Chapter Two: Methods and Results

2.1 Study Objective

Once the stream restoration candidates were selected, Henrico County identified the need to further analyze the streams to prioritize potential stream restoration projects in terms of restoration opportunities and feasibility constraints. The specific objective of this study is to develop a way to score the Reynolds study streams as potential restoration projects. This will provide the county with a documented, consistent and progressive decision support tool as they develop a body of stream restoration project work.

This is accomplished through the establishment of a theoretical potential restoration state, the identification and assessment of evaluation criteria, and the creation of a prioritization tool. The following sections present the development of the project methodology and its application to a pilot subwatershed containing nine of the Reynolds study streams (Appendix A).

2.2 Urban Stream Restoration

The term restoration has been used to describe a wide variety range of environmental practices. The National Research Council definition is perhaps the most well known and states that “restoration is the complete structural and functional return of a biophysical system to its predisturbance state” (Rhoads et al 1999). Returning an ecosystem to a predisturbance state is a worthwhile goal but one must recognize that, “restoration is not yet a perfected approach with accurate and precise predictive capabilities and, in fact, is still…an exercise in approximation” (Cairns 1991).

Restoring urban streams to a predisturbance state is typically not achievable because the watershed is permanently altered and cannot be restored to a predisturbance state (Riley 1998). In addition there are a number of social, institutional and infrastructure constraints to restoration in the urban environment (Moses and Gorman 1997a-b). Urban stream restoration “is really a compromise, something short of complete control and yet certainly better than doing nothing” (Keller and Hoffman 1977).

Urban stream restoration is actually more like “rehabilitation” in that it attempts to restore multiple environmental values and as much environmental health and integrity as possible (Moses and Gorman 1997a). The goal is the emulation of a “a natural, functioning, self regulating system that is integrated with the ecological landscape in which it occurs” (EPA 2000). This is accomplished through the establishment of a sustainable, morphological and hydraulically varied, dynamic fluvial system that is capable of supporting aquatic ecosystems (Rhoades 1999). In essence, urban stream restoration attempts to return structure, functions, and dynamics to the maximum extent possible given the constraints of our modern developed landscape (Riley 1998).

2.3 The Reference Reach Approach

A widely advocated method in the field of stream restoration design is the reference reach approach developed by Dave Rosgen of Wildland Hydrology (1996a). In this method, a morphological survey is conducted on a high quality reference reach and dimensionless morphological relationships are developed to guide the restoration design for the impaired stream (Rosgen 2001).

While this method is in vogue it has limited applicability in urban settings because urban watersheds are highly altered or subject to future alterations and no longer function like natural drainage basins (Moses and Morris 1998a). In addition, it can be hard to find a suitable reference stream within highly urbanized watersheds given the high level of degradation of the stream network. Typically, a reference reach is found in a less developed watershed and then applied to an urban stream (Harman 2001).

Applying stream morphology from a less developed watershed to an urban watershed is a major shortcoming of this method because the hydrology and sediment regimes, and therefore channel geometry developed under natural conditions in the reference reach, do not apply (Moses and Morris 1998b). This has led to catastrophic project failure in some instances (Schlindwien 2002) and design approaches based largely on reference river patterns and processes are rarely successful when applied in urban areas (Moses and Morris 1998b).

Furthermore, in terms of the utilization of the Rosgen method for this particular study, Henrico's physiographic location on the fall line between the Piedmont and Coastal Plain provinces results in three fundamentally different stream conditions. A generalization can be made that streams within the James River Basin are Piedmont (gravel-bed streams) and that streams within the Chicahominy River Basin are Coastal Plain (sand-bed streams). A third category of streams exists in Henrico County that can be characterized as "fall line" or "gravel-sand" streams. This third stream type exhibits characteristics of both Piedmont and Coastal Plain systems.

Given the state of urbanization in Henrico County, reference reaches, if they could be found, would have to be developed for the Piedmont, Coastal Plain, and "fall-line" streams at a minimum (Schlindwien 2002). Most of the better scoring streams included in the county wide stream assessment are in the Chicahominy River Basin and are Coastal Plain streams (CH2MHill 2000). Piedmont and "fall line" reference streams would most likely not be located in the county and therefore would not be as representative of Henrico County stream conditions.

2.4 The Potential Reference State

For these reasons, the widely accepted reference reach approach is impractical for use in this study. This researcher proposes that it is more practical to develop a theoretical restoration state that can be applied to all stream systems and therefore is applicable to the entire county. The restoration state is based on the fundamental idea that a restored stream in Henrico County should, to the maximum extent practicable, realize the functions and values associated with a natural healthy stream system within the constraints of the urban environment.

A review and synthesis of the existing literature on the functions and values of streams and the goals and objectives of stream restoration (Kondolf and Micheli 1995, Riley 1998, Ferguson 1991, USDA 1998) was used to develop a set of standards for a stream to be considered restored as a part of Henrico County's watershed program. The potential restoration state requires, to the maximum extent practicable, that a restored stream must:

1. Neither significantly aggrade or degrade its bed and erode its banks and display pattern, dimension, and profile consistent with natural stable channel morphology and exhibit a hydrologic connection to a functional floodplain.

2. Have a functioning forested riparian buffer at a minimum width of 25' for intermittent streams and 50' for perennial streams from the top of both stream banks.

3. Employ innovative stormwater management techniques such as pocket wetlands, energy dissipaters, and infiltration and filtering BMP's to address the water quality issues associated with the pipes, ditches, and other untreated discharges present along the stream.

The following sections describe the development of the above three conditions and place them in the context of the literature and prevailing professional practice in the field of stream restoration:

Neither significantly aggrade or degrade its bed and erode its banks and display pattern, dimension, and profile consistent with natural stable channel morphology and exhibit a hydrologic connection to a functional floodplain.

Natural streams are understood to have achieved or be approaching a state of *dynamic equilibrium*. The term *dynamic* reflects that streams do not exist in a steady state for any appreciable period of time. Streams balance sediment discharge and particle size with stream flow and stream slope. When a stream's sediment supply and stream flow are in balance it is said to be stable and in a state of *equilibrium* (Heede1986).

