Chapter One: Introduction

1.1 Background and Problem Statement

The United States has more than 3.5 million miles of rivers and streams that, along with closely associated floodplain and upland areas, comprise corridors of great economic, social, cultural, and environmental value (FISRWG 1998). Stream systems, being part of the natural ecosystem, normally function within natural ranges of flow, sediment movement, temperature, and other variables, termed “dynamic equilibrium.” When these variables change beyond their natural ranges, dynamic equilibrium may be lost, often resulting in adjustments in the ecosystem that might conflict with societal needs. Human activities have contributed to changes in the dynamic equilibrium of stream systems greatly, as a matter of fact, according to H.B.N. Hynes:

> “Human activity has profoundly affected rivers and streams in all parts of the world, to such an extent that it is now extremely difficult to find any stream which has not been in some way altered, and probably quite impossible to find any such river.” (1970)

Having recognized that natural or human-induced disturbances are damaging the structure and functions of the ecosystem or preventing its recovery to a sustainable condition, people should take actions to minimize the disturbance activities causing degradation or preventing recovery of the ecosystem, and subsequent actions to mitigate the impact from urbanization and restore/rehabilitate our stream systems. Restoration activities will include a broad range of actions and measures designed to enable stream corridors to recover dynamic equilibrium and function at a self-sustaining level. Because of the complexity nature of the stream ecosystems as well as the restoration activities, it is important to plan ahead the restoration procedures and methods before taking any actions. It is also because of this reason that environmental planners and restoration workers should study the nature of the stream ecosystems, as well as the methods of stream restoration.

The Stroubles Creek is a freshwater stream located in Blacksburg, Virginia. Over the past 100 years, it has experienced significant impact from urbanization in the Stroubles Creek Watershed. In the upper portion of the watershed a substantial part of the stream has been placed underground. Additionally, many segments of the stream were rerouted and the bio-integrity and water quality of the stream has declined. Being a university town, Blacksburg is growing considerably (and at a faster pace in the recent years). Thus, Stroubles Creek is facing the danger of degrading at an even faster rate.

The Stroubles Creek Water Initiative, originated by the Virginia Water Resources Research Center at Virginia Tech, has been assessing, analyzing and monitoring the creek. However, neither the Town of Blacksburg, nor Virginia Tech has yet prepared a comprehensive plan to rehabilitate and/or restore the upper portion of Stroubles Creek and to keep the creek from degrading further.

1.2 Goals, Objectives and Methodology

1.2.1. Goal

The goal of this paper is to study the methods of restoring urban stream ecosystems and stream restoration planning.

1.2.2. Objectives

The major objectives of this paper are:

1) To study the literatures on the subject of urban stream restoration/rehabilitation, thus to learn the methods of restoring urban stream ecosystems and stream restoration planning.
2) To develop a theoretical framework for the urban stream restoration/rehabilitation planning process.
3) To apply the theoretical knowledge of urban stream restoration and the urban stream restoration planning framework to the development of the Stroubles Creek Restoration/Rehabilitation Process Plan.

1.2.3. Methodology

A review of the literature helps form a restoration planning framework and establish the theoretical background for urban stream restoration. The study of stream restoration and restoration planning begins with a discussion of the definition of stream restoration/rehabilitation. The nature of the stream corridor ecosystem is briefly discussed and is followed by an explanation of the various human induced disturbances that causes the degradation of our urban streams. General stream restoration procedures and methods are explained and a discussion of "urban stream restoration case studies" is used to guide future decision-making related to Stroubles Creek restoration/rehabilitation.

The theoretical knowledge of urban stream restoration is applied to the Stroubles Creek in Blacksburg. Results of stream monitoring and other research by SCWI are used to inform the recommended planning process, while a process plan for the Stroubles Creek restoration/rehabilitation is laid out.

1.3 An Overview of the Paper

The following paper develops a planning framework for restoring and/or rehabilitating Stroubles Creek by examining stream restoration literature and highlighting the lessons learned from other urban stream restoration case studies.

Chapter Two: Theoretical Background first discusses the general theoretical background of the methodology of urban stream restoration/rehabilitation. Theoretical definitions of "restoration", "ecological rehabilitation" are discussed, and specific meaning of "stream restoration" of this paper is defined. Reasons for restoring/rehabilitating urban streams are explained by discussing various types of human induced disturbances including physical, chemical and biological disturbances. The paper also emphasizes the importance of considering different spatial scales (watershed, riparian corridor, and in-stream/reach) to stream restoration/rehabilitation. Finally, the paper discusses three successful cases on urban stream restoration/rehabilitation practices. The three cases are: Bluewater Creek case in New Mexico; Lititz Run Watershed in Lancaster, Pennsylvania; and Kingstowne Stream restoration project in Fairfax County, Virginia.

Chapter Three: Urban Stream Restoration Planning goes on to explain the methodology and process of planning an urban stream restoration project. It discusses major steps of urban stream restoration planning from process organization, problems and opportunity identification, to goals and objectives development; Then it goes on to discuss the critical issues in stream restoration/rehabilitation design, implementation, as well as evaluation, monitoring and long term management.

Chapter Four: Stroubles Creek Restoration Process Plan applies the theories explained in the previous two chapters to actually laying out a process plan for restoring/rehabilitating the Stroubles Creek in the town of Blacksburg, Virginia. The background information of the Stroubles Creek watershed is provided, and the historic studies on the Stroubles Creek are listed and explained. Then a detailed process plan for restoring/rehabilitating the Stroubles Creek is laid out with important steps explained and discussed in order.

Chapter Five: Conclusion summarizes the whole study on urban stream restoration process and discusses limitations of the study.

This article is for studying the nature and methods of urban stream restoration only. The *Stroubles Creek Restoration Process Plan* discussed in this paper is not an official plan.

Chapter Two: Theoretical Background

2.1 Definition

The Federal Interagency Stream Restoration Working Group (1998) defines "restoration" as the "reestablishment of the structure and function of ecosystems." Ideally, ecological restoration is the process of returning an ecosystem as closely as possible to pre-disturbance conditions and functions. In the U.S. "pre-disturbance" usually refers to pre-European settlement (Sweet 2003). However, since ecosystems are dynamic, perfect replication of a previous condition is generally impossible or impractical. The Society for Ecological Restoration Science and Policy Working Group (SER 2002, p2) defines "ecological restoration" to be "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."

Rehabilitation, the re-establishment of important physical, chemical and biological functions or processes, is viewed as the most practical approach to improve the condition of degraded streams in urban contexts (Heaton, et. al. 2002; Booth, Karr, Schauman, et. al. 2001). Frequently, when people discuss "stream restoration" they actually mean "stream rehabilitation".

For example, Riley (1998) describes stream restoration in urban areas as bringing back the physical attributes of a stream that has been degraded (by placement underground in a pipe, being encased in concrete, and/or made devoid of meanders and vegetation by other alterations). Despite differing definitions, the sole purpose of urban stream restoration/rehabilitation is to restore "stream health" by removing or lessening the impact of physical, chemical and biological disturbances.

The use of "stream restoration" in this paper should be taken to mean **assisting recovery by re-establishing important physical, chemical and biological processes.** Sometimes rehabilitation is added (making "restoration/rehabilitation") to remind the reader that these two words are viewed by the author to have similar and compatible meanings.

Physical disturbance includes any human induced disturbances that can change or degrade the streams physically. Physical disturbance effects may occur at any scale from landscape and stream corridor to stream and reach, where they can cause impacts locally or at locations far removed from the site of origin (FISRWG 1998).

Activities such as flood control, forest management, road building and maintenance, agricultural tillage, and irrigation, as well as urban encroachment, can have dramatic effects on the geomorphology and hydrology of a watershed and the stream corridor morphology within it. Dams, channelization and diversion dramatically change the physical nature of stream corridors. Before the mid 20th century, there were many channelization projects in the US. Hydraulic engineers designed these projects hoping to reduce flooding and to enlarge human-used lands where land resources were limited. Their philosophy was to enlarge a natural stream channel by widening and/or deepening it and to smooth the stream channel banks and straighten the course of the stream (Riley 1998).

However, along with this transformation from a natural landscape to an engineered channel, come many problems. Among them are water quality problems (Bohn and Kershner 2001), new and more intense flooding (FISRWG 1998; Randolph 2004; Riley 1998), loss of wildlife habitat (Nechishi et al. 2001), bank erosion, and above all, the loss of ecosystem equilibrium (Riley 1998).

Although storm water regulations and best management practices are assumed to be effective, high aggregation of impervious surfaces and deforestation in the urban area dramatically change stream patterns from their pre-disturbance stage (Riley 1998)

Chemically defined disturbance effects can be introduced through many activities including agriculture (pesticides and nutrients), urban activities (municipal and industrial waste contaminants), and mining (acid mine drainage and heavy metals) (FISRWG 1998; Riley 1998). They have the potential to disturb natural chemical cycles in streams, and thus to degrade water quality (Bohn and Kershner 2001).

Just as the Federal Interagency Stream Restoration Working Group has explained:

> "Chemical disturbances from agriculture are usually widespread, non-point sources. Municipal and industrial waste contaminants are typically point sources and often chronic in duration. Secondary effects, such as agricultural chemicals attached to sediments and increased soil salinity, frequently occur as a result of physical activities (irrigation or heavy application of herbicide). In these cases, it is better to control the physical activity at its source than to treat the symptoms within a stream corridor" (1998, pp 3-6)

Biologically defined disturbance effects occur within species (competition, cannibalism, etc.) and among species (competition, predation, etc.). These are natural interactions that are important determinants of population size and community organization in many ecosystems (Riley 1998).

Biological disturbances due to improper grazing management or recreational activities are frequently encountered. The introduction of exotic flora and fauna species can introduce widespread, intense, and continuous stress on native biological communities (FISRWG 1998).

Water flows through streams but is affected by the kinds of soils and alluvial features within the channel, in the floodplain, and in the uplands (FISRWG 1998). Thus, effective stream restoration planning requires that we have an integrated planning vision and use an ecosystem approach-referencing multiple scales and accounting for site and landscape change over time. Major issues that needed to be recognized in stream restoration strategy includes: history of the site and the people who use it, processes by which the site has changed over time, protecting areas that retain a high degree of ecological integrity, ensuring that all future human uses contribute to overall land/water health (Dahl et al. 2002).

A review of the various literature shows that there are roughly three levels of stream restoration planning and efforts: **watershed restoration/management, riparian restoration, and in-stream restoration** (FISRWG 1998, Sweet 2003).

2.2 Watershed Restoration/Management

A watershed is all land that contributes water to a stream, river or lake. Activities on the land impact the quality and quantity of that water. For example, urban land use disrupts the flow regime, diminishes water quality, and alters stream channels (Snyder 2003). This was proven by most stream research and monitoring work (Bohn and Kershner 2001; FISRWG 1998; McDonnell and Picket 1990; Miltner 2004; Randolph 2004; Riley 1998; Sweet 2003). Stream health is negatively correlated with the amount of urban land use in the surrounding watershed (Miltner et al. 2004). The effects of land use impacts can be manifold.

Since the condition of an urban stream is highly related to different land uses in its drainage area, to improve water quality, rehabilitate riparian habitats, and restore the physical, chemical and biological functions of our streams requires coordinated planning efforts at the whole-watershed level. Understanding the watershed also allows riparian and in-stream works to be done in a more effective and sustainable manner.

Effective watershed restoration/management requires an understanding of land and its relationship to water, and the understanding must be used in defining management programs and actions. The watershed approach provides: an understanding of watershed condition, an assessment of landscape capability, a basis to manage for clean water, the creation of stable ecosystems, and sustainable use of renewable resources (USDA, 2000).

2.3 Riparian Restoration

After understanding the larger picture of the stream's watershed, restoration planners and designers should pay their attention to the riparian corridor.

Riparian restoration focuses on vegetative plantings to create buffers along impaired streams and/or creating wetlands along certain segments of the stream, instead of directly working within the stream channel (FISRWG 1998; Larson et al. 2001; Riley 1998; Sweet 2003).

