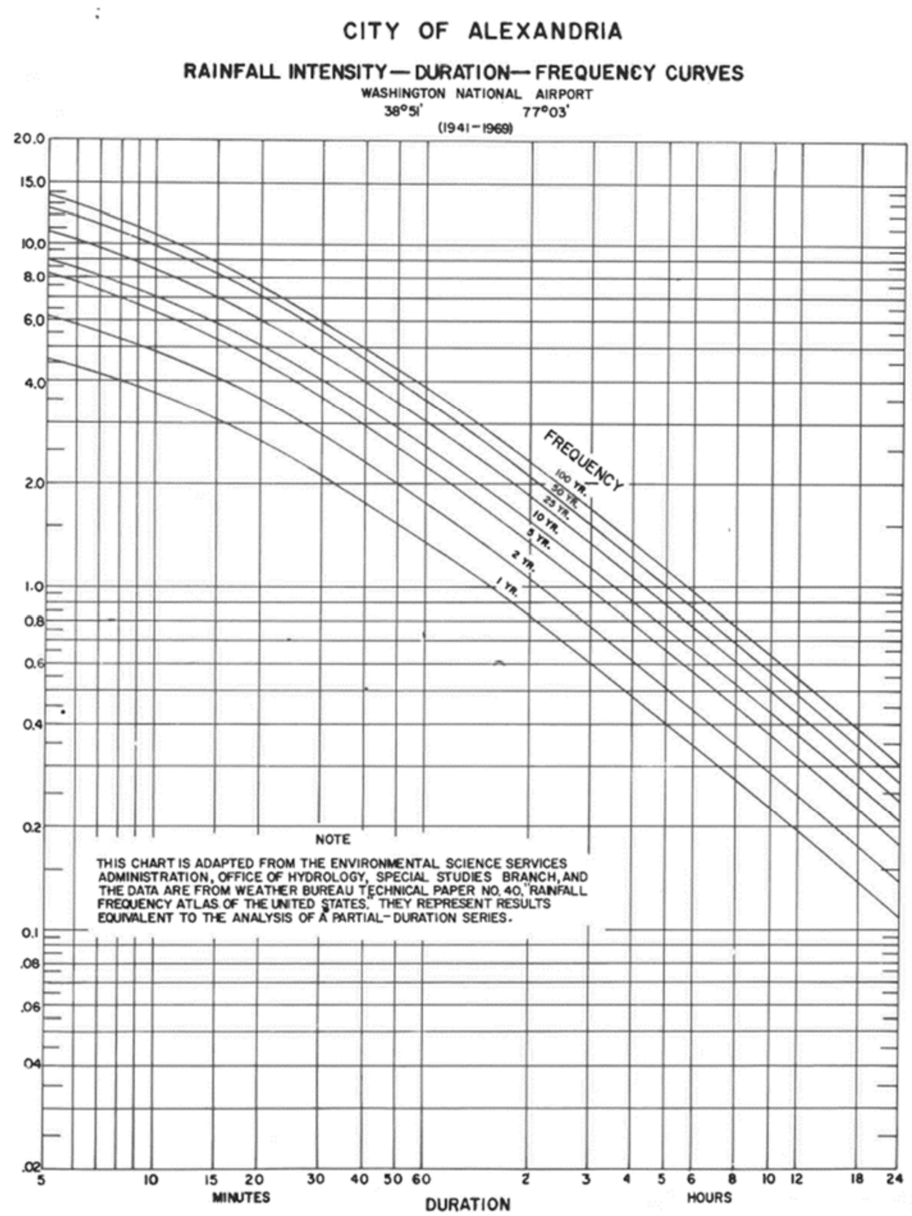


Figure 63. City of Alexandria IDF Curves

Project construction was completed in August of 2010. The next month (September 30, 2010), 4.66 inches of rainfall in a 24-hour period was recorded at the Reagan Gauge, corresponding to between a 5- and 10-year rainfall event. On July 21, 2018, the Four Mile Run Gauge collected 4.48 inches of rainfall over a 12-hour period, corresponding to between a 10- and 25-year rainfall event. A property owner adjacent to Strawberry Run posted a video (https://www.youtube.com/watch?v=r3s8V3QigCw) showing the July 21st rainfall event. A still frame from the video is shown in Figure 65. A comparison figure at baseflow conditions is shown in Figure 64. Additionally, on July 8, 2019, 2.7 inches of rain was recorded in 1-hour at the Four Mile Run Gauge, which corresponds to between a 10- and 25-year rainfall event.