This concept was first articulated by Lane in the 1950's and is presented graphically in the Lane's balance diagram (Figure 1). Dynamic equilibrium is portrayed as a scale with the sediment variables on one side and the stream flow variables on the other (USDA 1998, Riley 1998). The Lanes balance diagram provides the basis for the fundamental axiom of geomorphology. Geomorphology is based on theory that stream channel form expressed via cross section size and shape, plan-form geometry and profile are more or less adjusted to discharge and sediment regime and the nature of channel bed and bank materials (Moses and Morris1998b). Geomorphic processes form the foundation for stream restoration analysis and design (USDA 1998). Often the goal of stream restoration is to restore the stream to a state of dynamic equilibrium utilizing the principles of geomorphology (Ferguson 1991, Kondolf 1996, Riley 1998).

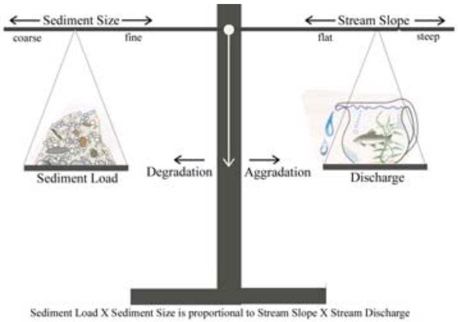

Figure 1: Lanes Balance Diagram (Adapted from Rosgen 1996(a)

The Lane's balance diagram sums up stream adjustment processes in a dichotomous model. This dichotomy predicts that streams are either degrading or aggrading in response to changes in the balance of dynamic equilibrium. Aggrading and degrading streams represent the two types of unstable urban streams (Riley 1998). Both degradation and aggradation continue until the stream has reached a balance between stream flow and sediment supply. This is expressed morphologically in a more stable plan, profile and/or cross-section depending on the specific adjustment processes that occur (Heede 1992, USDA 1998, Riley 1998).

Streams that have an excess of sediment compared to flow adjust by aggradation. Some sections can't carry the excess and deposit it in the stream bed and floodplain (Ferguson 1991). This initiates stream aggradation. At best, a new low flow channel forms within the sediment in the streambed and the stream is able to maintain a new equilibrium state (Riley 1998).

However, if the sediment increase is too dramatic, severe impacts to the stream system can occur. Possible results include channel braiding or formation of secondary channels and an increase in the frequency of overbank flows. This lowers the flood conveyance capacity of the channel and therefore increases the flood risk potential (Moses and Gorman 1997b). Erosion and scour of the floodplain and formation of secondary and multi-channeled systems are typical in aggraded stream reaches (Harman 2001)

In addition, the pool and riffle structure of the stream bottom is obliterated resulting in a loss of aquatic habitat structure and function. This can correspond with a reduction of aquatic productivity and species diversity (Ferguson 1991). Low gradient urban stream reaches are especially prone to aggradation in response to an elevated sediment supply. (Riley 1998)

Aggradation often occurs in urbanizing watersheds due to shortcomings in erosion and sediment control practices. This period of aggradation may last for up to ten years (Riley 1998). Road crossings also initiate stream aggradation, especially in lower gradient streams. Stream crossings sized down with culverts and bridges can't effectively pass higher flood flows. Undersized culverts commonly produce backwater effects and initiate channel sedimentation. Only if crossing is very generously sized does it not accumulate sediment and contribute to backwater conditions (Moses and Morris 1998a).

Streams that have an excess of flow compared to sediment adjust by degradation. Degradation can be a response to channelization, changes in land use, or lowering of base level (Harvey and Watson 1986). As impervious surface is established in urban systems, the watershed typically delivers higher frequency and magnitude flow events to the stream (USDA 1998). As the hydraulic capacity of the channel increases it experiences an excess of sediment transport capacity over sediment supply. This process initiates channel degradation (Harvey and Watson 1986).

Degradation usually begins with erosion of the stream bed. The stream attempts to achieve a gentler net slope and therefore a lower sediment transport capacity (Harvey and Watson 1986). This may also take place through plan form adjustments as the stream increases its meanders via bank erosion to add to its total stream length and therefore achieve a gentler net slope (Heede 1992). If streambed degradation is the primary adjustment mechanism this results in steeper and taller steam banks and the decoupling of the stream from its hydrologic floodplain (Riley 1998).

The combination of confined flood flows and over-steepened banks leads to more erosion and accelerated bank collapse, and erosion ensues (USDA 1998). This leads to channel enlargement as the stream develops a deeper and wider cross section (Harvey and Watson 1986). The rapid erosive flow is confined within the enlarged channel and the stream becomes functionally decoupled from its floodplain (Moses and Morris 1998b).

Enlargement can be gradual with proportional increases in width and depth, or can occur as rapid deepening disproportionate to the rate of increase in flow and width. This represents stream channel incision. Streams with relatively steep slopes and less cohesive substrates are more susceptible to incision. Widening continues until a new equilibrium is achieved (Heade 1992). Typically a meandering shallow low flow channel forms in the stream bank material that has deposited in the over widened cross section. The new channel has a stable slope for the new equilibrium conditions (USDA 1998). Catastrophic incision can be a major problem (Ferguson 1991). Impacts of degradation/incision include destruction of aquatic habitat, dewatering of riparian zones, undercutting of instream and streamside infrastructure, and loss of streamside land (Ferguson 1991).

A basis and fundamental goal of stream restoration efforts in Henrico County should be the return of aggrading and degrading streams systems to a more stable state. This state should resemble a natural system in terms of function and structure to the maximum extent practicable. This should be expressed through improvements to channel geomorphology that address plan, cross section, and profile to provide for a stream that is in a state of dynamic equilibrium.

Have a functioning forested riparian buffer at a minimum width of 50' from the top of both stream banks.

The riparian ecosystem is the transitional area between the stream and the adjacent upland land area. It is typically defined by soil characteristics and/or a distinct vegetative community associated with a higher water table and/or a flood driven hydrologic regime (Bureau of Land Management 1998). The riparian zone associated with a stream serves the primary functions of stabilizing stream banks and preventing erosion, filtering sediment, nutrients, and other pollutants delivered in runoff from the watershed, and moderating in-stream microclimate (USACE 1991). Forested riparian buffers are permanent areas of woody vegetation adjacent to streams that are managed to maintain the integrity of stream channels and to reduce the impacts of upland sources of pollution (Klapproth 1999).

