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A Review of Stream Assessment Methodologies and Restoration: The Case of Virginia, USA

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Abstract:

Rapid population growth and land use changes have severely degraded streams across the United States. In response, there has been a surge in the number of stream restoration projects, including stream restoration for mitigation purposes. Currently, most projects do not include evaluation and monitoring, which are critical in the success of stream restoration projects. The goal of this study is to review the current status of assessment methodologies and restoration approaches for streams in Virginia, with the aim of assisting the restoration community in making sound decisions. As part of the study, stream restoration projects data from a project in Fairfax County, Virginia was assessed. This review revealed that the stream assessment methodologies currently applied to restoration are visually-based and do not include biological data collection and/or a method to incorporate watershed information. It was found from the case study that out of the twenty nine restoration projects that had occurred between 1995 and 2003 in Fairfax County, nineteen projects reported bank stabilization as a goal or the only goal, indicating an emphasis on a single physical component rather than on the overall ecological integrity of streams. It also turned out that only seven projects conducted any level of monitoring as part of the restoration, confirming the lack of evaluation and monitoring. However, Fairfax County has recently improved its stream restoration practices by developing and incorporating watershed management plans. This now provides one of the better cases that might be looked upon by stakeholders when planning future stream restoration projects.

Keywords: Biological integrity, Stream assessment, Stream monitoring, Stream restoration, Success criteria, Watershed management

1. Introduction

Streams provide economic, social, cultural and environmental values to society [1, 2]. These values however, have been compromised due to rapid population growth and land use changes that have led to a decrease in forests and wetlands and an increase in impervious surfaces such as roads and buildings. Land use changes impact streams' physical, chemical, and biological processes by altering stream flows and increasing the streams' sediment loads [3-6]. These factors can lead to a decline in the stream quality [7, 8].

Stream restoration as a discipline has developed primarily as a result of wetland permitting processes requiring in-kind replacement of degraded or "impacted" streams [9]. In 1996, the Army Corps of Engineers (COE) issued Nationwide Permit 26 (now expired) which was at the time the only permit that addressed the improvement of impacted streams [10]. In 2002, all Nationwide Permits were reissued, and Nationwide Permit 27 was modified to address not only permits for wetland and riparian restoration but also stream restoration activities [10]. Under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899, the COE is authorized to approve activities in the waters of the United States and directed to protect the nation's aquatic resources. Perhaps due to the link between COE permitting and stream restoration, physical stream restoration practices often focus on meeting the permit requirements and not on the long-term ecological viability of the streams [9]. In addition, as part of the permitting process for stream restoration projects, the COE, Norfolk District and the Virginia Department of Environmental Quality (DEQ) have developed stream assessment methodologies to determine the required level of mitigation.

A stream restoration project which is designed to improve a reach of stream independent from a development project is known as a 'voluntary restoration.' A stream restoration project which is designed to offset the impacts to a stream from a development project is known as 'stream mitigation' [11]. Successful voluntary restoration projects should result in ecological net gains, whereas stream mitigation projects should result in no net loss of ecological conditions [11]. While stream restoration holds the promise of improving the stream quality, restoring a stream to its pre-disturbed state may not be possible as a result of widespread watershed changes [7, 12]. Moreover, the limited knowledge of the complexity and dynamics of streams has led

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to a lack of sound benchmarks for measuring the outcomes of stream restoration [13]. The restoration community still lacks a set of agreed success criteria of the kind which are needed for stream evaluation and monitoring. To ensure that the manipulation of streams leads to improved stream conditions in the future, lessons learned from current and future projects should be gathered and shared with the community.

This paper reviews several important components of stream restoration through a literary review and a case study. The goal of this study is to provide the stream restoration community and the public policy sector with an informational foundation for understanding and making sound decisions about stream restoration.

2. Materials and Methods

This paper reviews the available literature on stream restoration assessment methodologies, classification systems, biological integrity, success criteria, monitoring, evaluation and adaptive management. This information is primarily from Virginia, but also from across the United States. Northern Virginia (Fig. 1) was selected as the case study area due to the recent efforts of the city of Reston, in Fairfax County and of Fairfax and Arlington Counties in the development and use of watershed management plans to address stream improvements. Data on 25 stream restoration projects in the study area of Fairfax County was collected from the National River Restoration Science Synthesis (NRRSS) database [14]. Data was obtained on a further four stream restoration projects through interviews with project managers. The authors participated in a stream assessment training session to learn to the best way to apply the assessment methodologies discussed in this paper. Personal and phone interviews were held with 24 individuals employed by federal, state and local governments, community associations, environmental consultants, non-governmental organizations and academics.

3. Reviews

3.1. Stream Assessment Methodologies

Stream assessment methodologies have been developed for use with the current permit system, watershed and land use planning, water quality and stream habitat reporting and stream restoration. A recent study [15] analyzed more than 50 final and draft regulatory and non-regulatory stream assessment and mitigation methodologies applicable at a national or state level. The study included two methodologies developed for Virginia, the Stream Attributes Analysis: Impact and Mitigation Assessment (SAA) and the Fairfax County Stream Physical Assessment Protocols (Table 1). The COE in Norfolk District developed the SAA to rapidly review projects that impact upon perennial or intermittent streams and therefore require permits in accordance with Section 404 of the Clean Water Act. The SAA methodology scores six variables: riparian condition, watershed development, channel incision, bank erosion, channelization and in-stream habitat. Each variable is then assigned a numeric value ranging from 0 (poor) to 1.0 (excellent) [15].

