VIRGINIA MILITARY INSTITUTE

STORMWATER MASTER PLAN

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1.0 INTRODUCTION

This Stormwater Management Master Plan (SWM Plan) for Virginia Military Institute (VMI) is developed as part of the May 2007 Post Facilities Master Plan (Master Plan) and is provided as a planning tool for future projects at VMI.

1.1 Background / Purpose

The Department of Conservation and Recreation (DCR) requested that VMI complete a SWM Plan for the Post and VMIs other properties to be developed to provide solutions to stormwater management and potentially integrate sustainable (or low impact) design standards for individual projects within the context of the Master Plan in order to meet the current regulatory requirements.

The challenge for this Plan is to develop an approach for stormwater management that supports the future building programs, but also begins to mitigate past problems within the context of the Post - maintaining the qualities of culture, history and sense of place that are revered at VMI. This Plan will aid VMI in meeting these goals for both existing and future development.

This SWM Plan provides preliminary solutions for those areas that include improvements and new construction as part of the 2006 – 2012 Master Plan; a conceptual SWM plan would be prepared to incorporate future improvements beyond 2012. This report includes preliminary SWM plans for Main Post and McKethan Training Area and concept SWM plans for Lackey Park and New Market Battlefield site. The Master Plan for Main Post, North Post, McKethan Training Area, Lackey Park, and an aerial of New Market Battlefield are provided as Figures 1A through 1E, respectively.

1.2 Regulatory Requirements

There are regulatory programs related to stormwater that affect every component of this plan. The Virginia Stormwater Management Regulations (4 VAC 3-20-10 et.seq.) were amended in 1998 to reflect the ever changing environment that encompasses the definition and essential role of stormwater management. The amended stormwater

regulations were divided into three major components: Water Quality, Stream Channel Erosion, and Flooding.

1.2.1 Water Quality

One impact of stormwater is the quality of the runoff. Studies show that various soluble and particulate pollutants found in stormwater have an adverse effect on the natural ecosystem. The primary sources of these pollutants are atmospheric deposition, urban and agricultural lands, and natural spaces. Impervious surfaces such as roads, parking lots, and rooftops accumulate and readily transport these pollutants to receiving streams channels. Pervious surfaces that can also accumulate pollutants, particularly from fertilizers and herbicides, include golf courses, parks, and open spaces. Typical urban pollutants are as follows:

- *Nutrients* – Concentrations of nutrients, such as nitrogen and phosphorus, can cause eutrophication of receiving streams, lakes, rivers, and estuaries. As these nutrients collect in slower moving water bodies, they promote algae growth which can then block sunlight to bottom plants eventually depleting the water of dissolved oxygen.
- *Suspended Solids* – All natural channels have a natural sediment bed load which helps maintain a state of equilibrium within the channel of undeveloped watersheds. Increases in peak flow rates through the channel or stream system will disrupt the equilibrium by increasing the amount of sediment removed from the channel bed and banks. Suspended solids resulting from excessive erosion and scour of the stream channel, transport of sediments from impervious surfaces, and construction site runoff, can have many adverse affects on the aquatic life throughout the water column. When this sediment eventually settles in slower moving bodies of water it can suffocate the aquatic life on the bottom.
- *Bacteria* – The source of bacteria in stormwater runoff includes livestock operations, failing septic systems, unusually high concentrations of pet and wildlife droppings, leaking sewer lines, illicit connections between storm and sanitary lines, and combined sewer overflows. All of these sources can leave varying levels of bacteria in surface stormwater runoff creating public health concerns in receiving streams and rivers.

1.2.1.1 Pollutant Removal Mechanisms

Pollutant removal mechanisms employed by urban best management practices (BMPs) include settling, filtering, and biological processes. Settling or sedimentation is limited to particulate pollutants which drop out

of the water column by way of gravitational settling. Stormwater filtration is typically limited to BMPs which address water quality and utilize filter media, such as sand, grass, or various types of filter fabrics to strain pollutants out of the stormwater. Typically these structures are limited to drainage areas less than 5 acres since stormwater must pass through the filter media in order to be treated. Biological processes are the most effective removal mechanisms for soluble pollutants, such as nutrients. A combination of shallow permanent pool depths and abundant vegetation helps to create an environment in which natural processes remove the soluble nutrients from the stormwater runoff. BMPs best suited for this pollutant removal mechanism include enhanced detention, retention, constructed wetlands, and bioretention. The sizing criteria for these BMPs are generally based on permanent pool volume defined as a multiple of the water quality volume (WQV) (i.e. 2.0 or 3.0 times the WQV). Bioretention utilizes filtering as the primary pollutant removal mechanism.

1.2.1.2 Water Quality Volume

The Virginia Stormwater Management Regulations require that the first flush of runoff be captured and "treated" to remove pollutants. The first flush, or water quality volume, is generally defined as the first ½" to 1" of runoff from impervious surfaces. Therefore, BMPs which are dependent on volume, such as extended detention, constructed wetlands, and in some cases infiltration, have a required treatment volume of 2.0 x WQV. (Refer to Table 2-3 of the Virginia Stormwater Management Handbook for determination of which type of BMPs require multipliers for sizing of WQV BMPs.)

1.2.1.3 Technology-Based and Performance-Based Water Quality Criteria

The Performance-based water quality criteria for land development requires that the calculated post-development nonpoint source pollution

runoff load be compared to the calculated pre-development load based upon the average land cover condition or the existing site condition.

The Technology-based water quality criteria for land development requires that the post-developed stormwater runoff from the impervious cover will be treated by an appropriate BMP as required by the post-developed condition percent impervious cover as specified in Table 2-3 of the Virginia Stormwater Management Handbook.

It is our professional opinion that the design engineer should use the Performance-based water quality criteria when deciding on appropriate BMPs for a specific project site since DCR uses this methodology when checking the design calculations.

1.2.2 Stream Channel Erosion

In an urbanized setting, most of the drainage network is developed or improved to convey increased volumes and rates of runoff to the receiving stream channel. The stream channel then responds to the increase in flow by eroding to form a larger cross sectional flow area which, theoretically, should result in reduced flow velocities ($Q = V \times A$). An eroded channel, however, is quite often a very efficient conveyance system and promotes an even faster velocity of flow, which in turn, accelerates the channel degradation process. Once this process has begun, it is very difficult to stop because typical stream channel soils are highly erodible once the protective lining of cobble and/or vegetation is eroded away. The stream channel erosion component of the Virginia Stormwater Management Regulations (4 VAC 3-20-81) incorporates the technical provisions of stormwater runoff component of the Erosion and Sediment Control Regulations (Minimum Standard 19, 4 VAC 50-30-40.19) as required by law.

1.2.3 Flooding

When the rate of stormwater runoff exceeds the capacity of natural and manmade conveyance systems localized flooding occurs. In pre-developed conditions, most

streams have an adequate floodplain or flood fringe to convey and store out of bank flows with minimal damage. With urbanization and development, these floodplain areas are often disturbed or even eliminated. When flooding occurs in these developed areas pavement can be damaged or undermined, structures will be water damaged, and landscaping and other improvements not suited to inundation will be damaged. The flooding requirements are found in the technical provisions of stormwater runoff component of the Erosion and Sediment Control Regulations (Minimum Standard 19, 4 VAC 50-30-40.19) as required by law.