In urban stream corridors, a wide forested buffer provides physical protection of the stream channel from future disturbance or encroachment (USDA 1998). In addition, urban forested buffers as narrow as 20' can significantly contribute to water quality (Riley 1998). Established riparian buffers also provide important structural qualities that retard and prevent stream bank erosion (EPA 2000)

Re-establishing a forested riparian buffer should be an integral component of any stream restoration project. In urban areas, riparian buffers are often cleared and maintained as lawn as part of the development process. In addition, stream degradation can cause the loss of streamside trees as a consequence of channel enlargement (Ferguson 1991). Channel aggradation can affect the forested buffer area by depositing sediment that reduces oxygen supply to roots and increasing flooding hydrology, which can alter species composition.

A significant body of literature and robust debate exists over the extent, width, and composition of forested riparian buffers (Cacho 1992, Wenger 1999, Johnson and Ryba 1992) and a number of planning and design resources are available (Fischer and Martin 1999, Herson-Jones, et al 1995, Osborne and Kovacic 1993, CBLAD 1991). These references provide a level of detail that is beyond the needs of this study.

A review of the programs that require forested riparian buffers including the Resource Protection Area (RPA) requirements set forth in the Chesapeake Bay

Act, revealed that all require a fixed width buffer. This is in contrast to the prevailing preference in the literature for variable width forested riparian buffer planning. This debate has and will continue and centers on the state of the science versus the practicality of instituting regulations and requirements and is beyond the scope of this study. For the purposes of Henrico's watershed program a stream will be considered restored if it, at a minimum, provides a 50' forested buffer on both sides of the stream. This is a stated requirement for most streams under the Henrico County Environmental Program Manual (2001). Henrico County is not currently interested in pursuing a variable buffer width program (White 2001).

Employ innovative stormwater management techniques such as pocket wetlands, energy dissipaters, and infiltration and filtering best management practices to address the water quality issues associated with the pipes, ditches, and other untreated discharges present along the stream.

The previous two "restoration state" conditions address the structure and function of the stream corridor. However, restoration cannot just focus on the correction of instream impacts. Restoration must also address the stressors that altered watershed conditions place on the stream. Instream, riparian, and floodplain restoration techniques may fail if not considered in conjunction with stormwater management techniques since urban streams receive and convey stormwater from developing and developed watershed and therefore inherently interact with stormwater management programs (Ferguson 1991 and Keller and Hoffman 1977). Incorporating innovative stormwater techniques recognizes that the health and protection of the waterbody cannot be separated from watershed (EPA 2000).

Stormwater management is accomplished in three primary ways. The first is through conveyance. The primary goal of conveyance is moving runoff quickly from its point of origin to a discharge point using a pipe, gutter, ditch or swale. Until 1965 this was the only form of stormwater management used in this country (Ferguson 1998). The discharge point for conveyance is often a stream. These discharges add to the overall increase of flow magnitude and frequency and may have unstable and eroding outfalls and provide a transport/delivery mechanism for pollutants.

The second is detention/retention. Detention/retention provides temporary or permanent water storage typically in the form of a pond. The goal is the storage of pollutants by settling and a decrease in the frequency and magnitude of storm discharges to the stream network (Ferguson 1998) Stormwater ponds are the primary component of most municipal stormwater management programs in Virginia (Gavin 1999) and have been a common component of stormwater management since the 1970's (Ferguson 1991). However, the actual effectiveness of stormwater ponds is a matter of debate.

Stormwater ponds are designed to store all or portions of certain frequency storm and therefore are not based on actual rainfall and do not mimic natural watershed function (Ferguson 1991). Because stormwater ponds are designed to pass all flows above the design storage capacity and are not modeled at a watershed level using subcatchment routing, they may actually increase the peak frequency and magnitude of some larger storm events (Bork 1999). In addition, ponds settle out sediments and deliver “clear” or “hungry” erosive water that can erode the channel erode the channel and drive degradational processes (Ferguson 1991).

Infiltration based stormwater management techniques seek to replicate the natural hydrologic cycle of undeveloped landscapes (Riley 1998) and are a critical component of Low Impact Development strategies. Water is allowed to filter into the ground at or near its point of origin as runoff in the landscape (Sweet et al 2000). Infiltration techniques are considered microscale stormwater management and typically occur at the site scale (Prince George’s County 2000). Bioretention areas, or rain gardens, and bioswales are the most common infiltration best management practices and a number of resources concerning their planning and design are available (Richman et al 1999, Prince Georges County 2000, Engineering Technologies Associates and Biohabitats Inc. 1993).

The Henrico County Stream Assessment/Watershed Management program was developed in response to concerns about the overall effectiveness of approximately 500 onsite BMPS built in the county between 1991 and 2000 (Perry and White 2002). The program addresses detention/retention and infiltration stormwater management by requiring an onsite BMP depending on the proposed site’s watershed management designation, percent imperviousness, and nutrient removal requirements. If an onsite BMP is not required, a cash proffer is generally made to the County’s Environmental Fund based on $8,000 per pound of phosphorus the site is modeled to produce. These monies are used to fund regional stormwater BMP’s, regional online and offline constructed wetlands, and stream restoration, stabilization and obstruction removal efforts on a watershed basis (County of Henrico 2001).

The program also requires an energy dissipation device at all concentrated pipe or channel stormwater discharges to the stream channel. The dissipaters reduce velocities and deliver stormwater as sheet flow to the stream and therefore provide a progressive “adequate outfall” approach to conveyance based stormwater management (County of Henrico 2001).

However, the countywide stream assessment study inventoried numerous existing pipes and ditches discharging stormwater directly into streams that were not designed to provide adequate outfall. These present retrofit opportunities not currently incorporated in the Henrico County Environmental Program. This study proposes that for a stream to be restored as a part of the County’s environmental program that retrofits be made to existing concentrated discharges with innovative energy dissipation devices and filtering and infiltration best management practices.

2.5 Restoration Opportunities Criteria

Once the potential restoration state was developed, meetings were held with Henrico County staff to evaluate and develop methods that could be incorporated into criteria to score the streams in terms of their restoration potential or departure from the potential restoration state. Restoration opportunities criteria identified for inclusion in the study are:

- Channel stability
- Stream bank erosion rate
- Riparian forested buffers
- Stormwater discharges

Channel Stability

While many aspects of the stream system were addressed in work preceding this project, channel stability was not assessed. Channel stability assessment attempts to determine how far a stream has departed from a stable state. A stable channel balances its sediment supply and flow regime in a state of dynamic equilibrium and does not significantly degrade or aggrade its bed and has a connection to a hydrologic floodplain.

