G. B. Gunlogson Student Environmental Design Competition Open Format

Project Title: Design Implications of Policy Change on Solar Site Stormwater Management in Virginia

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Acknowledgements:

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Design Implications of Policy Change on Solar Site Stormwater Management in Virginia

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Abstract

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Additional Project Information Can Be Found at
https://sites.google.com/vt.edu/redwattchilipeppers/

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Background

The Commonwealth of Virginia has one of the most aggressive solar expansion programs in the United States. With the passage of the Virginia Clean Energy Act (VCEA) in 2020, the state's solar energy production is rapidly expanding (McGowan, 2021). The VCEA mandates that Dominion Energy and Appalachian Power, the two largest energy providers in the state of Virginia, must acquire 100% of their energy from renewable sources by 2045 and 2050 respectively; there are interim goals to make sure there is progression towards the final requirements (Virginia Department of Energy, 2020). As a result, several solar companies have been established to increase the sustainable energy generation capacity that larger companies require. In addition to an increase in solar site quantity, there is an increase in solar site scale. To meet increased demands, solar sites can be upwards of one thousand acres with seemingly endless rows of solar cells (E. Ould, personal communication, April 19, 2023). The solar industry will continue to grow globally as governments acknowledge the impacts of climate change and focus efforts on renewable energy generation. The impacts of utility-scale solar on the environment need to be studied to determine the implications of changing solar infrastructure on the surrounding ecosystems.

Stormwater management on solar sites is challenging, as ground-mounted solar sites have a unique layout of impervious surface. Additionally, the use of the NRCS curve number (USDA, 2021) on solar sites has not been thoroughly researched. In previous Virginia policy, the area of the solar panels was not included in the impervious area calculations, resulting in a lower curve number and lower quantities of water to control. Due to the underrepresentation of impervious area in the hydrologic calculations, stormwater detention structures on utility-scale solar sites are frequently under-designed: this results in solar sites with significant levels of erosion, inadequate conveyance channels, and failing detention systems (E. Ould, personal communication, April 19, 2023). Combined with soil loss from "dripline" erosion, caused by water running off solar panel edges, this often costs solar companies significant amounts of money to make repairs, denting profit margins. The erosion and stormwater issues negatively impact the surrounding landscape and, depending on the size and design volume of stormwater structures, can cause potential threats to life and property downstream of the site. While it is important to address these environmental issues, the upfront cost of designing higher-volume hydraulics could prevent projects from moving forward. Solar companies operate on already thin profit margins in efforts to compete with nonrenewable energy sources, and startup costs require additional planning for future projects. Solar projects also take years to establish: permitting is required from multiple government agencies and local electric utilities. Projects that are currently underway are threatened by updated policy changes, especially if a site has already been designed to old-policy standards but is still waiting on permits prior to the start of construction.

In March 2022, the Virginia Department of Environmental Quality (VADEQ) updated the stormwater policies on utility-scale solar sites in efforts to address these issues. The policy changed to include horizontal projected area of panels in the impervious area calculations, which impacts the water quality and water quantity treatment volumes (Rolband, 2022b). The increase in impervious area will increase the curve number, which will increase the treatment volumes needed on-site: additional or updated water control measures will be needed in the form of Best Management Practices (BMPs) to handle the increase in treatment volume on solar sites.

Problem Statement

This project aims to quantify the changes that utility-scale solar sites will incur in the future with the updated regulations. The updated VADEQ policy classifies the area of the solar panels as impervious, while the old policy only included solar panel supports and beams in the impervious area calculations. The change in area classified as impervious will increase the required water quality and water quantity treatment volumes through an increase site weighted curve number—which is based on the amount of impervious area—thus demanding larger stormwater systems. The need for more robust stormwater systems will increase the upfront cost of utility-scale solar site construction, which will impact the profit margins of solar companies. This project aims to illustrate the impact of the impervious area policy change on the design characteristics of projects, as well as the upfront cost. Figure 1 shows the implications of the policy change and the expected outcomes driving thi design problem.

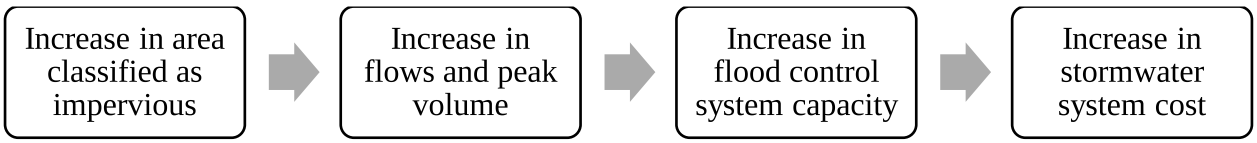

Figure 1. Cause and Effect Sequence of VADEQ Policy Change

Goals and Objectives

The goal of this project is to provide the client, Virginia-based solar company Energix Renewables, with a proposed design and cost estimate for a solar site compliant under the new DEQ stormwater regulations. The project deliverable is a set of design plans for a representative drainage basin from an under-construction Virginia solar site, redesigned to meet the new regulations. Existing solar site plans were provided by the client for two reasons: firstly, the design team wanted to be sure that updated stormwater infrastructure is feasible and realistic on current Engerix Renewables solar sites, and secondly, the updated design and cost estimate is more valuable when compared to the designs of solar sites as created under the old DEQ policy.

The site with existing plans selected for this problem is Energix's Axton, VA site. Axton is in southern Virginia, located just north of the Virginia/North Carolina state line. The solar site is on the border of Henry County and Pittsylvania County, which is an example of a site that might face additional permitting challenges due to its location in two different jurisdictions (permitting was outside the scope of this design project, but the implication is important to mention). The complete plan set for the Axton site is finalized, and the stormwater plans for the post-construction site conditions have been approved under the old stormwater policies. The Axton site will be grandfathered into the new regulations, allowing the site to legally operate under the old regulations once the new regulations take effect. The team's proposed design was created under Virginia's "new construction" assumption with the intention of comparing the effect of the policy change on the design of a stormwater management system: the original Axton site was a new construction project, so the redesign will be treated as a new construction project for a useful comparison. The consistency of grading and detention structure design was overall maintained to provide a more direct comparison between the old-policy site and the new-policy site. This project will serve as an example for Energix Renewables to forecast what changes may occur at their future solar sites because of the VADEQ policy change; in addition, Energix Renewables can forecast the upfront costs of future utility-scale solar site projects.

While grading for this project was not changed, new solutions may require regrading or different site layouts for better-functioning stormwater management systems.

The objectives for the redesigned Axton site under the update policy include the following:

1. Select an existing subarea of Energix's Axton, Virginia, utility-scale solar site
2. Calculate the new requirements for water quality and water quantity parameters, as changed by the classification of impervious area
3. Redesign the existing extended detention system to be compliant with Virginia's Channel Protection and Flood Protection regulations
4. Design BMPs to meet the increased total phosphorus (TP) reduction requirements, including an extended detention system, grassed channels, and panel stowing
5. Create a detailed cost estimate, specifically accounting for the aspects of the site that have changed, and compare with the Energix's original design

Criteria and Constraints

Criteria

Criteria are measurable rules that must be met by the project design. Most criteria deal with VADEQ standards and codes. The specific project criteria, including standards, are the following:

- Must comply with the new criteria as documented in VADEQ Guidance Memo No. 22-2012 - Stormwater Management and Erosion & Sediment Control Design Guide (Rolband, 2022b, 2022a)
- Must comply with the relevant VADEQ Stormwater Management Codes:
    - 9VAC25-870-63: Water quality design criteria requirements (Water quality design criteria requirements, 2014)
    - 9VAC25-870-65: Water quality compliance (Water quality compliance, 2014)
    - 9VAC25-870-66: Water quantity compliance (Water quantity compliance, 2014)
    - 9VAC25-870-85: Stormwater management impoundment structures or facilities (Stormwater management impoundment structures or facilities, 2014)
- Must fit within the existing drainage area boundary and property boundaries for the drainage subarea selected
- Must keep solar panels and underground wiring in existing orientations as to not impede photovoltaic electricity generation

