

# **VIRGINIA WATER RESOURCES RESEARCH CENTER**

## **Urban Stream Daylighting Design Application to Stroubles Creek, Blacksburg, Virginia**

### **SPECIAL REPORT**



**VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY  
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**Urban Stream Daylighting  
Design Application to Stroubles Creek, Blacksburg, Virginia**

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## Abstract

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Twenty-first century America is approaching a turning point in its approach to urban stormwater management. This turning point is precipitated by the deterioration of industrial-era pipes that were built to capture storm runoff and contain natural waterways that interrupted the dense urban development patterns of the 19<sup>th</sup> century. The objective of this report was to offer stream daylighting as an alternative green infrastructure technology to traditional urban stormwater management. Existing stream daylighting case studies were reviewed and compared against each other for similarities. The dominant land use types where existing daylighted streams were found ranged from highly urban business districts to suburban neighborhoods and residential backyards. Stream channel designs found in case study sites followed three common patterns : naturalized, channelized, and artificial streams. Based on a review of case study sites, a methodology called the "Daylighting Decision Matrix" was developed to facilitate site selection and stream channel design.

Options offered by the Matrix were then applied to designing a stream daylighting corridor for Stroubles Creek in Blacksburg, Virginia, where historic stream segments have been buried for more than 60 years. Hydrologic calculations were used to evaluate the final design and to confirm the designed channel's ability to handle 2- and 10-year storm events. It is concluded that the proposed Matrix successfully facilitates preliminary site selection and stream design decisions but its use should be limited to initial conceptual stages only. Detailed stream daylighting design rests on individual site characteristics, varying community objectives, and specific stream hydrology. The study indicates that stream daylighting can offer substantial ecological, financial, and engineering benefits over traditional approaches (pipes and culverts). Further research is recommended to document all daylighted stream channels and their corresponding sites to determine if additional standards might successfully apply to future projects.



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## 1. Introduction

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Twenty-first century America is approaching a turning point in its approach to urban stormwater management. This turning point is precipitated by the deterioration of industrial-era pipes that were built to capture storm runoff and contain natural waterways that interrupted the dense urban development patterns of the 19<sup>th</sup> century. Turn-of-the-century engineering that made rapid land development possible in communities across the country is now failing and creating a host of present-day problems. Cracked and collapsing pipes cause major urban floods; undersized culverts fail to handle today's large amounts of impervious surface area. The health of many streams is severely degraded and their inherent functions are severed from surrounding natural systems to deleterious effect on their ability to support life, transport material, and contain flood waters.

Further exacerbating this situation is the reality that much of the so-called "traditional" technology for controlling water in built environments is merely being replicated in today's communities. The act of placing or keeping natural water systems into underground pipes to facilitate land development continues unabated. The vision held by many contemporary municipalities is to replace this underground infrastructure system indefinitely.

The ongoing erasure of geologically unique water systems is symptomatic of a larger pattern in society: the homogenization of the American social and physical landscape. As with widespread and rapid urban development in the 19<sup>th</sup> century, contemporary sprawl patterns are eliminating physical differences in the physical and cultural landscape (topography, forests, streams, housing, and businesses). In so doing, the loss of unique physical characteristics is facilitating the loss of community connection, historic character, and a sense of "place". Neighborhoods and regions once identified by natural features and local businesses – "Mill Creek" or Vermont maple syrup – are being replaced with buried or channelized water (the Los Angeles River) and chain establishments (Starbucks, McDonald's).

But unlike the turn of the previous century, the traditional method of managing urban water systems is not the only approach available for community leaders. Emerging trends in environmental awareness and stewardship are making it possible to imagine and ultimately build more sustainable futures for American cities and their invisible rivers, streams, and creeks. Movements toward "green infrastructure", Low Impact Development, and environmental Best Management Practices are gaining ground in public debate, policy making, land planning and design.

Specifically, the new phenomenon of urban stream daylighting is emerging as a uniquely viable and multifaceted tool in the green infrastructure arsenal. On one hand, removing streams from underground pipes is a biological engineering technology that allows for some degree of restoration of vital stream functions, such as providing aquatic habitat and improving flood storage capacity. On the other hand it also provides meaningful and valuable public space in urban environments, and presents an innovative long-term land use planning tool that permits existing stream systems to evolve as their surrounding built contexts evolve simultaneously. The future character of many urban and suburban neighborhoods is directly linked to their past historic streams, and daylighting them reclaims valuable natural resources along with unique community identities. Stream daylighting can become an integral part of planning the future of both natural and human systems.

This report intends to investigate the challenges and opportunities that urban stream daylighting can offer any given community wishing to restore a buried stream to visibility. The report examines the history of urban stormwater management in order to understand present-day attitudes that affect the water use in urban, suburban and increasingly rural settings. The rise and consequence of modern-day sprawl development patterns – especially on water systems found within them - will be juxtaposed against the newly-coined "green infrastructure" ideology, which seeks to implement more holistic frameworks in which human and natural environments can co-exist successfully.

Urban stream daylighting is specifically examined via literature and case study findings for its effectiveness in restoring both lost ecosystems and community identities. Average outcomes, typical sites where projects occurred, and cost projections all factor into whether or not a particular stream reach and location are suitable for undertaking such a comprehensive restoration / intervention. These results are organized into a 'Daylighting Design Matrix', which is proposed as a means of facilitating preliminary decision-making related to what sort of daylighting outcome is likely given a certain set of physical site parameters. To test the validity of this approach, the matrix is applied to Stroubles Creek in Blacksburg, Virginia to explore the possibility of daylighting one growing community's historic stream.