1.3 Proposed Stormwater Management Regulations

DCR is currently in the process of revising the stormwater management regulations for the Commonwealth. The revised regulations are anticipated to be mandated in 2009. The major revision which will affect development on Post is the requirement that the post-development runoff rate of flow and runoff characteristics (velocity, volume, and time distribution) must replicate predevelopment runoff characteristics and site hydrology. This requirement will be challenging to meet for all developments, especially on Main Post with the proposed South Institute Hill Parking, South Post Aquatic Center, Field House, and parking, which are in-fill projects along the Town Branch tributary to the Maury River. This report addresses the proposed regulations with the alternatives and solutions.

2.0 MAIN POST

2.1 Existing Conditions

2.1.1 Historical Context

VMI was established on Main Post on November 11, 1839 and continues its legacy of excellence in education and military leadership today as a four-year undergraduate institution with over 1300 cadets and future growth in the Corps is expected to reach 1500 Cadets. In support of this excellence, VMI's Vision 2039 development plan provides a framework for facilities improvements and an extensive building program in order to continue the VMI legacy into the future.

Main Post is the primary location of the educational, athletics, and military training facilities for VMI. The original buildings at VMI were strategically built on the ridge between the Woods Creek and Town Branch watersheds, hereinafter referred to as Main Post. Today, North Post refers to the area along Woods Creek and South Post refers to the area along Route 11 and the Town Branch, both 'downhill' from Main Post.

2.1.2 Prior Studies

As part of the research for the SWM Plan, DAA reviewed previous reports and plans of projects within Post that were or are currently under construction. A summary of our review of these studies is provided in a letter report dated 23 March 2007 with a Summary of Existing Information is provided in Appendix A. Refer to Figure 2A – Main Post Existing Stormwater Management Facilities for facilities that are in place or are currently being constructed on Post.

2.1.3 Watershed Context

Main Post drainage patterns fall into two main sub-basins: 1) the Town Branch and 2) Woods Creek. Refer to Figures 2B - Woods Creek & Town Branch Watersheds, 2C – Main Post Aerial Photograph, and 2D – Main Post Sub-Basins for a delineation of the watersheds and topographic information. These watersheds are within the Maury River basin; the Town Branch converges with

Woods Creek prior its confluence with the River northeast of Post, near Jordan's Point Park.

2.1.3.1 North Post (Woods Creek)

The Woods Creek drainage area on Post is approximately 160 acres and is mainly developed with large grass areas, except for the steep slopes which are wooded or covered with rock for stabilization. Rock outcrops are shallow and common in this area. Refer to Figure 2C – Main Post Aerial Photograph.

Woods Creek enters the Post via an open channel and immediately enters an 870 foot, 12' x 20', corrugated steel arch culvert which passes under Patchin Field and Gray-Manor Stadium before daylighting into an open channel which runs approximately 1600 feet to its confluence with the Maury River. Existing storm sewer systems around North Post discharge directly into Woods Creek.

Recent and ongoing developments within this area, including the Leadership and Ethics Center, Gray-Minor Stadium, and Third Barracks, incorporate quantity and quality stormwater management into the design of the individual projects, which were previously approved by DCR.

<u>Floodplain</u>

The majority of Woods Creek (Creek) is within a regulatory Zone A floodplain area with undefined base flood elevations. Refer to Figures 2E and 2F for the Flood Insurance Rate Map.

In the late 1960s, VMI constructed the North Post sports fields by installing an 870 foot, 12' x 20', corrugated steel arch culvert so fill could be placed overtop of Woods Creek to provide the area needed for the playing fields. In 2006, the sports fields were upgraded; Gray-Minor

Stadium and Patchin Field are currently located over the channelized Creek.

In 2005, Draper Aden Associates completed an analysis of the base flood elevations of Woods Creek for the development of Gray-Minor Stadium. This analysis showed that the base flood elevation of the Creek overtops Patchin Field and Gray-Minor Stadium playing surfaces a maximum of 2.5 feet; the flood flows overland and through the culvert towards the open channel east of Gray-Minor Stadium, where the floodplain is contained within the banks of the Creek, until the backwater of the Maury River is met at the east end of the existing gravel parking lot. The affect of the Maury River backwater in this area results in a base flood elevation of 920+, which is over 10 feet above the surface elevation.

Soils

As identified from a review of the Soil Conservation Service "Soil Survey of Rockbridge County, Virginia", which is currently unpublished, the drainage area soil is comprised of Alonemill-Clubcaf Complex soils (hydrologic soil group B) and Chilhowie Rock Outcrop (hydrologic soil group C). For the purpose of the conceptual stormwater calculations, SCS hydrologic soil type "C" was used.

2.1.3.2 South Post (Town Branch)

The Town Branch total drainage area is approximately 420 acres, including 76 acres of Post, which is developed with academic and support facilities, housing, parking lots, and sports facilities, except for the area between Massie and Diamond Streets. Rock outcrops are shallow and common in this area. Refer to Figure 2B Woods Creek and Town Branch Watersheds.

Town Branch enters VMI property via a culvert system under Massie Street and daylights into an open channel west of Diamond Street for

approximately 450 feet, then into a series of culverts prior to daylighting into a channel west of Hook Lane, re-enters into a culvert, installed by the City of Lexington, which passes under Hook Lane and into a channel system east of Hook Lane which is off Post. Figure 2G – Town Branch Stormwater System (Existing) details the stormwater conveyance channels through South Post. The two (2) 6'x5' box culverts and 6'x6' box culvert east of Cameron Hall were constructed in 2006 and 2007 to replace damaged and inadequate culverts under Kilbourne Hall.

Recent and ongoing developments within this area, including the Kilbourne Hall Annex, Crozet Hall, Clarksen McKenna Addition, Renovation of Alumni Stadium and Delany Field, and North Institute Hill Parking, incorporated stormwater management into the design of the individual projects, which were previously approved by DCR. During the design development of the North Institute Hill parking lot, DCR expressed concern regarding potential downstream degradation of the stream because of the recent upgrades to the conveyance channels on Post; therefore, this parking lot was required to store the additional runoff volume required to maintain existing release rates for the 2-, 10, and 100-year storm events.

Floodplain

The Town Branch is not within a regulatory floodplain. Refer to Figures 2E and 2F for the Flood Insurance Rate Maps. Even though this area is not currently within a regulatory floodplain area, any development within this area will be subject to Executive Memorandum 2-97, which states that "new state-owned buildings shall not be constructed within 100-year floodplain, unless a variance is granted by the Director…."

In June 2007, Draper Aden Associates was tasked by VMI to complete a calibration of the hydrologic and hydraulic models recently prepared by Clark Nexsen in order to determine the accuracy of the models based on observed conditions and then, using the calibrated model, calculate the

existing base flood elevations between Massie and Diamond Streets. DCR required the base flood elevations to be conservatively determined based on a full-build out scenario for the entire watershed. A summary of the base flood elevations is found under Section 2.2.2.

A complete analysis and summary of findings is provided in the Town Branch Model Calibration Study dated 21 March 2008, via a separate submittal to VMI.

Soils

As identified from a review of the Soil Conservation Service "Soil Survey of Rockbridge County, Virginia", which is currently unpublished, the drainage area soil is comprised of Alonemill-Clubcaf Complex soils (hydrologic soil group B) and Chilhowie Rock Outcrop (hydrologic soil group C). For the purpose of the conceptual stormwater calculations, SCS hydrologic soil type "C" was used for the analysis.