Constraints

Constraints are limits to overall project quality. They are observable but not necessarily measurable quantitatively. The project constraints are the following:

- Maintain site feasibility
- Design stormwater system to last at least 25 years (lifespan of solar panels)
- Maximize drainage area treated by a single BMP
- Minimize surface area of BMPs
- Minimize required maintenance frequency and maintenance cost
- Reduce construction costs
- Include stowing in design

Methods

Subarea Selection

The Axton site plans, designed by Kimely-Horn, were provided by client Energix Renewables. The Axton site is planned to be constructed in multiple phases, so only the first phase of construction was considered in drainage area selection. Phase 1 of the site consists of 21 drainage areas, totaling 159.27 acres. One drainage area was selected for this design to maintain a reasonable project scope and timeline. The single drainage area was selected based on size and hydrologic characteristics. The drainage area should be of average size to be representative of areas across the Axton Phase 1 site. Additionally, the drainage subarea should include a detention pond that is *only* collecting runoff from that specific subarea. The topography of the Axton site contains steeper slopes, and to efficiently space, there are drainage areas without a subarea-specific detention basin; instead, the runoff is carried to a basin within the boundaries of another subarea. To simplify hydraulic calculations, a drainage area that had all water draining to one detention basin was selected.

Hydrologic Calculations

The slope for both pre-development and post-development site conditions was determined using the elevation data provided by consultant Kimely-Horn; computations were performed using ESRI ArcGIS Pro ("ArcGIS Pro," 2023). The pre-development slope was calculated by using the CAD contour shapefile to create an elevation raster. A slope raster was then made from the newly generated elevation raster. The "zonal statistics" tool was used to find the mean slope of the slope raster within the project drainage area, The post-development slope was calculated using a similar process, except using elevation points taken throughout the site, as contours were not provided for the proposed grading.

The total impervious surface area of A06 was calculated from the horizontal projected area of the panels at their stowed "rain position", as per the new DEQ regulations. The curve number for the subarea was calculated using the NRCS Curve Number Method (USDA, 2021) for both pre-development and post-development site conditions using the Virginia Runoff Reduction Method spreadsheet ("VRRM New Development Spreadsheet," 2017). In addition to calculating the total reduction of phosphorus required, the VRRM spreadsheet generates a weighted curve number for the site based on the land cover, which was used in future calculations.

Hydrographs were created and peak flows were calculated using the Hydrologic Engineering Center's Hydraulic Modeling Software (HEC-HMS) ("Hydraulic Modeling System (HEC-HMS)," 2022). The drainage area size and curve number were input into HEC-HMS, along with an extrapolated stage-storage curve for the existing detention pond; the stage-storage curve was included in the Kimley-Horn site plans. The rainfall depth input was acquired from NOAA's Atlas 14 Precipitation Frequency Database Server using the location of the Axton site. Using the "SCS Storm" method in HEC-HMS, the post-development storage volumes for the 2-year, 10-year, and 100-year storms were calculated. The hydrographs generated in HEC-HMS were input into the StormQC software for the design iterations ("StormQC," 2021).

Pond and Outlet Structure Design

The depth and volume of the detention basin were determined based on the output stage-storage curve from HEC-HMS. The peak water surface elevations were used to determine the depth of the pond. With the hydrograph inputs from HEC-HMS, StormQC's "Outlet Design/Reservoir Routing" tool was used to design the three-stage riser structure; a three-stage riser is needed to address the Virginia Water Quality requirements (based on 1" rain event), the Virginia channel protection requirements (based on 2-year storm), and the Virginia flood protection requirements (based on the 10-year storm) (Water quantity compliance, 2014). Water quantity regulations state that the hydraulic detention structures must reduce the 2-year and 10-year post-development peak flow rates to the respective pre-development flow rates. The 1-inch storm event, which serves as Virginia's water quality storm, also must be retained in the detention basin for approximately 24 hours (Virginia Department of Environmental Quality, 2013b). The emergency spillway was also designed in the "Outlet Design/Reservoir Routing" tool. Various sized and shaped orifices were tested until the design was compliant with the water quantity regulations. The top of the embankment was determined from the peak water surface elevation of the 100-year storm, assuming other spillway stages are inoperable, plus an additional one foot of freeboard.

Channel Design

The quantity and size of the grass channels was dictated by the design requirements outlined in the "Grass Channel" design specifications (Virginia Department of Environmental Quality, 2013a): the channel must be sized for the ten-year design storm and not erode during the two-year storm per Virginia's water quantity regulations (Water quantity compliance, 2014). The channel was sized by using the trapezoidal best hydraulic section based on Manning's equation; the Manning's n value was obtained from the DEQ specifications. Additionally, the channel must be sized to hold the 1-inch storm event at no more than a 4 inch depth, and have a velocity of less than 1 ft/s. If the velocity requirement could not be achieved, check dams would be added to meet that requirement. To obtain additional water quality credits, composted-amended grass channels were considered in addition to existing-soil grass channels (Virginia Department of Environmental Quality, 2013a, 2016)

Final Deliverables

Existing topography, panel placement, and proposed grading CAD drawing files (.dwg) were obtained from the client. The drainage area boundary and hydrologic soil group (HSG) boundaries were outlined by overlaying an image sized to match the existing features in the drawing atop the topography contours. It should be noted that the original Axton site is designed with fixed-tilt panels, but a mock-up of the site with single-axis trackers was provided by the client. Energix, among other solar companies, are designing most future projects with single-axis trackers to maximize electricity generation efficiency and enable stowing practices; this site mockup allowed for a more accurate and applicable final deliverable.

The design team was also provided with drawing files of proposed grading in the eastern part of the drainage area to maintain ground slopes compatible with single-axis tracking racking structures and supports. A TIN surface was created from the existing topography and clipped to surround the selected subarea. Using the previously calculated pond depth, a pond was created using the CAD Grading Creation tools and tied into the existing ground surface. A final merged surface was created to include the proposed grading, new pond, and the existing topography. Channels were also added centered between the rows of panels following the existing ground/proposed grading contours, although more detailed grading will likely be needed to implement these channels. A CAD plan set containing the overall site layout, basin design, design storm elevations, outlet protection specifications, and channel specifications will be provided by the design team.

Cost Estimation

An economic analysis was conducted using RSMeans online from Gordian, an industry-standard construction cost database. Only physical direct design differences between pre and post memo were considered; additional costs for labor were not considered in the economic analysis. Components that remained the same after the redesign were ignored. After obtaining unit cost estimates, a total project cost difference was calculated. Moreover, the quantity of energy needed to recoup additional costs was calculated, which was for the redesigned drainage area.

Results

Subarea Selection

Drainage area A06 was selected for this design project because previous civil engineering drawings included a detention basin and an area of 6.62 acres, which is slightly greater than the average Axton Phase 1 drainage area of 5.99 acres. All of drainage area A06 drains to a single detention basin. Subarea A06 is located on the northwestern portion of the Axton site and is located near the property boundary. There is also a stream to the west of the subarea where the finished detention outfall structure will connect.