Daylighting is a deliberately willful act. It seeks to render visible that which is currently invisible. It intentionally disrupts the neat patterns of pavement that characterize modern American settlements. It attempts to re-place missing pieces of a living system that are now easily ignored because they are officially 'out of the way', beneath our feet, and contained safely in a concrete box or pipe. It also endeavors to restore a crucial missing link in the human psyche by restoring water to its rightful place as an essential life-giving force. Without water, very little on earth would exist, including humans. Revealing buried waterways through stream daylighting is a catalyst not only for design, but for reconnecting ourselves to our total reliance on - and place in - nature, one stream at a time.

## 2. The History and Legacy of Urban Stormwater Management

The link between human settlement and the control of water flow in those settlements dates back at least 4,000 years. "Artificial drainage systems were developed as soon as humans attempted to control their environment" (Butler and Davies 2004). "Sites excavated in the Indus Valley and in Punjab show that bathrooms and drains were common in Indian cities 4 millennia ago. Even in two millennia B.C., the Greeks and Egyptians had adequate supplies of drinking water for their cities, drained streets, had bathrooms in their houses and, in Crete, water flushing arrangements for toilets" (James 1998). Earthenware pipes were used before 1500 B.C. and some pipes in Mesopotamian cities from that era are still in working order.

In European and American cities prior to the mid-1800's, small neighborhood grids allowed for the management of water with a localized supply and treatment approach that included collecting rainwater in cisterns and designing useful channels in narrow roads and alleys. However, when the industrial revolution came to full force, it was no longer possible to manage city water flow using pre-industrial methods (Figure 1).

As approaches to urban water management necessarily changed, so too did the terminology. "The English word sewer is derived from an Old French word, *esserver*, meaning 'to drain off', related to the Latin *ex-* (out) and *aqua* (water). The Oxford English Dictionary gives the earliest meaning as 'an artificial watercourse for draining marshy land and carrying off surface water into a river or the sea' (Butler and Davies 2004). Prior to 1600, the word was not associated with wastewater, but eventually they became linked and remained that way for the next 400 years. The development of drainage in London provides a good example of how the association between wastewater and stormwater came about. "Sewers originally had the meaning given above and their alignment was loosely based on the natural network of streams and ditches that preceded them. In a quite unconnected

arrangement, bodily waste was generally disposed of into cesspits (under the residence floor), which were periodically emptied. It remained illegal until 1815 to connect the overflow from cesspits to the sewers. By 1817, when the population of London exceeded one million, the only solution was to allow cesspit overflow to be connected to the sewers. This moved the problem elsewhere – namely, the River Thames. By the 1850s, the river was filthy and stinking and directly implicated in the spread of deadly cholera (Butler and Davies 2004). Thus the connection between rainwater and wastewater: streams began to be used directly to dispose of human waste.

In the United States, use of urban streams for sewage disposal--and, ultimately, as the beds of actual sewers--was also becoming standard practice for 19th and 20th century engineers. Initially, stream pollution and its deleterious affect on health was the main reason for undertaking such drastic measures.

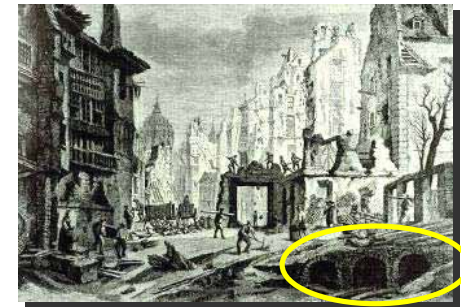


Figure 1. Image of the "industrial city"

By the second half of the 19th century, as epidemic diseases such as typhoid fever killed thousands of Philadelphians, providing proper sewerage and drainage became a subject of great concern, and city engineers began planning the culverting of creeks in advance of development. As early as 1853, City Surveyor Samuel H. Kneass acknowledged that natural waters would have to be utilized to provide proper drainage for the city. In the 1880s, when the City engineers drew up their preliminary drainage maps for Philadelphia's 129 square miles, converting many of the city's smaller streams into sewers was an integral part of the plan. Since it was standard sewage disposal practice to direct branch sewers downhill into the nearest stream, they knew that even pristine surface streams would become polluted once the areas around them were

developed. Culverting the streams before they became polluted was seen as a positive step to protect the public health (Levine 2005).

As rapid urban expansion took place, concern about pollution in public drinking water led to placing thousands if not millions of miles of creeks and rivers into pipes. Other streams were deliberately converted into sewer channels to efficiently remove human waste. "The much greater quantities of water needed...as well as the increased stormwater from the larger urban area generated the need for new technology, new management processes and new urban form. The industrial city had many new sources of waste that it could not manage" (Newman 2000).

A second but equally critical practice also emerged at this time: the act of burying streams in anticipation of automobiles. This is a very important historical development because culverting surface water channels necessitated filling in extensive valleys with many tons of fill dirt, a leveling process that was done in advance of urban expansion to facilitate vehicular traffic (Figure 2). "Cities that were developed before the automobile arrived were created in dense patterns. For them, stormwater created problems. Impossibly muddy streets and compromised sanitation prompted engineers of the time to develop systems of underground pipes to carry the wastewater...to adjacent rivers" (Gregg and Wenk 1998). Once the streams were buried underground, the towns also found it easier to grow. They built streets, housing, and industrial plants over the buried streams. And the public health problems also disappeared—at least for awhile (National Park Service, [www.nps.gov](http://www.nps.gov)).