Figure 64. Strawberry Run July 2, 2019, Baseflow Conditions (Upstream of Project Area)

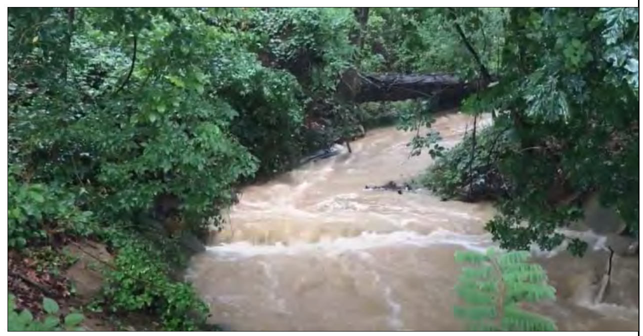


Figure 65. Strawberry Run July 21, 2018, Streamflow (Upstream of Project Area)

The rain gauge in the City of Alexandria Rain Gauge and Stream Flow tool (https://alxfloodwatch.onerain.com) located closest to the project site is at Francis Hammond Middle School. Rainfall data from the Francis Hammond Gauge became available in May of 2021. On August 15, 2021, 2.75 inches of rainfall was recorded in one hour (Figure 66). According to the City's IDF curves, 2.75 inches of rain in one hour corresponds to between a 10- and 25-year storm event for the project site.

Very large rainfall events have an acute impact to the system since they have the capability to reshape channels. However, the smaller, more frequent events have a chronic impact on the stream corridor. For example, between May 2021 and February 2022, there were four rainfall events that equaled or exceeded the 1-year point precipitation for a five-minute storm duration. See Figure 67. According to *WEG 2008 Design Plan*, the designer only evaluated the 1- and 2-yr storm events for peak discharge rates. As discussed in the following section, the 1-year storm has the capability to mobilize a large portion of the stream bed.

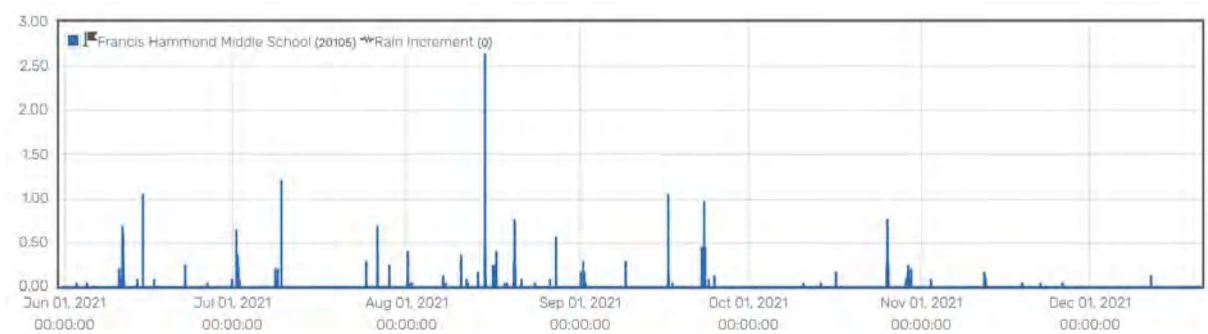


Figure 66. Sixty Minute Rainfall Duration at Francis Hammond Gauge

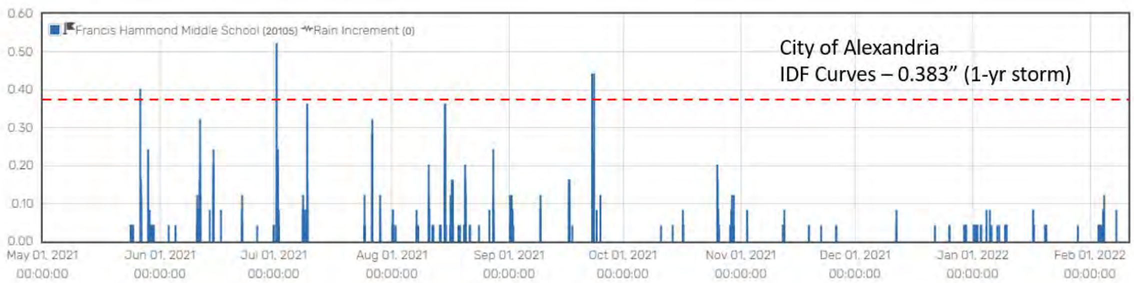


Figure 67. Five Minute Rainfall Duration at Francis Hammond Gauge

iv. Hydraulic Analysis

At-a-station hydraulic analyses were performed at the same four cross sections used for Rosgen stream classification to estimate applied shear stresses for a range of flow stages. The normal depth assumption is used for this analysis, which assumes the water surface is normal or parallel to the channel slope. The current bed slope of the previously restored reach is approximately 1.51% and the Manning’s Roughness Coefficient (n) is assumed to be 0.045, representative of natural cobble-bed streams.

Entrainment is associated with the hydraulic shear forces acting on and resisting bed particle movement. The initiation of particle movement is typically related to an applied shear stress or tractive force empirically correlated with the corresponding movement of various grain sizes. Sediment transport competence is the ability of the river to move the sediment particles made available from the immediate upstream supply (Rosgen 2011).