A review of existing methods for assessing channel stability was conducted and evaluated in terms of its applicability to the range of conditions present in Henrico County’s stream systems. Meetings were held with county staff and it was determined that there was no single and broadly applicable method to assess overall channel stability for the purposes of this study. It was decided that a new stability assessment would be developed for us in this study that was a blend of three existing models and methods. The models incorporated into the assessment tool are the Proper Functioning Condition (PFC) protocol, the Channel Evolution Model (CEM), and the Rosgen Stream Classification/Stability Assessment method.

The PFC protocol was developed by the Bureau of Land Management’s Proper Functioning Condition Work Group, originally published in 1993 and revised in 1995 and 1998. The protocol represents an interdisciplinary approach to understanding the level of functioning of riparian wetland complexes by assessing hydro-geomorphologic, vegetative, erosional and depositional, soil, and water quality attributes (Bureau of Land Management 1998). The assessment results in the placement of the system in question into one of three categories: proper functioning condition, functional-at-risk, or nonfunctional.

Riparian wetland complexes that are assessed as *proper functioning condition* systems display hydrologic, vegetative, and erosional attributes associated with high functioning and stable systems. Systems that are *functional-at risk* are in functioning condition but an assessed attribute or attributes makes the system susceptible to future loss of function. *Nonfunctional systems* do not display attributes that are associated with healthy systems (Rosenlieb et al 2002).

The PFC was developed and has been applied primarily to riparian-wetland complexes in the Western United States in non-urban environments. In this sense it is not applicable to the range of conditions present in Henrico County's stream corridors. However, several of the streams assessed were aggradational stream-wetland complexes. Including elements of the PFC provided a means to assess these streams.

The Channel Evolution Model (CEM) presents a series of five sequential stages that a stream passes through as it down cuts or incises, widens, aggrades, and eventually reestablishes a new floodplain and stable channel in a new valley (USDA 1998). The model is a "space for time substitution" and a "space-time analogue" (Harvey and Watson 1986). Any given stream corridor may display all five stages in the CEM along the stream corridor at a singular moment in time. At any given location in an incising stream corridor, incision is initiated in the first stage with later stages flowing in succession (Figure 2). Downstream reaches are in later stages of the sequence and upstream reaches are in earlier stages of the sequence (Harvey and Watson 1986).

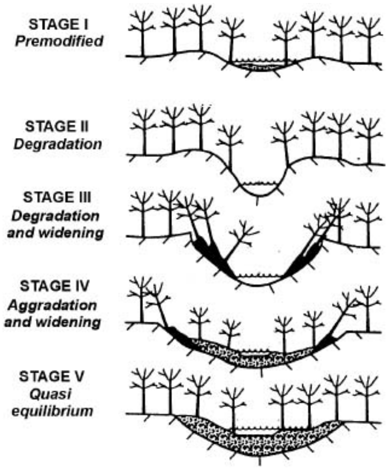

Figure 2: The Channel Evolution Model (Adapted from Simon and Hupp 1986)

This is because channel incision migrates upstream in the form of an active headcut. A headcut is a steep and erosive vertical change in elevation in the streambed. The headcut continues eroding the streambed in an upstream direction until the stream encounters a fixed bed element called a knickpoint that it cannot erode under or around or it cuts the entire streambed down to the underlying bedrock. Knickpoints can be large boulders, bedrock outcroppings, or urban areas culverts at the crossings with major roads (Heade 1992).

The CEM was incorporated because urban streams are particularly susceptible to incision. Many of the most impacted streams in Henrico County display evidence of present or historic incision. The CEM compliments the use of the PFC by providing a means to assess degrading streams.

Rosgen's stream classification system places streams in one of 7 major stream types based on the measurement of four major geomorphic variables (Rosgen 1996a). The development and use of the Rosgen classification system continues to be a source of much debate in the literature and amongst practitioners (Gilligan 1996, Goodwin 1999a, Goodwin1999b, Miller and Ritter 1996, Rosgen1996b). However, there is a general consensus that stream types provide a useful communications tool at the planning level (USDA 1998).

While stream classification in and of itself does not provide insight into channel stability, the Rosgen level III analysis that follows the level II classification is an assessment of channel stability. In addition, recent publications by Rosgen present channel evolutionary scenarios as progressional changes in channel type (Rosgen 2000) (Figure 3). Rosgen channel type was included in the channel stability tool because of its communication value and its applicability to both aggrading and degrading systems.

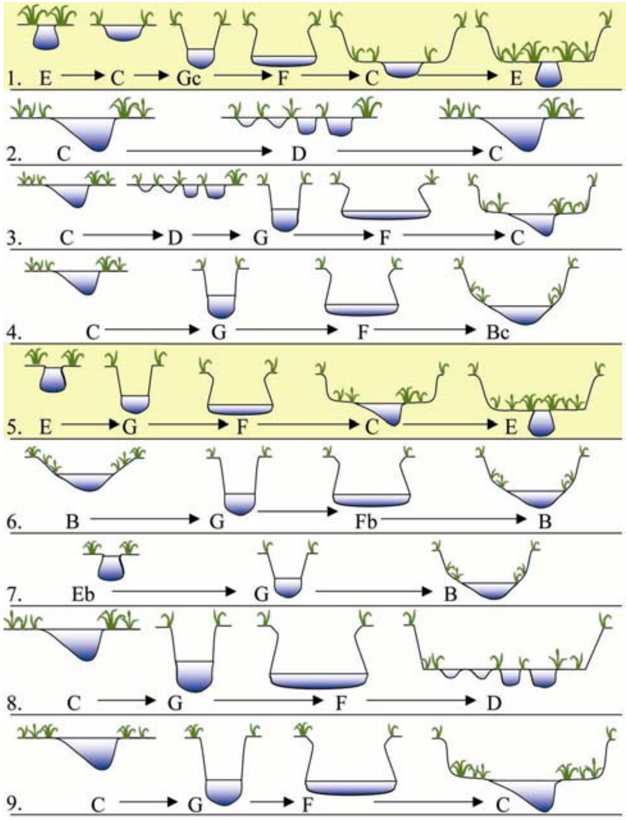

Figure 3: Rosgen stream types with channel evolution scenarios. 1 and 5 most typical of Henrico County streams (Source: Rosgen 2000)

A scoring form for channel stability was developed and is presented in Appendix C. Each of the nine streams was assessed using this form. A weighted score was calculated by multiplying the field score by the length of the stream segment it typified and dividing the sum of these values by the entire stream length.