"Building sewers in advance of development...gave engineers freedom in their designs....especially in areas of the city where the rectangular grid system of streets prevailed" (Levine 2005). By placing water systems underground, adequate sewage removal was achieved, large swaths of terrain were conveniently flattened, street grids were laid out, and real estate parcels were neatly divided and quickly sold.

This approach appeared to solve a wide range of problems believed to be caused by natural water in urban environments.

Sadly, while waste disposal management practices and land development patterns have changed in the past 150 years, the management approach toward urban streams has not. Many of today's stormwater management systems are replications of the ones that emerged well over a century ago. Streams, creeks and rivers in the way of intended real estate expansions are still largely considered nuisances worthy only of containment, control, and removal. Rainfall is still referred to as "wastewater" today.



**Figure 2. Wingohocking Creek Sewer under construction. Philadelphia. 1909.**

The spatial and hydrologic consequences are far-reaching. According to author Gary Strang, in contemporary cities the hydrology of the place is still largely ignored. "Drainage systems have been put underground unnecessarily or channelized with concrete, erasing the visual and spatial logic of the region" (Strang 1996). According to Richard Pinkham of the Rocky Mountain Institute, most urban dwellers have no idea that streams run underneath their feet (Pinkham 2000). The early engineering efforts have proven successful at wiping water literally off the map. For example, early in the 20th century, city planners realized the benefits of creating parks in stream valleys, but it was too late for most. The modern map of the city's surface streams is now disturbingly blank (Levine 2005).

From the standpoint of natural hydrologic processes, the past 150 years have not been kind and the continued application of old methodologies further jeopardizes water systems. "Today, 40 to 50 percent or more of the total land in urban areas is covered by impervious surfaces....This dramatically increases the rate and volume of storm water runoff and reduces nature's ability to clean our water....A significant increase in

impervious land cover and the loss of forestland increases the risk of flooding” (Benedict and McMahon 2006). For some towns, the volume of water flowing into the underground pipes has increased, and now, during winter storms, the pipes back up and water overflows onto streets (National Park Service, [www.nps.gov](http://www.nps.gov)). There are other ecological problems as well: “The development of wetlands, riparian areas, and other native ecosystems also reduces their capacity to perform their natural functions – control floods, trap sediment, and filter out toxins and excess nutrients” (Benedict and McMahon 2006).

There is a question of cultural values implicit in this investigation. What is it about the way water is treated physically in urban settings that reveals how we as a society value – or don’t value - the presence of such a crucial natural resource? Has that resource reached its own limits with society, pushing back against neglect, abuse and invisibility by becoming increasingly scarce (in the West), flooding city streets, and emptying itself of fish and other aquatic species?

Are our values changing in the face of this? If so, what is the impetus? In today’s post-industrial society it is likely that previously accepted methods for confining streams and stormwater are no longer valid. The old system may have worked temporarily to satisfy the needs of human settlement at the time, but it is becoming ever more apparent that piping streams is not a desirable scenario. A more holistic framework is needed to resist modern practices of land development and cultural and spatial homogenization.

### 3. The Emergence of Green Infrastructure and Suburban Sprawl

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"No single park, no matter how large and how well designed, would provide the citizens with the beneficial influences of nature...A connected system of parks and parkways is manifestly far more complete and useful" – *Frederick Law Olmsted*

#### **Green Infrastructure**

At the turn of the century, renowned landscape architect Frederick Law Olmsted held a vision of community development that was supported by wildlife biology and landscape ecology experts. Plants, animals, and ecosystem processes must be part of a network of protected natural areas in order to thrive (State Environmental Resource Center, [www.serconline.org](http://www.serconline.org)).

The concept of "green infrastructure" was only just emerging in the midst of the Industrial Revolution, but it would take another hundred years to be fully defined. Today, it is considered a new approach to land conservation and natural resource management that looks at preservation in conjunction with land development and engineered infrastructure planning. It is a post-industrial conservation approach that considers ecological needs within the context of human activities. "Green infrastructure provides a framework that can be used to guide future growth and future land development and land conservation decisions to accommodate population growth and protect and preserve community assets and natural resources" (Benedict and McMahon 2006).

The term green infrastructure is fairly new, but the overall concept is not. "The green infrastructure movement is rooted in studies of the land and the interrelationship of man and nature that began over 150 years ago" (Benedict and McMahon 2006). As early as 1847, public attention was being drawn to the destruction of land by human activities, especially deforestation. By the mid-1800's, proponents such as

Olmsted believed that "biologically artificial" urban environments were "detrimental to our mental and physical health" and incorporated parks and greenways into the plans he created for cities and towns throughout the country (Benedict and McMahon 2006).

The subsequent trajectory of green infrastructure took on several forms at relatively consistent intervals, only some of which will be highlighted here. By the late 1800's federal and state governments were getting involved in land conservation and setting aside the first national parks for recreational use. Over time, the Wilderness Society was founded in 1935 in response to concerns that the size of these national parks was not large enough to sustain certain animal species and that the rise of the automobile was changing the American landscape for the worse. They proposed "a national system of wildland belts along rivers and mountains to preserve...a primitive condition, and to foster a deeper appreciation of the natural features of the earth which are characteristics of the United States" (Benedict and McMahon 2006). This proposal reflects an attempt to establish what has been referred to as a nationwide green infrastructure network.

However, it would take several decades before these principles would be applied to the professions of urban planning and landscape architecture. Ian McHarg led the charge in 1969 with his ground-breaking book *Design With Nature*, where he emphasized the need for planners and designers to incorporate a more ecological approach to land use. He introduced the use of map overlays to quantify and display large amounts of spatial data to implement this new design approach (Benedict and McMahon 2006).