In Virginia, the interaction between the COE, Norfolk District and the DEQ produced several methodologies for evaluating stream conditions. In late 2003, the COE and Norfolk District, in collaboration with the DEQ, released a revised version of the SAA called the Stream Attributes and Crediting Methodology: Impact and Compensation Reaches (SACM). This document was revised and released as the Stream Attributes Assessment Methodology (SAAM) in 2005 (Table 1). The SACM, which excluded watershed development as a variable, was modeled on the EPA Rapid Bioassessment Protocols [16] and was designed to determine overall stream condition and the necessary mitigation in the Piedmont physiographic region [17]. The DEQ has also developed a methodology, the Stream Impact Compensation Assessment Methodology (SICAM). This is used to determine the overall stream condition and the need for stream restoration

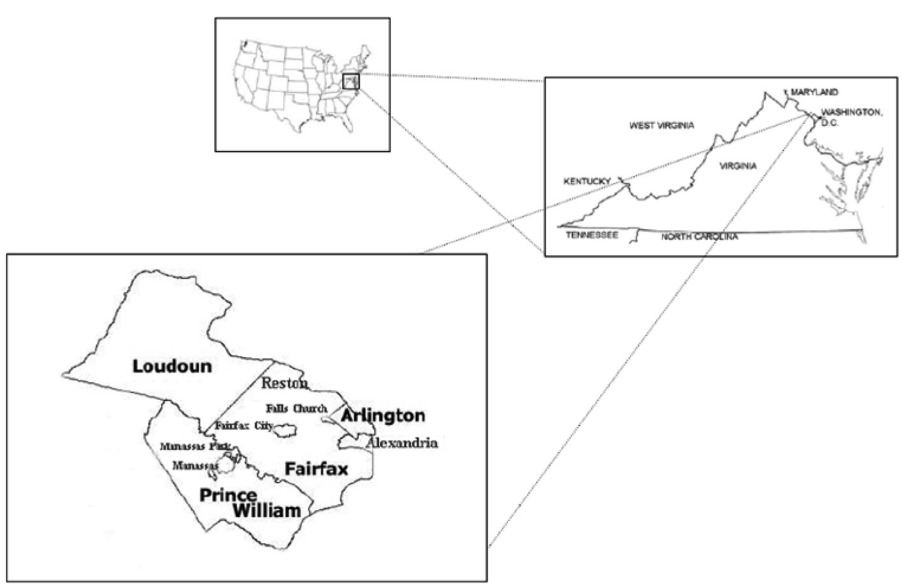

Fig. 1. Map of Northern Virginia that shows several counties where active stream restoration and mitigation occur.

Table 1. History of the development of a stream assessment protocol in Virginia

Protocol Title / Author	Effective Date	Application	Geographic Applicability	Status
Stream Attributes Analysis: Impact and Mitigation Assessment (SAA) / COE, Norfolk District	Unknown	To rapidly review projects that require permits to impact perennial or intermittent streams in accordance with the Clean Water Act Section 404 regulatory program. Released by the U.S. Army Corps of Engineers, Norfolk District (COE, Norfolk District)	Virginia Piedmont physiographic region	Modified and jointly released with the Virginia Department of Environmental Quality (DEQ)
Stream Attributes Crediting Methodology: Impact and Compensation Reaches (SACM) – *known as the Stream Attributes Assessment Methodology (SAAM)* / COE, Norfolk District	January 15, 2004 via web only Public Notice on December 19, 2003	To quantify impacts and mitigation to streams, the COE, Norfolk District recommended that all permit applications use the SACM Methodology	Virginia Piedmont physiographic region	Solicited feedback during a 3-month review period, after which time the COE, Norfolk District and DEQ would continue to review and revise the methodology quarterly for twelve months, then it would be reviewed annually
SAAM – *revised methodology based on twelve month review period* / COE Norfolk District	Public Notice on December 20, 2004	To quantify impacts and mitigation to streams, use recommended	Virginia Piedmont physiographic region	Formation of teams to field test methodology on several stream reaches
Stream Attribute Assessment Methodology / COE, Norfolk District; Stream Impact Compensation Assessment Methodology / DEQ	Joint Public Notice on December 29, 2005; DEQ methodology available after January 6, 2006	To quantify impacts and mitigation to streams * use of these methodologies at this time encouraged but not mandatory	Commonwealth of Virginia	COE, Norfolk District and DEQ to continue the evaluation of both methodologies and collect data with the goal of developing one methodology
Stream Attribute Assessment Methodology / COE, Norfolk District; Stream Impact Compensation Assessment Methodology / DEQ	Joint Public Notice on March 3, 2006	To quantify impacts and mitigation to streams * guidance on when to use both methodologies	A. State Program General Permit (SPGP) development projects in Category A and B where stream impacts are less than 300 linear feet use of the methodologies is not required. B. SPGP development projects in Category C, DEQ general permits, and all individual permits both methodologies is required. C. Projects that qualify for a COE Nationwide Permit and propose impacts that require pre-construction notification, the use of SAAM is required.	Joint agency meetings were held in the summer to work towards the development of one methodology, which will be released in early 2007
Unified Stream Methodology (USM) / COE, Norfolk District and DEQ	Joint Public Notice January 18, 2007 beginning February 1, 2007	To assess proposed stream impacts and determine stream mitigation requirements. The USM is a technical manual only, not an agency regulation.	Wadeable perennial and intermittent streams in Virginia	Joint agency release. Final draft for implementation while they solicit comments.