The resulting scores for each reach assessed are presented in Table One. A score of five represents the most stable stream possible and a score of one represents the least stable stream. Aggrading systems are scored on the left side of the form and degrading/incising are scored on the right side of the form, with stable stream systems in the middle of the form.

Stream Bank Erosion Rate

Streams are subject to severe stream bank erosion in response to the changes in flow regime and sediment supply associated with urbanization (Riley 1998). An actively incising and widening stream may increase its total cross sectional area by a factor between two and ten. All of this eroded bank material ends up in the streams. Increased sedimentation in streams can result in loss of land, severely impact in-stream habitat conditions, and pollute the stream and its receiving water bodies like the Chesapeake Bay. An overall net loss in stream function is evident when streams significantly erode their banks. This criterion addresses the bank erosion element of the first component of the “potential restoration state”.

The amount of bank erosion that can be reduced through appropriate restoration design and construction can be projected by calculating a theoretical or a measured value on the rate a stream bank is eroding. Stream bank erosion rates provide a clearly understandable numeric value to compare the severity of the occurrence between reaches. Stream bank erosion rates also serve as an effective means to communicate the value gained from restoration to property owners and community members, developers seeking mitigation, and environmental regulators.

This study employs a modified version of the procedure presented by Dave Rosgen in A Practical Method of Computing Streambank Erosion Rate (1999). In the modified method, the Bank Erodibility Hazard Index (BEHI) assessment was conducted for all nine reaches and a weighted BEHI value was calculated for each reach. The BEHI method assesses incision ratio, bank angle, density of roots, bank surface protection, and percent of total bank with roots (Figure 4). The indexed scores from the assessment are couple with a measurement of near bank shear stress to read an erosion rate from curve data.

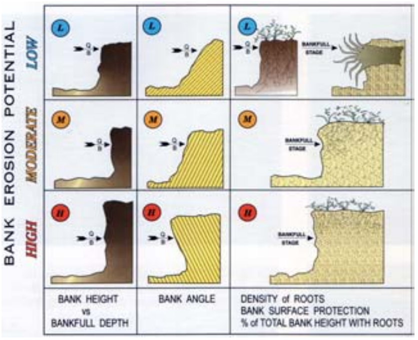

Figure 4: BEHI variables (Source: Rosgen 1996a)

However, because most of the streams were not flowing when the assessment was conducted, the water surface slopes necessary to calculate shear stress were not assessable. A shear stress value of moderate was assumed for all nine reaches. Use of a moderate shear stress value is a commonly used practice in lieu of measured shear stress values (Harman 2001, Halley 2003).

The stream bank erosion rates were found on the Colorado data curve presented in the Rosgen paper using the weighted BEHI value and an assumption of moderate shear stress for each of the streams. The stream bank erosion rate was multiplied by bank height and length for both the left and right banks to get a reach total in cubic feet that was then converted to cubic yards. A per-linear-foot value was then calculated by dividing the reach total by the length of the reach. The per-linear-foot value can be understood as the erosion rate in square feet that each linear foot of the stream is predicted to erode per year or as cubic feet per foot of stream length per year.

The BEHI results for each reach and the stream bank erosion rate calculations are presented in Appendix B. The reach rates per linear foot are listed in Table One.

Stormwater Discharges

During the countywide stream inventory, occurrences of pipes and ditches that discharged directly to a stream were documented. These occurrences represent direct sources of untreated runoff entering the stream channel and are often directly connected to impervious surface. Directly connected impervious surface is referred to as effective impervious cover (Center For Watershed Protection 1998). Effective impervious cover creates a fast and efficient delivery system for stormwater runoff laden with sediment, pollutants, trash, and pathogens (Terrence Institute 1994). In addition, thermal impacts of stormwater runoff can further impact stream systems (Ferguson 1998).

Pipes and ditches discharging directly into stream channels often have erosive and unstable outfalls. Observations of the inventoried pipes and ditches during the stability and bank erosion assessment and subsequent field work in neighboring municipalities has revealed that the degree of outfall instability appears to be associated with channel incision since the outfall was originally set at the pre-disturbance channel bed elevation. As the channel downcut, this initiates gullying in the earthen and lined stormwater ditches and can dislodge the end piece of pipe discharges (Figures 5 and 6).

Figure 5: Undercut pipe discharge.

Figure 6: Undercut earthen and rocked discharge channel.

This study assumes that all pipes and ditches have retrofit potential that would result in water quality and/or channel stability improvements. The county has expressed an interest in the potential to retrofit ditches with pocket wetlands (White 2001). This would facilitate pollutant removal and help recharge groundwater by increasing infiltration. If pipes and ditches cannot be treated for water quality within the stream corridor, infiltration and filtering BMP's can be installed upstream of the discharge location to provide some level of pre-treatment before stormwater is conveyed to the stream.

Dissipation devices at pipe and ditch outfalls within 25’ of a stream bank are a requirement of the Environmental Program (County of Henrico 2001). This same technology could be used to retrofit existing outfalls. Providing stable outfalls would greatly reduce localized sources of bank erosion and bed scour.

Stormwater discharges were assessed by tallying the number of pipe and ditch inventory points recorded in the stream assessment database for each study stream. The assessment assumes that all pipes and ditches represent an opportunity to improve in-stream physical and chemical water quality and are all considered equally. The number of stormwater inventory points is listed in Table One.

Riparian Forested Buffers

The countywide stream inventory described the location and extent of inadequate forested riparian buffers along the stream reaches assessed. Riparian forested buffers provide filtration of stormwater runoff delivered to the stream as sheet flow. This runoff is typically not directly connected to impervious surfaces but still may contain many of the stream contaminants listed above (Klapproth 1999). These contaminants are trapped, filtered and converted in the near surface root zone (USDA 1998). Infiltration of stormwater also helps to recharge groundwater and maintain instream baseflow levels (Palone and Todd 1997).