As in the 1930's the growing environmental movement in the 1960's was fueled by concern in the general public about human impacts on the environment. Prevailing attitudes about nature, and who was responsible for protecting it, were being challenged. During this era, the Environmental Protection Agency was established, Congress passed the Wilderness Act (1964), the Water Pollution Control Act (1972),



the Clean Water Act (1977), and the Endangered Species Act (1973) (Benedict and McMahon 2006).

As a result of these shifts in cultural values, “Over the next two decades, interest grew in the concepts of green infrastructure planning and design and refinement of land conservation practices. Conservation strategies became more holistic and comprehensive, and regulatory approaches gave way to non-regulatory approaches like ecosystem management, sustainable development, and regional planning.” (Benedict and McMahon 2006). It was recognized among many professions that natural areas needed to be connected at larger scales to protect biodiversity and whole ecosystems.

### ***Suburban Sprawl***

But there was another, less beneficent, force at work at the same time that these initiatives emerged: sprawl development. Sprawl happens when a city and its suburbs start to spread out over rural and agricultural land lying at the edges of an urban area. Contemporary sprawl development patterns consume “much more land than traditional urban developments because new developments are of low density...The impact of low density development in many communities is that developed...land is increasing at a faster rate than the population” (www.wikipedia.com).

The negative impacts of sprawl are many and far-reaching: open land fragmentation, habitat loss, overdependence on automobiles to travel greater distances, increased infrastructure costs to provide utilities and services to outlying communities. Of particular relevance is the impact that sprawl development has on existing natural water systems. Water resources continue to be degraded in spite of the shift in real estate development from dense urban grids to spreading, single-family lots. “Due to the larger area consumed by sprawling suburbs compared to urban neighborhoods, more farmland and wildlife habitats are displaced per resident. As forest cover is cleared and covered with concrete in the suburbs, rainfall is less effectively

absorbed into the ground water aquifers. This threatens both the quality and quantity of water supplies. Sprawl increases water pollution as rain water picks up gasoline and oil runoff from parking lots and roads” (www.wikipedia.com).

Developing over wetlands, streams, and riparian zones reduces the ability of these systems to hold flood waters, filter pollutants and trap sediment. Today, impervious surface cover is typically over 50 percent in urban areas, dramatically increasing the rate and volume of stormwater runoff (Benedict and McMahon 2006). Streams in the way of urban and suburban sprawl are particularly threatened. They are frequently damaged by increased sediment loads as well as water volume and velocity entering them from development sites, and the damage takes years (even decades) to repair, assuming no further damage occurs (Hession and Wynn 2006). Another threat stems from the continuation of “traditional” engineering methods to contain streams on said sites: placing them into pipes and culverts (Figure 3). These efficient pieces of “infrastructure” are added to residential and commercial land to facilitate ongoing expansion into undeveloped areas.



**Figure 3. Piped Stream**

But the long-term impacts of such interventions are only just beginning to emerge. Even the smallest of headwater streams is rich with complicated and interconnected processes that serve to feed the rest of the water system downstream. Placing a stream or river into a pipe or concrete channel greatly impedes the natural processes that create and keep it healthy and functioning. These natural processes include the seemingly negative event of flooding, which is a vital part of dynamic hydrologic systems. Even the shortest length of pipe can, over time, significantly impact the ability of upstream and downstream stream sections to successfully adjust to their new constriction. It can negatively alter the form of the overall stream channel and reduce its ability to carry sediment or flood waters effectively or provide healthy aquatic habitat (Hession and Wynn 2006).

Sprawl development and its attempts to cover over significant land features in the way of its expansion have also resulted in the loss of historic character and local cultural identity. As large-scale neighborhoods and commercial enterprises - identical to each other in design and layout - replace existing communities and businesses, a sense of social uniqueness disappears. These "...changes in the landscape are disruptive to a person's sense of history...The places that are dearest to our hearts are often among those destined for development...Each year sees further erosion of other historic resources through demolition, neglect, increasing sprawl, and highway construction..." (Benedict and McMahon 2006).

In an unexpected alliance between nature and culture, early movements to preserve historic buildings morphed into efforts to save entire landscapes from sprawl. The National Trust for Historic Preservation was founded in 1949 to save diverse historic places and revitalize existing communities. Initially focused on preserving historic buildings urban architecture, it expanded to protect historic sites including Civil War battlefields. Late in the 20<sup>th</sup> century, suburban sprawl began to threaten whole landscapes: "By the 1980s suburban sprawl began encroaching on already protected landmarks...and the pace of change threatened to remove or obscure visible reminders of the nation's past...heightened environmental concern contributed to a growing realization of what might be lost through economic development...and by the 1970s historic city spaces had gained landmark status...Perhaps most famously, New York's Central Park experienced a renewal in the 1980s, as private and public efforts combined to re-create the park using the original plans and visions of its creators, Frederick Law Olmsted and Calvert Vaux" ([www.answers.com](http://www.answers.com)).

Yet economic growth continues to dictate physical change of the American landscape – physically and culturally. The continued spread of sprawl development requires constant vigilance to protect against unchecked loss of land and community identity. Fortunately, the deleterious effects that present-day land development has on natural and human communities alike have triggered new efforts to resist it.