Snyder et al. (2003) has described a positive relationship between riparian buffers and wetlands and stream integrity, indicating that creating vegetation buffers and/or wetlands:

- Provide shade that reduces water temperature.
- Cause deposition of (i.e., filter) sediments and other contaminants.
- Reduce nutrient loads of streams.
- Stabilize stream-banks with vegetation.
- Reduce erosion caused by uncontrolled runoff.
- Provide riparian wildlife habitat.
- Protect fish habitat.
- Maintain aquatic food webs.
- Provide a visually appealing greenbelt.
- Provide recreational opportunities.

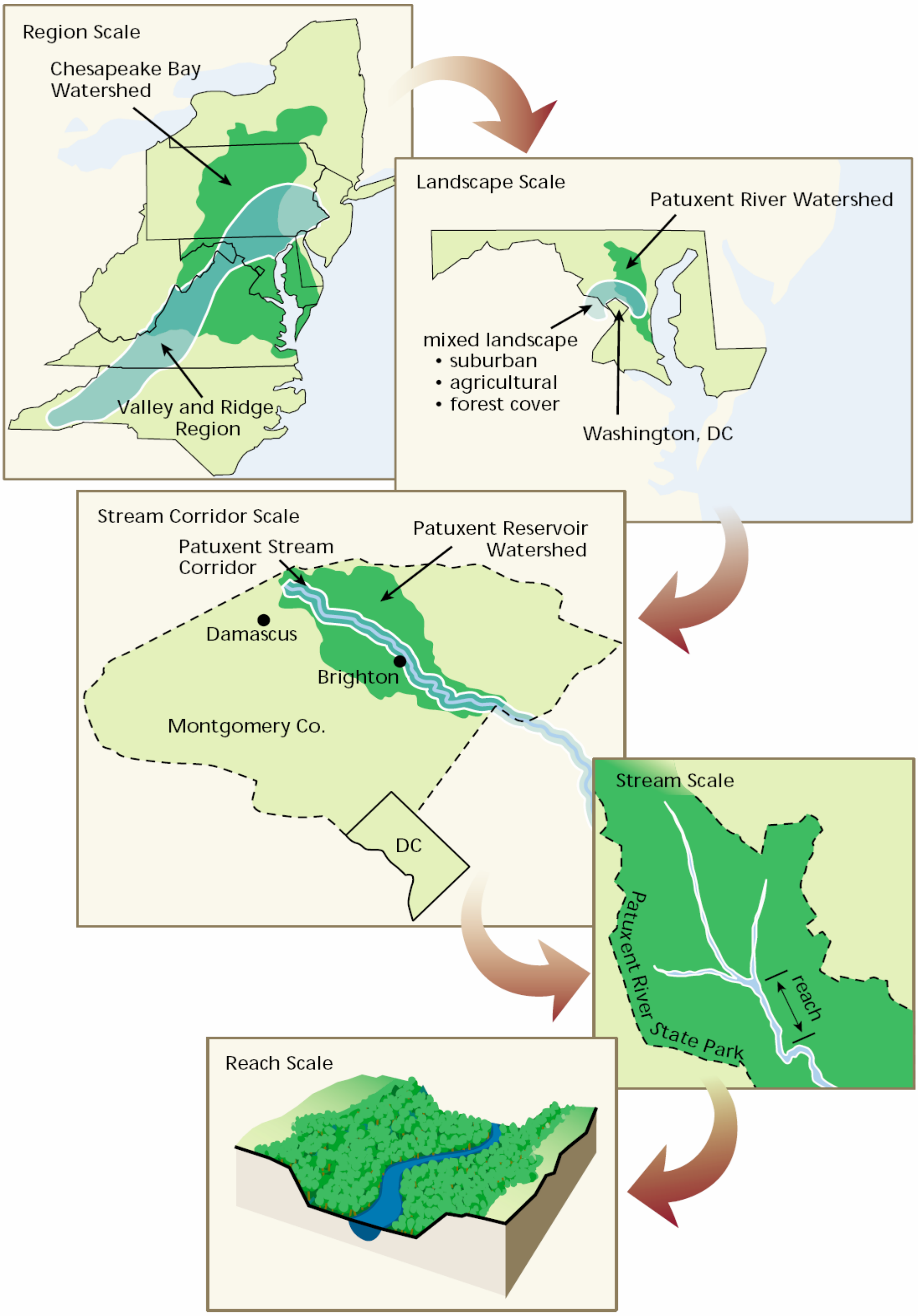

Figure 2-1: Different Spatial Scales of Stream Systems (Source: FISRWG 1998)

Forman (1995) indicates that first-order riparian corridor widths should be based upon the steepness of surrounding slopes, local precipitation rates, the rates of dissolved substance flowing towards the stream, and sources of dissolved substances (such as intermittent streams). Dense, soil-holding vegetation and well structured, organic soils combine to create excellent buffers along streams and rivers. Widths should be greater where the potential for negative inputs are higher.

Although the value of buffer strips is well recognized, often economic and legal considerations have taken precedence over ecological factors (FISRWG 1998). In urban settings buffer sizing criteria may be based on existing site controls as well as economic, legal, and ecological factors.

2.4 In-stream Restoration

In-stream restoration includes stream **channel reconstruction, stream bank restoration, and stream habitat recovery**.

In-stream restoration basically restores the physical nature of the stream channel to its pre-disturbance state (FISRWG 1998; Riley 1998; Sweet 2003). Methods of in-stream channel restoration include: dam removal, levee breaching, modified flow control, vegetative protection of stream banks, etc. (Bennett, et al, 2002; Purcell, et al, 2002).

If land use changes in the watershed or other factors have altered sediment yields or hydrology *and* restoration to an historic channel condition is possible a new channel design is needed, hence **channel reconstruction** (FISRWG 1998; Shields, et al. 2003). The basic procedures for channel reconstruction include (FISRWG 1998):

- Describing the physical aspects of the watershed and characterizing its hydrologic response;
- Considering each stream reach and its constraints, selecting a preliminary right-of-way for the restored stream channel corridor, and computing the valley length and slope;
- Determining approximate bed material sizes and distribution for the new channel;
- Conducting a hydrologic and hydraulic analysis to select a design discharge or range of discharges; and
- Predicting stable plan/form type (straight, meandering, or braided).

In some cases, it might be desirable to divert a straightened stream into a meandering alignment for restoration purposes (Rinaldi and Johnson, 1997; Bennett, 1999). Such cases are numerous. For example, the incised, straightened channel of the River Blackwater (Norfolk, United Kingdom) was restored to a meandering form by excavating a new low-level floodplain about 50 to 65 feet wide containing a sinuous channel about 16 feet wide and 3 feet deep (Hey 1995).

Even where streams retain relatively natural patterns of flow and flooding, **stream bank restoration** might require that stream banks be temporarily (years to decades) stabilized while floodplain vegetation recovers. The objective in such instances is to arrest the accelerated erosion often associated with unvegetated banks, and to reduce erosion to rates appropriate for the stream system and setting. In these situations, initial stream bank protection may be provided primarily with vegetation, wood, and rock. In other cases, land development or modified flows may dictate the use of hard structures to ensure long-term stream stability, with vegetation primarily being used to address specific ecological deficiencies, such as a lack of channel shading (FISRWG 1998).

Habitat is the place where a population of animals lives and includes living (biotic) and nonliving (abiotic) components. Design of channels, structures, or restoration features can be guided and fine tuned by assessing the quality and quantity of habitats provided by the proposed design, hence **stream habitat recovery**. The best approach to habitat recovery is to restore a fully functional, well-vegetated stream corridor within a well-managed watershed. Man-made structures are generally considered to be "less sustainable" and are rarely as effective as channels that are restored to a condition known as "dynamic equilibrium" or relative stability (FISRWG 1998). Studies have shown that in-stream habitat structures, if properly designed, can enhance physical aquatic habitat quality and quantity (Riley 1998; FISRWG 1998; Nechishi et al. 2001; Sweet 2003).

2.5 Case Studies

It is axiomatic that no restoration can ever be perfect; it is impossible to replicate the biogeochemical and climatological sequence of events over geological time that led to the creation and placement of even one particle of soil, much less to exactly reproduce an entire ecosystem (FISRWG 1998). Stream restoration activities are also extremely complex because of the social, economic, and cultural interests related to them. Therefore, every single stream restoration project is an experiment or an exercise that approximately reconstructs the natural ecosystem based on limited knowledge, expertise, and funding sources.

All knowledge is gained by practicing and learning. The following three case studies demonstrated good practice of stream restoration at watershed, corridor and in-stream restoration. The Bluewater Creek project in the state of New Mexico shows thorough analysis at watershed scale and solving problems at in-stream scale to improve the ecosystem of Bluewater Creek. The Lititz Run watershed project in the City of Lancaster, Pennsylvania is a national show case on EPA website (available at: http://www.epa.gov/owow/showcase/lititzrun/). It is a very successful example of involving the community with various interest groups and solving conflict between the urban growth issues and the protection of the urban stream systems. It also shows good practices of riparian corridor restoration and management. The Kingstowne Stream Restoration project in Fairfax County, Virginia shows some innovative an environmental friendly way to treat erosion problems in highly urbanized area.

Although not all of the cases are directly applicable to a small urban stream system like the Stroubles Creek discussed in this paper, the general methodology and experiences described are useful references.

2.5.1. Bluewater Creek Watershed Management, New Mexico

The watershed analysis and subsequent treatments performed at Bluewater Creek, New Mexico, demonstrate successful watershed and stream corridor restoration (FISRWG 1998). The intermixing of federal and private lands, as well as the values and needs of the varied publics concerned with the watershed make it a valuable case study.

Located in the Zuni Mountains of north-central New Mexico, Bluewater Creek drains a 52,042-acre watershed that enters Bluewater Lake, a 2,350-acre reservoir in the East Rio San Jose watershed. The project, begun in 1984, has a record of progress and improved land management. The watershed received the 1997 Chief's Stewardship Award from the Chief of the Forest Service and continues to host numerous studies and research projects.

The watershed has a lengthy history of complex land uses. Between 1890 and 1940, extensive logging using narrow-gauge railroad technology cut over much of the watershed. Extensive grazing of livestock, uncontrolled fires, and some mining activity also occurred. Following logging by private enterprises, large portions of the watershed were sold to the USDA Forest Service in the early 1940s. Grazing, some logging, extensive roading, and increased recreational use continued in the watershed.

The Forest Service, as the major land manager in the watershed, conducted a thorough analysis on the lands it managed and implemented a restoration initiative and monitoring that continue to this day.

The effort has been based on five **goals** (FISRWG 1998):

- Reduce peak flows and prolong base flows,
- Reduce soil loss and downstream channel and lake sedimentation,
- Increase fish and wildlife productivity,
- Improve timber and range productivity, and
- Demonstrate proper watershed analysis and treatment methods.

For analysis purposes, the watershed was divided into 13 subwatersheds and further stratified based on vegetation, geology, and slope. Eight major **conclusions** were drawn from data collection and analysis:

- Areas forested with mixed conifer and ponderosa pine species were generally able to handle rainfall and snowmelt runoff;
- Excessive peak flows, as well as normal flows continually undercut steep channel banks, causing large volumes of bank material to enter the stream and lake system;
- Most perennial and intermittent channels were lacking the riparian vegetation they needed to maintain streambank integrity;
- Most watersheds had an excessive number of roads;
- Trails caused by livestock, particularly cattle, concentrate runoff into small streams and erodible areas;
- Several key watersheds suffered from livestock overuse and improper grazing management systems;
- Some instances of timber management practices were exacerbating watershed problems;
- Excessive runoff in some subwatersheds continued to degrade the main channel.

Figure 2-2: Porous fence revetment designed to reduce bank failure. (Source: FISRWG 1998)

Figure 2-3: Porous fence revetments after two growing seasons. (Source: FISRWG 1998)

Figure 2-4: Multiple elevated culvert array at crossing of wet meadow. (Source: FISRWG 1998)

Treatments such as channel improvements, riparian plantings and pastures, beaver management, meander reestablishment, channel relocation, best management practices were incorporated. The results are satisfactory (FISRWG 1998).