projects across the State [18]. In 2006, the DEQ, the COE and Norfolk District encouraged the use of both methodologies and informed the public of the conditions under which these methodologies should be used. Then, in mid 2006, the DEQ, the COE and Norfolk District reversed their course and entered into discussions to work towards the development of the Unified Stream Methodology (USM). A final draft of the USM was released for public comment on January 18, 2007 (Table 1).

3.1.1. SAAM and SICAM field application

In the spring of 2006, the authors participated in a stream assessment training session to learn how best to apply the SAAM and SICAM methodologies in the field. The team assessed a site located in Loudoun County, Virginia, consisting of eight streams and 17 stream reaches totaling 2,183.4 linear meters before any environmental impact had occurred. The stream reaches were classified by stream type, with ten intermittent streams, six perennial streams and one stream for which the upstream section was classified as intermittent and the downstream section as perennial. In addition, the stream reaches were classified by the stream order, with thirteen 1st order and four 2nd order streams [19]. Observations for each variable were logged in the field and later entered into forms. For the SAAM, each variable is evaluated and rated on a numerical scale, ranging from zero to ten for two variables and from zero to eleven for three variables. In both cases the highest value is the most favorable condition for each stream reach [16]. For the SICAM, each variable is evaluated and rated on a qualitative scale from severe to optimal (Table 2).

The application of the SAAM and SICAM methodologies varies. Firstly, the SAAM field form is an electronic spreadsheet based on Microsoft Excel and includes the calculations necessary to determine the Reach Condition Index (RCI), which is an overall numeric indicator for the stream [17]. The evaluator only needs to enter the data collected into the spreadsheet, with each stream reach requiring its own form and being scored separately. For example, one stream reach (86.1 linear meters) observed during the field study scored a pre-impact RCI of 5.02. Because this stream will be impacted, a restoration project in the same watershed must be identified as a proposed stream for the mitigation. The mitigation stream must also be assessed to determine its RCI and then the proposed mitigation plan is applied to the SAAM to determine the new RCI for the stream post-restoration. The difference between these two RCI values is known as the mitigation lift RCI. To determine the linear meters of restoration required, the RCI of the impacted stream, in this case 5.02, is divided by the mitigation lift RCI and then multiplied by the linear meters of impact, in this case 86.1 linear meters. The number of linear meters calculated represents the number of linear meters of restoration required for the 86.1 linear meters of impact.

(5.02/Mitigation Lift RCI) x 86.1 linear meters (lm) =
Linear meters of restoration required at mitigation stream for 86.1 lm of stream impact

In contrast, the SICAM method for calculating the RCI is quite different. Because the SICAM is a qualitative measurement of the stream, the surveyor must complete the field form by checking the correct score for each variable. Once each variable is scored, the surveyor must refer to the flowcharts provided in the SICAM manual [18] to determine the RCI, which is then converted to a stream quality factor (SQF) which ranges from 1.0 to 1.6. The SQF range excludes1.4 with no explanation provided as to why. This factor correlates to a qualitative measure rang-

Table 2. Comparison of the Stream Attribute Assessment Methodology (SAAM), Stream Impact Compensation Assessment Manual (SICAM), and Unified Stream Methodology (USM) Variables and Scoring

SAAM Variables	SAAM Scoring	SICAM Variables	SICAM Scoring	USM Variables	USM Variables
Channel Incision	Measure bankfull depth and top of lowest bank	Channel Condition	Severe, Poor, Marginal, Suboptimal, Optimal	Channel Condition	Severe, Poor, Marginal, Suboptimal, Optimal
Riparian Areas*	0-2 (Poor) 3-5 (Marginal) 6-8 (Sub-optimal) 9-10 (Optimal)	Riparian Buffer	Poor, Marginal, Suboptimal, Optimal	Riparian Buffer	Poor, Marginal, Suboptimal, Optimal
In-stream Habitat / Available Cover*	0-2 (Poor) 3-5 (Marginal) 6-8 (Sub-optimal) 9-11 (Optimal)	In-stream Habitat	Poor, Marginal, Optimal	In-stream Habitat	Poor, Marginal, Suboptimal, Optimal
Channel Alteration*	0-2 (Poor) 3-5 (Marginal) 6-8 (Sub-optimal) 9-11 (Optimal)	Channel Alteration	Severe, Moderate, Minor, Negligible/None	Channel Alteration	Severe, Moderate, Minor, Negligible
Bank Stability*	0-2 (Poor) 3-5 (Marginal) 6-8 (Sub-optimal) 9-10 (Optimal)	Man-made channel assessment			
Sediment Deposition*	0-2 (Poor) 3-5 (Marginal) 6-8 (Sub-optimal) 9-11 (Optimal)				