2.2 Future Stormwater Conditions & Alternatives Analysis

2.2.1 North Post

VMI is planning to renovate the obstacle courses and high element training areas along the ridge line dividing Woods Creek and the Maury River. A new rifle range is planned for McKethan Park. The Post Master Plan includes the requirement to remediate and demolish the existing rifle range located in North Post to make room for the construction of a Leadership Reaction Course (LRC). Also, drill fields and an improved access drive are proposed along Woods Creek. Refer to Figure 1B. In order to construct and provide sufficient width for the drill fields, a portion of the slope north of the Creek will be excavated, creating a wall; this area is considered in the calculations.

Beyond 2012, it is anticipated that an elevated soccer/lacrosse stadium, including parking below the stadium, will be constructed in the area of the drill fields. With

the exception of additional water quality controls for the soccer/lacrosse stadium, the following analysis assumes post-2012 build-out conditions.

Floodplain Analysis

The drill fields and improved access drive are proposed adjacent to and within the Zone A floodplain of Woods Creek, upstream of the Maury River. Refer to Figures 2H and 2I – Woods Creek Cross Section Locations & Floodplain Boundaries. A Zone A floodplain is an unstudied area without established base flood elevations (BFE).

Draper Aden Associates (DAA) was provided a copy of the HEC-RAS model prepared by Clark Nexsen (CN) in June 2003, which was prepared for the addition to the Patchin Field House. The CN model analyzed Woods Creek from the confluence with the Maury River upstream to the downstream end of the arch culvert. According to the CNs report dated June 20, 2003, the HEC-RAS model was created from the original HEC-2 data, the original FEMA cross-sections, and the FIS flow rates for Woods Creek. DAA revised the cross-sections of the 'corrective effective model' with updated topographic data and ran the model to determine the BFE along Woods Creek in the North Post Master Plan area. The following is a summary of the results from this model.

Cross-Section ID	Location	Approx. Top of Creek Bank (north side) Elevation	100-Year BFE with Maury Backwater	100-Year BFE w/o Maury Backwater
1	Confluence w/ Maury River		920.20	905.30
2			920.38	908.99
3			920.42	909.61
4			920.43	909.83
	East Limits of VMI Property			
5	U/S of Moses Mill Road	910	920.43	909.93
6	Construction Staging Area	906	920.48	910.63
7	Construction Staging Area	916	920.40	912.29
8	East End of Existing Gravel Lot	924	920.38	918.90
9	Exist. Gravel Lot	928	921.90	921.15
10	Mid-Proposed Stadium	932	925.05	925.05
11	Tennis Courts	932	933.87	933.87
12	Anderson Drive	940	940.04	940.04
13	Parking Lot	942	942.10	942.10
14	Patchin Field House	948	946.06	946.06
	West Limits of VMI Property			
15	U / S of Culvert		961.24	961.24
16			961.23	961.23
17			961.30	961.30

The proposed drill fields and access drive are proposed to be developed at or near existing grade and no buildings are proposed; therefore, this development is acceptable within the floodplain. Any future buildings downstream of section 8, including the future elevated soccer/lacrosse stadium, potentially could encroach on the floodplain and the lowest floor elevation will need to be above the BFE. Any future buildings or significant fill in this area may require coordination with FEMA to establish the base flood elevation in order to conform with State regulations regarding building within the floodplain.

Stormwater Management Alternatives

Based on the proposed improvements on North Post, the impacts of the runoff are summarized in the table below.

	Overall			Virginia Military Institute			
Sub-Basin	Tributary Area (ac.)	Pre-Developed RCN*	Post-Developed RCN*	Tributary Area (ac.)	Pre-Developed RCN*	Post-Developed RCN*	% of Total Tributary Area
Woods Creek	4995.0	71	71	159.6	82	83	3%

RCN = Runoff Curve Number
* Assumes full build-out of sub-basin area

The stormwater management solutions for the proposed development are limited due to the floodplain elevations and the presence of shallow rock formations and karst geology. The stormwater management facilities must discharge above the BFE of Woods Creek, which are not influenced by the Maury River backwater effect. This requirement eliminates the possibility of manufactured underground systems for both water quality and quantity. Infiltration is not permissible by DCR in karst areas, thereby eliminating the possibility of bioretention. The above issues also minimize the potential to utilize porous pavements and pervious pavers for proposed impervious surfaces, which would reduce the total impervious area, since these systems are most effective and cost efficient in areas

where the subsurface soil conditions are conducive for infiltration into the groundwater.

Alternative stormwater solutions for North Post include surface facilities that discharge above the BFE and do not rely on infiltration; solutions possibly could include one or a combination of the following best management practices (BMPs):

1. Sediment Forebays that allow sediment to settle from the runoff before entering the main BMP. (Minimum Standard 3.04)

2. Extended Detention Facilities designed to provide water quality improvement, quantity control, and reduction of runoff rates to minimize channel erosion. (Minimum Standard 3.07)

3. Constructed wetlands planted with native vegetative materials to the region to provide staged water quality and quantity controls. (Minimum Standard 3.09)

4. Creation of a riparian buffer (vegetative filter strip) along Woods Creek planted with native vegetative materials. (Minimum Standard 3.14)

2.2.2 South Post

VMI is planning to develop South Institute Parking Lot and the Aquatics Center, Field House and additional parking (AC/FH) between Massie and Diamond Streets along the Town Branch. Refer to Figure 1A. Additional parking is proposed to be below the AC/FH. Refer to Appendix B - South Post Feasibility Study prepared by Clark Nexsen dated 23 June 2006 for additional details regarding the proposed developments.

Floodplain Analysis

The proposed development is tributary to the Town Branch, upstream of Diamond Avenue. Even though this area is not currently within a regulatory floodplain area, any development within this area will be subject to Executive Memorandum 2-97; in meetings with DCR, the base flood elevations of the Town Branch will need to be determined in order to set the lowest floor elevation of the proposed buildings. As noted in Section 2.1.3.2, Draper Aden Associated completed

analysis of the base flood elevations and the comprehensive summary of findings is found in Appendix J - Town Branch Model Calibration Study. The 'full-build out' floodplain boundary is shown on Figure 2M – Town Branch – Floodplain Boundary. The following table summarizes the base flood elevations between Massie and Diamond Street.

Cross Section	100-Year, 24- Hour Storm BFEs in feet
4424	985.35
4383	985.19
4374	Massie Street
4365	980.25
4132	977.61
4121	Gas Pump Culvert
4110	976.58
4035	975.56
3918	972.80
3763	971.50
3642	969.69
3554	968.84
3432	968.81
2415	Diamond Street

Stormwater Management Alternatives

Based on the proposed improvements to South Post, the impacts of the runoff are summarized in the table below.

	Overall			Virginia Military Institute			
Sub-Basin	Tributary Area (ac.)	Pre-Developed RCN*	Post-Developed RCN*	Tributary Area (ac.)	Pre-Developed RCN*	Post-Developed RCN*	% of Total Tributary Area
Town Branch	421.0	80	80	76.1	85	86	18%

RCN = Runoff Curve Number
* Assumes full build-out of sub-basin area

The South Institute Hill Parking Lot is currently under conceptual design. The development will integrate underground stormwater management systems into the design to meet required quality and quantity stormwater management standards.