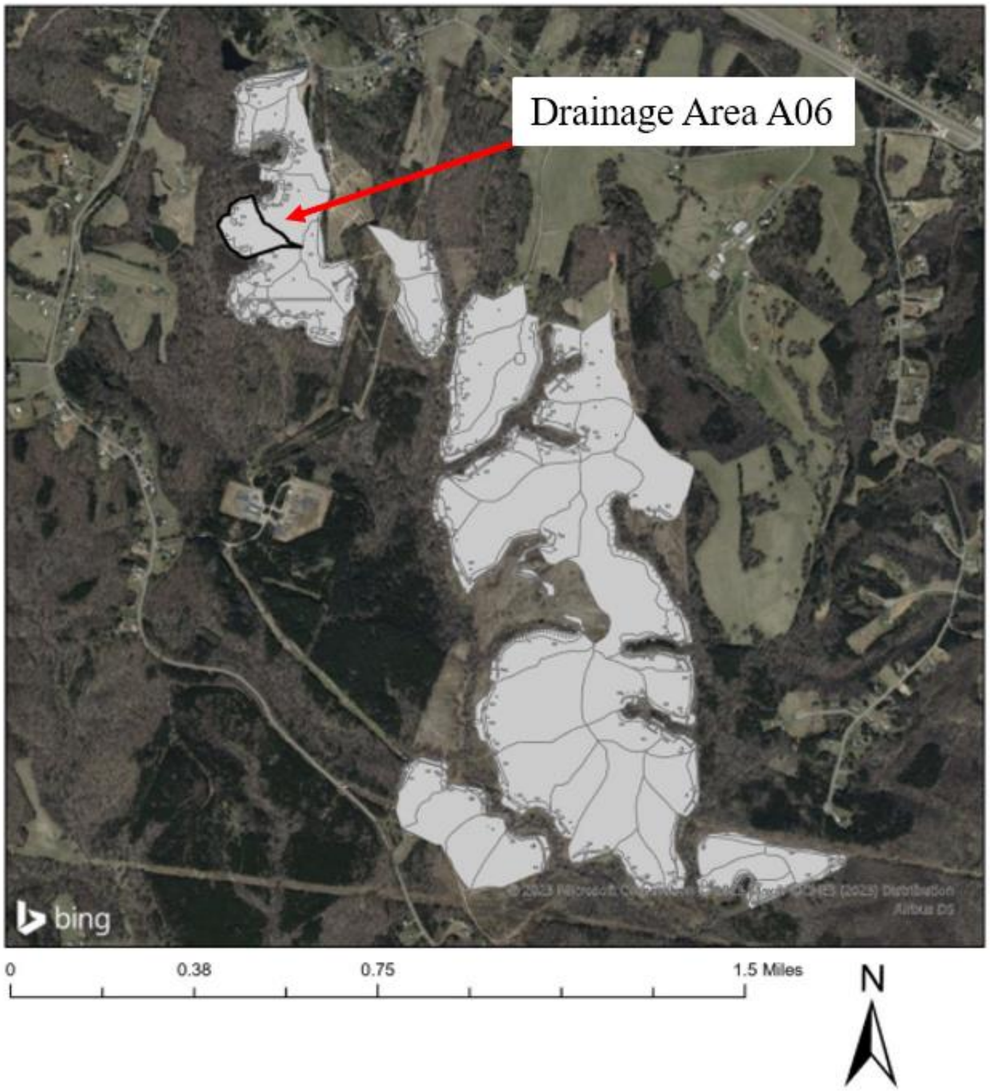

Figure 2. Location of Drainage Area A06 on Axton, VA Solar Site

Hydrologic Calculations

Drainage area A06 has an average pre-development site slope of 8.23%, an average post-development site slope of 9%, and an impervious surface area of 10.6%. Slope rasters are located in Appendix A. Impervious surface area for this site was adjusted to the horizontal projected area of panels, accommodating for the "stowing" capacity of the panels to rotate to their maximum 55-degree angle from horizontal during rain events; therefore, the area of the panels was calculated as the cosine of 55 degrees times the panel size. As for land characteristics, approximately 56% of drainage area A06 consists of HSG D soils and 44% HSG C soils. Based on these parameters, as input into the VRRM spreadsheet, a post-development curve number of 77 was calculated for drainage area A06, compared to a pre-development curve number of 55 ("VRRM New Development Spreadsheet," 2017). As predicted, this increase in the curve number results in an increase of sheet flow and volume of runoff in the drainage area. The increase in flow for the 2-year post-development site is about 15 times that of the pre-development site, necessitating considerable flow reduction. HEC-HMS hydrographs can be found in Appendix B and show the detailed impact of the curve number change on the peak flow rates.

Final Design

Stowing

Stowing is the practice of rotating panels to a "rain position" during a storm event. For the single-axis tracking panels specific to the Axton site, the maximum angle for the rotator shaft mechanism is 55 degrees from horizontal. Stowing practices can either be manually initiated or programmed with an on-site weather station to automatically stow panels when rainfall reaches a certain intensity. Panel stowing was used to move forward with all further design calculations, assuming a horizontal projection of impervious panel area in a rain storage position.

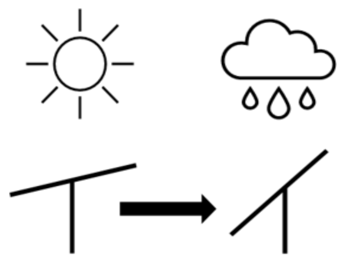

Figure 3. Panel Stowing Diagram

Extended Detention System

An extended detention basin was designed in the footprint of the original Kimley-Horn pre-regulation design. The stage-storage relationship provided for the A06 basin was extrapolated to determine the depth of the proposed basin would increase by 3 feet. Figure 4 shows the overall site layout, including the solar panel layout, detention pond location, and grass channel placement—additional grading or grading changes may be necessary for proper functioning of hydraulic structures, particularly with the proposed grass channels. More details regarding the extended detention system components are located in Appendix C.

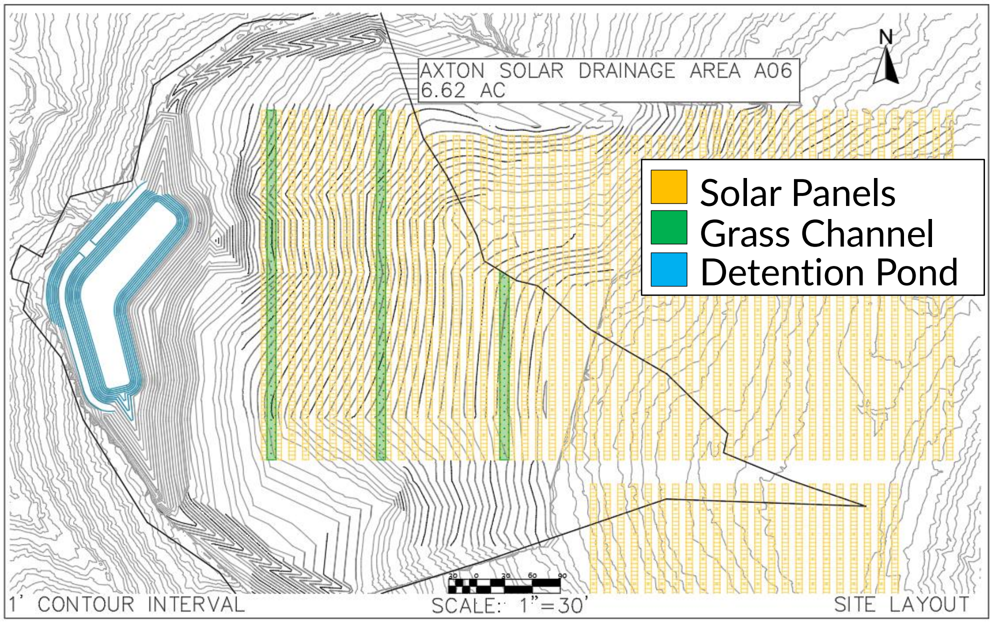

Figure 4. Site Overview

<u>Grass Channels</u>

To address TP reduction requirements—now required on the site, which was not the case under the old regulations—three grass channels were placed among the rows of solar panels. Panel post structures are located 14 feet apart, and the distance between panels at a completely horizontal angle is 8 feet. With a channel top width of approximately 10 feet, these channels sit between the solar panel racking structures without issue. The depth of about 1.2 feet is also feasible on the solar site, as the channels will not interfere with the solar system wiring, located an average of 3 feet below the ground surface. The channel cross section with dimensions is shown in Figure 5.