(*)) based on the Rapid Bioassessment Protocols by Barbour and others (1999) ing from severe to exceptional that measures the overall quality of the stream reach. To compare the SAAM and the SICAM, the Virginia DEQ [18] developed a table to convert the RCI value obtained for the SAAM to an SQF value. Sixty percent of the stream reaches surveyed received the same score from both methodologies, with the SQF ranging from optimal (1.5) to sub-optimal (1.3) with one reach scored as marginal (1.2) (Fig. 2). However, this analysis also showed clear differences, although small, in the evaluation of stream conditions between the two methodologies.

The SAAM and SICAM are both visually based habitat assessments and therefore do not include any biological sampling as part of the field application. In order to correctly determine the ecological integrity of a stream, these methodologies should be performed in tandem with biological sampling [16]. In addition to this, the values assigned to score each variable in the methodologies differ, which might confuse users (Table 2). Through the field application exercise, the authors could also see a potential scoring bias for the variables depending on the surveyor's experience and knowledge. It was found that surveyor variability in classifying the stream reaches and stream habitat attributes increased, especially when the number of categories from which to choose also increased [20, 21].

3.1.2. Unified stream methodology

In January 2007, the COE, Norfolk District and the DEQ released a draft USM [22]. This methodology superseded the SAAM and SICAM, but without significant change. Like its predecessors, the USM is a visually based habitat assessment that scores four variables; channel condition, riparian buffer, instream habitat and channel alteration, with each variable being evaluated and rated on a qualitative scale from severe to optimal (Table 2). However, the USM does not address the issues with the previous assessment methodologies as previously discussed. In addition, the USM lacks a biological assessment as is the case with the SAAM and SICAM.

3.2. Stream Classification Systems

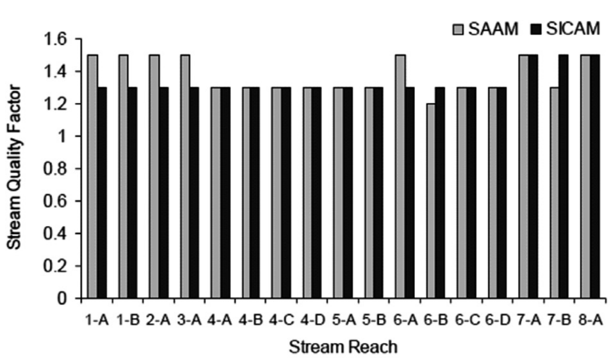

Fig. 2. Stream Quality Factor (SQF) for 17 stream reaches in Loudoun County, Virginia using the Stream Attribute Assessment Methodology (SAAM) and Stream Impact and Compensation Assessment Manual (SICAM) protocols to assess stream condition and to determine the level of mitigation required to avoid a net loss of aquatic resources. The stream reach SQF scores, measure of the current stream condition, ranged from 1.0, severe; 1.1 poor; 1.2, marginal; 1.3, sub-optimal; 1.5, optimal; to 1.6, exceptional.

While stream assessments are useful in determining the stream conditions, understanding stream classification systems correctly is imperative in stream assessments. The classification of streams is not a new technique and multiple classification tools exist. The classification of a stream prior to a stream assessment has been recommended in order to reduce the inconsistency in physical stream variables [15]. Niezgoda and Johnson [5] identified thirty stream classification systems dating from 1899 to 2000, with most of these being primarily developed to classify natural streams located in stable environments. One of the most popular systems classifies streams at the watershed scale [5, 19]. Other systems classify streams into several types based on morphological measurements such as stream patterns, sinuosity, entrenchment, channel width, depth and the bank materials [5, 23, 24]. Another classification system known as the Impervious Cover Model (ICM) [25] categorizes stream condition based on the percentage of impervious cover in the watershed [25, 26].

The complexity and usefulness of different stream classification systems varies widely. The Strahler stream order system [19] provides a general guideline of the stream characteristics, which change as the stream size increases. The river continuum concept correlates stream order to the type of aquatic community. This however does not include a description of how these characteristics change between a disturbed or non-disturbed watershed and it applies only to perennial streams [1, 27]. The Rosgen stream classification system [23, 24] is currently used across the United States. However, in order to apply this methodology appropriately, this system requires the establishment of reference conditions. This may be readily possible for rural streams that have not been heavily impacted, but may be more difficult for urban streams that have been impacted. The ICM [25] can be good at providing a quick snap shot of the current stream condition, but should be supported by the collection of field data such as that on benthic macroinvertebrates.