The proposed AC/FH poses a challenge to meet the stormwater management requirements. The stormwater management solutions for this development are limited due to the floodplain and the presence of shallow rock formations and karst geology. Infiltration is not permissible by DCR in karst areas, thereby eliminating the possibility of true bioretention; also, bioretention can be used for water quality control with an underdrain system, only if there is sufficient area remaining on the property to construct this system. The above issues also minimize the potential to utilize porous pavements and permeable pavers for proposed impervious surfaces, except with the use of an underdrain system, since these systems are most effective and cost efficient in areas where the subsurface soil conditions are conducive for infiltration into the groundwater.

Water Quantity

Because the proposed location of the AC/FH includes closing an open channel and floodplain area, stormwater storage will need to be provided for both the existing floodplain storage volume (approximately 168,000 cubic feet) and stormwater quantity requirements for the project. Through discussions with DCR, this volume can be met through using 'in-line' storage with the requirements that 1) the base flood elevation is contained below the structure (including the surface of the parking garage) in conduits and 2) existing runoff characteristics (velocity, volume, and time distribution) for the 2-, 10-, and 100-year storm events are not exceeded at Diamond Street. The parking facility can be used, with strict controls on usage of the facility, for the 500-year overflow route for the Town Branch.

The alternatives for quantity control are limited due to the site and the above regulatory constraints for the AC/FH. There is insufficient area available either along Main Street or behind the proposed building to reroute the Town Branch around the perimeter of the building and provide adequate storage volume, including considerations for vehicular and pedestrian safety. The remaining

option for storage is under the proposed facility either in culverts or as part of the foundation design of the building.

Water Quality

Alternative stormwater quality solutions for the AC/FH include surface facilities that discharge above the BFE and do not rely on infiltration; solutions possibly could include one or a combination of the following:

1. Bioretention swales, or rain gardens, with underdrain systems, planted with native vegetation adjacent to the building. (Minimum Standards 3.11 and 3.13)

2. Green roof system on a portion or the entire roof. This can also minimize the water quantity requirement

3. Cisterns to capture the stormwater runoff for use as gray water within the building. This can also minimize the water quantity requirement

4. Manufactured BMP water quality systems, such as a StormFilter or StormTreat System, connected to the downspouts and storm drainage system. (Minimum Standard 3.15)

2.3 Preliminary Stormwater Management Design & Cost Estimates

2.3.1 North Post

Stormwater Management Design

For the current Master Plan, Figure 2J - North Post - Preliminary Stormwater Management Plan and the following summarizes the recommended design of the stormwater management facilities for the Leadership Reaction Course, Obstacle Courses, High Ropes/High Element Training Area, Warm-up Area, drill fields and access drive, and future elevated soccer/lacrosse stadium. Refer to Appendix C for detailed calculations.

1. A sediment forebay and an extended detention facility are proposed to control quality and quantity. Calculations show that the minimum storage capacity of sediment forbay should be approximately 4500 cubic feet and of the extended detention basin be approximately 40,600 cubic feet.

2. A riparian buffer is proposed between the proposed road and Woods Creek to provide additional quantity control and to return a portion of the area adjacent to the creek to natural conditions.

3. The basins are located below the regulatory base flood elevation (BFE) of approximately 920, which is the BFE due to the Maury River backwater effect.

4. The basins are designed to discharge above the BFEs which are not influenced by the Maury River backwater effect. Under this scenario, the 100-year BFE is 912 and the 10-year BFE is 908.

5. The basins are proposed to be constructed below existing grades; therefore, the basins do not reduce the amount of floodplain storage available during the extreme flooding event.

With reference to cross-section 7 on Figure 2J, a conceptual section is provided (Figure 2K) depicting a vision of the riparian buffer and the stormwater management within the context of Post. The types of vegetation shown in this cross-section are included in the cost estimate below.

Cost Estimate

The preliminary opinion of probable construction cost for the North Post stormwater management improvements, including the riparian buffer from Anderson Drive to Jordon's Point, as discussed above is approximately $350,200. A detailed cost estimate is provided in Figure 2L.

2.3.2 South Post

Water Quantity

The water quantity requirements can be met utilizing the existing two (2), 6' x 4' box culverts as the outlet structure, without modification, at Diamond Street and conveyance structures below the parking facility. The preliminary design is for approximately six (6), 6' x 6' box culverts 735 feet long (each) for a total length of 7350 feet. A junction box is proposed to connect the box culverts to the existing outlet pipes west of Diamond Streets; this is proposed to be a cast in-

place structure which is integrated into the site design of the AC/FH. Refer to Figure 2N - South Post - Preliminary Stormwater Management Plan.

A six (6) foot high structure (or culvert) is the minimum height allowable, based on DCR's criteria that the BFE ('full build-out') is contained within the system at the upstream end. Since the BFE and existing ground elevation at the west face of the building are approximately 978 and 972.5, respectively, the minimum recommended height of the opening is six (6) feet.

The existing runoff characteristics (velocity, volume, and time distribution) for the 2-, 10-, and 100-year storm events are not exceeded at Diamond Street. This design provides a proposed release rate at the Diamond Street culverts that is less than or equivalent to the existing for the 2-, 10-, and 100-year storm events (refer to Table below) and the shape of the outfall hydrograph (time distribution) is approximately equivalent to the existing hydrograph. For detailed calculations, refer to Appendix D for South Post Preliminary Stormwater Calculations.

	Release Rate at Diamond Street (cfs)	
Storm Event (years)	**Existing**	**Post-Development**
2	199	199
10	401	400
100	793	740

DCR noted the Town Branch conveyance system northeast of Hook Lane is not adequate under current conditions. VMI is aware of this issue and continues to coordinate with the City of Lexington (City) and the Virginia Department of Transportation (VDOT) to discuss potential system improvements with the understanding that the City and VDOT are the major contributors to this system.

Water Quality

Because of the tight site constraints of the AC/FH building, water quality could be achieved by a combination of a storm filter system and bioretention facilities, as

well as capture and reuse of roof runoff. A StormFilter, or equivalent system, is proposed to capture roof runoff from the east portion of the building, just north of the proposed junction box; the StormFilter System outfall is to tie into junction box. Bioretention facilities are recommended along the north face of the building adjacent to Main Street; these facilities can provide aesthetic value to the landscape of the building, as well as provide water quality enhancement. Refer to Figure 2N - South Post - Preliminary Stormwater Management Plan for the proposed locations of these facilities and Appendix D for calculations.

The water quality calculations show that the StormFilter system will not provide sufficient water quality controls; therefore the proposed use of bioretention facilities. The bioretention facilities should be maximized within the constraints of the landscape and site design of the building. Additionally, it is recommended during the planning and design of the facility to consider the capture and reuse of roof runoff for graywater uses (toilets) within the facility. The graywater system is not included in the cost estimate.

Cost Estimate

The preliminary opinion of probable construction cost for the South Post stormwater management improvements, including the bioretention facilities, as discussed above is approximately $3,413,000. A detailed cost estimate is provided in Figure 2O.

2.4 Existing Drainage Issues

2.4.1 Maiden Lane

Maiden Lane is a narrow, steep, one-way access drive connecting Letcher Avenue on Post to U.S. Route 11 (Main Street). This road has poor drainage and, therefore, the pavement is failing in several locations, as shown on the pictures on page 20. There is one drainage structure near the entrance drive to the housing north of Main Post, which appears to capture very little runoff.