Urban stream daylighting is one such effort. It attempts to address the complex and dynamic hydrologic processes at work in streams surrounded by human development without eliminating either of them. It acknowledges the simultaneous existence of both water systems and human systems and attempts to restore and protect streams *amidst* built contexts. If it is asserted that green infrastructure as an ideology takes natural and human environments into account together, then it is possible to claim that stream daylighting is a direct manifestation of green infrastructure. It is one variation of stream restoration that is in direct response to human activity by revealing and engaging the natural water systems that originally sustained early settlements.

As attitudes toward water in urban environments change over time, it is imperative that practices affecting said water also change. Stream daylighting embodies the most radical potential of such an evolution: "Policy makers, planners, engineers, and builders increasingly recognize the value of maintaining natural drainage patterns and stream channels in new development" (Pinkham 2000). In the next section, stream daylighting will be explored in greater detail and results of case study comparisons will be used to construct a method for selecting potential sites – and outcomes – for daylighting streams in a variety of locations.

#### 4. Daylighting Streams - Introduction and Case Studies

Stream daylighting is a relatively new phenomenon. The first “official” daylighting project occurred along a section of Strawberry Creek at a park in Berkeley, California in 1984 (Figure 4). While other projects re-exposed creeks in the 1970s, the Strawberry Creek project is widely considered the archetype of daylighting (Pinkham 2000). The word itself - ‘daylighting’ - is often unfamiliar to most people, who confuse it with bringing daylight into the interior of a room or building. “The term describes projects that deliberately expose some or all of the flow of a previously covered river, creek, or stormwater drainage” (Pinkham 2000). In short, daylighting projects usually remove a stream from an underground pipe and restore the waterway to open air. It is sometimes referred to as an urban stormwater BMP (Best Management Practice) retrofit, as it is a practice usually put into place in physical surroundings already substantially built upon.

In the past decade, daylighting projects have steadily increased across the country (Pinkham 2000). Over two dozen stream sections have been pulled out of their underground pipes since the mid-1980’s. Literature sources list several general motivations for, and benefits of, daylighting. It is recognized that stream daylighting can improve riparian habitat and water quality along newly created stream banks and reduce flood impacts by increasing storage capacity over that of a culvert (Pinkham 2000). It can potentially reduce the urban “heat island effect” and reduce greenhouse gases by increasing tree canopy cover (Williams 2006). Economically, “many communities are finding that the costs associated with ‘daylighting’ a stream can be less than designing new pipes and re-burying the stream” (National Park Service, [www.nps.gov](http://www.nps.gov)). Daylighted streams can increase property values and business investment opportunities in stream redevelopment zones, add intrinsically valuable public open space to dense urban communities, and reduce municipal budgets by replacing deteriorating culverts with open streams that are easier to maintain and repair (Pinkham 2000; Williams 2006).

Stream daylighting offers psychological benefits as well. “In many ways these streams are a metaphor for the way we have ‘buried’ our connection with nature. Daylighting these streams restores not only natural ecological processes, but...it can restore a sense of place and the natural importance of water even in the most urban settings” (Williams, quoting Jessica Hall, 2006). It is this sense of place and the value of water in urban settings that is most appealing about the practice of stream daylighting. Daylighting asserts the inherent value that water has to the human psyche and the human community – as a provider. Without water it is unlikely that any settled societies would have taken place, as there would have been no reliable source for drinking water, for tending crops and livestock, or for travel or the transport of goods.



Figure 4. Strawberry Creek daylighting, 1984

##### **Case Studies – General Findings**

An investigation was conducted into existing completed daylighting projects to better understand the impetus, benefits, and outcomes of the practice – and to determine whether or not it is a viable stormwater management alternative to urban drainage pipes. Case study reviews were chosen as the primary research method due to the relatively limited number of publications about stream daylighting. While there is more than sufficient literature available related to stream ecology, environmental hydrology, and stream restoration, there is much less literature written specifically about the art and science of stream daylighting. Therefore, case study documentation is the best source of information about the practice.

A detailed report of all known case study findings can be found in a recent report (Buchholz and Younos 2007). That particular report reviewed a total of 19 completed projects across the United States. The projects represented a wide range of political, economic, hydrologic, and geographic issues. Eight were from the West Coast, six from

the Midwest, three from the Southeast, and two from the Northeast. Some were small backyard projects that cost only a few thousand dollars to implement while others involved the redesign of several city blocks and cost millions of dollars. Specific details of those case studies will not be pursued within the body of this paper. Instead, this section presents overall trends, comparison results, and logistical considerations regarding site selection and design possibilities.

Despite apparent contrasts, similarities were found among them and were categorized to facilitate a comparison process. First, daylighting was found to be “feasible in a variety of situations” (Pinkham 2000), regardless of geography, stream size, hydrologic function, and available funding. Second, daylighting is a new phenomenon under the broader umbrella of stream restoration work; the majority of known projects in the United States have taken place within the last ten years. Trends in project goals revealed five basic catalysts for daylighting a stream. These goals revealed social attitudes toward urban water systems and indicated what aspects of these resources are considered valuable. Those categories are:

- *Creation of a Park Amenity* – using a new stream as the focus of a public park project;
- *Economic Development / Flood Reduction* – using the natural flood capacity of a new stream to prevent flooding in business districts and to facilitate commercial development;
- *Ecological Restoration* – improving habitat structures, water quality and quantity, and removing fish barriers to restore aquatic health to a new stream;
- *Creation of an Outdoor Classroom / Campus Amenity* – building an outdoor space to study the effects of new streams and ponds on aquatic species and creating greenways to schools;
- *Residential Daylighting* – improving water flow on private property by restoring natural stream systems in backyards