As previously discussed, the stream bed substrate is a heterogeneous mix of sand, gravel, cobble, and boulders. “Shields relationship” was developed from laboratory data to correlate critical applied shear stress and grain size to predict the “threshold of motion” for stream sediment.[11] Rosgen found that Shields relationship generally underestimates the particle sizes of heterogenous bed material, so he developed a relationship based on measured field data “appropriate for gravel-, cobble- and boulder-bed stream types generally of a heterogeneous mixture”.[12]

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[11] Fluvial Processes in Geomorphology, Leopold, Wolman, and Miller (1964).
[12] The River Stability Field Guide 2nd Edition, Dave Rosgen (2014).

"The dimensional shear stress equation,

$$\text{Shear Stress} = \tau = \gamma \times R \times s$$

where:

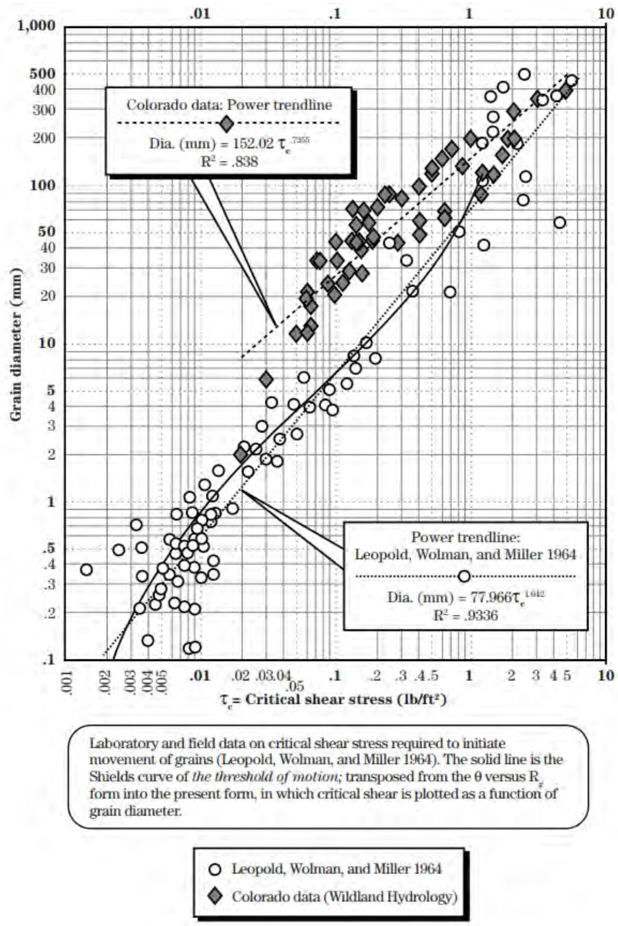
γ = specific weight of water (62.4 lb/ft^3)

R = hydraulic radius (area/wetted perimeter) (ft)

s = slope (ft/ft)

is used with a revised Shields relation using Colorado data (Rosgen's trendline), and a grain size corresponding to the shear stress is selected to determine what particle sizes the stream can potentially move" (Rosgen 2011). See Figure 68.

The first hydraulic analysis performed was to determine what depth of water in each of the sections is required to mobilize, or entrain, the D_{95} of the bed. The D_{95} of the bed is 130 mm; meaning that 95% of the bed is finer (smaller) than 130 mm.



Rosgen 2014

Figure 68. Relation Between Grain Diameter for Entrainment and Shear Stress

The required shear stress to mobilize the D_{95} (130 mm particle) is 0.81 lb/ft^2. For the four cross sections the depth required to entrain the D_{95} ranged from approximately 1.0 to 1.4 feet and the corresponding discharges ranged from 25 to 46 ft^3/sec. Just over one foot of water in the stream channel has the potential to mobilize 95% of the bed material.

Table 4: Shear Stress Required to Move the D_{95} of the Bed

Location	T Shear Stress (lb/ft^2) to move D95 (130 mm)	Depth (ft)	Q Discharge (ft^3/s)
Cross Section 0+50	0.81	1.25	41
Cross Section 3+00		1.09	46
Cross Section 4+00		1.40	39
Cross Section 4+90		1.43	25

Note: Manning's n of 0.045 and slope of 1.51% used for discharge computations

From the *WEG 2008 Design Plan*, the 1-year peak discharge was computed to be 110 ft^3/sec. As illustrated in Table 4, the discharges required to mobilize the bed are significantly less (approximately 40%) than the 1-year discharge. One would expect the channel to fill up with just over a foot of water and mobilize up to the D_{95} several times every year. If the 1-year storm (110 ft^3/sec) is applied to each of the cross sections, the particles expected to mobilize range from 175 mm to 208 mm. These exceed the largest particles found on the point bar for the sieve analysis (100 mm and 105 mm particles).