As part of the proposed development of the South Institute Hill Parking Lot, we recommend reconstructing the road, including stabilization of the subgrade and/or subbase, as required following a geotechnical investigation, to provide cross-slope towards a curb and gutter system in order to channelize the runoff from the pavement towards curb inlets. Curb inlets should be provided upstream of any access points in order to minimize the amount of sheet flow across intersections. These inlets should connect to the South Institute Hill Parking Lot storm sewer system.

2.4.2 Gray-Minor Stadium Bank Erosion / Anderson Drive (north) Runoff Issues

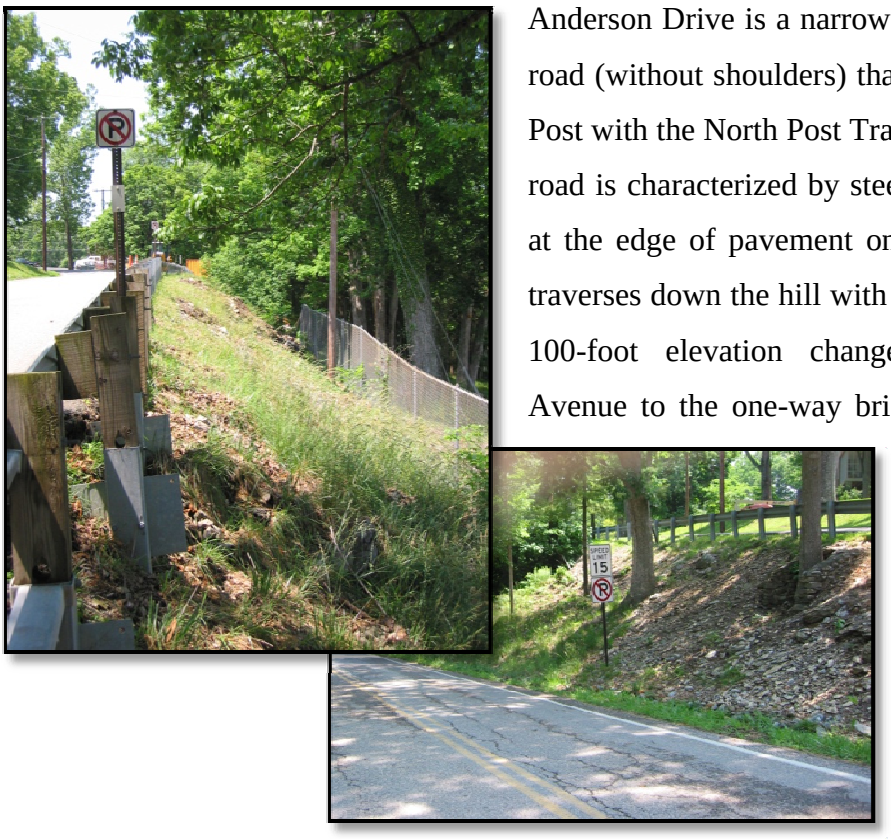
The embankment north of Gray-Minor Stadium is being eroded during significant storm events from runoff from the upstream watershed, which includes the Woods Creek Trail. The following photographs show the bank erosion back to the source along the Woods Creek Trail.

The ‘ditch’ along the south side of the Woods Creek Trail captures runoff from the hillside to the north and has naturally created a drainage path under the safety fence, which ultimately discharges, and therefore creating erosion issues, down the embankment.

A potential solution to this problem would be to install trench drain system or simply construct a swale to deliberately direct the runoff toward the inlet, which is west of Anderson Drive and north of the embankment of Gray-Minor Stadium (see picture to the above left). The swale design may include a curb system, either asphalt or concrete, as needed to control the runoff.

The inlet and outlet pipe should be cleaned of debris and an earthen or asphalt/concrete berm of approximately 6-inches should be constructed on the south side of the inlet in order to ‘force’ the runoff into the storm sewer system. This will help to mitigate erosion of the embankment and surface runoff issues along Anderson Drive.

2.4.3 Anderson Drive (south) Erosion and Runoff Issues



Anderson Drive is a narrow, steep, two-way road (without shoulders) that connects Main Post with the North Post Training Area. The road is characterized by steep embankments at the edge of pavement on each side as it traverses down the hill with approximately a 100-foot elevation change from Parade Avenue to the one-way bridge that crosses Woods Creek.

A potential, short-term solution to minimize erosion and flooding issues along Anderson Drive is to install a trench drain system between the toe of the slope along the south edge of pavement; however, because of the shallow rock formations, this trench drain system would only be a few feet deep with capacity only for the small, frequent storm events. Any long-term widening or improvements to Anderson Drive should include provisions for the trench drain system and a curb and gutter and storm sewer system along the north edge of pavement.

2.4.4 Institute Hill / Main Street Runoff Issues

VMI indicated that during heavy storm events Main Street is inundated with stormwater runoff from Institute Hill. From observations, it appears the runoff is from seepage through the retaining wall and its drainage system, which discharges with force through the retaining walls or curb line via small diameter pipes. This

is potentially due to the head and pressure on the pipe caused by a high flow and a small diameter system.

The South Institute Hill Parking Lot storm sewer design should mitigate this issue of the adjacent retaining walls by capturing the surface runoff, detaining the runoff, possibly connecting and rerouting the retaining wall drainage system directly to the storm sewer, and discharging it to the storm sewer system at Main Street and/or directly to the Town Branch.

Additionally, the retaining walls, mortar-set field stone walls, are in good condition, except certain areas should be rebuilt with the existing stone by removing the old mortar and setting the original stones with new mortar. The drainage and weep hole system should be connected to a storm sewer system where possible.

3.0 MCKETHAN TRAINING AREA

3.1 Existing Conditions

3.1.1 Historical Context

The McKethan Training Area is approximately 226 acres located three miles to the east of VMI's Main Post where Interstate 81 crosses over the Maury River. Vehicular access to the site is via Route 631 and pedestrian access via the Chessie Nature Trail. Currently, this area houses a firing range (to be relocated from North Post to McKethan Park), two patrol bases, a softball field, an Observatory, a Military Operations on Urban Terrain (MOUT) facility, and a Command and Control Facility.

3.1.2 Prior Studies

There are no prior studies in this area.

3.1.3 Watershed Context

The majority of the site is undisturbed, except for the existing facilities, access drives, the open area where the softball field is located, and where VDOT placed fill into a large sink hole as part of the bridge improvements on I-81 in 2006. Refer to Figure 3A – McKethan Area – Aerial Photograph.