The most important finding of the case study review was in the overall outcome for daylighted streams: most were not daylighted to restore ecological function, but rather to provide an amenity for human use and aesthetic enjoyment. This was an

unexpected discovery given that one of the main justifications for daylighting is the restoration of ecological function, including water quality, aquatic habitat, and riparian buffers (Pinkham 2000; Williams 2006; Brown and Schueler 2004). In reality, out of the total 19 projects, twelve were undertaken with either primary or secondary goals to create a park for human use and enjoyment. Only four projects were initiated strictly to improve water quality and/or fish passage and habitat within the daylighted stream section. A fifth project, Jolly Giant Creek in Arcata, California was simultaneously an ecological restoration and outdoor classroom endeavor. Thus, out of all the projects, almost 75% of them focused on long-term benefits to humans while 25% were concerned with the stream itself (Buchholz and Younos 2007). Of the projects that were concerned with the stream, most if not all focused on improving fish habitat and removing barriers to fish passage. Water quality improvements for other species (such as benthic macro-invertebrates) or riparian buffers for safe migration of other wildlife were not considered.

What led to this outcome? According to Ken Brown and Tom Schueler of the Center for Watershed Protection, “While all of these [ecological] objectives are important and legitimate in urban settings, only a few seek to actually restore stream conditions in an ecological sense. Indeed, full ecological restoration may be difficult or impossible to achieve in many urban streams” (Brown and Schueler 2004). For example, they rate the support capabilities of streams using percentage of impervious surface cover (IC) as an indicator of restoration success. “Subwatersheds at the lower end of the IC range (25 to 40% IC) may show promise for partial restoration, but are so dominated by hydrologic and water quality stresses that they normally cannot attain pre-development biological conditions, without continued maintenance” (Brown and Schueler 2004). Therefore, efforts are typically focused on creating human amenities, making a more naturalistic-looking channel, and preventing stream bank erosion. This is supported by results of the case studies reviewed to date (Buchholz and Younos, 2007).

A second conclusion was that there are underlying assumptions about stream daylighting that influence people’s ideas about its long-term impact on streams. Most

people instinctively think that a body of water flowing on earth's surface is better than having it in a pipe and that exposing it to air and sunlight will automatically improve water quality with no further intervention required. But the science of daylighting is not necessarily the same thing as *stream restoration*. Simply placing water at earth's surface and rendering it visible again does not necessarily make it healthy, alive, or valuable to any species other than humans (Hession and Wynn 2006). A few case studies produced nothing more than a concrete canal that contained the newly daylighted stream in highly built commercial districts. This was fine for keeping the stream in place but did little to help fish or other aquatic species, or to improve water quality or urban vegetation.

Finally, the definition of a 'successful' project varied widely. Projects that focused solely on water containment and park creation were deemed successful even if the physical form of the new stream was the concrete canal mentioned above. In terms of general "green infrastructure" function, these sorts of streams did indeed reduce urban flooding caused by failing pipes. Some downtown business districts no longer need to purchase flood insurance (Arcadia Creek, Kalamazoo, MI), and other localized flooding at smaller sites has all but disappeared (Blackberry Creek, Berkeley, CA). The few projects that did restore some form of 'naturalized' stream using earthen bottoms, meander bends appropriate to the stream type, and riparian vegetation were also considered successful: several different types of fish species and aquatic insects have re-appeared, and native vegetation re-established itself less than five years after projects were completed (Buchholz and Younos 2006).

#### ***Daylighting "Decision Matrix": Site Selection and Stream Outcomes***

One of the most important questions about stream daylighting – if not the *most important* question – is how does one select a site and stream length to daylight? Even though there are no definitive rules regarding "when and where" to do it, there must be some way to evaluate the feasibility of such a comprehensive project prior to its undertaking. Essentially, two questions must be addressed: 1) what makes a

site a good candidate for stream daylighting?; and 2) what kind of outcome can be reasonably expected on that site?

Case study results provide clues to answering these questions. The frequency with which certain types of daylighting occurred – and in which locations those daylighted streams were found – yielded patterns in the practice. These patterns can guide future decisions and the following section categorizes the patterns according to physical location and resulting stream types. The intersection of these categories is called the 'Decision Matrix'. This matrix is proposed as a methodology for simplifying preliminary decisions regarding where to daylight and what sort of stream channel might work best in that location.

#### ***Site Selection***

What makes a site a good candidate for stream daylighting? This is the first of two key questions that must be answered prior to initiating a daylighting project, and it is not always an easy question to answer. There are several factors at play when choosing a site and piped stream segment, and they must be considered very carefully.

The Rocky Mountain Institute conducted the original case study overview of completed projects in the United States and compiled the following list of sites that were successfully transformed into surface streams (Pinkham 2000):

- Vacant land
- Schoolyards
- Former rail yards
- Open space and playing fields
- Golf courses
- Parking lots
- Residential backyards
- Commercial properties in downtown districts



This list documents what *has* been done already. It is certainly helpful to know, but how is a *new site* identified? The Center for Watershed Protection has put together a list of more specific factors to look for when deciding if daylighting is a feasible option. These can be found in the Center's "Urban Stream Repair Practices Manual" (Brown and Schueler 2004) and are as follows:

- Connection with the existing stream network (to lengthen the total corridor)
- Outfall pipe diameter (short lengths of culverts that disrupt two healthy stream reaches should be investigated)
- Presence of perennial flow (derived from groundwater)
- Distance of unobstructed pipe (the greater the distance that a storm water pipe travels without obstructions the better)
- Width of drainage easement (the wider the better)
- Depth of overburden (if a pipe is buried deep underground, it may be infeasible to excavate and haul off that much soil and debris)
- Invert of outfall in relation to the stream (a drop as small as a few feet between the outfall and the stream may make the new stream gradient too steep and require extensive regrading)