The site mainly consists of HSG C and D soil, attributed to having low infiltration rates. The channels were designed with compost amended soils to increase infiltration rates and reduce the total number of channels required to meet TP reduction criteria; grass channels with the existing HSG C and HSG D soils on site were considered, but there would need to be panels in nearly every row to meet the TP reduction requirement. Having channels between all the rows of panels would require constant maintenance, be a construction nightmare with lots of fine grading, and is not realistically feasible. Maintenance of the grass channels between panels is feasible with the site conditions. When flat, the solar panel edges are 8 feet apart and the racking structures for the panels sit 14 feet apart, which leaves enough space for machinery to move through the channel for frequent mowing. Results from the VRRM Spreadsheet, indicating water quality compliance, can be found in Appendix D.

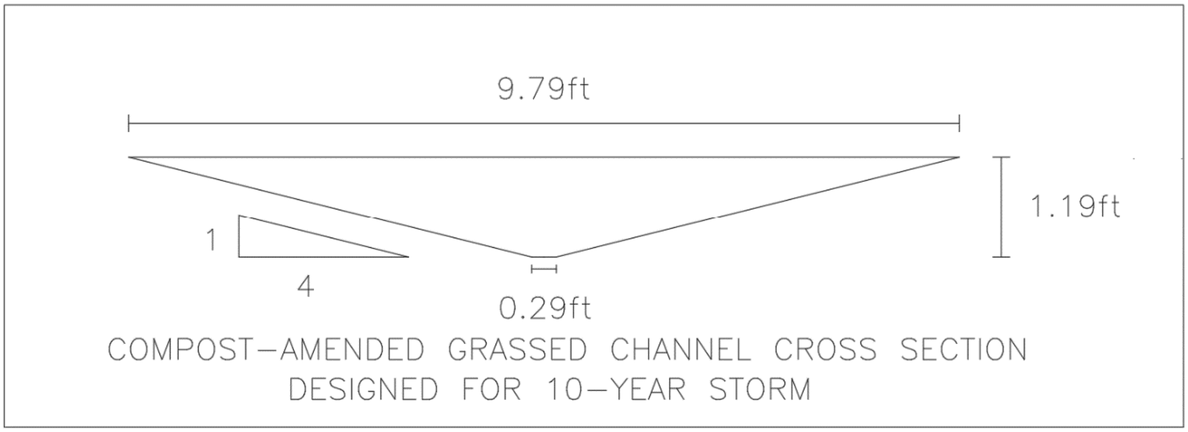

Figure 5. Compost-Amended Grass Channel Cross Section

Economic Analysis

An economic analysis was conducted to calculate the cost difference between the original Kimley-Horn design and the updated design compliant under the new policy. Only design components within the drainage area that changed after the policy change were calculated in the analysis: the cost difference of the policy change is more valuable than an entire site estimation for Energix, which has many utility-scale solar sites operating throughout the Virginia. The aspects of the design unaltered by the redesign were not included in the analysis. Additionally, the cost of stowing was not considered because the infrastructure for this behavioral BMP is already integrated into sites. The infrastructure that is used for single-axis tracking and maximum power generation is the infrastructure that would be used for stowing, which is already include on site. The only updates would be for automatic stowing, which consists of a program to set the panels to their 55 degree orientation based on inputs from the site's weather station. Since Energix's future sites will all include single-axis tracking systems, the cost of stowing is considered negligible in the overall cost of the stormwater system.

The analysis and associated unit prices were calculated through RSMeans online. The total cost difference was approximately $12,000 for the A06 drainage area. It is important to note that there are 21 total drainage areas on the Axton site; therefore, the total post-memo cost for Axton Phase 1 would be upwards $250,000 based on multiplying the cost of the improvements for drainage area A06 by the 21 Phase 1 drainage areas. This estimation does not include a time-cost analysis for design work nor any time-cost analysis for additional time needed for construction; however, these values are also predicted to increase. Figures 6 and 7 visualize the breakdown of the components. A detailed cost table, including unit prices, is located in Appendix E.

It should be noted that simply multiplying the cost estimate for A06 by 21 to determine a total site cost estimate is not precise due to the varying topography, panel coverage, and flow from one drainage area to the next. Thus, completing analysis of multiple drainage areas would be the best option for accurately representing the change in cost. For an accurate cost estimation for the Axton site, Phases 2 and 3, should be considered in addition to Phase 1 for future Energix projects.