Summary and Lessons Learned

In summary, the case of Bluewater Creek is a good example of watershed analysis and successful stream corridor and in-stream restoration treatment. The project deals with a mixture of federal and private lands, as well as the values and needs of the varied publics concerned with the watershed. Lessons learned are that restoration planners or workers should understand and analyze the problems of the target stream from a watershed scale. Subsequent problem treatment may be conducted more efficient to at a local level (corridor or in-stream).

2.5.2. Lititz Run Watershed, City of Lancaster, Pennsylvania

The Lititz Run Watershed Restoration Project has engaged citizens, scientists, and local and state government agencies as local watershed alliance partners in a coordinated set of 15 restoration projects in key locations throughout the watershed. This community is improving its water quality through a comprehensive long-term watershed management strategy that combined techniques in natural resource management, land use planning, education and community involvement in addressing non-point source pollution (EPA 2002).

The Lititz Run Watershed is in the Central Appalachian Broadleaf Forest, lower piedmont physiographic province of the Northeastern US. Lititz Run is a third order pastoral limestone stream with its main source of water bubbling out of the Lititz Spring Park in downtown Lititz, PA.

Figure 2-5: Location of Lancaster County, PA

With Lancaster County converting from rural to suburban, non-point source pollution associated with stormwater run-off, erosion and sedimentation, and nitrogen and phosphorus loading are responsible for the degradation of Lititz Run. The community of Lancaster is improving its water quality through a comprehensive long-term watershed management strategy that combined techniques in natural resource management, land use planning, education and community involvement in addressing non-point source pollution.

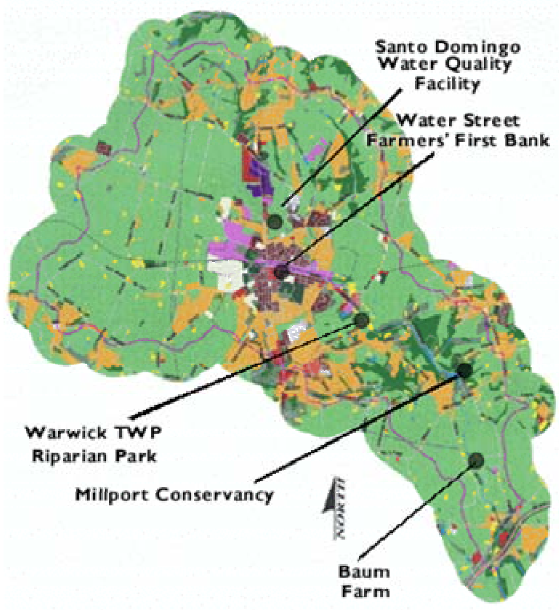

Figure 2-6: The Lititz Run Watershed showing project area locations
(Source: EPA National Showcase Website: http://www.epa.gov/owow/showcase)

A brief list of associated projects (see map) includes agricultural management plans throughout the watershed, natural channel design using fluvial geomorphology, planning and construction of a regional water quality facility, creation of GIS database and mapping of mitigation banking sites and water quality monitoring data, streambank stabilization and establishment of forested riparian buffers along the stream; along with public educational material such as a brochure and video about the watershed as well as a watershed education booklet (1999 rivers conservation plan).

The success of the initiative is evident through the formation of an active community group and receipt of over $400,000 in grants and donations for improving the watershed. Initially, a group of 15 - 20 community residents have met monthly since the year 2000 to discuss watershed issues. This group known as The Lititz Run Watershed Alliance (LRWA) has been very instrumental in soliciting input, support and involvement from citizens, businesses, non-profit affiliations, farmers, and local, county, state and federal governments. With over sixteen individual projects installed or in planning stages, the success of the projects is shown by tangible and intangible results. Tangible results include improvement in water quality as demonstrated in the monitoring program established by faculty and students from the local high school, sighting of a Black Crowned Night Heron at the created wetland of the regional water quality facility, improved wildlife habitat along a restored section of a stream, and the revegetated banks of Lititz Run. Intangible results include the aesthetic beauty of the wetlands and increased community awareness of natural resource issues (EPA 2002).

Summary and Lessons Learned

The Lititz Run watershed project demonstrated a successful case of engaging the citizens and various interest groups into a series of watershed wide stream restoration/water quality protection projects. The lessons learned from this case are that urban stream restoration project often involves conflicting interests. A successful urban stream restoration/protection project always needs to actively engage conflicting interest parties. Good organization and community involvement is the key.

2.5.3. Kingstowne Stream Restoration Project, Fairfax, Virginia

The Kingstowne Stream in the Alexandria portion of Fairfax County suffered considerably from upstream development. The Kingstowne stream is a main tributary of Dogue Creek. It begins behind Edison High School and feeds into the Potomac River, less than six miles downstream. Upstream development has replaced natural vegetation with more and more impervious (nonporous) surfaces, such as roofs, roads, and parking lots. Fewer plants, shrubs, and trees are available to slow down and absorb the flow and to allow infiltration of stormwater into the soil. More and faster water flowing into the stream led to erosion of the material from the bottom and sides of the channel. On its own, the stream would have reshaped itself over time to accommodate the larger volume of runoff, but not before tons of sediment and attached nutrients were carried downstream to the wetlands of Huntley Meadows, the Potomac River, and the Chesapeake Bay.

Figure 2-7: bank erosion before treatment
(Source: Fairfax Co., VA website, 2004)

Figure 2-8: channel treatment
(Source: Fairfax Co., VA website, 2004)

In 1998, Northern Virginia Soil & Water Conservation District (NVSWCD) joined forces with Fairfax County, state and federal agencies, and two citizens groups to implement a demonstration project that would serve as a model for the "softer," more environmentally-friendly approach to solving erosion problems. The project site was chosen on several large properties, which are relatively undeveloped. However, these pieces of properties are quickly being surrounded by newer residential subdivisions. The site analysis and project design took nearly a year to complete. Construction began in October of 1999 and was finished within two months. Through cutting and filling of soil material, this project restored gentle meanders to the stream and raised the level of the channel to reach the floodplain. The project used live plant materials native to the area to stabilize the stream banks.

Today grass is growing on the floodplain, live stakes are in bloom on the banks, and tree and shrub seedlings are maturing. NVSWCD continues to monitor the Kingstowne stream and to participate in similar restoration or stabilization projects.

Summary and Lessons Learned

Although this is a very small project, it shows environmental friendly methods to treat stream erosion problems in the highly urbanized areas. From the impact of urban development, the streams often show down cutting erosion problems. Stabilizing stream bed with boulders and native plants, and recreate natural meander could be a potential way of restoration.

Chapter Three: Urban Stream Restoration Planning

3.1 Overview

Urban stream restoration planning follows the basic four-step process of knowing, as described by John Randolph in *Environmental Land Use Planning and Management* (2004):

- What do we want?
- What do we have?
- What do we do? and
- How do we do it?

The urban stream restoration planning follows the general planning process, which includes (FISRWG 1998):

- Getting organized;
- Identifying problems and opportunities;
- Developing goals, objectives and restoration alternatives; and then
- Implementing, monitoring, evaluating and adapting.

It is also helpful to keep in mind a 12 self answering question steps process to guide a restoration planning, according to Rutherfurd et al. (2000):

Step 1 What are your goals for rehabilitating the stream?
Step 2 Who shares your goals for the stream?
Step 3 How has your stream changed since European settlement?
Step 4 What are the stream's main natural assets and problems?
Step 5 Setting priorities: which reaches should you work on first?
Step 6 What are your strategies to protect assets and improve your stream?
Step 7 What are your specific and measurable objectives?
Step 8 Are your objectives feasible?
Step 9 How will you design your project to achieve your objectives?
Step 10 How will you evaluate your project?
Step 11 How will you plan and implement your project?
Step 12 Has your project worked?

The following flow chart vividly explained the process (Rutherfurd et al. 2000):

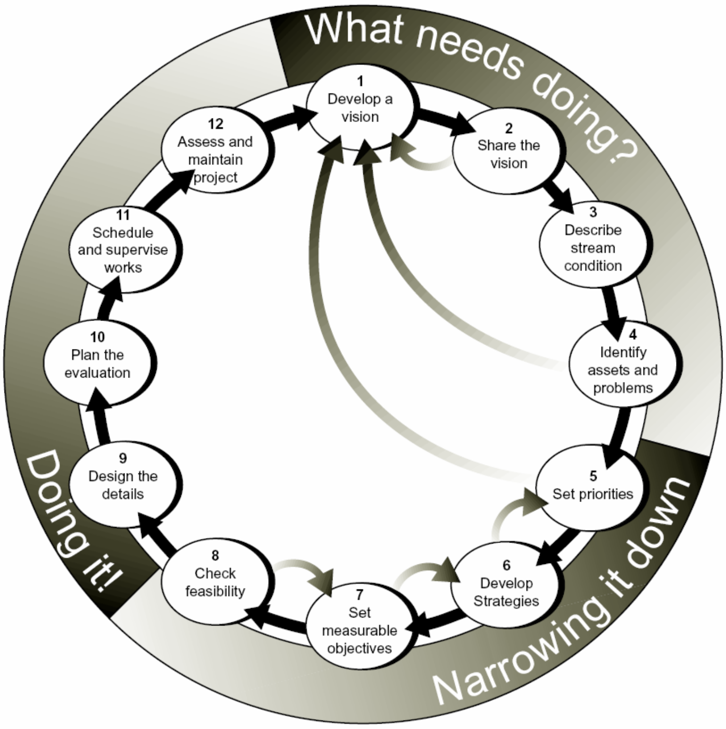

Figure 3-1: 12 step stream restoration/rehabilitation procedure flow chart
(Source: A Rehabilitation Manual for Australian Streams)

3.2 Organizing the Process

To have an effective urban stream corridor restoration/rehabilitation effort, we need a highly organized process for insuring the success of the plan. The key components of organizing and preparing a stream corridor restoration plan involves establishing a planning and management framework to facilitate communication among all involved and interested parties. Such a framework includes (FISRWG 1998):

- Setting boundaries
- Forming an advisory group
- Establishing technical teams
- Identifying funding sources
- Establishing points of contact and a decision structure
- Facilitating involvement and information sharing among participants, and
- Documenting the process.

Ensuring the involvement of all partners and beginning to secure their commitment to the project is a central aspect of "getting organized" and undertaking a restoration initiative. It is often helpful to identify a common motivation for taking action and to develop a rough outline of restoration goals (FISRWG 1998; Riley 1998).

In addition, defining the scale of the stream corridor restoration/rehabilitation initiative is important. Often the issues to be addressed require that restoration be considered on a watershed or whole reach basis, rather than by an individual jurisdiction or one or two landholders (Miltner et al. 2004).

3.3 Identifying Problems and Opportunities

Development of stream corridor restoration/rehabilitation goals and objectives is preceded by an analysis of resource conditions in the corridor. It is also preceded by the formulation of a problem/opportunity statement that identifies conditions to be improved through and benefit from restoration/rehabilitation activities (FISRWG 1998).

Identifying problems and opportunities is the most important step in the stream restoration planning process, since it defines the goals and objectives of the entire project. Problem and opportunity identification can be accomplished by undertaking the following six steps (FISRWG 1998):

1) Data collection and analysis;
2) Definition of existing stream corridor conditions (structure, function and dynamics) and the causes of disturbance;
3) Comparison of existing conditions to desired (short- and long-term) conditions (which may be in the form of a reference condition);
4) Analysis of the causes (disturbances) of the altered or impaired stream corridor conditions;
5) Determination of how management practices might be affecting stream corridor structure, function, and dynamics;
6) Development of both “problem” and “opportunity” statements.

Important steps are discussed in detail below.

3.3.1 Data Collection

Data collection and analysis are important to all aspects of decision making and are conducted throughout the duration of the restoration process. Data collection should begin with a technical team, in consultation with the advisory group and the decision maker, identifying potential data needs based on technical and institutional requirements. The perspective of the public should then be solicited from participants or through public forums (FISRWG 1998; Riley 1998).