In addition to the above factors, there are other site considerations to keep in mind. A short list of them includes:

- Underground utilities – they have to be moved to daylight any given stream;

- Presence of contaminated soils – if extensive on the site, they may eliminate daylighting as an option because stream flows should not run through polluted soils;
- Water table level – if the channel will lose or gain water, this could be a long-term problem worth avoiding by not daylighting or by lining the channel bottom with concrete (not an ideal stream outcome);
- Significant landscape features – rock outcroppings or stands of mature trees might prevent building a new stream channel on the site;
- Surrounding buildings – the presence of densely built commercial, institutional, or residential structures may impede both the stream design and construction process of a new surface channel. They can also impact what types and sizes of vegetation can grow successfully along the new corridor.

Using these quick reference lists, an example of a site ideally suited for stream daylighting might be one where a short length of stream (300 feet long or less) is buried in a pipe less than three feet underground in uncontaminated soils on a one-acre vacant lot. The pipe itself interrupts an otherwise healthy and stable stream system on either end and no significant elevation change occurs across the length of the site. The pipe is old – it was installed in anticipation of development that never occurred – and fails during seasonal rainfall events, flooding portions of the vacant lot and those adjacent to it. Sediment and other debris accumulate at the outfall end of the pipe, threatening to disturb the existing stability of the downstream reach. Over time, weeds and small invasive trees have appeared on the site, further attracting trash and vandalism to the area. A stream daylighting project under these circumstances will provide an excellent opportunity to restore the buried stream segment, protect its downstream reaches, introduce a new park-like setting that will probably receive greater care and reduce crime and vandalism in the neighborhood. It will most likely be a very cost effective intervention that benefits both human and natural environments.

Less-than-ideal sites are still candidates for stream daylighting. However, their selection rests more heavily upon what sort of stream channel can be achieved upon them. The “Stream Design Outcomes” section presents these types of channels and where they work the best.

#### *Stream Design Outcomes*

What kind of outcome can be reasonably expected on a chosen site? Most people envision some sort of “babbling brook” or shady, wooded creek tumbling over cobbles and logs when they think of streams, and this is not incorrect in a naturalized setting such as a large undisturbed piece of land or national park. But achieving that result in a highly disturbed urban locale is next to impossible even with the best of modern science and technology at our disposal. Within the field of stream restoration, stream channel design is a new science that frequently progresses on a trial-and-error basis (Hession and Wynn 2006). It is a highly technical endeavor that combines extensive training in hydrology, fluvial geomorphology, mathematics, fluid mechanics, sediment transport, and aquatic biology. The blessing is that restored streams are more likely to succeed when all of these specialties are brought to bear on their form. According to landscape architect Gary Mason, “You have to know what the water wants to do. If you’re not totally respectful of the water, it’ll come back and bite you” (Pinkham 2000). The curse is that all of these scientific factors do not guarantee a successful restoration. Stream channel design is truly a daunting task.

The first and most important question in traditional stream restoration design is *what type of stream already exists (or existed) on the site?* Before any channel can be re-established, it is imperative to know as much as possible about what was already taking place on the site, how wide or steep any prior channels were, how much water flowed through them and how fast, and what particle size was carried by them (Hession and Wynn 2006). These are critical pieces of data to be used in determining new channel geometry, cross

sections, sinuosity, slope, and the need or not for in-stream structures like weirs or check dams (Pinkham 2000).

Streams found in nature fall into several types of categories depending on the classification system used to identify them. One way to determine what type of stream already exists on a site, and therefore what it is capable of doing once daylighted, is to determine its morphology (or physical form). The Montgomery and Buffington stream classification system is commonly used to do this. This system identifies six primary forms of streams based on slope, velocity, corridor width, and average size of particles (stones) found in them (Montgomery and Buffington 1997). Chart in page 17 of this report depicts the six primary morphologies.

But these are not necessarily the forms they will take post-daylighting if they are situated in highly urban corridors. A daylighted stream can take several different physical forms depending on its ultimate location. Adding to the complexity are experts in urban stream restoration who stress that restoration techniques which work in rural or natural areas usually do not work in urban contexts, and it is nearly impossible to duplicate pristine pre-development stream conditions. The more urban the location and the more constrained the potential corridor, the more difficult the stream channel design will be and it can be nearly impossible to achieve naturalistic forms. Thus, the types of streams that result from a daylighting project are usually limited to just a few. The amount of horizontal / lateral width available on any given site seems to be the single most important feature that influences what typology can be achieved. Trends found in completed projects dovetail findings from the Center for Watershed Protection and reveal three typical outcomes for daylighted streams. These are illustrated on page 18 (Buchholz and Younos 2007; Brown and Schueler 2004).