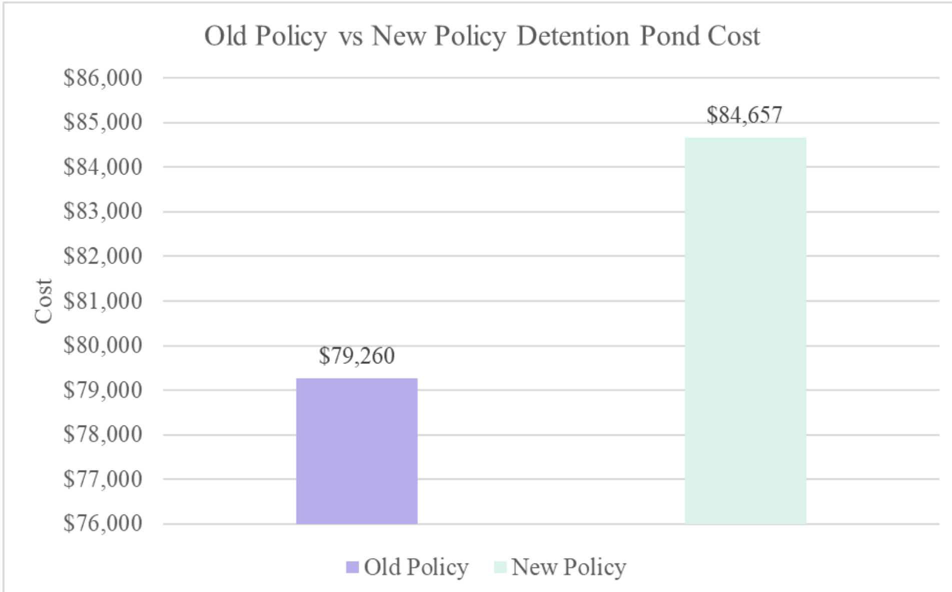

Figure 6. Detention Pond Cost Comparison

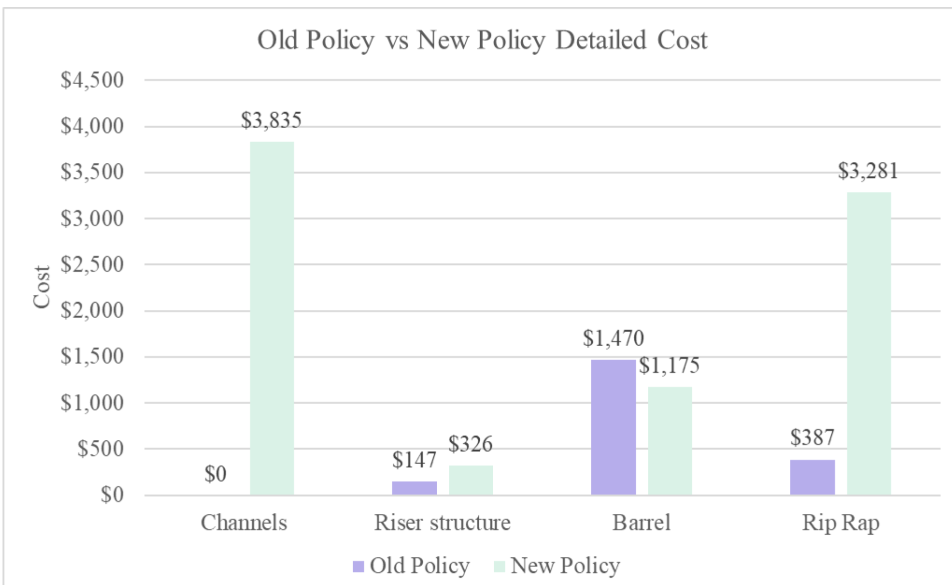

Figure 7. Detailed Cost Comparison

After calculating the cost differences, the cost was used to determine the quantity of energy needed to recoup the cost to illustrate the effect of this policy change on profit margins for the client. A power purchase agreement (PPA) of $45.66/MWh was used. The value reflects the average North American solar energy PPA price from the 2022 Quarter 4 LevelTen Energy PPA Price Index (LevelTen Energy, 2023)To recover the cost of the new stormwater system, Energix Renewables would need to produce 263,002 kWh of electricity. Likewise, this value is representative of the single drainage area used in the design. It is difficult to estimate a payback time for the generation of electricity, as output production from solar farms varies with demand and generation efficiency based on cloud cover.

Key Design Differences

Table 1 summarizes the key design differences between the original design by Kimley-Horn, compliant under the old regulations, and the updated design by the Red Watt Chili Peppers, compliant under the new regulations. The policy change required an increase in the size of many components of the design.

Table 1. Design Element Comparison

Design Element	Original Design	Updated Design	Units
Top-of-Embankment Elevation	917	920	ft
Inlet Dimensions	2 x 3	3.5 x 3.5	ft
Total Pond Volume	1.44	1.86	ac-ft
Area of Channels	0	7628	ft^2

Conclusions

The complete design package for drainage area A06 on Energix's Axton, VA site includes an extended detention basin, grass channels, and a behavioral BMP of stowing; the behavioral BMP of stowing was assumed for all water quantity and quality calculations. Specifications for stormwater BMPs on the Axton Solar site are designed for management of 2-year and 10-year 24-hour design storms, as well as emergency flood protection. Grass channels between panels are proposed to reduce runoff volume as well as satisfy the phosphorous-based water quality standards. For future Energix solar sites to be compliant with Virginia stormwater regulations, as well as economically profitable, a cost to implement and maintain stormwater management measures was estimated. The design for this drainage area is intended to aid Energix as new solar projects are designed to accommodate additional space for detention basins while generating a profit from electricity generation. Future work may include more design work on the Axton site to reflect the site-wide implications of the policy change. Additionally, investigating erosion and sediment control practices (ESC) for the construction phase of development could be beneficial to Energix to plan for additional construction costs. Solidifying the approach to automatic panel stowing systems would likely have the largest impact on the stormwater systems for solar sites of all investments in stormwater infrastructure; it is relatively inexpensive to code the automatic stowing system and can be applied to all site under Energix's jurisdiction. An Electrical and Computer Engineering senior design team at Virginia Tech has completed some preliminary design work for this system.

The final design and cost analysis from this project illustrates the impact that the March 2022 VADEQ memo will have on solar sites across the state of Virginia, including those operated and maintained by Energix Renewables. Resultant increase in impervious area equates to higher water storage and quality requirements, which requires stormwater infrastructure capable of managing higher flows. It is important to highlight the impact that stowing had on our design by limiting the impervious area in our calculations: without panel stowing, far more stormwater infrastructure is needed to meet required flows. A site without panel stowing would have more impervious area, which would require a larger infrastructure footprint and be more expensive. Panel stowing is highly recommended for all solar sites operating under the updated

DEQ regulations, regardless of the stormwater management approach used on a site-by site basis. Moreover, the additional upfront cost means the solar-energy-production industry in Virginia will be burdened when trying to make a profit. Ultimately, turning a profit is the bottom line for Energix Renewables and other solar energy companies. With the new regulations, solar companies across the state of Virginia will likely see profit margins tighten. Companies like Energix Renewables may decide to purchase more land up-front to help produce the required amount of energy, as well as account for larger pond surface areas. Depending on site location, land may be too expensive for this to be realistic.

Ultimately, solar sites and solar contracts in Virginia are dictated by the Virginia Clean Energy Act (VCEA) and Regional Transmission Organizations (RTOs); for this project, the RTO is PJM Interconnected. Solar site contracts are written with an agreement that a specific site will provide the grid with a certain output, generally given in Megawatts (MW). The DEQ policy change threatens site production outputs; with the updated stormwater infrastructure requiring a larger footprint, the footprint available for solar panels decreases, causing a decrease in site electricity output. According to industry professionals, the updated policy can cause up to 20% of utility-scale solar land to change from panels to stormwater infrastructure to meet the new stormwater management requirements: this would result in a 20% decrease in energy output from a site. For this particular drainage area, the total surface area covered by BMPs is only expected to increase by approximately 3.4%. However, this is not expected to be the case for all utility-scale sites contracted through PJM, as considerations such as panel coverage and slope make stormwater management compliance unique for every site. If this site is leasing a certain amount of land and cannot utilize the land effectively to meet the electrical output demands and the stormwater regulations from DEQ, the project may not be able to move forward. The threat of projects being killed by their inability to meet energy and stormwater requirements is the largest implication of this policy change: these threats are being felt by solar energy companies across the Commonwealth of Virginia (E. Ould & M. Short, personal communication, May 4, 2023).

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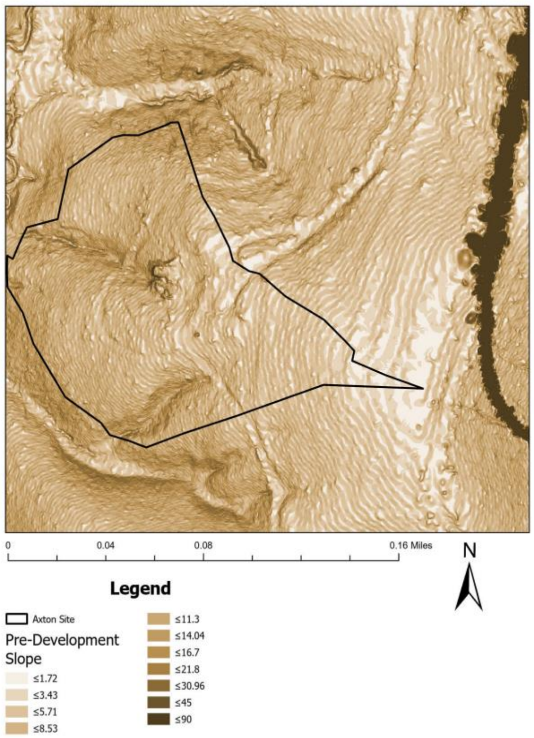
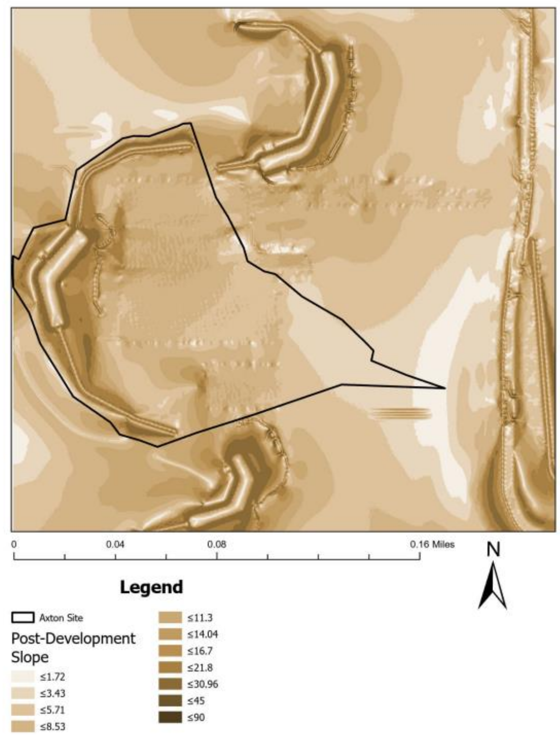
Appendices