Data targeted for collection should generally provide information on both the **historical and baseline conditions** of stream corridor structure and functions, as well as the social, cultural, and economic conditions of the corridor and the larger watershed.

It is also important to identify historical conditions and activities to understand the present stream corridor condition. Historical conditions and/or reference conditions, when compared with the baseline conditions can help determine cumulative effects on the stream corridor’s structure and functions (i.e., hydrologic, geomorphic, habitat, etc.) (FISRWG 1998; Riley 1998; SER 2002).

As stated by the FISRWG (1998) baseline data consist of the existing structure and functions of the stream corridor and surrounding ecosystems across scales, as well as the associated disturbance factors.

The following indicators are important in defining the existing structure and functions of the stream corridor and surrounding ecosystems across scales, as well as the associated disturbance factors (FISRWG 1998; Riley 1998):

- Hydrology

- Erosion and sediment yield
- Floodplain/riparian vegetation
- Channel processes
- Connectivity
- Water quality
- Aquatic and riparian species and critical habitats
- Corridor dimension

3.3.2 Problem Analysis: The Reference Approach

Using a set of reference conditions for the "target" or "proposed" stream and comparing these conditions with current stream corridor conditions helps the project team to more clearly define the conditions within which stream corridor problems (and opportunities) occur and provides a measurable goal or "composite description" (SER 2002, p5) for restoration/rehabilitation planning and evaluation. Use of reference conditions as a model for what is desirable is called a reference approach.

> "The reference condition might be similar to what the stream corridor would have been like had it remained relatively stable. It might represent a condition less ideal than the pristine, but substantially improved from the present condition." (FISRWG 1998, pp 4-20)

The following information sources can be very helpful in defining reference conditions (SER 2002; FISRWG 1998; Riley 1998):

- Published literature may provide information for developing reference conditions.
- Hydrologic data can often be used to describe natural flow and sediment regimes, and regional hydraulic geometry relations may define reference conditions for channel dimensions, pattern, and profile.
- Published soil surveys contain soil map-unit descriptions and interpretations reflecting long-term ecological conditions that may be suitable for reference.
- Species lists of plants and animals (both historical and present) and literature on species habitat needs provide information on the distribution of organisms, both by habitat characteristics and by geographic range.
- Comparison with reference reaches or sites believed to be indicative of the natural potential of the stream corridor. The reference site might be the pre-disturbance condition of the stream to be restored, where such conditions are established by examining relic areas (enclosures, preserves), historical photos, survey notes, and/or other descriptive accounts.
- Nearby stream corridors in similar physiographic settings if those streams are minimally impacted by natural and human-caused disturbances.
- Other stream corridors that have been or are in the process of being restored may also serve as useful references, particularly if detailed documentation of such "case study" sites is available.

After determining a “target stream” by use of the reference approach, a thorough analysis of the cause or causes of stream corridor alterations or impairments is fundamental to identifying management opportunities and constraints and to defining realistic and attainable restoration objectives. As discussed before, the causes of impairment could be at various scales: watershed, stream corridor, and/or reach. Thus, causes of problems should be analyzed at various scales.

3.4 Developing Goals and Objectives for Stream Restoration/Rehabilitation Efforts

After identifying problems and opportunities, goals and objectives should be developed. There are four major steps in development of goals and objectives in stream restoration planning:

- Define the desired future condition.
- Identify scale considerations.
- Identify restoration constraints and issues.
- Define goals and objectives.

3.4.1 Define the Desired Future Condition

The development of goals and objectives should begin with the definition of the desired future condition for the stream corridor and the surrounding landscape (FISRWG 1998). Ideally, the desired future condition should represent the common vision of all participants. The development of this vision statement should be seen as an opportunity for participants to articulate an ambitious ecological vision. This vision will ultimately be integrated with important social, political, economic, and cultural values (Riley 1998).

3.4.2 Identify Scale Considerations

The scale of stream corridor restoration efforts can vary greatly, from working on a short in-stream reach to managing an entire watershed. Because functions of a specific stream bank, reach, or ecosystem are linked to associated ecosystems in the surrounding landscape, goals and objectives should recognize the larger stream corridor and its surrounding landscape.

3.4.3 Identify Restoration/Rehabilitation Constraints and Issues

The process of identifying restoration/rehabilitation constraints and issues is important in that it helps team members and the public understand the limitations associated with establishing specific restoration goals and objectives. Moreover, it provides the information that will be needed when integrating ecological, social, political, and economic values (FISRWG 1998).

The major constraints and issues in stream restoration are both technical and non-technical. Technical constraints include the availability of data and restoration technologies, and limitations of tools or techniques used to analyze or collect stream corridor data (Sweet 2003; FISRWG 1998; Riley 1998). To overcome technical constraints, we need quality control and assurance.

Additional constraints and issues come from non-technical aspects. Non-technical constraints consist of financial, political, institutional, legal and regulatory, social, and cultural constraints, as well as current and future land and water use conflicts.

3.4.4 Define Restoration/Rehabilitation Goals and Objectives

Restoration/rehabilitation goals should be defined by the decision maker(s) with the consensus of the advisory group and input from the interdisciplinary technical team(s) and other participants. In defining realistic restoration goals, it might be helpful to divide these goals into two separate, yet connected, categories—primary and secondary.

Primary goals should follow from the problem/opportunity identification and analysis, incorporate the participants' vision of the desired future condition, and reflect a recognition of project constraints and issues such as spatial scale, the needs found in baseline data collection, practical aspects of budget and human resources requirements, and special requirements for certain target or endangered species (FISRWG 1998).

Secondary goals should be developed to either directly or indirectly support the primary goals of the restoration/rehabilitation effort.

Objectives give direction to the general approach, design, and implementation of the restoration/rehabilitation effort. Objectives should support the goals and also flow directly from problem/opportunity identification and analysis. It is imperative that objectives be realistic for the area or site, and be **measurable** (FISRWG 1998; Rutherfurd et al. 2000). Objectives must therefore be based on the site's expected capability and not necessarily on its unaltered natural potential (FISRWG 1998).

3.5 Stream Restoration/Rehabilitation Alternatives and Design

The successful selection of meaningful alternatives and good design is the key to solve the identified problems, realize restoration opportunities, and accomplish restoration/rehabilitation goals and objectives. The usual approach is to conceptualize, evaluate, and select overall strategies before developing specific alternatives.

In developing alternatives, special considerations should be given to "managing causes" as opposed to "treating symptoms", tailoring restoration design to the appropriate scale (watershed/corridor/stream), and other scale-related issues (FISRWG 1998).

3.5.1 Cause Management or Symptom Treatment

If the causes of impairment can realistically be eliminated, complete ecosystem restoration to a "more natural" condition might be a feasible objective and the focus of the restoration activity will be clear. If the causes of impairment cannot realistically be eliminated (which is likely in the urban context), it is critical to identify what options exist to manage either the causes or symptoms of altered conditions and what effect, if any, those management options might have on the subject conditions (Skabelund 2003).

If it is not feasible to manage the cause(s) of impaired conditions, then mitigating the impacts of disturbance(s) is an alternative method of implementing sustainable stream corridor restoration/rehabilitation. By choosing mitigation, the focus of the restoration effort might then be on addressing only the symptoms of impaired conditions.

3.5.2 Scale Consideration

As discussed earlier, to have effective stream restoration/rehabilitation, restoration designers should consider the target stream in its various scales, from watershed to riparian corridor, then to stream and reach. This requires a good inventory and analysis of conditions and functions on all levels including stream structure (both vertical and horizontal) and human activities within the watershed (Bohn and Kershner 2001; FISRWG 1998; McDonnell and Picket 1990; Miltner 2004; Randolph 2004; Riley 1998; Sweet 2003).

The restoration/rehabilitation design should include innovative solutions to prevent or mitigate, to the extent possible, negative impacts on the stream corridor from upstream land uses. Because it is usually not possible to remove the human activities that disturb stream corridors, especially in urban settings where seemingly detrimental activities like damming, enclosing/culverting, and road crossings are present in the watershed or in the stream corridor itself, restoration/rehabilitation design should provide the best possible solutions for maintaining optimum stream corridor functions while meeting economic and social objectives.

3.5.3 Other Supporting Analyses for Selecting Alternatives

Apart from the above major considerations for selecting appropriate stream corridor restoration/rehabilitation alternatives, there are other supporting quantitative analysis we can do to evaluate all the feasible alternatives and management options. In general, the application of the following supporting analytical approaches ensures the selection of the best alternative or group of alternatives for the restoration initiative:

- Cost-effectiveness and incremental cost analysis
- Evaluation of benefits and long-term management requirements
- Risk assessment
- Environmental impact analysis

3.5.4 Alternative Selection Components

The major components of an effective stream corridor restoration/rehabilitation alternative selection process includes the following (FISRWG 1998):

- Detailed site description containing relevant discussion of all variables having a bearing on that alternative.
- Identification and quantification of existing stream corridor conditions.
- Analysis of the various causes of impairment and the effect of management activities on these impaired conditions and causes in the past.
- Statement of specific restoration objectives, expressed in terms of measurable stream corridor conditions and ranked in priority order.
- Preliminary design alternatives and feasibility analysis.
- Cost-effectiveness analysis for each treatment or alternative.
- Assessment of project risks.
- Appropriate cultural and environmental clearances.
- Monitoring plan linked to stream corridor conditions.
- Anticipated management and maintenance needs and schedule.
- Alternative schedule and budget.
- Provision to make adjustments per adaptive management.

In short, the institutional capacity of the community to undertake "desired restoration/rehabilitation work" must be ascertained in order to determine how to best accomplish stream corridor restoration efforts with available human, financial and technical resources (Skabelund 2003).

3.5.5 Restoration Detailed Design

After selecting the restoration/ rehabilitation alternatives, it is vital to turn these general strategies into detailed designs to achieve the goals and objectives. Design can be defined as the intentional shaping of matter, energy and process to meet an expressed need (FISRWG 1998). Design is especially important because design implement planning and strategies, and connect natural processes and cultural needs through exchanges materials, flows of energy, and choices of land use and management.

Restoration designers should pay specially attention to valley form, connectivity, and dimension; soil properties; plant communities; habitat measures. Design effort can be focused on stream channel restoration design, streambank restoration design, and in-stream habitat recovery design.

3.6 Restoration/Rehabilitation Implementation

Restoration Implementation includes all the activities necessary to execute the restoration design and achieve restoration goals and objectives. Successful restoration implementation demands a high level of advance scheduling and foresight that constitutes planning by any measure (FISRWG 1998; Rutherfurd et al. 2000).

To have successful restoration implementation, it is always important to pay special attention to securing the funding, identifying and selecting the proper tools for restoration implementation, dividing restoration responsibilities, and the installation of restoration measures (FISRWG 1998; Rutherfurd et al. 2000; Riley 1998).

3.6.1 Securing Funding for Restoration/Rehabilitation Implementation

As discussed previously, identifying potential funding sources should be one of the first priorities of the advisory group and decision maker. Thus, it is also critical to use measures to secure the funding sources for restoration implementation at this stage.

An effective measure of securing funding for restoration is linking the available resources to the specific activities that will be part of implementation (FISRWG 1998). So a good restoration planner should categorize the various activities that will be part of the restoration, determine how much each activity will cost to implement, and determine how much funding is available for each activity. When there is not sufficient funding, which is often the case, an effort should be made, however, to prioritize restoration activities, execute them as effectively and efficiently as possible, and document success (Rutherfurd et al. 2000).

3.6.2 Identifying Tools to Facilitate Restoration/Rehabilitation Implementation

Numerous tools are available in stream restoration/rehabilitation. Tools available to the stream corridor restoration practitioner include a mix of both nonregulatory or incentive-based mechanisms and regulatory mechanisms. Some of these tools are: education; technical assistance; tax advantages; cost sharing to individuals; cross-compliance among existing programs; direct purchase of stream corridors or of lands causing the greatest problems; nonregulatory site inspections; direct regulation of land use and production activities; easements; donations; financing.