Because a habitat assessment or stream classification system alone will not provide information on the stream functions, it is important that they be applied in tandem. The classification of a stream prior to a stream assessment will also increase consistency in determining physical stream variables [15]. Too often stream restoration is based on stream morphology and the stream's functions are not considered [5]. It is this relationship between the structure and function of a stream system that is critical in sound stream restoration [28]. To some degree, stream classification systems are used to guide stream restoration, however their use and the system are not consistent across restoration projects. For example, in the field application discussed in this paper, the streams were classified by stream type and order. Recently, in Fairfax County, Wedderburn stream was reclassified from perennial to intermittent because of a loophole in the county regulation. This was because the regulation only required that there was no visible water flowing in the stream [29], a full discussion of this can be found in the Case Study.

3.3. Biological Integrity

Several studies have shown that a stream's biological condition can be measured by using an 'Index of Biological Integrity (IBI)' [30-32]. Biological integrity is defined as where a stream has "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition and functional organization comparable to that of the natural habitat of the region" [33]. Since its inception, several IBIs have been developed and applied to various aquatic resources including streams, rivers, wetlands and estuaries [30, 34-36].

Montgomery County, Maryland developed a biological monitoring program to conduct a base-line measurement for reference streams. These were the highest quality streams in an area primarily located in forested or rural areas [32]. The county formed a working group to develop a biological monitoring program and sought guidance from the U.S. EPA to develop an IBI for each ecological region [32]. The county collected data for all of its 23 watersheds and identified altered flow and sediment as two stressors. This information was then applied to present and future land use practices to identify and develop draft watershed management plans [32]. More recently, the State of Maryland revised the fish and benthic macroinvertebrate IBIs in order to better assess stream conditions [37]. The Maryland Biological Stream Survey found that although there are no longer any pristine streams left in the state, there are high quality streams that have received minimal disruption [37].

In response to the degradation of streams throughout Fairfax County, the County conducted a baseline study to determine the overall quality of their streams [38]. The county used a benthic macroinvertebrate IBI (B-IBI) and found that for the B-IBI streams they rated 32% in fair condition and 45% in poor to very poor condition with medium to low biological integrity [38]. Not every county uses this method as part of the stream assessment or monitoring, in fact very few, but Fairfax County is one that has adopted the application of the B-IBI. The IBIs are not regularly used in assessing changes in stream degradation and planning stream restoration. Biological monitoring is critical to the protection of stream systems [39]. The IBI increases the understanding of what is occurring at the watershed scale and when combined with the stream assessment as previously discussed, will lead to restoration decisions being made based on sound scientific data.

3.4. Evaluating Stream Restoration: Success Criteria and Monitoring Needs

How is the 'success' of stream restoration currently measured? For many, a project is deemed either a success or failure based on whether it complies with the permit requirements [9]. Currently, the measures of success focus on the faithful implementation of a mitigation plan that may not conduct any evaluation for the ecological integrity of the streams being restored. Moreover, since the plans may differ from project to project, it is hard to establish a set of criteria that can be consistently applied to measure the success of various stream restoration projects. Ryder and Miller [28] propose the use of quantitative ecological indicators to measure the success of stream restoration. In contrast, Ehrenfeld [40] proposes that restoration goals should be project specific. Restoration does not guarantee the recreation of a "natural" system and the limitations of a restoration project should be recognized at the outset. Still, most success criteria proposed or mentioned do not address a means of measuring the success of the replacement's functional attributes that restoration projects should truly be designed and conducted for.

Stream assessments are suggested as an alternative, if modified to include a biological assessment, these could provide the foundation to determine the success or failure of restoration projects. The application of the IBI is important in monitoring the recovery of 'processes' and/or 'functions' that may or may not occur during and after the restoration, as well as monitoring physical and structural aspects [28]. As the success criteria continue to be debated among the restoration community, it is critical that state and federal agencies take the first step in requiring a minimum of monitoring and evaluation for all restoration projects along with the development of these criteria. Due to the change in stream characteristics over time, universal success criteria will not be agreed upon, however success criteria designed for a specific project may be more realistic.

Another frequent criticism of existing stream restoration practices is that the monitoring and evaluation are not standardized. Current monitoring tends to focus on the physical response to stream restoration techniques, it is however the biological response that will measure the effectiveness of the restoration [41, 42]. To improve restoration practices, it is critical that restoration projects include an appropriate monitoring and evaluation plan because the knowledge gained is helpful to the design of future projects [43-47].

When the monitoring and evaluation data is collected, studies show the amount of variance in techniques used [46, 48, 49]. Monitoring and evaluation was once primarily for academia, however it is slowly being required of less suited groups such as non-governmental or local government agencies [50, 51]. As a result, the monitoring component often lacks a framework or the correct methods in which the data should be collected [50, 51]. To avoid inconsistencies, there should be a coordinated effort amongst all the groups monitoring the stream's condition [51], this would have the additional benefit of promoting data sharing [52].

While it is evident that monitoring and evaluation are important, several obstacles do exist. Traditionally, resource management focuses on the data collection and does not include development of a monitoring plan to assess the project goals [53]. Data collection also tends to focus only on individual habitats, this steers managers towards restoration at a single spatial scale while ignoring changes in the fluvial process [48]. In addition, environmental managers often lack adequate baseline data, funds and guidance [46, 54]. The funds required for post-project evaluation often do not make it into the original cost estimates [45]. In order for the long-term monitoring programs to be successful, the costs should be included into the initial design phase budget [55].