Appendix A: GIS Maps of Pre-Development and Post-Development Site Topography





Figures A1 and A2. Pre-Development and Post-Development GIS Maps

Appendix B: HEC-HMS Hydrograph Outputs

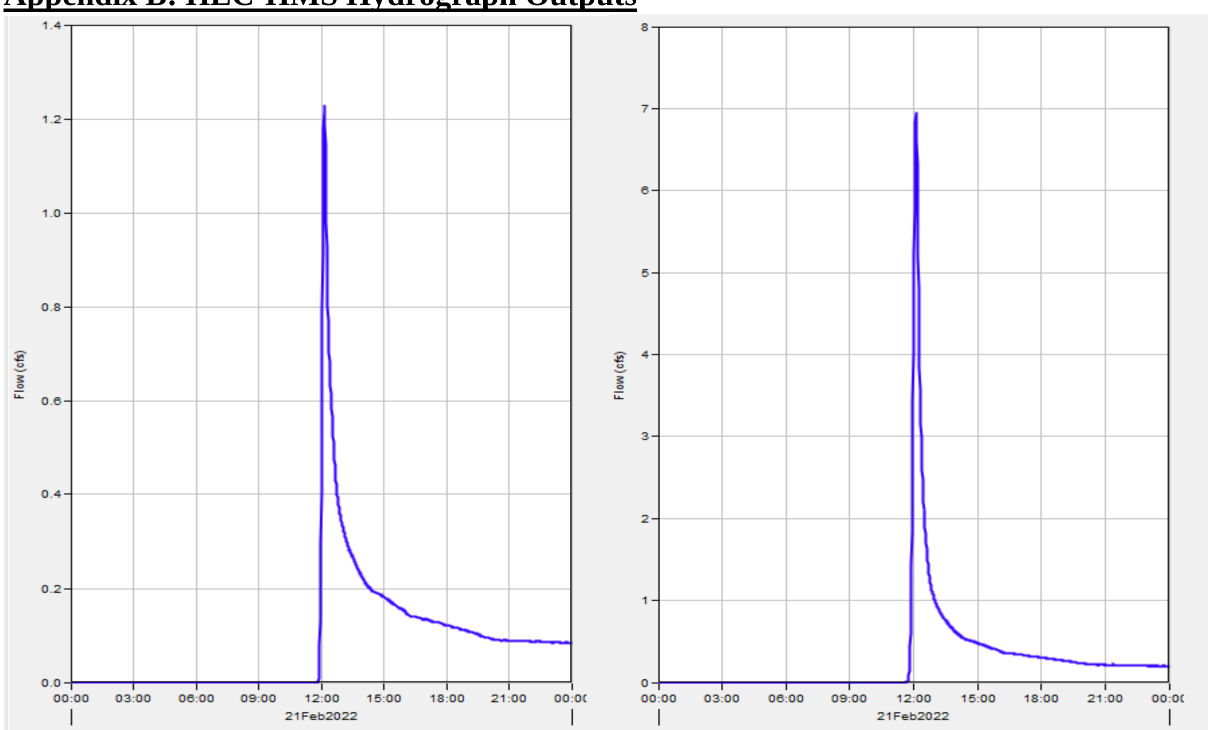


Figure B1. 2-year and 10-year storm hydrographs pre-development

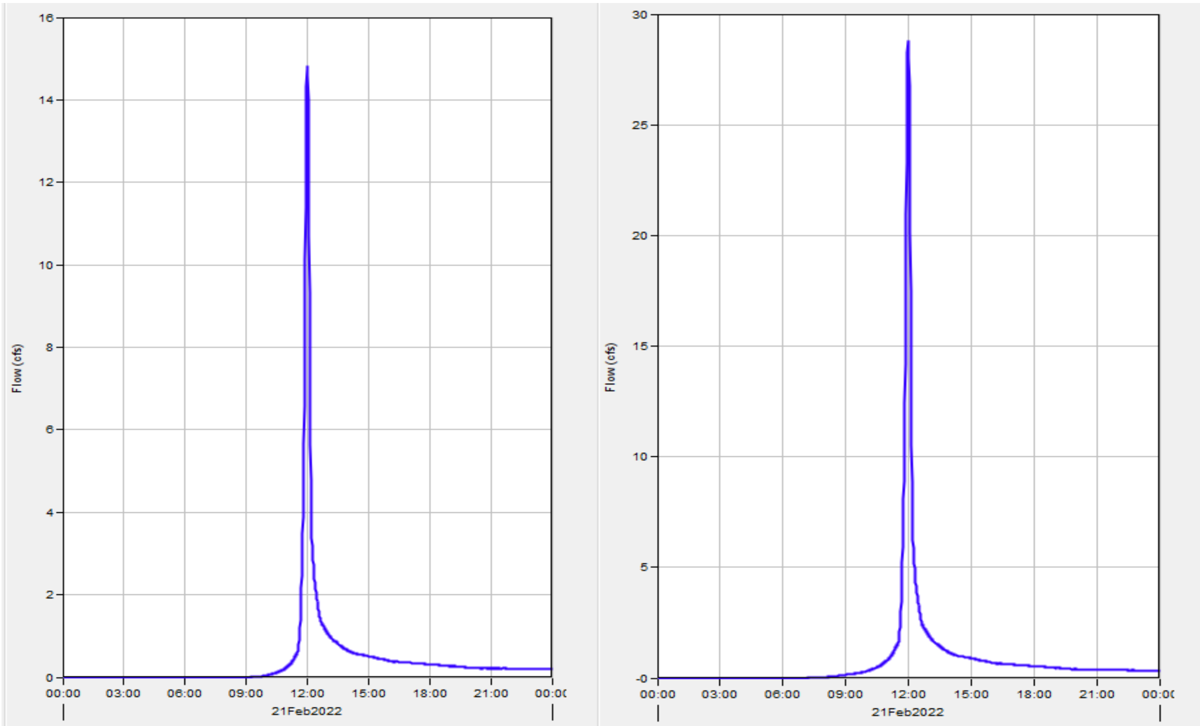