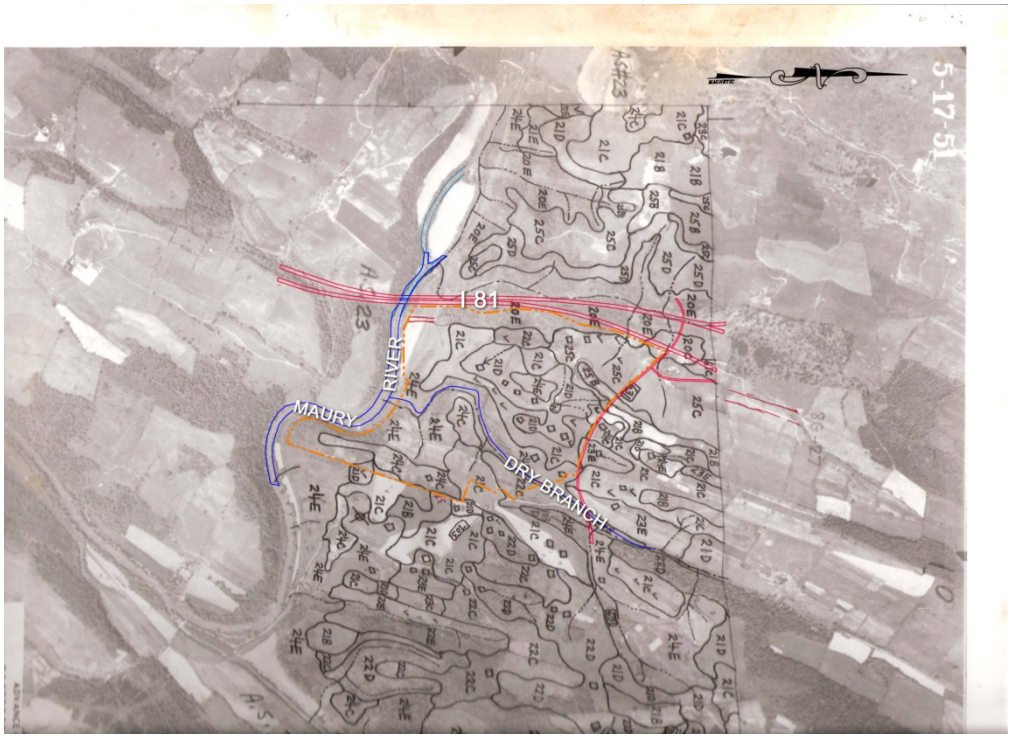
The entire area is tributary to the Maury River; the majority of the site directly discharges into the Dry Branch of the River, which bisects the property. Refer to Figure 3C.

Floodplains

The Dry Branch is within a Zone A floodplain, an unstudied area without established base flood elevations (BFE). Refer to Figure 3B – McKethan Training Area – Flood Insurance Rate Map.

Soils

As identified from a review of the Soil Conservation Service "Soil Survey of Rockbridge County, Virginia", which is currently unpublished (see below), the native soil is comprised of Frederick silt loam, Chilhowie Rock Outcrop (hydrologic soil group C), and Hagerstown-Rock outcrop complex. For the purpose of the stormwater calculations, SCS hydrologic soil type "C" was used. The red line in the soil map below indicates the approximate location of I-81 and the blue line is the Maury River.



3.2 Future Stormwater Conditions & Alternatives Analysis

Based on the proposed improvements to the McKethan Training Area, the impacts of the runoff are summarized in the table below.

The stormwater management solutions for the proposed development are limited by the presence of shallow rock formations and karst geology. Infiltration is not permissible by DCR in karst areas, thereby eliminating the possibility of true bioretention; however, bioretention can be used for water quality control with an underdrain system. The above issues also minimize the potential to utilize porous pavements and permeable pavers for proposed impervious surfaces, except with the use of an underdrain system, since these systems are most effective and cost efficient in areas where the subsurface soil conditions are conducive for infiltration into the groundwater.

Because of the footprint of the proposed patrol bases are below 10,000 square feet, stormwater management is currently not required. Stormwater management for the entrance road extension and the 30 point baffled firing range and ammunition storage facility may be required, depending on the area of disturbance. Stormwater management will be required for the proposed Command and Control support facility and adjacent parking area.

Alternative stormwater solutions for quality and quantity control at McKethan Training Area possibly could include one or a combination of the following best management practices (BMPs):

1. Creation of and/or maintain a riparian buffer (vegetative filter strip) along Dry Branch, planted with native vegetative materials. (Minimum Standard 3.14)

2. Bioretention filters/swales, or rain gardens, with underdrain systems, planted with native vegetation adjacent to the building and parking areas. (Minimum Standards 3.11 and 3.13)

3. Green roof system on a portion or the entire roof of the Support Facility building. This can also minimize the water quantity requirement

4. Cisterns to capture the stormwater runoff for use as gray water within the Support Facility building. This can also minimize the water quantity requirement

5. Manufactured BMP water quality systems, such as a StormFilter or StormTreat System, connected to the downspouts and storm drainage system of the parking area. (Minimum Standard 3.15)

3.3 Preliminary Stormwater Management Design & Cost Estimates

Stormwater Management

A bioretention filter is recommended for the Command and Control support facility and adjacent parking area. A bioretention filter/swale is proposed for the proposed road extension. Refer to Figure 3C - McKethan Training Area - Preliminary Stormwater Management Plan for the proposed locations of the bioretention facilities and Appendix E - McKethan Training Area Preliminary Stormwater Calculations for detailed calculations for the bioretention filter.

It is recommended that a riparian buffer area is created and maintained along the Dry Branch to provide additional stormwater filtering and to enhance and maintain existing vegetation and environment.

DCR requested drainage improvements and stabilization of the existing VDOT haul road. DCR acknowledges that the requirement for these improvements will be determined by the magnitude of future development at McKethan Park; the understanding is that if the proposed improvements are minor in nature, the VDOT haul road improvements would probably not be required.

Cost Estimate

The preliminary opinion of probable construction cost for the McKethan Park stormwater management improvements, as discussed above, is approximately $63,000. A detailed cost estimate is provided in Figure 3D.

4.0 LACKEY PARK

4.1 Existing Conditions

4.1.1 Historical Context

The Lackey Park is approximately 79 acres and is located north of Main Post, north of the Maury River, and is accessed via Route 11 and Greenhouse Road. The property was donated to VMI by Mr. I.F. and Mrs. Mamie Lackey in April 1948. VMI donated portions of this property, a total of approximately 21 acres, to the Rockbridge County School Board and leased approximately six acres to the Virginia Department of Military Affairs in order to construct a National Guard Armory. Although mainly undeveloped, VMI recently relocated the Building and Grounds Facility and the ROTC motor pool to Lackey Park near the Virginia National Guard Armory. The remainder of the Lackey Park property will be retained for future development to include expansion of the Physical Plant (formally Building and Grounds Facility), warehouse space, Bachelor Officers Quarters, remote parking, and expansion of the National Guard Armory.

4.1.2 Prior Studies

Buildings and Grounds Facility: Physical Plant and ROTC Motor Pool

Draper Aden Associates obtained a copy of the civil plans and calculations for the relocated Building and Grounds Facility and ROTC motor pool from HSMM dated September 28, 2005. At present there are three bioretention facilities for quality control (BMPs 1-3) that discharge any overflow into a detention pond (BMP-4) used solely for quantity control. Future development of this area includes a building expansion, staff parking lot, and a portion of a future access road from Route 11. According to the HSMM study, this future impervious area is accounted for in the sizing of the existing bioretention and detention pond facilities. Refer to Appendix F for the Post-Development Drainage Map - Water Quality Control from the HSMM Civil Calculations Report dated 28 September 2005.

4.1.3 Watershed Context

The northwest portion of Lackey Park is developed with the Building and Grounds Facility and the ROTC motor pool facilities. In the southeast corner of the property there is a plateau that was previously disturbed to provide a softball field for the VMI cadets. With the exception of these areas, the remaining areas are grassed open space or wooded with steep slopes. Refer to Figure 4A – Lackey Park – Aerial Photograph.