Table 5: Particles Entrained for 1-Year Design Discharge

Location	1-YR Design Discharge (110 ft^3/s)	Depth (ft)	T Shear Stress (lb/ft^2)	Mobilized Particle (mm)
Cross Section 0+50	**110**	**2.11**	**1.21**	**175**
Cross Section 3+00		**1.77**	**1.25**	**179**
Cross Section 4+00		**2.23**	**1.35**	**189**
Cross Section 4+90		**2.98**	**1.54**	**208**

Note: Manning's n of 0.045 and slope of 1.51% used for discharge computations

This analysis confirms that normal rainfall events that occur frequently are exerting hydraulic forces that exceed the resistance of the bed substrate. Wood's interpretation of this hydraulic analysis is that the channel bed material was not adequately sized to resist movement and adjustments to the bed such as headcutting and mobilizing the entire bed were likely to occur.

To further investigate hydraulic forces acting on the stream bed, dimensionless shear stress is calculated using the D_{50} of the bed material along with the D_{max} and D_{50} taken from the bar sample. Dimensionless shear stress (τ*) is computed by the following equation when the ratio D_{max}/D_{50} is within the range of 1.3-3.0 (Rosgen 2011).

$$\frac{D_{max}}{D_{50}} = \frac{105 \text{ mm}}{64 \text{ mm}} = 1.64$$

$$\text{Dimensionless Shear Stress} = \tau^* = 0.0384 \left(\frac{D_{max}}{D_{50}}\right)^{-0.887}$$

$$\tau^* = 0.0384(1.64)^{-0.887} = 0.025$$

where:

D_{50} = median diameter of the riffle bed

D_{max} = largest particle from the bar sample (or the subpavement sample)

The depth required for entrainment of the largest particle in the bar sample (105 mm), is calculated by the following equation.

$$d = 1.65 \times \tau^* \times \frac{D_{max}}{S}$$

$$d = 1.65 \times 0.025 \times \frac{\left(\frac{105}{304.8}\right)}{0.0151} = 0.94\ ft$$

where:

τ^* = dimensionless shear stress

D_{max} = largest particle from bar sample (or subpavement sample) (ft)

S = slope (ft/ft)

This analysis of dimensionless shear stress supports the findings for dimensional shear stress, in that the largest particle in the bar sample would be entrained, or moved, with approximately one foot of flow depth in the channel, which corresponds to frequent flow events.

According to the hydraulic summary in the *WEG 2008 Design Plan*, "the hydraulic analysis was used to determine the overall conveyance capacity characteristics of the primary, and bankfull bench elevations that would allow flow conveyance during larger storm events."[13] HEC-RAS was used to determine channel shear stress for the 1- and 2-year recurrence intervals for both existing and proposed conditions. WEG evaluated the 1- and 2-year storm events for peak discharge rates. These design storm events were then input into the US Army Corps of Engineers "HEC-RAS: River Analysis System" in order to determine baseline flow rates, boundary conditions, and flow parameters that were used in the stream restoration design."[14] According to the hydraulic summary table in the *WEG 2008 Design Plan*, the predicted 2-year shear stress for proposed conditions ranges from 0.51 lb/ft^2 to 2.29 lb/ft^2 along the restored reach. According to the competence graph in Figure 69, the particle size expected to move under these shear stresses would range from approximately 100 to 300 mm. As previously discussed, the largest particles found on the point bar were 100 and 105 mm. This competency analysis illustrates that the entire bed would be expected to mobilize under the applied shear stresses computed in the *WEG 2008 Design Plan*.

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[13] Hydraulic summary narrative from the Williamsburg Environmental Group *Stream Restoration Plan* stamped 1/16/2008.

[14] Hydrologic summary narrative from the Williamsburg Environmental Group *Stream Restoration Plan* stamped 1/16/2008.