According to the FISRWG, some of the tips to keep in mind when selecting restoration implementation tools are:

- "Without targeted and effective education programs, technical assistance and cost sharing alone will not ensure implementation.
- Enforcement programs can also be costly because of the necessary inspections and personnel needed to make them effective.
- The most successful efforts appear to use a mix of both regulatory and incentive-based approaches. An effective combination might include variable cost-share rates, market-based incentives, and regulatory backup coupled with support services (governmental and private) to keep controls maintained and properly functioning." (1998, pp6-4).

3.6.3 Dividing Restoration/Rehabilitation Responsibilities

The key points in this step includes: breaking the project (including evaluation) into individual jobs; deciding the order in which the jobs should be completed; deciding who will complete each job (Rutherfurd et al. 2000).

The restoration/rehabilitation project is defined as a set of solutions and strategies that you have decided on to meet the objectives. Each of these solutions and strategies should be broken down into a series of jobs, each of which embodies one 'deliverable' of the project (Rutherfurd et al. 2000).

According to FISRWG and *A Rehabilitation Manual for Australian Streams*, it is also important to prioritize and decide the order of the jobs. When doing this, check for prerequisite jobs, identify 'key' jobs, which are essential to the restoration/rehabilitation project, determine how long will each job take, and also see if some jobs can be done to save time and work more efficiently (Rutherfurd et al. 2000). Besides, a good flow chart will help organize the timing and process.

Decide who the right person is for each individual job is also crucial to insure the success of the project. It is helpful to set up a responsibility column, because it ties people to the project for its duration. They can see how long the project goes for and what is expected of them. They will also be able to see if they have too many simultaneous tasks to complete (FISRWG 1998; Rutherfurd et al. 2000).

3.6.4 Installing Restoration/Rehabilitation Measures

A final element of stream corridor restoration implementation is the initiation of management and/or installation of restoration measures in accordance with the restoration design.

Whatever the scale of the restoration/rehabilitation action, the process of installing restoration/rehabilitation typically involves several stages. These stages generally include site preparation, site clearing, site construction, and site inspection (FISRWG 1998; Rutherfurd et al. 2000). Each stage must be carefully executed to ensure successful installation of restoration measures.

Some of the major steps in planning restoration/rehabilitation installations are: determining the schedule, obtaining the necessary permits, holding pre-installation conferences, involving property owners, securing site access, locating existing utilities, confirming sources and ensuring material standards (FISRWG 1998).

3.7 Restoration/Rehabilitation Evaluation, Monitoring, and Management

Stream restoration planning cannot be considered complete without the plans for evaluation, monitoring, and adaptive management (FISRWG 1998; Rutherfurd et al. 2000). Evaluation, monitoring, and adaptive management are essential components that must be undertaken to ensure the success of stream corridor restoration.

Restoration/rehabilitation evaluation and monitoring is important for three reasons. First, evaluation ensures people can learn from the experience of the project. Second, evaluation ensures that planners and designers, funding agencies, and the public, will know if the project has achieved its aims. Third, monitoring, or continuous evaluation can help the project be adjusted and improved as it goes along (FISRWG 1998; Rutherfurd et al. 2000).

3.7.1 Define Measurable Objectives

When it comes to evaluation, monitoring, and adaptive management, several key points must be remembered. First, it is very important to have measurable objectives. You want to be exactly sure what you want from your project and what to measure. According to Rutherfurd et al. (2000), evaluation can measure outputs (what you did) or outcomes (change that occurred because of what you did).

> "…The temptation is to believe that all of your objectives need to relate to outcomes—changes in the stream (e.g. decreased erosion rate), change in creatures in the stream (e.g. more fish), or even aesthetic improvements. In reality, outputs, such as execution of the project, and survival of the works, can also be evaluated…" (Rutherfurd, et al. 2000, pp167)

3.7.2 Design Restoration/Rehabilitation Evaluation, Monitoring, and Management Program

Important points to keep in mind in designing a restoration/rehabilitation evaluation, monitoring, and adaptive management program:

- *Sampling before and after restoration/rehabilitation*, which is the main way to tell if the restoration/rehabilitation really caused a difference to the stream;
- *Setting up control/reference site(s)* (a control, or a reference, is a site that is as similar as possible to the restoration/rehabilitation site, but is not influenced by the restoration/rehabilitation. The control site will tell whether restoration/rehabilitation has made a difference.) (Rutherfurd et al. 2000);

A good evaluation, monitoring, and management program should be able to answer the following questions:

- *What should you measure?* (The evaluation needs to indicate if the objectives of the project have been met.)
- *How frequently should you measure?* (There are two possible sampling strategies: sample at regular intervals, which will show up trends and variation in the data; or, sample after any flood events greater than a certain size.)
- *How long should your evaluation go?* (Monitor until the stream has responded in full to the rehabilitation project.)
- *Who will take the measurements?* (The people responsible for the evaluation must have the necessary expertise to use the chosen techniques, the persistence, and objectivity.)

- *How will they record the results?* (It is very important to have a standard recording sheet for data collection, especially during fieldwork.)
- *How will you analyze the information?* (It is vitally important to have considered the analysis at the planning stage of your evaluation, as many statistical techniques are restricted in the sorts of data they can handle.)

In conclusion, as SER has indicated during the restoration/rehabilitation planning process, it is crucial to have "explicit/detailed plans, schedules and budgets for site preparation, installation and post-installation activities" (2002, p8). Further more, it is equally important to set up "performance standards, with monitoring protocols by which the project can be evaluated" and "strategies for long-term protection and maintenance of the restored ecosystem." (SER, 2002, p8)

Chapter Four: Stroubles Creek Restoration Process Plan

4.1 The Stroubles Creek Background Information

4.1.1 The Stroubles Creek Watershed

The Stroubles Creek locates in the heart of town of Blacksburg. The watershed is a heavily urbanized watershed. The Stroubles Creek Water Initiative (SCWI), originated by the Virginia Water Resources Research Center at Virginia Tech, has been monitoring the creek for a number of years. The detailed background information of Stroubles Creek watershed can be found on the SCWI website (http://www.vwrrc.vt.edu/awra/SCWI/watershed/watershed.html) as well as its publications.

According to the SCWI (2001), the Stroubles Creek watershed is a small sub-watershed (5,802 hectares or 14,336 acres) within the New River watershed in southwest Virginia. The upper reaches of Stroubles Creek are located in the heart of Town of Blacksburg and the creek flows down into Montgomery County, Virginia where the watershed is characterized by limestone/dolomite formations, sink holes, and natural springs. The Stroubles Creek bed is alluvium-flood-plain deposits of stratified unconsolidated sand, silt, and clay with beds and lenses of pebbles and cobles.

The freshwater stream, Stroubles Creek, runs about 9.2-miles in length, through urban and urbanizing areas of Blacksburg, the university (Virginia Tech), and agricultural and rural areas and discharges into the New River. According to the SCWI (2001), major land use changes have occurred within the Stroubles Creek watershed during the past one-hundred years, primarily residential and agricultural development. In 1900, the urban land use was insignificant; the town was a few square blocks, and the university consisted of a few buildings and experimental agricultural fields. From the mid 1800s to 1930s, deep coal mining was an active industry in the watershed. The current land use in the Stroubles Creek watershed is 40% forest, 29% agriculture, 19% urban, 0.24% water, and 12% unknown, according to the SCWI report (2001).

One event of significant ecological consequence occurred in 1937 when the natural course of the central branch of Stroubles Creek was altered and partially covered (physical disturbance) in order to accommodate building a drill field on the Virginia Tech campus (SCWI 2001). At about the same time, a small dam was built to expand an existing small pond, the Duck Pond, for recreational purposes. The pond serves as a stormwater management facility for urban runoff from the town of Blacksburg and parts of the university.

According to DEQ water quality monitoring reports, a 4.87 miles segment of the stream in the lower part of the Stroubles Creek watershed violates benthic standards and included the segment in Virginia's Section 303(d) impaired list (DEQ 1998). The impaired segment begins at the edge of Virginia Tech's the main campus, just below its Duck Pond. The speculated impairment source is nonpoint source pollution from agricultural activity and increased urbanization of the upper portion of the watershed. Sinking Creek, a pristine freshwater stream in Giles County, Virginia within the same ecoregion was used as a reference to determine the impairment status for Stoubles Creek.

4.1.2 Historic Studies on the Stroubles Creek

The SCWI report (2001) also conducted a review on historical studies done on Stroubles Creek watershed. According to SCWI, in the oldest available report investigated the water quality and self-purification of Stroubles Creek, Sutton (1914) observed high concentrations of Bacillus coli-bacterium in Stroubles Creek water and attributed the presence of bacteria to effluent from the university septic tanks, privies, and runoff from nearby horse stables. Later Taft (1949) reported immediate water quality recovery as indicated by increased dissolved oxygen and decreased biochemical oxygen demand when the septic system was replaced with a sewage treatment plant that started operating about 2.8 miles downstream from the septic field.

Subsequently, several studies were performed on the ecology and water quality of Stroubles Creek (Kelsey, 1973; Hayles, 1973; Hoehn et al., 1975; Woodside, 1988). Kelsey (1973) investigated the effects of chlorinated municipal sewage effluent on Stroubles Creek water and its impact on aquatic life in the lower part of the watershed (below the old sewage treatment plant) using bluegill fish (Leopmis macrochirus) and the benthic organism, coperculate snail (Goniobasis), as indicators. The study concluded that during the warm water (>8 C°) portion of study, the dissolved oxygen concentrations in the stream were more than adequate to sustain aquatic life, but a chlorine residual toxic to most forms of aquatic life existed for a distance of 4.84 miles downstream from the treatment plant outfall. During the cold water (<8 C°) portion of the study, a chlorine residual toxic to most forms of aquatic life existed for a distance of 6.26 miles downstream from the treatment plant outfall. Hayles (1973) reported high levels of pollution in the upper urbanized parts of the watershed (above the old sewage treatment plant) using seven macroinvertebrate taxa (Ephemeroptera, Odanata, Plecopetra, Megalopetra, Coleoptera, Tricoptera, and Diptera) as indicators to determining the degree of pollution in Stroubles Creek.

From the above information, we can conclude that the Stroubles Creek watershed was impaired in the following ways:

1) **The natural landscape of the watershed was disturbed by land use changes activities in the past 100 years such as agriculture, urbanization, and mining;**
2) **The course of central branch of the creek was altered and partially covered (physical disturbance);**
3) **There are wild life species disturbed by these impacts.**
4) **The water quality of the creek was also impaired, with its main impaired segments in the urbanized areas.**

These existing studies and conclusions drawn are vital to planning the process of the Stroubles Creek Restoration/Rehabilitation.

4.1.3 Thoughts on the Stroubles Creek

The general process discussed in this chapter from getting organized, identifying problem and opportunities, developing goals and objectives to restoration designing, implementing, monitoring and management shall apply to the restoration and rehabilitation of the Stroubles Creek. However, because of the special characteristics of the Stroubles Creek and the unique situation of the Town of Blacksburg, certain steps of the restoration process shall be emphasized.

First, it is especially important to set up advisory groups so that the different interest groups in the Town of Blacksburg (including experts from the university community) will be actively engaged from the beginning of the project. Being a stream system in a highly urbanized area, the Stroubles Creek runs through numerous different properties of different jurisdictions, including town, county, state (VPI), and private land.