The Lackey Park property contains three sub-basins: DA-1, -2, and -3. Refer to Figure 4C – Lackey Park – Conceptual Stormwater Management Plan. DA-1 and -2 drains to the south and are tributary to the Maury River via existing overland flow channels. DA – 3 drains northeast via overland flow towards an unnamed tributary of the Maury River.

Floodplain

The entire area lies within a Zone X floodplain, an area outside the 500-year flood elevation. Refer to Figure 4B – Lackey Park – Flood Insurance Rate Map.

Soils

As identified from a review of the Soil Conservation Service "Soil Survey of Rockbridge County, Virginia", which is currently unpublished, the native soil is comprised of Hagerstown silt loam (hydrologic soil group C), Frederick silt loam, and Chilhowie Rock Outcrop (hydrologic soil group C). These soils are typically rocky with shallow rock outcrops. For the purpose of the stormwater calculations, SCS hydrologic soil type "C" was used.

4.2 Future Stormwater Conditions & Alternatives Analysis

Based on the proposed remote parking facilities and future building pad areas at Lackey Park, the impacts of the runoff are summarized in the table below.

	Overall			Virginia Military Institute			
Sub-Basin	Tributary Area (ac.)	Pre-Developed RCN	Post-Developed RCN	Tributary Area (ac.)	Pre-Developed RCN	Post-Developed RCN	% of Total Tributary Area
DA-1	100.0	69	69	15.0	55	58	15%
DA-2	104.0	68	72	43.0	68	73	41%
DA-3	65.0	72	72	18.0	59	62	28%

RCN = Runoff Curve Number

The stormwater management solutions for the proposed and future developments are limited by the presence of shallow rock formations and karst geology. Infiltration is not permissible by DCR in karst areas, thereby eliminating the possibility of true bioretention; however, bioretention can be used for water quality control with an underdrain system. The above issues also minimize the potential to utilize porous pavements and permeable pavers for proposed impervious surfaces, except with the use of an underdrain system. These systems are most effective and cost efficient in areas where the subsurface soil conditions are conducive for infiltration into the groundwater.

The remote parking area is currently under design by Commonwealth Architects / Anderson & Associates and a stormwater management facility is proposed. Refer to Figure 4C: Lackey Park - Conceptual Stormwater Management Plan for the location of this proposed facility and Appendix G: Lackey Park - Surface Parking - Grading and Drainage Plan prepared by Anderson and Associates. This report assumes this stormwater facility will be constructed as part of the remote parking area construction, compliant with the Virginia Stormwater Management Regulations (4 VAC 3-20-10 et.seq.) Erosion and Sediment Control Regulations (Minimum Standard 19, 4 VAC 50-30-40.19) as required by law.

Portions of the future building areas may be tributary to the proposed stormwater facility for the parking area. If so, this facility could possibly be expanded and the outlet modified, at the time of development, to account for the future buildings. Commonwealth Architects / Anderson & Associates should consider this future expansion in the design.

For the areas of the future buildings and the access road not tributary to the proposed parking stormwater management facility, stormwater solutions could include one or a combination of the following best management practices (BMPs):

Water Quantity

1. Sediment Forebays that allow sediment to settle from the runoff before entering the main BMP. (Minimum Standard 3.04)

2. Extended Detention Facilities designed to provide water quality improvement, quantity control, and reduction of runoff rates to minimize channel erosion. (Minimum Standard 3.07)

3. Detention Basins designed to provide quantity control and reduction of runoff rates to minimize channel erosion. (Minimum Standard 3.08)

Water Quality

1. Bioretention filters/swales, or rain gardens, with underdrain systems, planted with native vegetation adjacent to the building and parking areas. (Minimum Standards 3.11 and 3.13)

2. Green roof system on a portion or the entire roof. This can also minimize the water quantity requirement.

3. Cisterns to capture the stormwater runoff for use as gray water within the building. This can also minimize the water quantity requirement.

4. Manufactured BMP water quality systems, such as a StormFilter or StormTreat System, connected to the downspouts and storm drainage system of the parking area. (Minimum Standard 3.15)Expand parking lot detention basin

4.3 Conceptual Stormwater Management Design & Cost Estimates

Stormwater Management

The conceptual stormwater management design is based on the area of the future building pad areas assuming 100 percent impervious surfaces, for a conservative estimate. The following is a summary of recommended stormwater management strategies for Lackey Park, as shown on Figure 4C: Lackey Park - Conceptual Stormwater Management Plan. Refer to Appendix H for detailed Lackey Park Conceptual Stormwater Calculations.

Drainage Area 1 (DA-1): The stormwater management facility for the future building pad to the southwest of the Physical Plant site should be an extended detention basin.

Drainage Area 2 (DA-2): The stormwater management facility, quantity and quality, for a portion of future building pads east of the National Guard Readiness Center should be provided, as needed, in the facility currently proposed for the future parking area. This facility and related stormwater system should be designed such that it can be easily expanded in the future for the building pads tributary to it.

Drainage Area 3 (DA-3): The stormwater management facility, quantity and quality, for the majority of the future building area footprint east of the National Guard Readiness Center should be provided in an Enhanced Extended Detention facility.

Cost Estimate

A conceptual opinion of probable construction cost for the Lackey Park stormwater management improvements, as discussed above, but excluding the DA-2 stormwater facility future expansion, is approximately $440,000. A detailed cost estimate is provided in Figure 4D.

5.0 NEW MARKET BATTLEFIELD STATE HISTORICAL PARK

5.1 Existing Conditions

5.1.1 Historical Context

VMI owns the New Market Battlefield State Historical Park, which was opened in 1967, and other properties in the New Market area, totaling approximately 300 acres, in order to preserve and interpret the Battle of New Market as a memorial to the VMI Cadets who lost their lives in the Battle. In addition to the Park, VMI currently owns the Shirley House, a portion of Shirley's Hill, and a few additional parcels south of the Park.

5.1.2 Prior Studies

There are no prior stormwater studies for these properties.

5.1.3 Watershed Context

The Battlefield site is strategically located on a ridge line that divides the North Fork Shenandoah River and Smith Creek. The west portion of the site tributary to the Shenandoah River and the east portion are tributary to Smith Creek via three ravines on the east side of I-81. The west portion of the site is mainly open space and is significantly elevated above the River, with access drives to the Hall of Valor Museum and the Bushong Farm, as well as a perimeter access drive around the Battlefield Site. The east portion of the site that is near the North Fork Shenandoah River is wooded with very steep slopes towards the River. A large abandoned quarry, which served as a borrow pit for the I-81 construction, is located in the northeast corner of the site. Refer to Figure 5A – New Market Battlefield – Aerial Photograph.

The Shirley House is located adjacent to the City Branch, which is a tributary of the North Fork Shenandoah River.