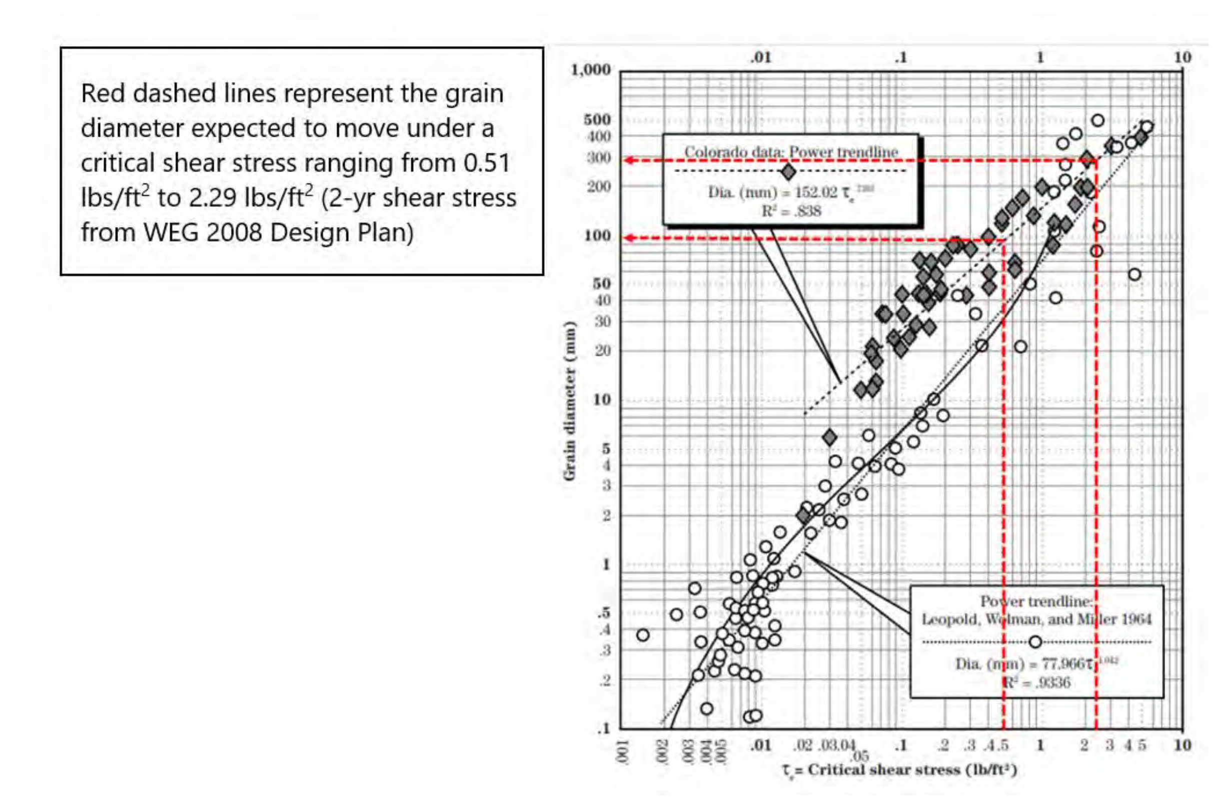

Figure 69. Particles Expected to Mobilize Under a Range of Design Shear Stresses from WEG Plan

The primary conclusion from the hydraulic analysis is that most of the substrate in this channel is too small to resist mobilization during the regular high flows in this urban stream system. There is nothing on the plans to indicate that native bed material was supplemented with larger substrate material. Since the watershed does not provide large-size sediments to replace the transported substrate, the net effect is loss of bed substrate resulting in downcutting, or incision. As this process occurs around the boulder Cross-Vanes and J-Hook Vanes, the structures are undermined and begin to collapse, resulting in structure failure and upstream migration of headcutting.

C. CONTRIBUTING FACTORS

Based on Wood's assessment, there are several factors contributing to channel disequilibrium along the previously restored reach of Strawberry Run. These issues are categorized into major and minor factors.

i. Major Factors

Three factors have been identified as major contributors to the degradation and aggradation along the restored reach. However, the over-arching issue is that the boundary conditions were not sufficient to resist the applied forces. The major factors are listed below and further described in the following paragraphs.

1. Bed substrate size insufficient to resist applied shear stresses during high-flow events.
    - Most of the bed will be mobilized during routine flow events (repeated, expected events, < 1-yr return interval), resulting in incision.
2. Planform layout inappropriate for natural meandering stream in equilibrium.
    - The channel planform was not adjusted to provide a natural equilibrium meander pattern that supports energy dissipation and bedform diversity (Figure 70), resulting in high near-bank shear stress where streamflow is working to create meanders.
    - The location and selection of in-stream rock vane structures did not provide sufficient resistance to undesirable lateral migration based on natural stream planform geometry ratios of pool-to-pool spacing, meander length, belt width, and radius of curvature.
3. Constructed channel as shown on as-built survey not matching the design profile (Figure 71) and cross section.

Stream bed erosion resulting in vertical incision is primarily due to the first factor listed above, as predicted by the hydraulic analysis in the previous section. While the size of the rock Cross-Vane structure boulders was sufficient for this application, the bed substrate in the riffles and pools was too small to resist the forces acting along the stream bed. In the *WEG 2008 Design Plan* shear stresses were only computed for the 1- and 2-year return intervals. There was a lack of evidence of transport analysis in the *WEG 2008 Design Plan* that the computed shear stresses were used to size substrate that would resist the applied forces. Additionally, a larger frequency design storm should be used to determine the applied shear stress and subsequent sizing of the bed material to resist entrainment. As opposed to a 1- or 2-year design storm, larger less frequent design storms (e.g., 100-year) should be analyzed to meet the standard of care.

Bank erosion resulting in lateral adjustments to the planform layout is primarily due to the second factor. The restoration design planform followed the existing alignment without considering the natural meandering tendencies of streams in low-slope valleys. The rock Cross-Vane structures were not located appropriately to fully achieve the objective of reducing bank erosion and providing channel lateral stability. Structures are typically placed at the end of riffles to provide grade control and help redirect flows away from channel banks in pools. Additionally, the structure construction appears to have lacked sufficient bank tie-ins to prevent flanking in all cases.