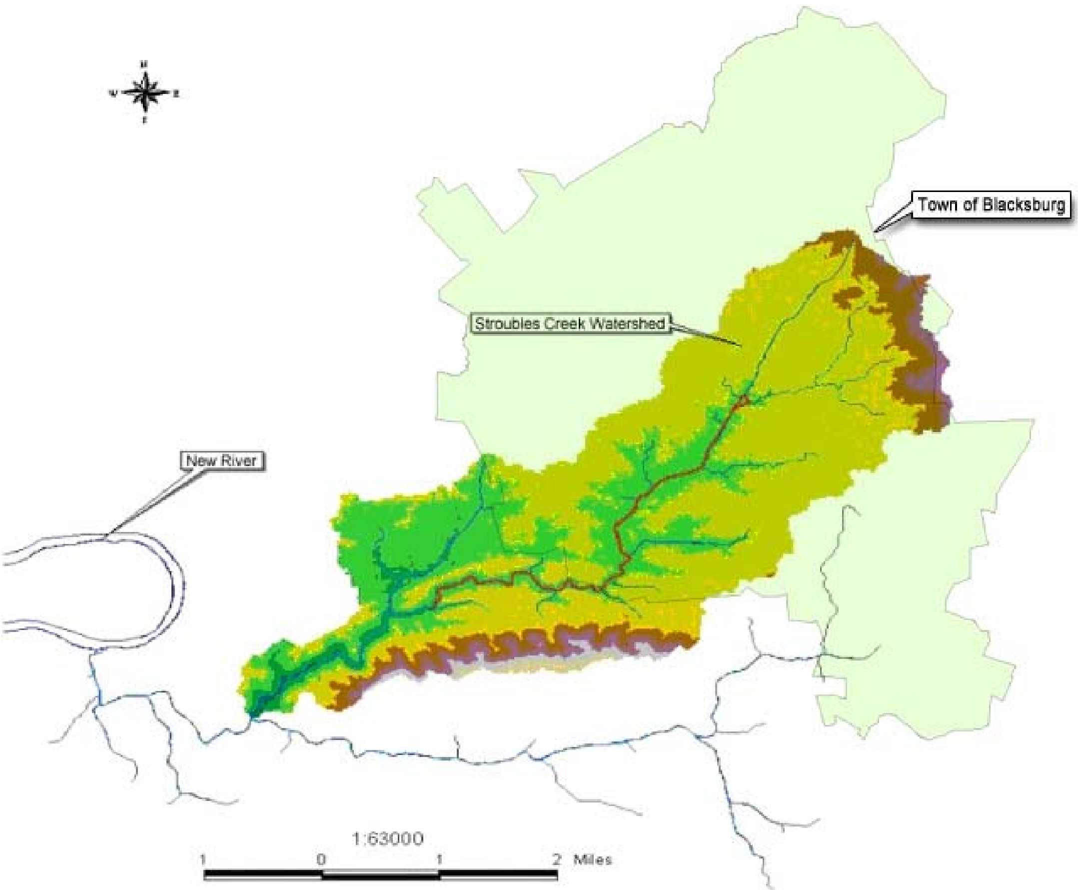

Figure 4-1: Location of Stroubles Creek Watershed and Town of Blacksburg

Second, because there are limited stream restoration expertise in the local government of the Town of Blacksburg and Montgomery County, it is especially important for the decision makers to identify restoration technical expertise resources at the beginning of the project, and also develop realistic goals and objectives. As a prestigious university, Virginia Tech has both academic and professional expertise in the area of environmental science, landscape architecture and planning. It will be an important resource for technical advisory for the Stroubles Creek restoration project.

Third, as most projects do, the Stroubles Creek restoration project probably will face the fact of insufficient funding. So, it is very vital to set up realistic goals and objectives for the project, prioritize each objective, and break down the whole project into various phases. Finish the job one step at a time.

4.2 Process Organization

4.2.1 Setting Boundaries

Integrating these disciplines will be an important resource for technical support during work on the Stroubles Creek restoration project (a long-term endeavor).

As discussed in the first chapter, to have effective stream restoration/rehabilitation work must be done on three scales: watershed, riparian, and stream/reach. To address the primary source of degradation, Stroubles Creek restoration should be focused on the urbanized portion of the watershed. Thus, for the purpose of watershed analysis and effective restoration, the boundary of the Stroubles Creek restoration/rehabilitation project should be the portion of the watershed within the Town of Blacksburg.

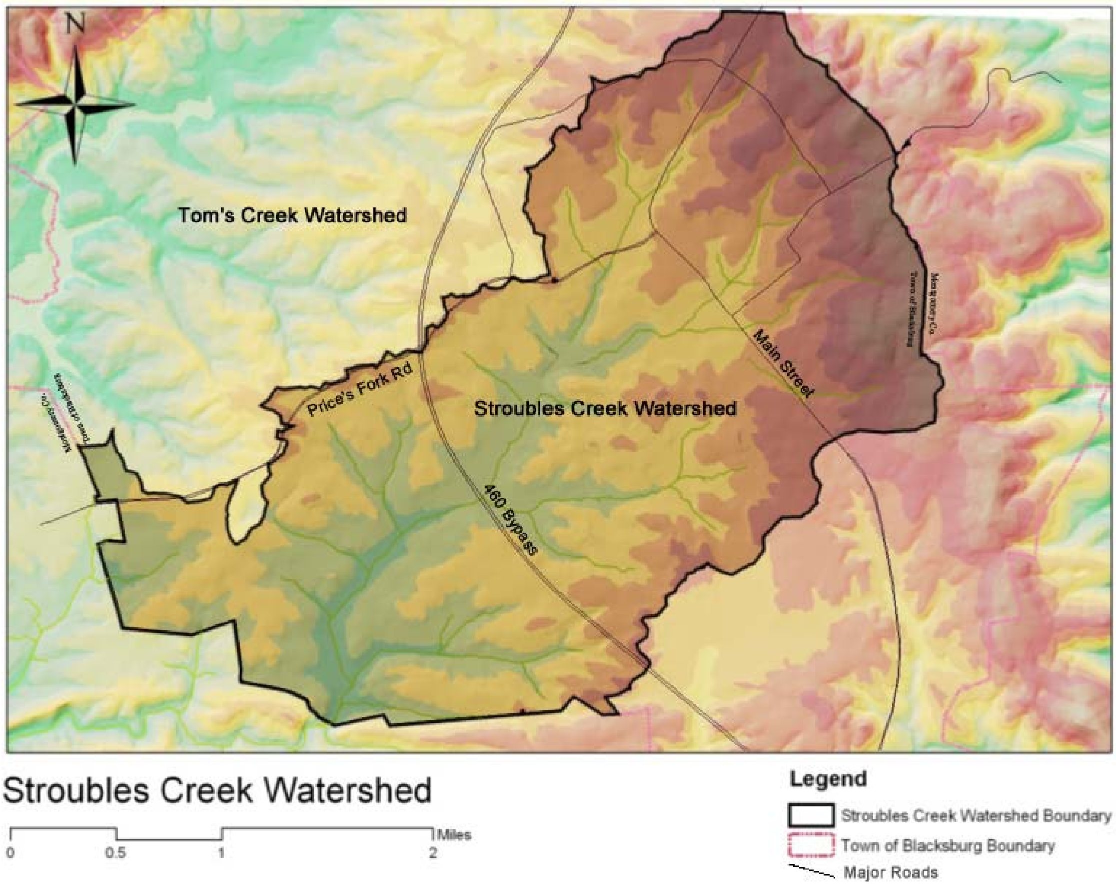

Figure 4-2: Stroubles Creek Watershed within the Town of Blacksburg

4.2.2 Forming an Advisory Group

The appropriate advisory group of the Stroubles Creek Restoration/Rehabilitation Plan project should include representatives for:

- Private local citizens of the town of Blacksburg, VA;
- Public interest groups

- Public officials of the Town of Blacksburg and Montgomery County, VA
- Economic interests groups
- University expertise

To insure successful public/community involvement, local citizens of the town of Blacksburg should be enlisted and informed to the extent that their values and preferences drive decision making with technical guidance from agency participants.

The advisory group generally meets for the following purposes: carrying out the Stroubles Creek restoration/rehabilitation planning activities; coordinating plan implementation; identifying the public's interest in the restoration effort; making diverse viewpoints and objectives known to decision makers; ensuring that local values are taken into account during the Stroubles Creek restoration/rehabilitation process.

Since the Stroubles Creek Watershed Initiative of Virginia Water Resources Research Center has done previous researches on the Stroubles Creek, their expertise and research results shall be a part of and a useful resource to the advisory group.

It is the responsibility of the decision maker, the Town of Blacksburg, to identify and organize the members of the advisory group.

4.2.3 Establishing Technical Teams

To insure successful restoration/rehabilitation of the Stroubles Creek, a team with a broad technical background is needed and should include expertise in both engineering and biological disciplines, particularly in aquatic and terrestrial ecology, hydrology, hydraulics, geomorphology, and sediment transport. University expertise of Virginia Tech is also a vital resource to the technical teams.

4.2.4 Identifying Funding Sources

Although the Stroubles Creek is a local stream, its impaired stream segments are listed in the DEQ's impaired stream list. Funding of a restoration/rehabilitation project of the Stroubles Creek may come from VA state or federal sources that have recognized the need for restoration due to the efforts of local citizens' groups. Funding may also come from Town of Blacksburg or Montgomery County. Philanthropic organizations, nongovernmental organizations, landowners' associations, and voluntary contributions are other funding sources.

Specific grant/project proposals should clearly explain the need for reclamation/restoration and should describe previous monitoring, planning/design, and on-site restoration efforts by Virginia Tech faculty/students, special interest groups, local citizens, and others.

4.2.5 Establishing Points of Contact and a Decision Structure

> "The primary decision-making authority should reside in the hands of the stakeholders." (FISRWG 1998).

For the Stroubles Creek restoration/rehabilitation project, both decision makers and advisory groups should establish some basic protocols to facilitate decision making and communication.

Within each group some of the following rules of thumb apply:

- Select officers
- Establish ground rules
- Establish a planning budget
- Appoint technical teams

In addition, the sponsor, advisory group, and relevant subcommittees need to establish points of contact.

4.2.6 Facilitating Involvement and Information Sharing Among Participants

The whole planning process shall operate under the principles of both information giving and information receiving. Tools can be used for receiving input include: public hearings; task forces; training seminars; surveys; focus groups; workshops; interviews review groups; referendums; phone-in radio programs; internet web sites, and etc. Tools can be used for informing participants includes: public meetings; internet web sites; fact sheets; news releases; newsletters; brochures; radio or TV programs or announcements; telephone hotlines; report summaries; federal register, and so on.

4.2.7 Documenting the Process.

The whole Stroubles Creek restoration/rehabilitation process should be documented, and organizers should keep track of activities as they occur. An effective way to identify important restoration issues and activities as well as keep track of those activities is through the use of a "restoration checklist" (National Research Council, 1992).

4.3 Problems and Opportunity Analysis

4.3.1 Data Collection

Baseline data collection

Baseline data that provides an accurate account of existing conditions of Stroubles Creek should be collected. The data need to be collected include physical conditions data (hydrology, erosion and sediment yield, corridor dimension, channel processes, connectivity, floodplain/riparian vegetation); chemical conditions data (water quality); and biological conditions data (aquatic and riparian species and critical habitats). In addition, land use land cover data about the entire watershed should also be collected.

Baseline data can be collected by conducting stream reach physical, chemical, or biological surveys. In addition, the Virginia Water Resources Research Center as well as other agencies monitors and maintains Stroubles Creek stream condition data, and can be a potential data source. Arial and satellite photos are also helpful.

Historic data collection

During the same time of collecting baseline data, historic data about pre-disturbance condition on Stroubles Creek should also be collected. Historic photographs of the creek, corridor conditions, and watershed conditions are ideal. Text descriptions concerning the natural environment about the Stroubles Creek and town of Blacksburg are also desirable.

Social, cultural and economic data collection (Stroubles Creek corridor and its watershed)

Properly designed surveys of social attitudes, values, and perceptions can be used to collect social, cultural and economic data collection (Stroubles creek corridor and its watershed). In addition, we also could use help from interested participants and stakeholders, get their opinions.

4.3.2 Definition of Existing Stream Corridor Conditions and the Causes of Disturbance

After collecting the baseline and historical data about Stroubles Creek, typical stream reaches which best represent the stream corridor conditions of Stroubles Creek should be identified and selected. For example, one or more typical reaches should be selected to best represent Stroubles Creek's reaches in the Virginia Tech campus area. Several stream reaches should also be selected to represent the stream conditions within the downtown area. Reaches representing headwater and downstream areas should also be selected.