3.5. Watershed-Based, Adaptive Management of Stream Restoration

To address the declining stream conditions found recently in Virginia, former Governor Mark Warner signed an executive order in 2005 which was designed to improve stream health and water quality through stream restoration [56]. However, without a regulation that requires science-based stream assessment and restoration [15, 57], restoration goals may not be readily achieved. Regulations should enforce the development of watershed management plans, requiring assessment and monitoring at the watershed scale [58-60]. To be effective, stream restoration should be designed at the watershed scale and incorporate knowledge of the upstream conditions and of land management practices [7, 41, 43, 45, 60, 61]. This shift from the reach to the watershed scale leads to the selection of appropriate techniques and restoration projects from which the greatest gains will be achieved in the long-term. Watershed assessments can demonstrate to planners the importance and benefit of a holistic approach [62] and they are the start of good watershed management plans [63]. Therefore, a watershed assessment should be the first step in the identification and prioritization of stream restoration projects [41]. The methods used to conduct a watershed assessment should at a minimum include data collection on the physical, chemical and biological integrity of the streams in relation to the current and future watershed development.

Adaptive management is an approach to assist managers with the decision making process when faced with the uncertainty of complex environmental issues [64]. Despite the wide application of adaptive management, there are relatively few success stories [64, 65]. Adaptive management is applied to natural resource management to recognize that the process must be integrated and multi-disciplinary and to acknowledge the uncertainty in restoration [66-70]. Stated more simply, adaptive management is "learning by doing" [71] and allows for the integration of economic and social understanding from the outset and emphasizes the role of effective communication between stakeholders [66]. There are two adaptive management approaches, passive and active [72]. Often managers lean towards active adaptive management because it is believed that it will improve knowledge and increase scientific understanding in a shorter period of time, though the opportunity costs tend to be higher [64, 65]. Prior to selecting adaptive management as an approach to address the uncertainty in stream restoration, managers are recommended to consider four criteria 1) spatial and temporal scale, 2) uncertainty, 3) costs, benefits and risks, and 4) stakeholder and institutional support [64].

4. Case Study: Fairfax County, Northern Virginia

4.1. Introduction

In response to the rapid population growth in Northern Virginia, part of the Washington District of the Columbia metropolitan area (Fig. 1), local governments have had to identify solutions to restore degraded streams. Fairfax County covers 1,026 square kilometers with more than one million residents and more than 1,448 linear kilometers of perennial streams (Fig. 1) [73]. In the early 1900s, Fairfax County was primarily composed of rural and agricultural land [38]. By 1998 close to 80 percent of the county was developed, the agricultural land had disappeared and the remaining 20 percent of the land remained forested [74]. To respond to the changes within the watershed and the degradation of streams, in 2002 the county started to develop watershed management plans for each of its 30 sub-watersheds to be completed by 2009. Based on a review of the literature and several restoration projects, this section discusses the recent efforts of Fairfax County in stream assessment and restoration. It evaluates the development of watershed management plans and introduces an exemplary case of a watershed approach for stream restoration in the city of Reston.

4.2. Stream Assessments

Twenty eight projects in Fairfax County and one project in Arlington County (Fig. 1) were analyzed for this study, with the data being collected from the NRRSS database [14] and project managers. Most projects reported more than one project goal. Moreover, out of the seven project goals listed, nineteen projects reported bank stabilization, four reported water quality management and channel reconfiguration and three reported riparian management. One reported each of habitat improvement, aesthetics, recreation, education and stormwater management (Fig. 3). Only eight of the projects reported some level of biological, physical or chemical monitoring. Several of these projects took place in the mid to late 1990s. Due to the limited knowledge on the effectiveness of stream restoration techniques or to the lack of well-established success criteria, it is difficult to know whether the restoration undertaken so far will continue to meet the objectives initially set out [14, 60].

Throughout our interviews with the project managers from four of the projects, we learned that assessment methodologies had been recommended for use in the permit process, but not actually used. Three of the stream restoration projects (Snakeden Branch Headwater and Upper Snakeden Branch, both located in the city of Reston and Donaldson Run located in Arlington County) were identified during the development of watershed management plans. In the city of Reston, physical, biological, chemical and hydraulic assessments were conducted [75]. Assessment tools included the Bank Erosion Hazard Index (BEHI), a qualitative measurement to estimate the susceptibility of stream banks to erosion [24], a habitat assessment modeled after the EPA Rapid Bioassessment Protocols [16] and hydraulic modeling [75]. Only stream reaches that showed a significant sign of bank erosion received a BEHI score and rating [75]. Of the 34 reaches assessed for BEHI, 32 scored high and two very high for potential erosion. Of the 42 reaches assessed for habitat quality, 26 scored poor, 13 scored marginal and 3 scored optimal (Table 3). In Arlington County, streams were assessed using a modified version of the Rapid Stream Assessment Technique (RSAT). This measurement scheme evaluates stream condition