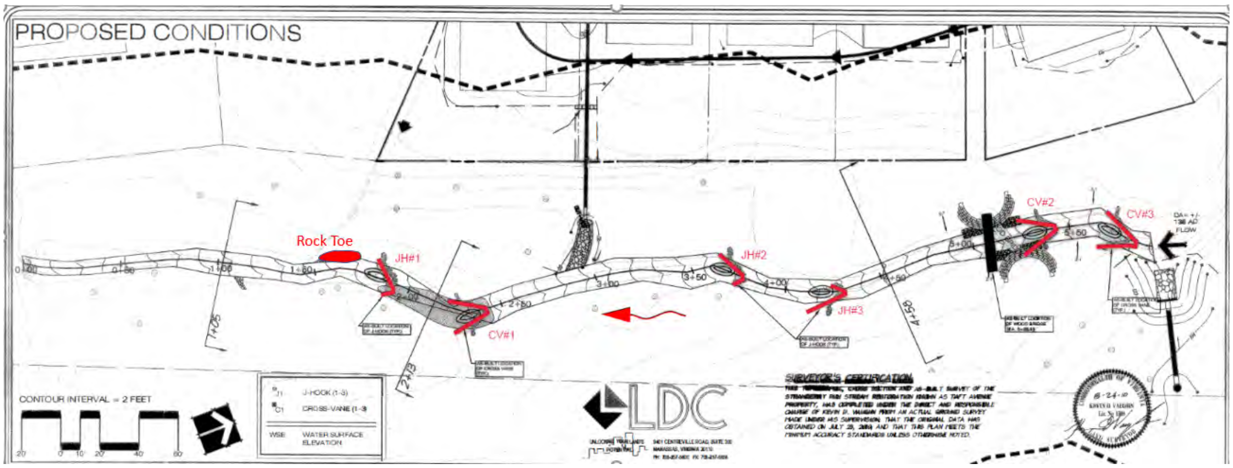

Figure 70. Plan Form As-Built

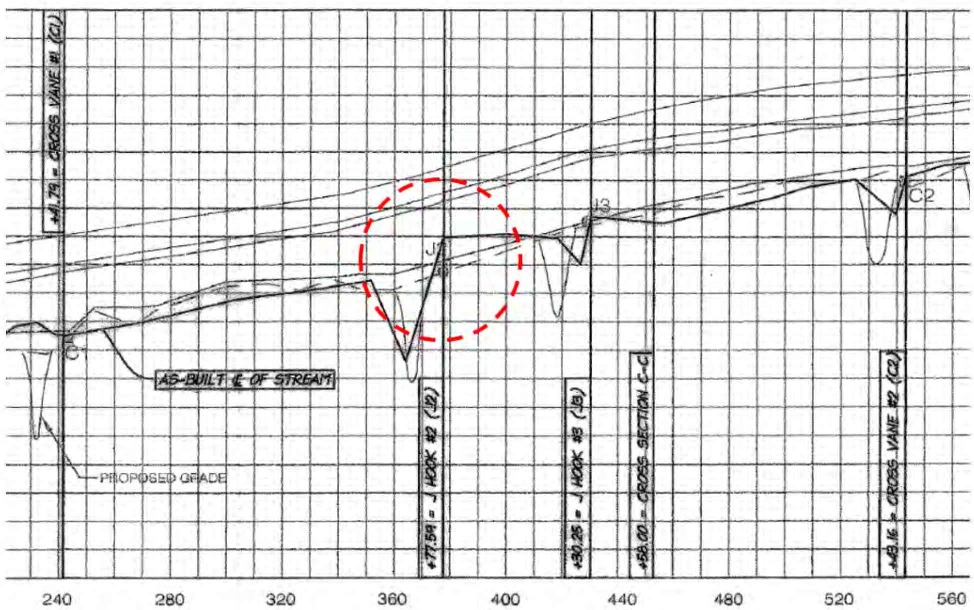

Figure 71. As-Built Profile Comparison at J-Hook Vane #2

Comparison of the design profile with existing conditions illustrates that the proposed grades were matched along the existing grades, except where pools were proposed to be dug just downstream of the structures. It was also noted that the as-built grades showed J-Hook Vane #2 was built over 1 foot higher than the proposed design. In addition, the *WEG 2010 As-Built Stream Plan* indicates discrepancies with the construction of bankfull benches. Benches at As-Built Cross Section 4+58 appears to be as much as 0.5 foot lower than proposed while those at As-Built Cross Section 1+05 appear to be missing. See Figure 72 and Figure 73. According to the *City of Alexandria Abstract for the SER Mid-Atlantic Chapter Annual Conference*

2013 for *Strawberry Run Stream Restoration: The Good, Bad, and Downright Ugly*, Claudia Hamblin-Katnik noted that one of the Cross-Vanes filled in with cobble during the first storm. Most of the pools show signs of filling between the design and as-built, but the one that remained the deepest was where the structure (J-Hook Vane #2) was placed at higher elevation, which was able to maintain the pool scour due to a larger drop over the structure.