Figure 4-3: Piped Stroubles Creek stream segments in the downtown Blacksburg area (near Blacksburg police station)

Figure 4-4: Diverted Stroubles Creek stream segment near Price’s Fork Rd.

Figure 4-5: Stroubles Creek piped underground in the Virginia Tech Campus

Figure 4-6: Segments of Stroubles Creek covered under the Drill Field, Virginia Tech.

Figure 4-7: Downstream of Stroubles Creek near Foxridge/Hethwood

Figure 4-8: Downstream of Stroubles Creek near VPI farm

4.3.3 Analyze the Problems of the Stroubles Creek by the Reference Approach

Pre-disturbance/historic condition of the Stroubles Creek, as well as less disturbed existing reach of the Stroubles Creek can be used as a reference reach for restoring/rehabilitating the Stroubles Creek. If a relatively undisturbed or less disturbed reach cannot be found, we should find an undisturbed or less disturbed stream reach of another stream that has the similar context with the Stroubles Creek (same order stream, similar scale, and also in the similar urban context). The existing land use land cover of the Stroubles Creek watershed within the town of Blacksburg area should also be compared with the land use conditions before the intensive development of the century.

By comparing the existing condition with the reference condition, the causes (disturbances) of the altered or impaired Stroubles Creek stream corridor condition can be analyzed. The causes or disturbances that affect the Stroubles Creek expect to be in three levels of scales, watershed level, riparian level and stream/reach level.

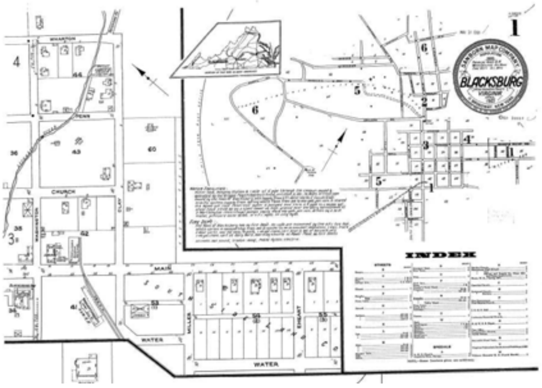

Figure 4-9: Using historical photo as a reference (Source: Sanborn Map, 1921)

Figure 4-10: Less disturbed Stroubles Creek segment on West property, a possible reference site.

4.3.4 Determination of Management Role on Stream Recovery

For each reach of Stroubles Creek, decisions should be made on the roles of management: cause management, symptom mitigation with additional treatment, or symptom management without treatment.

The determination of management role on stream corridor structure, function and dynamics became important when it comes to restoring a stream in a highly urbanized area like Stroubles Creek. Attentions should be paid to the urban context of the restoration effort. For example, it might never be possible to restore the piped segments of Stroubles Creek under the Drill Field on Virginia Tech campus. In some places near downtown area, there may not be enough space to re-create a natural stream channel for Stroubles Creek. Thus, more effort should be paid on managing and mitigating the impact of impervious surfaces within highly urbanized areas, while in the more rural areas of the town, efforts can be used on restoring Stroubles Creek's natural channels.

4.3.5 Problems and Opportunity Statement

A concise problems/opportunity statement of the Stroubles Creek restoration/rehabilitation should be developed after finishing the above steps. The statement(s) should describe impaired Stroubles Creek corridor conditions that are stated in measurable units and can be related to specific processes within its corridor. This statement should also describe deviations from the desired reference condition (reaches experiencing relative dynamic equilibrium) and the "properly functioning condition" for Stroubles Creek along each impaired section of the stream.

4.4 Goals and Objectives

4.4.1 Define Restoration/Rehabilitation Vision Statement for the Stroubles Creek.

A Stroubles Creek restoration/rehabilitation vision statement should be made with the participation of all the stakeholders and participants. The development of this vision statement is an opportunity for participants the community of town of Blacksburg to articulate an ecological vision. This vision should also consistent with town of Blacksburg's social, political, economic, and cultural values.

4.4.2 Identify Constraints and Issues.

At this stage of the planning process, it is also appropriate to involve the public to identify and recognize any constraints and issues that are related with the Stroubles Creek restoration/rehabilitation project. Technical constraints include the availability of data and restoration technologies, and limitations of tools or techniques used to analyze or collect stream corridor data; while the nontechnical constraints include financial, political, institutional, legal and regulatory, social, and cultural constraints, as well as current and future land and water use conflicts.

4.4.3 Define Goals and Objectives.

Then the Stroubles Creek restoration/rehabilitation goals should be defined by the Town of Blacksburg decision makers with the involvement of the advisory group and input from the interdisciplinary technical teams and other participants. To make the restoration/rehabilitation goals realistic, they should be divided into primary goals and secondary goals.

The Stroubles Creek restoration/rehabilitation objectives should also be defined with the involvement of the advisory group, technical teams and other participants. The restoration/rehabilitation objectives should be clear, concise, feasible, measurable and supporting the goals and problems/opportunities statements.

4.5 Restoration/Rehabilitation Design

4.5.1 Design Elements of the Stroubles Creek Restoration/Rehabilitation

The Stroubles Creek Restoration/Rehabilitation Detailed Design Plan should consider at least the following elements:

- Design the spatial dimensions of the Stroubles Creek corridor restoration, including: valley form, connectivity, dimensions, and how will it correspond with the surrounding landscape.

- Analyze the soil properties in the watershed and riparian corridor.
- Design the plant communities in the Stroubles Creek riparian corridor, ensuring all landscape functions are addressed.

4.5.2 Components of the Stroubles Creek Restoration/Rehabilitation Design

The Stroubles Creek Restoration/Rehabilitation Detailed Design plan could be incorporate the following components:

Managing Land Use in the Watershed

Manage and mitigate the land use impact to Stroubles Creek. To minimize the impact of the existing and future urban development to the Stroubles Creek, codes and design standards should be incorporated to the properties in the drainage basin of the Stroubles Creek. Low Impact Development (LID) practices and stormwater management measures can help mitigate the impact of existing and future urban development. LID practices should be used extensively on newer urban developments. LID practices and stormwater management help to hold more water in the upstream areas, provide greater baseflow, and help purify water. Such LID practices, especially within future residential, commercial and institutional developments in the few undeveloped parcels in the headwater area would serve as models of "water-sensitive" development.

Stream Channel Restoration

If possible, design to restore the Stroubles Creek stream segments that are channelized, piped or buried underground to their natural conditions. If not possible to do this, measures should be taken to mitigate the impact of channelization onsite or offsite, for example, using filtration techniques, and/or vegetation buffers offsite.

Streambank Restoration

In severely eroded areas, design streambank restoration treatment, e.g. bank stabilization. These bank stabilization projects should use environmental friendly approaches, such as the use of vegetation for stabilization. However, there will be occasions where there is not enough space for these approaches, alternative approaches should be used.

In-stream Habitat Rehabilitation

Decide whether in-stream habitat structure is needed for the Stroubles Creek. Design or select the type and way of installation of in-stream habitat structure for the Stroubles Creek if necessary.

These series of project designs should be recognized as an opportunity for public education and involvement. Demonstration projects should start with the recognition of citizens and stakeholders.

4.6 Implementation and Installation

4.6.1 Secure Funding for the Stroubles Creek Restoration/Rehabilitation

Link the available resources to the specific Stroubles Creek Restoration/Rehabilitation activities that will be part of implementation. Categorize the various activities that will be part of the restoration, determine how much each activity will cost to implement, and determine how much funding is available for each activity.

If there is not sufficient funding, prioritize restoration activities and execute them as effectively and efficiently as possible.

4.6.2 Identify Regulatory and Non-Regulatory Tools to Facilitate Implementation

Identify, choose, or design an array of regulatory and non-regulatory tools to facilitate the implementation of the Stroubles Creek Restoration/Rehabilitation project. Some of the tools available are: education; technical assistance; tax advantages; cost-share to individuals; cross-compliance among existing programs; direct purchase of stream corridors or of lands causing the greatest problems; non-regulatory site inspections; peers; direct regulation of land use and production activities; easements; donations; financing.

4.6.3 Assign Restoration/Rehabilitation Responsibilities

Break the Stroubles Creek Restoration/Rehabilitation project (including evaluation) into individual jobs; then decide the priority and the order in which the jobs should be completed, considering limited time and funding availability.

When doing this, a flowing chart that recognize the timing and process of the project should be developed; finally, decide who will complete which job, when doing this, set up a responsibility column, which ties people to the project for its duration.

4.6.4 Implementation Considerations

The installation of the Stroubles Creek restoration/rehabilitation will involve four major stages: site preparation, site clearing, site construction, and site inspection. However, before these actual installation stages, proper installation planning should be conducted. These will include: determining the schedule, obtaining the necessary permits, holding pre-installation conferences, involving property owners, securing site access, locating existing utilities, confirming sources and ensuring material standards.

4.7 Evaluation, Monitoring and Management

The final step in the Stroubles Creek Restoration/Rehabilitation process is to design an evaluation, monitoring and management plan.

4.7.1 Evaluating and Monitoring Success

Set up performance standards and monitoring protocols to evaluate the Stroubles Creek Restoration/Rehabilitation project. The protocols should regulate the following:

- A series of indicators that can be measured to evaluate whether the project has fulfilled its objectives;
- The sampling and measuring of the indicators should be conducted on a regular basis;
- The results of the measurement should be compared to appropriate performance standards;
- Assigning responsibility of sampling and taking measurement, and expertise requirement standards of the people taking measurement;
- Standardized recording sheet for taking measurements;
- The way of analyzing the samples taken and measurements.

The evaluation and monitoring plan should also require that sampling should be conducted both before and after the restoration/rehabilitation project. Reference sites should also be set up.

4.7.2 Long Term Protection and Management

Strategies for long-term protection and maintenance of the restored ecosystem of Stroubles Creek should be set up. Protection and maintenance protocols should be set up to protect the restored Stroubles Creek riparian corridor from future human and natural disturbances. The protocols should be able to protect any habitat rehabilitating structures, bank stabilization facilities, and all other installations made during the Stroubles Creek restoration/rehabilitation process. The protocols should also be able to help regulate ongoing maintenance and protection of the riparian vegetation along Stroubles Creek. Finally, the protocols should coordinate the relationship of human riparian recreation and stream habitat protection.

Chapter Five: Summary and Conclusion

Streams along with closely associated floodplain and upland areas, comprise corridors of great economic, social, cultural and environmental value. These corridors are complex ecosystems that include the land, plants, animals, and network of streams within them. They perform a number of ecological functions such as modulating stream flow, storing water, removing harmful materials from water, and providing habitat for aquatic and terrestrial plants and animals.

Stream corridors evolve in response to changes in its surrounding ecosystem. Changes within its surrounding ecosystem, for example, its watershed, will impact the physical, chemical, and biological process occurring within a stream corridor. Among the various impacts, the most important and dramatic impacts to stream systems are the human induced physical, chemical and biological disturbances. Physical disturbances, which include, intentional or unintentional changes to the channel formation, land use changes to stream watersheds, changes to the riparian vegetation, and so on, will change the flow regime, sediment movement, temperature, and other variables, in what is termed "dynamic equilibrium." Chemical disturbances, also highly associated with urban and agricultural activities, have the potential to disturb natural chemical cycles in streams, and thus to degrade water quality. Biological disturbances due to improper grazing management or recreational activities, such as, introduction of exotic flora and fauna species, can introduce widespread, intense, and continuous stress on native biological communities. As a matter of fact, these physical, chemical and biological disturbances are so widely spread that it is extremely difficult to find any stream that has not been in some way changed.

Given these fact, the necessity of restoring/rehabilitating the ecosystem of our stream corridors and protecting them from further damage is pressing. Stroubles Creek is a freshwater stream located in Blacksburg, Virginia. Over the past 100 years, it has experienced significant impact from urbanization in the Stroubles Creek Watershed. It is one of the urban streams need restoration and rehabilitation urgently.