In addition to the filtering and infiltration benefits associated with forested riparian buffers, the streamside woody vegetation provides an integral stability component of the stream bank. The roots are a structural element of the bank and help mitigate channel enlargement and erosion processes (Klapproth 1999). Re-establishing stable stream banks planted with woody vegetation is a typical component of a stream restoration projects and can greatly improve the chances for short and long term project success (Kondolf 1996).

This study assumes that all deficient forested riparian buffers represent opportunities for water quality and stream stability improvements at the planning level. However it is important to note that slope, width, runoff velocity, sediment particle size, vegetation, soil conditions, depth to water table, and presence of floodplains and wetlands all effect the potential effectiveness of a riparian forested buffer and should be considered in design (Herson-Jones et al 1995). To assess the comparative potential for each of the nine study streams, the length of deficient buffers was totaled and is presented by reach in Table One.

Restoration Opportunities Assessment Results

The results of the restoration opportunities constraints assessment are presented in the Table One below. The table allows the reader to compare the reaches against each other and consider the reaches in terms of the different criteria discussed. Units for each criteria are also listed.

Reach ID	DFB03	DFB04	DCB06	DRN13	DRN14	DRN22	DRN26	DRN28	DSR08
Channel Stability	2.00	2.08	3.00	3.00	3.00	2.40	3.35	3.35	1.00
Bank Erosion	0.30	0.76	0.71	0.32	0.30	0.76	0.26	0.44	0.90
Pipes/ Ditches	0	3	7	2	2	6	7	4	2
Riparian Buffers	1950	0	700	0	100	1240	1660	700	1700

Table One: Restoration Opportunities Assessment Results. Channel Stability results are unitless. Bank erosion results are rate in feet per linear foot or square foot per foot. Pipes and ditches are in number of occurrences. Riparian buffers are in linear feet.

2.6 Feasibility Constraints Criteria

The importance of recognizing practical constraints to stream restoration projects in addition to their environmental improvement value is well recognized (EPA 2000 and Moses and Morris1997a-b) and was discussed in project initiation meetings with County staff as a driving factor in their ability to implement stream restoration projects (Perry and White 2002). By choosing projects with minimal constraints, project funds are freed up for actual design, construction, and maintenance (Moses and Garman 1997a).

Three feasibility constraints criteria were identified for inclusion on this study. They are ownership, access, and permitting. Two other areas of concern were also identified but could not be included in this study. Potential cost could not be assessed without having at least a conceptual restoration design for each stream. Utility infrastructure constraints could not be incorporated beyond the presence/absence assessment conducted during the county's previous stream inventory because of the lack of digital information on the geographical extents and locations of these features.

Ownership

The practicality and attainability of stream restoration, in part, depends on social consent (EPA 2000). In Virginia, stream channels are private property. A stream restoration design may have the potential to vastly improve the condition and function of a stream. However, it cannot be built as designed without the consent of all of the owners whose property contains a portion of the stream. Further complicating property owner consent is the fact that regulatory agencies typically require that the stream be placed in a preservation easement or restricted covenant as a permit condition.

Private property rights are a strong component of the land ethic in Virginia, and are reflected in the Commonwealth's laws. Landowners may be unwilling to agree to legal restrictions on the use of their land or want financial compensation for doing so. In addition, stream restoration projects involve real risks to property and a real chance of failure either due to design, construction, or aftercare considerations (Moses and Garman 1997a).

Ownership issues can severely constrain and, in some cases, can be the deciding factor that kills a stream restoration project (Siegfried 2002). Throughout a project, rapport must be maintained with property owners along the stream. This involves participation of local residents in obtaining rights-of-ways and frank discussion of the project with property owners (Keller and Hoffman 1977).

Owner consent is a major factor for municipalities implementing watershed management and stream restoration programs. For example, in Hanover County a regional BMP program was developed and many pond sites taken to 90% design. However many of the landowners have refused to allow the ponds to be built on their land in spite of months of negotiation (Gould 2001). The county is currently considering pursuing the legal possibility of “taking” the land through eminent domain on the basis that the public health and safety concerns are a “greater good” than individual property rights.

Two ownership factors are important to assess. The number of property owners and the type of property owners can be used to differentiate or predict how constraining ownership issues may be. Cleary the more property owners involved, the more time and money must be invested in getting all parties to agree to allow the work. If 50 property owners are present, 49 may agree to the project while one may not. This one landowner may severely limit the project.

The type of property owner should also be considered. Single-family residential “owner/occupants” are often the most constraining. This type of owner has little to gain from allowing the project and may perceive adding meanders, floodplains, riparian buffers, and other features and practices in urban stream restoration as a “taking” of these portions of their property. This may be countered somewhat if the stream is eroding its banks and threatening their property or infrastructure. Many single family residential owners “like things the way they are” and do not want the inconvenience of construction.

Multifamily residential properties are less constraining than single family. Usually the occupants do not own the property and therefore are generally less invested and less likely to oppose the project. In addition, one non-occupying owner/entity often holds the decision making power for the entire property. Multifamily residential properties typically contain significantly more stream frontage than a single-family property.

This type of owner may be more willing or able to see the improvement to the stream as adding amenity value to their property and may be able to utilize the restored stream as mitigation for impacts to other properties. However, an increase in net length or area of stream as a result of the project may still be perceived as a "taking"

Commercial and industrial owners are likely to be more accepting of stream restoration projects than multifamily residential owners. Often stream frontage on this property type faces the back of the buildings and is considered non-usable or non-developable land. There is also an increased possibility that the owner may be able to use the project in a beneficial way either by generating positive environmental PR or as a form of mitigation for impacts on other properties.

In some cases properties containing portions of the project stream may be controlled by homeowners associations (HOA's) and non-profits including churches and environmental organizations. These types of owners are less likely to constrain the project by refusing to allow the work. HOA's often own the stream corridor for the purpose of preserving it as an amenity or because it is considered un-developable. Non-profits are likely to understand how their mission and goals can be connected to the project's restoration goals. In either case, the entity probably did not acquire the land to develop it for profit and is less likely to see the project as a "taking".

The least constraining ownership is land that the county already owns. It can be assumed that such properties will not cause increased constraints by property type. This is the most favorable type of property ownership in terms of stream restoration project feasibility.