Figure B2. 2-year and 10-year storm hydrographs post-development

Appendix C: Additional CAD Design Specifications

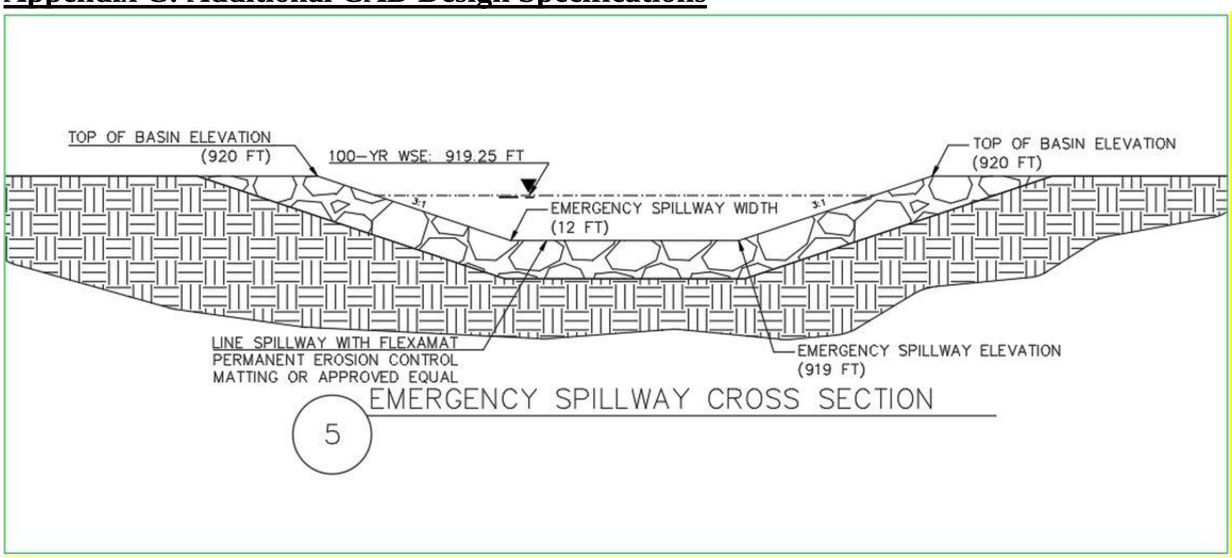


Figure C1. Emergency spillway design

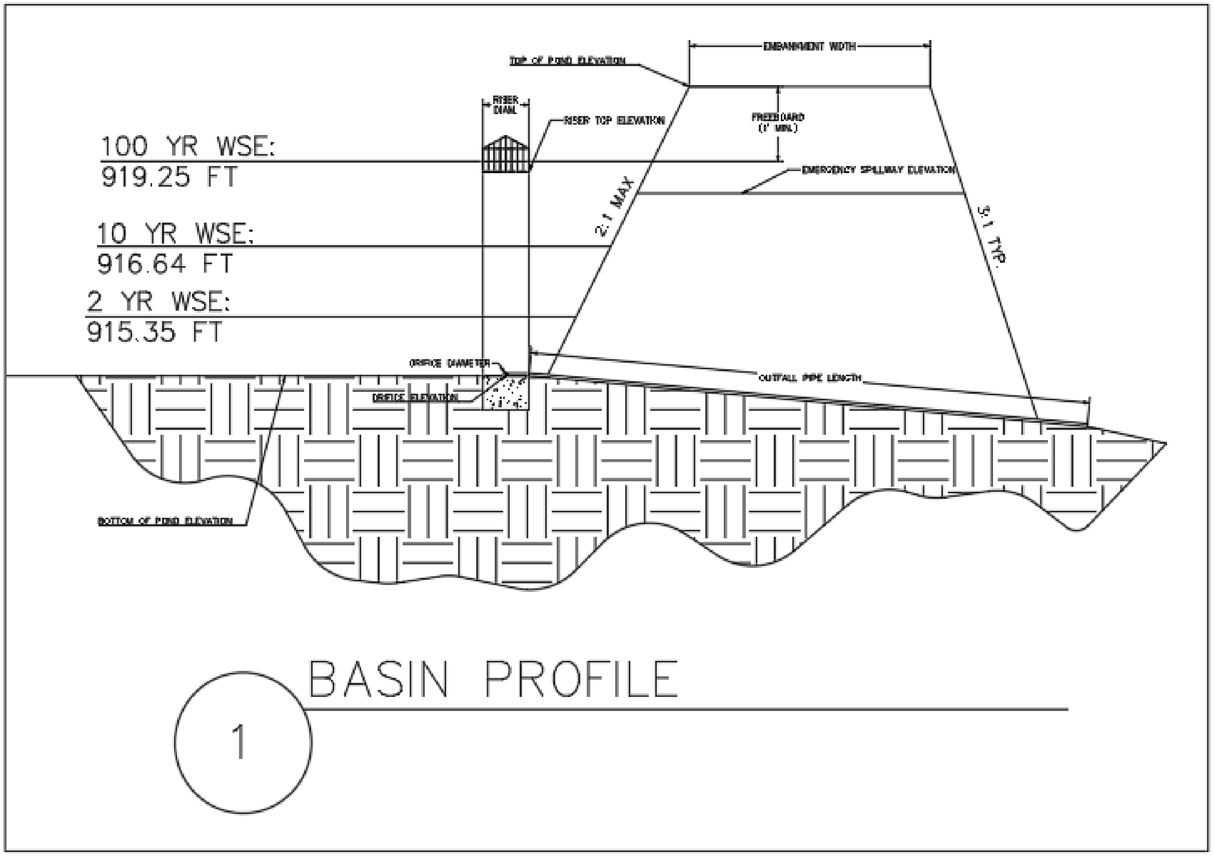


Figure C2. Outlet structure and basin profile with 2-, 10-, and 100-year water surface elevations