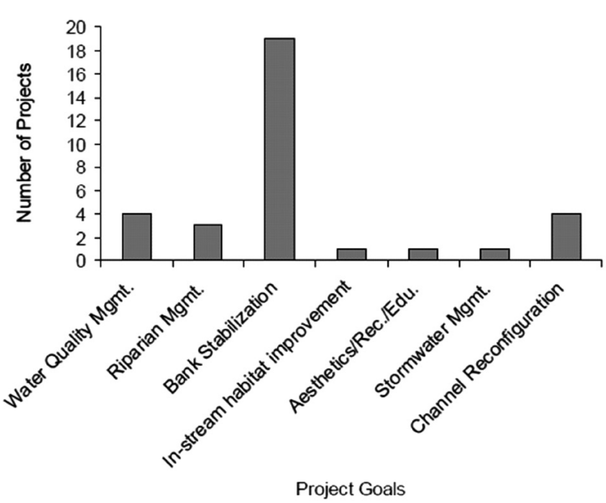

Fig. 3. Stream restoration project goals for 28 selected projects in Fairfax County, Virginia and one selected project in Arlington County, Virginia. Several of the projects listed more than one project goal. The timeframe for these projects ranged from 1995 to 2003. Source of data comes from the National River Restoration Science Synthesis (NRRSS) database (Bernhardt et al. 2005) and personal communication with program managers.

Table 3. Average Bank Erosion Hazard Index (BEHI) and Habitat Scores for sub-watersheds, Reston, Virginia

Sub-watershed	Average BEHI Score[3]	Average Habitat Score[4]	Total Number of Reaches Assessed
Main Branch above Lake Audobon	38 (high)	56 (poor)	10
Snakeden Tributary	39 (high)	51 (poor)	6
Main Branch below Lake Audobon	36 (high)	125 (sub-optimal)	3
Western Lower Snakeden Tributary	42 (high)	78 (marginal)	3[1]
Eastern Lower Snakeden Tributary	41 (high)	54 (poor)	3[1]
Sugarland Run	38 (high)	75 (marginal)	10[2]
Buttermilk Creek	38 (high)	43 (poor)	3
Brown's Chapel Creek	41 (very high)	46 (poor)	2
Lake Anne Tributary	39 (high)	52 (poor)	2

Data obtained from the Reston Watershed Management Plan prepared by GKY and Associates (2002)
[1]For the BEHI score, only two reaches were assessed
[2]For the BEHI score, only four reaches were assessed
[3]Extreme erosion potential (46-50); very high erosion potential (40-45); high erosion potential (30-39.5); and moderate erosion potential (20-29.5)
[4]Poor habitat condition (0-57); marginal habitat condition (58-107); and sub-optimal habitat condition (108-160)

based on chemical, physical and biological indicators relative to a reference stream [76-78]. The stream inventory found that most streams were in a condition rated as fair, there were however no streams evaluated as being excellent [77, 78]. Although these assessments, conducted at the local level, determine stream conditions based on physical, chemical and biological indicators, there is no consistency in the methodology used. To improve the stream health and water quality through stream restoration, the State should improve upon the current stream assessment methodology. The best means to do this is by incorporating a biological component and require its use in voluntary and mitigation restorations, as well as in the development of watershed management plans.

In 2002, the re-issuance of Nationwide Permits distinguished between perennial and intermittent streams [10]. So when is a stream not a stream? In Fairfax County, the hydrological, physical and biological characteristics of a stream determine whether it is perennial or intermittent [73]. Perennial streams flow continuously throughout the year in a natural or man-made channel during a year of normal precipitation [79]. Intermittent streams, either natural or man-made, rely on the ground water table or surface water sources and only flow at certain times of year [73, 80, 81]. In 2001, as part of the Chesapeake Bay Preservation Ordinance, the county revised the language from only requiring Resource Protection Areas (RPAs) around tributary streams which were depicted on U.S. Geological Survey maps to requiring Resource Protection Areas around all water bodies with a perennial flow [82]. The RPA does not allow development within 30 meters of either side of a perennial stream [29]. Because the maps depicting perennial streams were outdated, the county conducted the Perennial Streams Identification Mapping Project [73] following the adoption of the new RPAs. This project resulted in a small change from 1,368 linear kilometers to 1,377 linear kilometers, excluding shorelines, being defined as perennial and classified as an RPA in the county [73].

The regulatory language, however, had one loophole, it lacked guidance based on sound scientific data to approve the reclassification of a stream from perennial to intermittent. The regulation only required that there was no visible water flowing in the stream to be reclassified [29]. This vagueness resulted in the reclassification of a few streams such as Wedderburn stream from perennial to intermittent [29], making them vulnerable to development activities. The county realized that clearer guidance must be provided to ensure the protection of streams, as a result the codes were once again amended in 2006 to require that before any reclassification a water body with perennial flow will be identified using scientifically valid indicators as outlined in Section 6-1704 of the Public Facilities Manual [79].