To assess the ownership criteria the County's GIS parcel layer was analyzed in ArcView 3.2. The number and type of property owners within 50' of either side of the centerline of the stream were recorded. A value was calculated for each reach by adding up the total number of owners and multiplying each owner by a type factor. County ownership was multiplied by a factor of one (no-effect), HOA/non-profit properties by 1.25, commercial industrial owners by 1.5, multifamily owners by 1.75, and single-family owners by 2 (Appendix D). The results are summarized in Table Two.

Access

Urban streams often present challenges in providing an appropriate source and reasonable degree of flexibility in terms of construction access (Piage 2003). Streams that cross a publicly owned and maintained paved road are perhaps the least constraining. Streams that are located between residential lots and have no road access require a temporary access agreement with a landowner and perhaps are the most constraining.

In addition to the question of public/improved access versus private/unimproved access is the issue of how many access points are available to the party constructing the design. Multiple access points allow the contractor increased flexibility in terms of staging, stockpiling, and direction of work in relation to stream flow, and dealing innovatively with unexpected discoveries that may result in changes to the design (Gilman 2003). This can result in a lower bid estimate and/or lower costs associated with change orders.

Furthermore, having two or more access points facilitates conducting multiple activities at the site simultaneously while lowering safety risks. Construction is inherently dangerous. Being able to spatially separate inspection visits, regulatory site visits, volunteer labor activities, school field trips, and data gathering activities from areas being worked by heavy equipment can greatly reduce risks.

The number of access points from paved, public roads was assessed for the nine study streams using Henrico County's GIS layers in ArcView 3.2. The results are presented in Table Two.

Permitting

In addition to social consent and adequate access, the practicality and attainability of stream restoration also depends on obtaining legal authority (EPA 2000). The U.S. Army Corps of Engineers (USACE) and, in the Commonwealth of Virginia, the Virginia Department of Environmental Quality (VDEQ) regulate work below the "ordinary high water mark" in "navigable Waters of the United States" and their perennial and intermittent tributaries. Their jurisdiction comes under the regulatory authority of the 401/404 sections of the federal Clean Water Act (CWA) (Institute for Water Resources 1994 and Virginia Department of Environmental Quality 2003). Environmental permitting is an important feasibility factor to consider when planning stream restoration projects.

Regulatory officials in Virginia do not currently have the degree of training and technical expertise in streams and stream restoration that exists in some other states (Culpepper 2002). Unlike North Carolina, Kentucky, Maryland, Georgia, and Pennsylvania, Virginia currently has no official regulatory guidance on stream assessment or mitigation of stream impacts. The lack of guidance and expertise amongst the Virginia regulatory community can create confusion, inconsistency, and ultimately time and financial constraints when permitting stream restoration projects.

This uncertainty presents a challenge in developing a method to assess the constraints presented by permitting. However, a progression from general permits involving only the USACE to general permits involving more than one agency, to individual permits involving several agencies can serve as a general indicator of the time and financial resources that permitting a project will require.

The USACE issues <u>Nationwide Permit 27: Stream and Wetland Restoration Activities</u> for project activities "associated with…the restoration of non-tidal streams…provided that there are net gains in aquatic resource functions and values". Nationwide 27 is subject to General Condition 14: Notification. This requires a pre construction notification (PCN) with a 30-day completeness review period with one request for additional information allowed and a 45-day review period once the application is complete (Federal Registrar 2002). A typical total time frame for a nationwide permits is 2-4 months.

The VDEQ automatically has certified all Nationwide 27 permits as of March 2002 for projects affecting less than 500 linear feet of perennial streams and 1500 linear feet of intermittent streams and no additional permit is required. For projects affecting longer stream lengths, an individual VDEQ Water Protection Permit is required. An application for an individual permit is subject to a 15-calendar day completeness review. VDEQ may make as many request for additional information as deemed necessary to complete the application. Once the application is deemed complete, VDEQ has 120 calendar days to issue or deny the permit. The agency can make further requests for additional information and request a public hearing, which may extend the permit timeframe beyond 120 days (Virginia Department of Environmental Quality 2003). VDEQ individual permits rarely take less than 6 months and may take up to year to issue.

In some cases the USACE will use discretionary authority to require an individual permit for stream restoration activities (Holley 2003). Larger, more complex projects with analytical modeling and engineering components may be more difficult for regulators to support without the longer review periods and the higher level of scrutiny of and individual permit. USACE individual permits require a public notice and potentially a public hearing and a longer time frame. Obtaining an individual permit from both agencies may take up to 18 months.

Stream restoration projects implemented under the County's Environmental Program are not compensation for permitted impacts to streams. Therefore they result in a net gain in stream functions and values. This gain has the potential to be sold as credits. In Virginia this requires a commercial mitigation banking instrument. Several Virginia municipalities including the County of Henrico have expressed interested in pursuing stream bank opportunities as they develop their stream and watershed programs.

A wetland mitigation review team (WMRT) is comprised by staff from the USACE, VADEQ and the state and federal commenting agencies in response to a specific proposed mitigation banking project. The Board is formed to review and approve applications for commercial stream and wetland banks. This process is considerably more time intensive and has more specific requirements than USACE and VDEQ individual permits. It can take 1-2 years.

For the purposes of this study, the feasibility constraint criteria for each of the nine streams was assessed by placing it in one of three scenarios:

Scenario One: Intermittent stream, less than 1500 linear feet. Perennial stream, less than 500 linear feet. Project can be permitted under *Nationwide 27: Stream and Wetland Restoration Activities.* Pre-authorization from VDEQ.

Scenario Two: Intermittent stream, greater than 1500 linear feet of impacts. Perennial stream, greater than 500 linear feet of impacts. Requires *NWP 27* or individual permit from USACE and an individual permit from VDEQ with associated state agency comments.

Scenario Three: Project justifies pursuing credit as “bank”. This requires a significantly longer review and approval process. No approved stream mitigation banks currently exist in Virginia. This criterion is not applied in the current study but is reserved for future use as the county’s program develops.

Feasibility Constraints Assessment Results

The results of the feasibility assessment are presented in the Table Two below. The table allows the reader to compare the reaches against each other and consider the reaches in terms of the different criteria discussed. Units for each criteria are also listed.