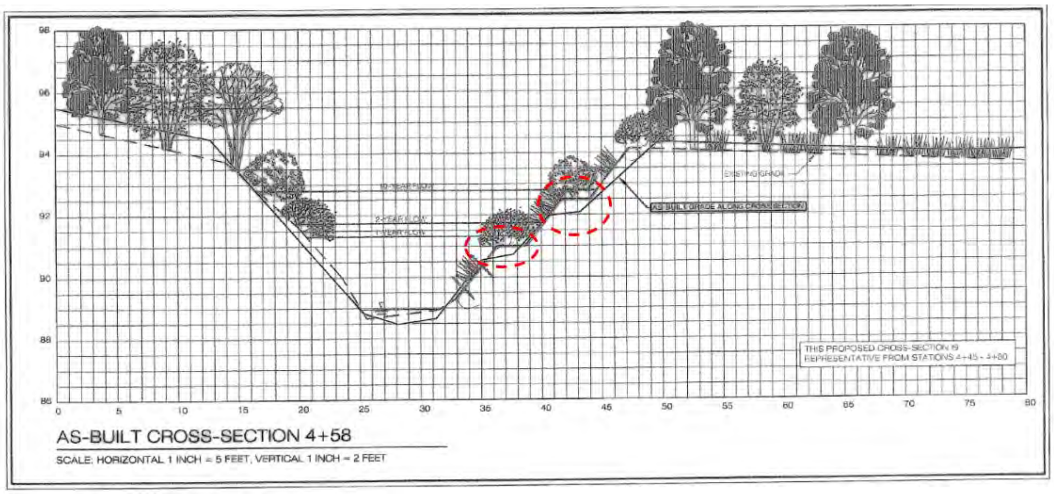

Figure 72. As-Built Cross-Section 4+58

** Red circles indicate areas where bankfull benches were constructed at an incorrect elevation.*

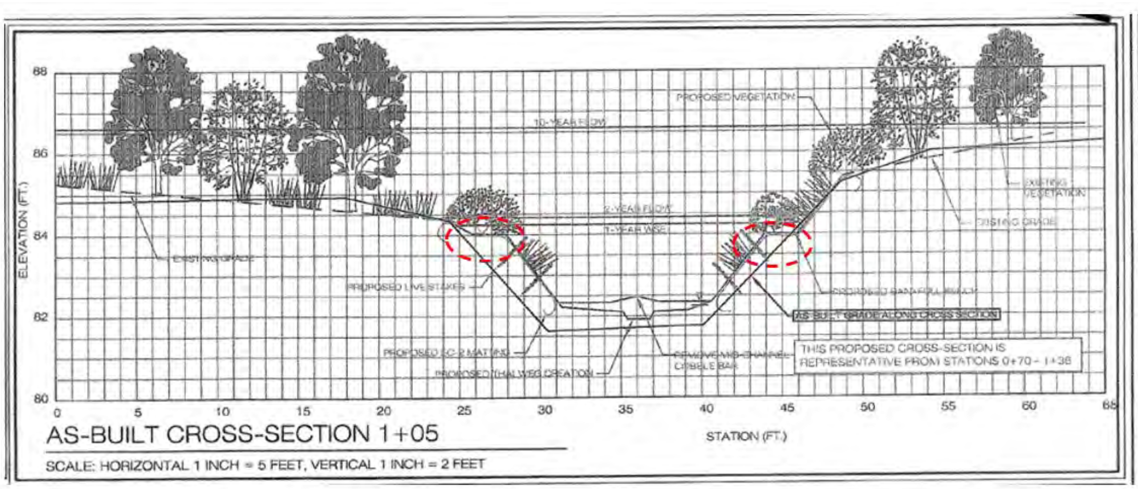

Figure 73. As-Built Cross-Section 1+05

** Red circles indicate absence of areas where bankfull benches were to be constructed.*

ii. Minor Factors

Additional factors that have been identified as minor contributors to loss of channel stability along the reach include the following:

1. Upstream bedload supply (Figure 74). Ideally restoration of the upstream section should have been conducted before restoring the downstream reach. Excess sediment in the channel contributes to aggradation and lateral channel instability and widening.
2. Lack of rock toe protection throughout restored reach. Larger material (Figure 75) would have better resisted the applied forces along the channel banks.
3. Downed trees/channel blockages (Figures 76 and 78). Like excess sediment, channel blockages and debris have the potential to cause local flow accelerations and flow diversions leading to bank erosion and widening. While logs can be useful as bank protection measures, structures need to be securely anchored and placed to prevent washout (Figures 77 and 79).
4. Aggradation resulting from localized erosion within reach leading to lateral instability and potential channel widening.
5. Discontinuous bankfull bench designed throughout the reach leading to contraction and expansion issues and limited floodplain relief.