4.3. Watershed Approach for Stream Restoration – The Case of the City of Reston

Reston is a planned community in Fairfax County that was developed about 35 years ago (Fig. 1). Located at the headwaters of three major tributaries flowing into the Potomac River, as such Reston has good opportunities to practice stream restoration without interference from upstream activities [75]. Land use in Reston consists of 67% of the space split between residential, commercial, transportation, education and industrial and the remaining 33% being open space with a total of 25% of the land cover being impervious surfaces [75]. Land use changes have negatively impacted streams in Reston primarily through the increased sediment load and discharge. To help prioritize stream restoration projects, Reston assessed the conditions in the watershed, which led to the development of a watershed management plan. Reston followed the advice of many studies that advocate the use of a watershed assessment and watershed approach to stream restoration [47, 62, 63].

The Reston Association first assessed their streams as part of the development of a watershed management plan, which was then used as a tool to inform the public about stream conditions. Because the public was initially hesitant on the sub-

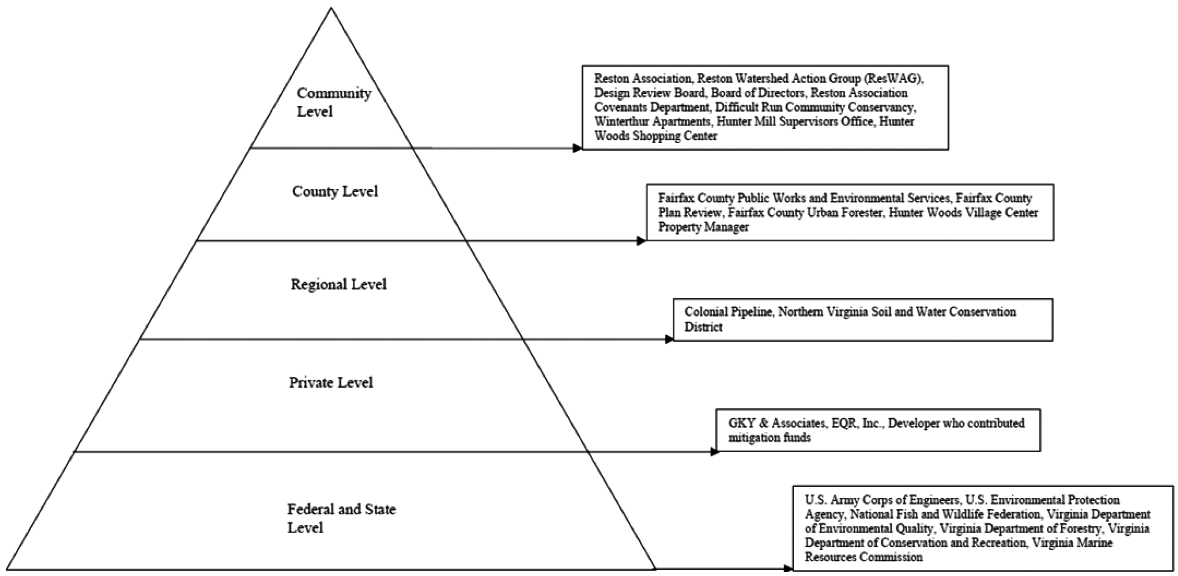

Fig. 4. The stakeholder pyramid for the Snakeden Branch Restoration Project Phase II (240 linear meter) in Reston (Fairfax County), Virginia. Heavily modified from (Schueler 2005).

ject of stream restoration, the Association selected the Upper Snakeden Branch as the first voluntary project, aiming to restore 240 linear meters with the goal of reconnecting the stream to its floodplain. Stream restoration involves stakeholders at the federal, state, regional, county, community and private levels. The stakeholder pyramid outlines the key players at each level for the case of the Snakeden Branch restoration project (Fig. 4). The stakeholders at the base of this pyramid were informed of the restoration project at the time of the permit application or at a pre-application meeting and were not intimately aware of the watershed problems. As one moves up the pyramid, the involvement of the stakeholder groups increased, with the stakeholders at the apex being the driving force for this restoration project [83]. The Reston case showed that all stakeholders must be informed of restoration projects, the goals, expected outcomes and budgets [84].

5. Conclusions

This review discusses several areas in which the USM stream assessment methodology could be improved. By adding a biological assessment, the methodology would produce a more informed reading of the overall stream condition. Not only does the biological assessment add value to the initial stream assessment, but the data collected from this assessment could serve as the baseline for the future monitoring and evaluation of the stream condition. In addition, the methodology should consider information on current and future watershed conditions, which can be obtained by collaborating with county staff. How the success of a restoration project is measured should move away from the faithful implementation of a mitigation plan towards success criteria that have been agreed upon in advance, that would include the improvement of the stream's ecological integrity. These evaluative methodologies are the first step in stream restoration because watershed conditions can reverse any benefits of a stream restoration project. Therefore, stream restoration and watershed changes must be addressed simultaneously through the development and implementation of watershed management plans. In Northern Virginia, Fairfax and Arlington Counties and the city of Reston have adopted a watershed approach. These plans take a comprehensive approach to address the multiple issues that the watersheds face and are designed to guide the Counties and City in placing financial resources in areas where the greatest return can be earned.

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