Reach ID	DFB03	DFB04	DCB06	DRN13	DRN14	DRN22	DRN26	DRN28	DSR08
Access	56	50	26.25	3.5	1.5	2	54.25	13	6
Ownership	2	1	2	0	1	1	1	1	1
Permitting	2	2	2	1	1	2	2	2	2

Table Two: Feasibility Constraints Assessment Results. Access results are number of improved access points. Ownership is number of owners X type of ownership. Permitting is based on the three scenarios presented in section 2.6.

2.7 Stream Prioritization Decision Support Tool

Once the criteria were assessed, the final step was the creation of a prioritization spreadsheet used to differentiate the stream reaches in terms of their potential restoration value and feasibility constraints. The development of a tool to accomplish this specific task is unprecedented in the literature but was informed by two draft tools developed by USACE districts to evaluate a stream reach to be impacted versus a stream reach to be restored. These are included in full in Appendix F.

The first tool is a Norfolk, Virginia USACE draft guidance document (2003). The document uses a six-parameter stream assessment. Percent watershed developed, bank erosion, channelization, habitat features/embeddedness, incision, and riparian condition are each scored between 0 and 1. The scores are indexed into three value ranges; 0-.25, .25-.75, and greater than .75. The index value is then multiplied by the stream length affected and divided by the total stream length.

The tool is used to assess the stream to be impacted and a debit score is produced that represents the loss of the functions and values the parameters represent. The proposed stream restoration reach is then scored as credits using the same parameters. The credit value of must be equal to or greater than the debit score to be considered mitigation for impacts (USACE 2003).

The Savanna, Georgia USACE regulatory district has developed a stream mitigation worksheet that assesses the impact reach using six factors. The factors are lost stream type, existing conditions (degree of impairment), duration (of the impact), control (type of legal restriction), dominant impact, linear distance, and priority area. These factors are summed and multiplied by the linear feet of impact to generate a “mitigation credits required score”.

The proposed restoration project is scored using 7 factors. The factors are net benefit, monitoring/contingency, priority area, location, control, kind (in or out-of), and credits (timing of impacts vs. restoration). These factors are summed and multiplied by linear feet to determine the “total restoration credits” (USACE Savannah District 2000).

The USACE draft tools provided insight into how to generate credit scores for the restoration potential factors. However, the tools did not provide insight into how to incorporate the feasibility constraints. Using the USACE drafts as a starting point for discussion, a series of meetings were held with Henrico County staff to make key decisions concerning the development of the prioritization.

The first decision made as the result of the meetings was that all criteria should be considered equally with the option to weight specific criteria as the county determines how to best use the tool. This was accomplished by indexing the calculated values for each criterion into a score of one through five. In the Norfolk tool all parameters are considered equally and indexed into one of three values (USACE Norfolk District 2003). In the Savannah tool, factors are given weight by having different scoring ranges for different factors. For example, linear distance is scored on a range of 0 to 1 while dominant impact is scored on a range of 0-3 (USACE Savannah District 2000)

The second decision was that the high and low values used to index the scores should be based on either the range between the observed high and low calculated values or on the range of either the high or low value, and a value determined from the theoretical reference state. This decision allows for the streams to be compared to each other with the inclusion of the highest possible restored value.

For example, the highest streambank erosion rate value was 0.90 and the lowest was 0.26. However, the 0.26 value still reflects an erosion rate for that entire reach of 27.92 cubic yards of erosion a year. The potential restoration state dictates that a stream does not significantly erode its banks. Therefore, a theoretical rate of 0.16 was used as the low range value. This was determined by assuming a *low* BEHI score with moderate shear stress and reading a 0.16 value from the Colorado curve. A bank height value of 2.5 feet was used because this was approximately the bankfull height observed for most of the nine streams assessed. By setting the bank height at the bankfull height it is assumed that the restored reach will be functionally connected to a floodplain. Connection to a floodplain is another condition of the potential restoration state.

The third decision was that while the streams are compared to the nine stream sample size, it should be possible to add more and eventually all of the counties priority streams to the tool. This is possible by changing the high and low values, which automatically updates the index equations. This decision allows for meaningful comparison of the nine reaches included in this study while accommodating the addition of data from other reaches and subwatersheds as well. This allows for comparison on an intra- and inter- subwatershed basis as the County adds more streams to the tool. The County has expressed an interest in furthering and refining the tool (Perry and White 2002).

The fourth decision addressed how to combine the total improvement score based on the first four criteria with the feasibility constraint score. A decision was made to add the scores together. Lower scoring streams have more improvement value; they have low feasibility constraints (low score) and experience a greater degree of departure from the restoration state (low score). This results in a scoring system where the lowest possible score is the best project. The project with the most improvement potential and the least constraints would receive a score of 7 and the project with the least improvement potential and the most constraints would score a 35.

An improvement ratio and a constraints ratio were calculated as well as an overall ratio of improvements to constraints. The improvement and constraints ratios can also be looked at as percentages of total possible improvement or constraints. For example a stream with an improvement ratio of .25 and a constraint ratio of .75 can potentially achieve 25% of the possible improvement value but faces 75% of the possible constraints.

The overall improvement to constraints ratio compares improvement potential to constraints. A value of 2 in this category means improvements outweigh constraints by a factor of 2:1. A value of .5 this category means constraints outweigh improvements by a factor of 2:1. Results are presented below in Table Three. The prioritization tool in its entirety is presented in Appendix E.

Reach	DSR08	DRN22	DCB06	DRN14	DRN28	DFB03	DRN26	DFB04	DRN13
Total	14.73	15.26	16.43	20.93	20.99	21.24	21.28	22.69	23.17
Improvement Total	7.37	8.18	9.59	15.90	13.11	12.24	10.40	12.12	15.99
Improvement Ratio	0.79	0.74	0.65	0.26	0.43	0.48	0.60	0.49	0.25
Constraint Total	7.36	7.07	6.84	5.04	7.87	9.00	10.87	10.56	7.18
Constraint Ratio	0.36	0.34	0.32	0.17	0.41	0.50	0.66	0.63	0.35
Imp:Const Ratio	2.17	2.18	2.03	1.51	1.06	0.97	0.91	.78	0.72

Table 3. Summary of total scores, improvement scores, constraint scores, and improvement to constraint ratio by reach.