Stream restoration, which means *assisting stream's recovery by re-establishing important physical, chemical and biological processes*, is most effective when planned and conducted on various scales: watershed, riparian corridor, and in-stream/reach.

Apart from various literatures available on the methodology of urban stream restoration, ambient successful cases give insight into what we can do to insure successful urban stream restoration effort. In the first example, the watershed analysis and subsequent treatments performed at Bluewater Creek, New Mexico, showed us a good methodology of watershed analysis and stream corridor restoration. The Lititz Run Watershed Restoration Project is a national showcase project. It has engaged citizens, scientists, and local and state government agencies as local watershed alliance partners in a coordinated set of 15 restoration projects in key locations throughout the watershed, and this community is improving its water quality through a comprehensive long-term watershed management strategy that combined techniques in natural resource management, land use planning, education and community involvement in addressing non-point source pollution. The Kingstowne Stream Restoration Project at Fairfax, Virginia shows environmental friendly methods to treat stream erosion problems in the highly urbanized areas.

A stream restoration/rehabilitation plan, that sets a bold vision and can be implemented in logical phases as socio-political will and funding allow, is the first step to ensure successful restoration results. A good stream restoration/rehabilitation plan shall pay good attention to process organization, problems and opportunities identification, goals, objectives development, restoration alternatives design, and implementation, monitoring, evaluating and adapting.

Organizing the process, which includes setting boundaries, forming an advisory group, establishing technical teams, identifying funding sources, establishing points of contact and a decision structure, facilitating involvement and information sharing among participants, and documenting the process, is the first step to planning a restoration project effectively and efficiently. Identifying problems and opportunities is the most important step in the stream restoration planning process, since it the basis upon which the goals and objectives of the entire project are defined. The reference approach, a method of using a set of reference conditions for the "target" or "proposed" stream and comparing these conditions with current stream corridor conditions, is often uses for identifying problems and opportunities. Goals and Objectives should be defined with the fours steps of defining the desired future condition, identifying scale considerations, identifying restoration constraints and issues, and preparing goals and objectives statement. Restoration/rehabilitation design should involve hydrology and hydraulic design, channel and bank treatment, riparian vegetation planting plan, habitat rehabilitation plan. In choosing restoration design alternatives, special considerations should be given to "managing causes" as opposed to "treating symptoms", tailoring restoration design to the appropriate scale (watershed/corridor/stream), and other scale-related issues, as well as other supportive analysis. To successfully implement the restoration plan, one need to pay special attention to funding securing, identifying tools to facilitate implementation, dividing responsibilities, and installation measures. The whole restoration project is not considered finished without detailed plans of evaluating, monitoring and long term protection and management of the restored ecosystems.

From the vast literature and success stories, general methodology for laying out a process plan is applied to the Stroubles Creek in the town of Blacksburg, Virginia. The plan emphasizes in involving stakeholders and participants and coordinating the various different interest towards the Stroubles Creek, since it locates in a highly urbanized area. Goals and objectives development is also emphasized because it not only directs the whole project but also provides the basis for post-restoration activities, such as evaluation, monitoring and management, which is essential for the Stroubles Creek.

However, we shall recognize that theories of urban stream restoration are not a cook book. Despite general steps of planning stream restoration projects are clearly laid out in various literatures, there are numerous challenges a restoration planner will face in the process of stream restoration.

The first challenge is usually the protection of private property right versus the restoration of a stream. The restoration of a stream usually requires plenty of riparian buffers and restriction of recreation and cattle access. Property owners will see this as a restriction on their property, thus no willingly support stream restoration activities. However, if restoration planners can find ways to associate the benefit of the restored stream, for instance raise of property value, with property owner themselves, the chance of gaining support will be strengthened.

With the first challenge of property right issue comes the issue of public involvement. Because stream restoration usually involves numerous different private and public interests, it cannot succeed without public support. However, public involvement can be exiting and frustrating at the same time. It is useful but also hard to do well. Thus, public involvement organization skills are indispensable for a good restoration planner.

Public education on theories and benefits of stream restoration will help the public understand the necessity and help motivate the public in engaging local stream restoration projects. Without understanding of the public, stream restoration works will face much more resistance and obstacles.

Other issues such as not enough funding sources, unavailability of data information can also be huge challenges to restoration planners. Thus, for planners, in addition to identifying as many funding sources as possible, it is especially important to set up realistic restoration goals and objectives, prioritize each objective and finish the job step by step. Most restoration planners and workers will face the fact of not enough data to work with. So the success of restoration work depends, to some extent, on the sound judgments of restoration workers. In this case, it is critical to identify and recognize restoration expertise.

On the whole, this paper summarizes the theories and concluded the general procedures for conducting an urban stream restoration/rehabilitation project. It also discussed critical issues related with each step of urban stream restoration. The application of the stream restoration/rehabilitation theories on the Stroubles Creek is conducted mainly on the literatures read, and without actually conducting first hand data collection and analysis. However, since it is a laid-out framework for planning a real Stroubles Creek corridor restoration/rehabilitation project, it will be a useful reference for the local municipal government, environmental groups or community organizations interested in this topic.

Bibliography

Bennett James P. (1999), Quasi-Two-Dimensional Simulation of Scour and Deposition in Alluvial Channels, *Journal of Hydraulic Engineering* / February 1999

Bennett Sean J., Pirim Taner, Barkdoll Brian D. (2002) Using simulated emergent vegetation to alter stream flow direction within a straight experimental channel, *Geomorphology* Vol. 44 pp. 115– 126

Bohn B. A. and Kershner J. L. (2002), Establishing aquatic restoration priorities using a watershed approach, *Journal of Environmental Management* Vol. 64, pp. 355–363

Booth Derek B., Karr James R., Schauman Sally, Konrad Christopher P., Morley Sarah A., Larson Marit G., Henshaw Patricia C., Nelson Erin J., Burges Stephen J. (2001), *Urban Stream Rehabilitation in the Pacific Northwest- Final report of EPA Grant Number R82-5284-010.* University of Washington. Also available at: http://depts.washington.edu/cwws/Research/Reports/final%20rehab%20report.pdf

Dahl Bernie, Hough Michael, and Skabelund Lee R. (2002), Principle for Urban Ecological Restoration, draft.

DEQ, 1998. Virginia 303(d) *Total Maximum Daily Load Priority List and Report*. Prepared by the Department of Environmental Quality and the Department of Conservation and Recreation, Richmond, Virginia. Revised June 1998.

EPA. (2002). Lititz Run Watershed. EPA National Showcase Watersheds website. Available at: http://www.epa.gov/owow/showcase/lititzrun/, last accessed on April 27th, 2004.

Fairfax County, VA. (2004), Kingstowne Stream Restoration Project. Fairfax County, VA website. Last Modified: Tuesday, February 10, 2004. Available online at: http://www.co.fairfax.va.us/nvswcd/kingstowne.htm

FISRWG (1998). *Stream Corridor Restoration: Principles, Processes, and Practices*. By the Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US gov't). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3. Also available online at: http://www.usda.gov/stream_restoration/

Forman, RTT. (1995), *Land Mosaics: The Ecology of Landscape and Regions*. Cambridge University Press.

Hayles, V.M. (1973), Biological and Chemical Monitoring of Three Streams in the Area of Blacksburg, Virginia. M.S. Thesis in Zoology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Heaton Mark G., Grillmayer Rick, Imhof Jack G. (2002) *Ontario's Stream Rehabilitation Manual.* Ontario Streams, 17266 Old Main Street, Belfountain, Ontario, L0N 1B0. Also available online at: http://www.ontariostreams.on.ca/OSRM/toc.htm

Hey, R.D. (1995), "River processes and management", In *Environmental science for environmental management*. ed. T. O'Riordan, pp. 131-150. Longman Group Limited, Essex, U.K., and John Wiley, New York.

Hoehn, R.C., Childrey M.R. and Contractor D.N. (1975), Modeling the Effect of Waste Discharge in a Small Mountain Stream. VWRRC Bull. 76. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Kelsey, R.G. (1973), Some Effects of a Chlorinated Municipal Sewage Effluent on a Small Creek. M.S. Thesis in Sanitary Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

McCarty, K. and Newcomb T. J. (1999) A Historical Review of Stroubles Creek Restoration. Virginia Tech Chapter of the American Fisheries Society, Department of Fisheries and Wildlife Sciences, Virginia Tech. Unpublished Report.

McDonnell M. J. and Pickett S. T. A. (1990) Ecosystem Structure and Function along Urban-Rural Gradients: An Unexploited Opportunity for Ecology, *Ecology*, Vol. 71, No. 4, pp. 1232-1237.

Miltner Robert J., White Dale, and Yoder Chris (2004) The Biotic Integrity of Streams in Urban and Suburbanizing Landscapes, *Landscape and Urban Planning*.

Negishi J . N., Inoue M. and Nunokawa M. (2002), Effects of channelisation on stream habitat in relation to a spate and flow refugia for macroinvertebrates in northern Japan, *Freshwater Biology* Vol. 47, pp. 1515–1529

Purcell Alison H., Friedrich Carla, and Resh Vincent H. (Dec. 2002), An Assessment of a Small Urban Stream Restoration Project in Northern California*, Restoration Ecology* Vol. 10 No. 4, pp. 685–694,

Randolph John (2004), *Environmental Land Use Planning and Management,* Island Press.

Rindaldi Massimo and Johnson Peggy A. (1997) Characterization of Stream Meanders for Stream Restoration, *Journal of Hydraulic Engineering*, June, 1997/567.

Riley, A. (1998) *Restoring Streams in Cities: A Guide for Planners, Policy Makers and Citizens*, Washington: Island Press.

Rutherfurd Ian D., Jerie Kathryn and Marsh Nicholas. (2000). *A Rehabilitation Manual for Australian Streams*, Vol. 1. Cooperative Research Center for Catchment Hydrology Land and Water Resources Research and Development Corporation, also available at Australian Government Land and Water Australia website, http://www.lwa.gov.au/downloads/PR000324.pdf

SCWI (2001) Watershed Information, Stroubles Creek Watershed Initiative website, available at: http://www.vwrrc.vt.edu/awra/SCWI/watershed/watershed.html, last accessed on April 27th, 2004.

SER (2002) By the Society for Ecological Restoration Science & Policy Working Group. The SER Primer on Ecological Restoration. Also online at SER website at: www.ser.org/.

Shields F. Douglas Jr., Copeland Ronald R., Klingeman Peter C., Doyle Martin W., and Simon Andrew (2003), Design for Stream Restoration, *Journal of Hydraulic Engineering* pp. 575

Skabelund Lee R. (2003), Ecological Restoration as Public Education in Urban Settings, Department of Landscape Architecture, College of Architecture & Urban Studies Virginia Polytechnic Institute & State University.

Snyder C.D., Young J.A., Villella R. and Lemarie D.P. (2003), Influence of Upland and Riparian Land Use Patterns on Stream Biotic Integrity, *Landscape Ecology* Vol. 18, pp. 647-664.

Sweet Dan I. (2003), The Development of a Stream Restoration Decision Support Tool for the County of Henrico Stream Assessment and Watershed Management Program, MS. Thesis in Landscape Architecture, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

Sutton, L.E. (1914) A Study of Self-Purification of Stroubles Creek. Thesis in Bacteriology, Virginia Polytechnic Institute, Blacksburg, Virginia.

Taft, W.D. (1949) An Investigation to Determine Rate and Recovery of Stroubles Creek after Diversion of Poorly Treated Sewage. M.S. Thesis in Sanitary Engineering, Virginia Polytechnic Institute, Blacksburg, Virginia.

USDA. (2000) Unified Federal Policy for a Watershed Approach to Federal Land and Resource Management, Available at: http://www.wminteractive.org/Articles/fr10-18.htm

Woodside, M. (1988) Analysis of Water Quality Problems in VPI & SU Duck Pond and Suggested Management Alternatives. M.S. in Environmental Science and Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.