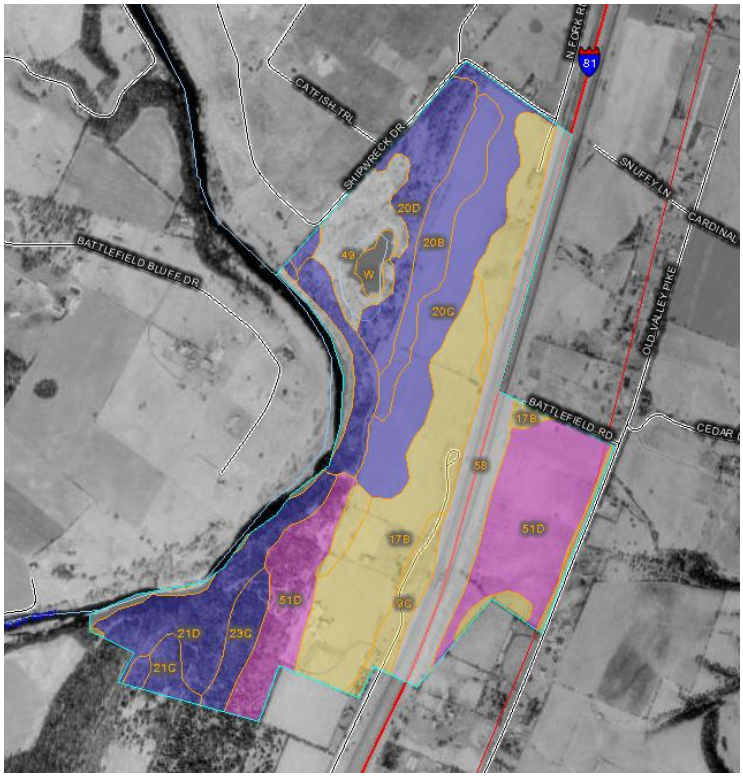
The Shirley's Hill property is mainly grass open areas and is tributary to the City Branch.

Floodplain

With the exception of the Battlefield site adjacent to the North Fork Shenandoah River, the VMI property in New Market are within a Zone X floodplain, an area outside the 500-year flood elevation. Refer to Figure 5B – New Market Battlefield – Flood Insurance Rate Map.

Soils

As identified from a review of the Soil Conservation Service "Soil Survey of Shenandoah County, Virginia", which is currently unpublished (see below), the native soil is comprised of Frederick and Poplimento silt loams (hydrologic soil group B), Carbo-Endcav complex (hydrologic soil group C), Endcav silt loam (hydrologic soil group C), and Rock outcrop-Carbo complex (hydrologic soil group D). These soils are typically rocky with shallow rock outcrops. For the purpose of the stormwater calculations, SCS hydrologic soil type "C" was used.



5.2 Future Stormwater Conditions & Alternatives Analysis

Based on conversations with VMI and a site visit, the future projects may include a maintenance facility at New Market Battlefield Park, improved access at Shirley's House, and an interpretive center at Shirley's Hill (refer to Figure 5C). VMI is currently working on a Feasibility Study to further define the potential of these and other developments of VMI property in New Market. Based on the future improvements proposed for the New Market Area, the impacts of the runoff are summarized in the table below.

	Overall			Virginia Military Institute			
Sub-Basin	Tributary Area (ac.)	Pre-Developed RCN	Post-Developed RCN	Tributary Area (ac.)	Pre-Developed RCN	Post-Developed RCN	% of Total Tributary Area
N.F. Shenandoah	231.0	70	70	132.5	70	71	57%
Smith Creek	156.0	63	63	153.5	63	63	98%

RCN = Runoff Curve Number

An additional potential impact on stormwater management is the pending widening of I-81. More information is needed from VDOT to determine the impacts, if any.

The stormwater management solutions for the future developments are limited by the presence of shallow rock formations and karst geology found in the New Market area. Infiltration is not permissible by DCR in karst areas, thereby eliminating the possibility of true bioretention; however, bioretention can be used for water quality control with an underdrain system. The above issues also minimize the potential to utilize porous pavements and permeable pavers for proposed impervious surfaces, except with the use of an underdrain system, since these systems are most effective and cost efficient in areas where the subsurface soil conditions are conducive for infiltration into the groundwater.

5.2.1 New Market Battlefield Park

The Park wishes to construct a Maintenance Facility west and 'downhill' of the existing museum to provide storage and parking for maintenance vehicles. This future development is within the North Fork Shenandoah River basin.

Stormwater solutions for both quantity and quality control could include one or a combination of the following best management practices (BMPs):

1. Bioretention filters/swales, or rain gardens, with underdrain systems, planted with native vegetation adjacent to the building and storage areas. (Minimum Standards 3.11 and 3.13).

2. Green roof system on a portion or the entire roof of a new building. This can also minimize the water quantity requirement.

3. Manufactured BMP water quality systems, such as a StormFilter or StormTreat System, connected to the downspouts and storm drainage system of the parking area. (Minimum Standard 3.15)

5.2.2 Shirley's House

VMI owns the Shirley's House and would like to construct an improved access drive on the west side of the building to provide better access for maintenance and delivery vehicles. This development is adjacent and tributary to City Branch. Depending on the area of disturbance, stormwater management may be required. Stormwater solutions for both quantity and quality control could include one or a combination of the following best management practices (BMPs):

1. Bioretention filters/swales, or rain gardens, with underdrain systems, planted with native vegetation adjacent to the building and storage areas. (Minimum Standards 3.11 and 3.13).

2. Manufactured BMP water quality systems, such as a StormFilter or StormTreat System, connected to the downspouts and storm drainage system of the parking area. (Minimum Standard 3.15)

5.2.3 Shirley's Hill

VMI owns the historic Shirley's Hill and wishes to develop in the future an interpretive center and a small parking area on the Hill as well as an access drive from the Frontage Road. This development is tributary to City Branch. Stormwater solutions for both quantity and quality control could include one or a combination of the following best management practices (BMPs):

1. Bioretention filters/swales, or rain gardens, with underdrain systems, planted with native vegetation adjacent to the building and storage areas. (Minimum Standards 3.11 and 3.13).

2. Manufactured BMP water quality systems, such as a StormFilter or StormTreat System, connected to the storm drainage system of the parking area. (Minimum Standard 3.15)

5.3 Conceptual Stormwater Management Design & Cost Estimates

The following are suggestions for stormwater management controls for the potential future projects associated with New Market Battlefield Park; since the scope, size and location of each project is undefined, a conceptual stormwater management solution is premature at this time. However, below are typical unit prices for the stormwater management alternatives described above.

1. Bioretention filters/swales, or rain gardens, with underdrain systems, planted with native vegetation: *$5 TO $7 per square foot* (includes 2.5-feet of soil media, filter fabric, 6-12" drain stone, 4-6" perforated wrapped drain pipe, liner, planting, and seeding)

2. Bio-swale (10-feet in width): *$14 to $16 linear foot* (includes 6-inch soil media, filter fabric, 24" wide x 12" depth drain stone, with 4-6" perforated HDPE drain pipe, planting, and seeding); $500 to $1000 each cast-in-place concrete weir/flow splitter in drainage ditch for offline bioretention, as needed.

3. Green roof system: *$22 to $28 square foot extensive green roof* (includes everything above the roof insulation, including roof membrane system, drainage board, soil media, and plants) Does not include pavers for accessibility to mechanical units and their support systems.

4. Manufactured BMP water quality systems, such as a StormFilter or StormTreat System: (pending information from vendors)

5. Cisterns: *$5,000 per 1000 gallon tank* (does not include full plumbing and uv treatment for gray water interior use)

6. Sediment Forebays*: $3,500 and up to $6,500 for larger drainage areas* (includes concrete spillway, dissipater riprap, excavation, and minimal planting along edges)

7. Extended Detention Facilities: *Cost requires specific design of site and facility.* Enhanced facilities involve extensive planting and fine grading for accurate drainage patterns mimicking high and low marsh areas.