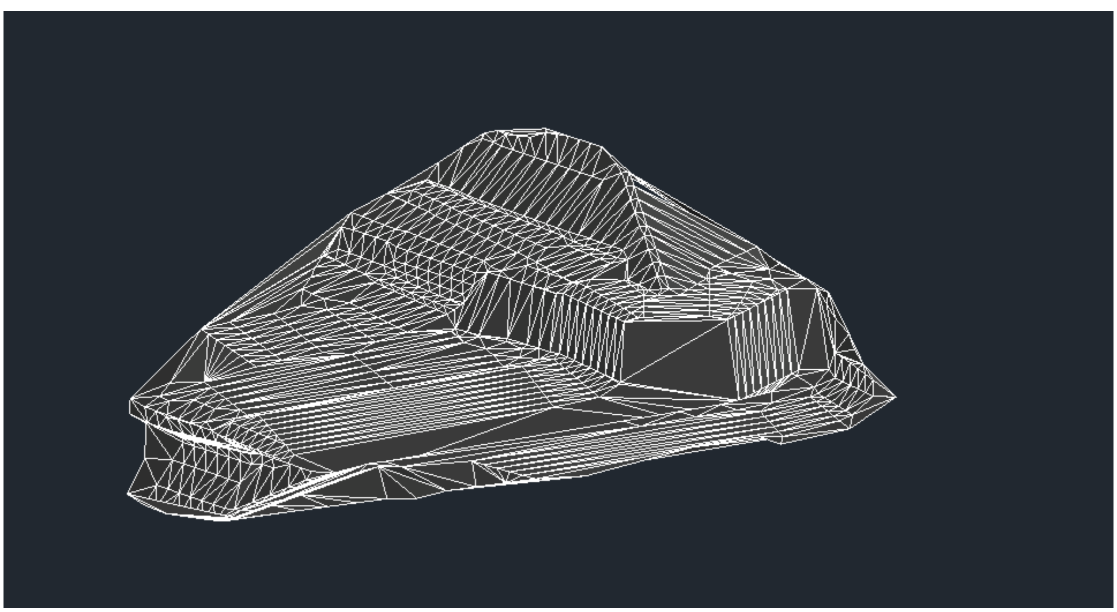


Figure C3. 3D representation of extended detention pond

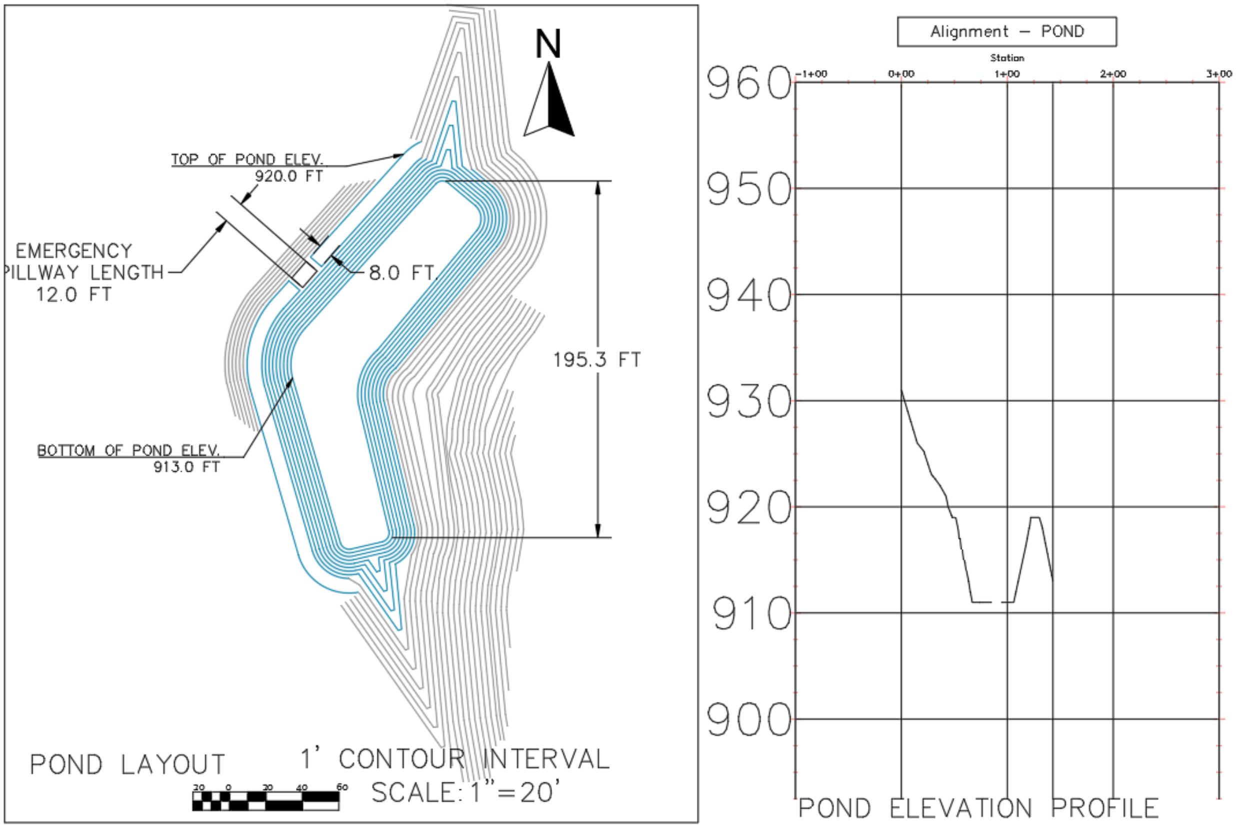


Figure C4. Extended detention pond specifications and alignment profile

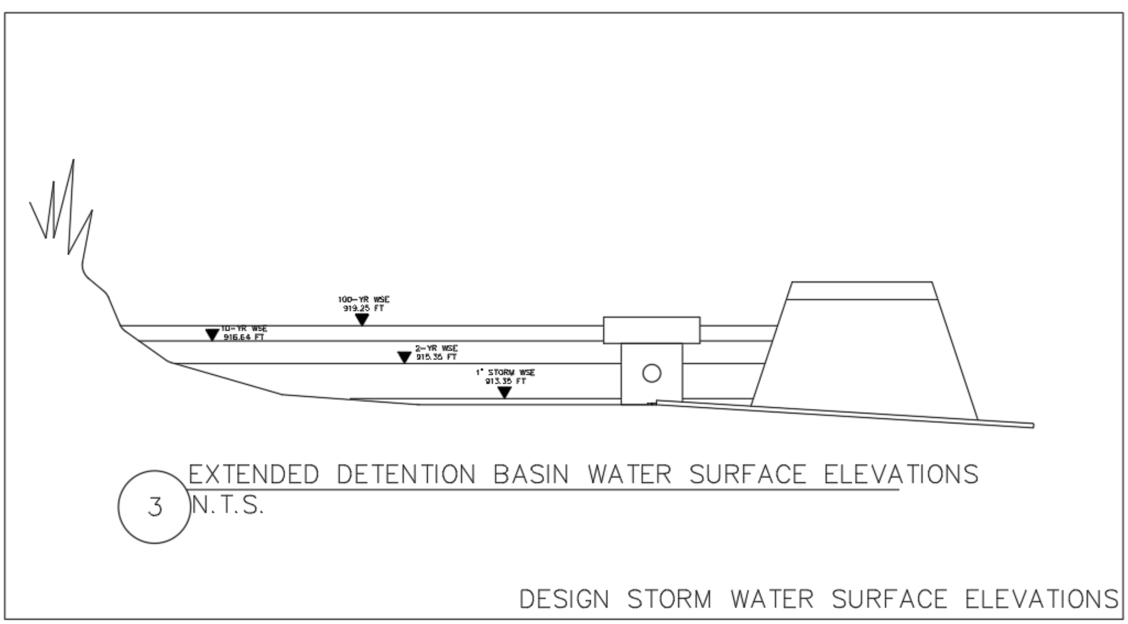


Figure C5. Pond profile and water surface elevations

Appendix D. Virginia Runoff Reduction Method Spreadsheet

Total Phosphorus	
FINAL POST-DEVELOPMENT TP LOAD (lb/yr)	4.58
TP LOAD REDUCTION REQUIRED (lb/yr)	1.87
TP LOAD REDUCTION ACHIEVED (lb/yr)	1.91
TP LOAD REMAINING (lb/yr):	2.67
REMAINING TP LOAD REDUCTION REQUIRED (lb/yr):	0.00 **

** TARGET TP REDUCTION EXCEEDED BY 0.05 LB/YEAR **

Total Nitrogen (For Information Purposes)	
POST-DEVELOPMENT LOAD (lb/yr)	32.76
NITROGEN LOAD REDUCTION ACHIEVED (lb/yr)	13.75
REMAINING POST-DEVELOPMENT NITROGEN LOAD (lb/yr)	19.01

Figure D1. VRRM "Water Quality Compliance" Tab

Post-Development Project (Treatment Volume and Loads)

Land Cover (acres)

	A Soils	B Soils	C Soils	D Soils	Totals
Forest/Open Space (acres) -- undisturbed, protected forest/open space or reforested land			0.02	0.34	0.36 *
Managed Turf (acres) -- disturbed, graded for yards or other turf to be mowed/managed			2.26	3.29	5.55
Impervious Cover (acres)			0.63	0.08	0.71
					6.62

** Forest/Open Space areas must be protected in accordance with the Virginia Runoff Reduction Method*

Figure D2. VRRM Site Land Cover Inputs

Appendix E. New Policy Cost Estimation

Table E1. Detailed New Policy Cost Estimate

Item	Quantity	Unit	Cost (USD)
Concrete Riser	1.863	ton	146.61
RCP Barrel 18 in	54	ft	1469.88
Channel Sod	0	sf	0
Channel Watering	0	sf	0
Channel Mowing	0	mi	0
Cut	36749	bcy	76437.92
Fill	3282	lcy	2822.52
Check Dam	0	lcy	0
Riprap outlet	6	lcy	387.48

Table E2. Detailed Old-Policy Cost Estimate

Item	Quantity	Unit	Cost (USD)
Concrete riser	4.13	ton	325.53
RCP Barrel 12 in	54	ft	1175.04
Channel Sod	7627.76	sf	3792.34
Channel Watering	7627.76	sf	25.26
Channel Mowing	0.143	mi	17.08
Cut	39304	bcy	81752.32
Fill	3377	lcy	2904.22
Check Dam	47.25	lcy	3051.41
Riprap outlet	3.56	lcy	229.9

Unit prices obtained from RSMeans