	
Figure 74. Upstream Sediment Supply	**Figure 75**. Rock Toe (Station 1+60)

Figure 76. Downed Tree (January 2021, Station 1+90)

Figure 77. Same Location: Tree Washed Away (November 2021, Station 1+90)

Figure 78. Downed Tree (January 2021, Station 2+20)

Figure 79. Same Location: Tree Washed Away (November 2021, Station 2+20)

SECTION 4 – RECOMMENDATIONS AND SUMMARY

4. RECOMMENDATIONS AND SUMMARY

A. RECOMMENDATIONS

Based on Wood's analysis and using the *Consensus Recommendations for Improving the Application of the Prevented Sediment Protocol for Urban Stream Restoration Projects Build for Pollutant Removal Credit (2021),* the previously restored portion of Strawberry Run is experiencing failure along more than 50% of the reach. This classifies the project as having failed. As a result, the management action is "Lose credit and abandon the project or reconstruct a new stable channel."

i. Immediate/Short-Term: Pedestrian Bridge Abutment Protection

The most urgent need for this reach of the stream is to protect and maintain the structural integrity of the pedestrian bridge abutments (Figure 80). This can be done through the following:

- Establish a new rock grade control structure (i.e., rock Cross-Vane) downstream of the bridge with an invert elevation of 0.3 feet less than the invert of the existing upstream Cross-Vane structure (Cross-Vane #2, Figure 81). This will lift the bed elevation under the bridge and prevent future headcutting from threatening the bridge abutments.
- Add large bed substrate to the scour pool and riffle between the two Cross-Vanes upstream and downstream of the bridge abutments to resist extreme applied hydraulic forces during maximum-flow events.

In addition, based on the findings of this investigation, the City should report the failure of the project in its next MS4 annual report and adjust planning for Chesapeake Bay TMDL compliance accordingly.

Figure 80. Erosion Underneath Bridge

Figure 81. Knickpoint at Cross-Vane #2

ii. Long-Term: Design and Implement an Equilibrium Threshold Bed Stream Restoration

The long-term management recommendation is to reconstruct the stream channel and floodplain to provide long-term resilience. Wood does not recommend abandoning the project for the following reasons:

- Risks to infrastructure (pedestrian bridge, storm sewer)
- Public safety concerns (at crossing and along corridor)
- Continued erosion and trend towards lateral instability creating future risk to private property
- Loss of TMDL credit
- Continued erosion and tree loss
- Loss of conveyance capacity
- Increasing/on-going channel maintenance requirements
- Downstream conveyance impacts for the piped portions of the stream
- Sedimentation impacts to the Lake Cook forebay (Figures 82 and 83) that may impact the water quality function of the forebay and require frequent, costly maintenance to ensure proper functioning

	
Figure 82. Lake Cook Forebay	**Figure 83.** Sediment Accumulation at Entrance of Lake Cook (Looking Upstream)

Wood recommends reconstructing the channel using a design to resist expected shear forces over a range of discharges maintaining bedform and bank stability to achieve City and stakeholder design objectives. Consideration should be given to the restoration of the upstream portion of Strawberry Run to ensure the long-term success and stability of the reconstructed channel.

B. SUMMARY

The field data and hydraulic analysis support the conclusion that the 600-ft restored section of Strawberry Run has been experiencing excessive hydraulic stress that causes channel disequilibrium with undesirable vertical and lateral adjustments. The design did not encompass the full spectrum of NCD principles typically employed for urban stream restoration projects, including but not limited to, appropriate planform layout, stable geometry, structure application and location, and bed substrate enhancement. The forces acting along the stream bed during storm flows are greater than the ability of the materials to resist entrainment. The resulting incision and migrating headcut has caused undermining and collapse of rock vane grade control structures. The erosion processes appear to be accelerating as the stream becomes more incised and entrenched, as evidenced by the substantial headcut migration between January and November of 2021. If the City and its stakeholders pursue reconstruction of the channel, Wood recommends a meandering threshold riffle-pool stream system with sufficient bankfull floodplain to dissipate energy and resist the forces being applied for larger, less frequent storm events.

SECTION 5 – REFERENCES AND RESOURCES

5. REFERENCES AND RESOURCES

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Documents Provided by the City of Alexandria:

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Taft Avenue Properties Water Quality Major Impact Assessment; Williamsburg Environmental Group (WEG 2006 WQIA)

Stream Restoration Plan Taft Avenue Approved Plan DSP2007-00018; Williamsburg Environmental Group (WEG 2008 Design Plan)

Stream Restoration Maintenance and Monitoring Agreement; City of Alexandria 2008.

Stream Restoration As-Built Taft Avenue Property; Williamsburg Environmental Group (WEG 2010 As-Built Stream Plan)

Taft Avenue Property Approved As-Built Site Plan DSP2004-0018; Williamsburg Environmental Group (WEG 2010 As-Built Site Plan)