## SIX STREAM MORPHOLOGIES



**Bedrock** – stream beds and banks controlled by bedrock (least amount of lateral stream migration); narrow channel widths; steep slopes; largest particle size; fastest water velocity



**Cascade** – stream beds and banks controlled by bedrock and large boulders / cobbles (lesser amount of lateral stream migration); narrow channel widths; steep slopes; large to medium particle size; fairly fast water velocity



**Step pool** – stream beds and banks controlled by some bedrock, large boulders, cobbles and exposed earth (medium amount of lateral stream migration); increasing channel widths; moderate slopes; medium particle size; fast water velocity



**Plane bed** – stream beds and banks less controlled by bedrock, greater quantity of small boulders, cobbles, gravel and fines (medium amount of lateral stream migration); increasing channel widths; moderate to low slopes; medium and small particle sizes present; medium water velocity



**Pool riffle** – stream beds and banks controlled by earthen slopes, beds have less cobbles and more gravel and fines (larger amount of lateral stream migration); large channel widths (15' or more); low slopes; medium and small particle sizes present; medium to slow water velocity



**Dune ripple** – stream beds and banks controlled by earthen slopes, beds have few cobbles, some gravel and lots of fines (largest amount of lateral stream migration); largest channel widths (15' or more); very low slopes; mostly small particle sizes present; slowest water velocity

*Photos: Tracy Buchholz*



## TYPICAL STREAM DAYLIGHTING OUTCOMES

Figure 5. Artificial Stream



- A high degree of stream bank and bed armoring is required
- Highly erosive forces
- Very narrow corridors
- Considered 'stream fronts' and have same basic qualities of urban drainage systems
- Used to raise public awareness of buried streams

Figure 6. Channelized Stream



- Rigid bank stabilization required to prevent erosion
- Hard grade controls installed along stream beds to prevent incision
- Contain some aquatic habitat
- Riparian planting zones
- Considered 'non-supporting' streams

Figure 7. Naturalized Stream



- Natural stream banks
- Stable stream beds
- 'Normal' stream geometry
- Principles of channel design are used
- Considered analogous to impacted streams

### *DAYLIGHTING DESIGN MATRIX*

A simplified method for deciding which type of stream design will work best in a given location is illustrated in the “Daylighting Design Matrix”. It combines the six stream morphologies with four primary land use categories to create a quick reference chart for basic site selection and channel design. The resulting stream outcomes closely resemble those defined above by the Center for Watershed Protection and offer tangible clues to what works best in a given setting.

The intersection of stream morphology and physical location yields a visual example of the most likely stream design within that given setting. For example, in a highly built urban environment where there is little room for a meandering, shaded stream bed, the resulting daylighted stream will need to be rigidly controlled on all sides, most likely in a lined concrete channel between buildings. This is akin to urban drainage and the new stream resembles the hard control found in bedrock and cascade channels. The outcome in this scenario is an ‘artificial stream’ and has little ecological function except to contain and control water flow.

In a suburban setting (or urban area with large vacant parcels), a new stream will likely require stream bank stabilization and some grade controls to prevent erosion and bed incision. The physical setting results in stream designs that resemble step-pool, plane bed, and pool-riffle streams, and accommodate these in-stream features along with room for riparian vegetation. These are considered ‘channelized streams’ and offer a higher degree of ecological function than the artificial streams.

Finally, in rural settings or on large pieces of property such as school fields and campuses, there is greater room to re-establish floodplains, wetlands and ponds, sinuous natural stream banks, and wider stretches of riparian plantings and forest buffers. These are considered ‘naturalized streams’ and

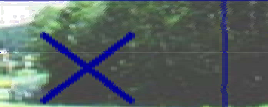
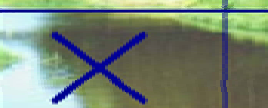
closely resemble pool-riffle and dune-ripple stream systems. These offer the highest degree of ecological function and typically see the largest number of returning fish and insect species within their channels (Buchholz and Younos 2007).

### *A Note on When Not to Daylight*

The Rocky Mountain Institute reminds proponents of daylighting that “Not every buried waterway is a good candidate for daylighting. There are many excellent technical, economic, institutional, and other reasons many buried waterways should not be unearthed” (Pinkham 2000). To date there are no hard rules that clearly define when stream daylighting is not recommended. However, experts are confident that there are three specific scenarios best avoided. The first is that of the combined sewer system, where human waste and rainfall runoff are sent into the same pipe system for treatment and discharge. In “The History of Philadelphia’s Watersheds and Sewers” author Adam Levine stresses that daylighting older combined sewer systems would be prohibitively expensive “...since it would mean building a completely separate system of pipes to carry the sewage” (Levine 2005).

The second scenario involves the presence of contaminated soils on a site. Any groundwater exchange or bank-topping storm event can interact with polluted soil and degrade water quality further downstream. It is best to cap those soils and leave the stream in its culvert for protection. The third scenario involves the stream’s health. The Center for Watershed Protection rates the support capabilities of streams using percentage of impervious surface cover as an indicator. “*Non-supporting streams* range between 25 and 60% impervious cover [IC] and no longer support their designated uses, as defined by hydrology, channel stability habitat, water quality or biological indicators...the primary restoration strategy is often to meet community objectives such as protecting infrastructure, creating a more natural stream corridor and preventing bank erosion” (Brown and Schueler 2004). As a result, situations involving non-supporting streams may have to rule out daylighting for ecological purposes altogether.

## Daylighting Design

| Channel Mobility<br>↓ | Least Ecological → Most Ecological                                                              |                                                                                     |                                                                                         |                                                                                         |
|-----------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
|                       | Urban CBD                                                                                       | Suburban neighborhood                                                               | Suburban schoolyard                                                                     | Rural/<br>Open Fields                                                                   |
|                       |  Bedrock       |  X |  X    |                                                                                         |
|                       |  Cascade       |  X |  X    |                                                                                         |
|                       |  Step-pool     |  X |  X    |                                                                                         |
|                       |  Plane Bed    |                                                                                     |  X  |  X  |
|                       |  Pool-rifle  |                                                                                     |  X |  X |
|                       |  Dune-ripple |                                                                                     |  X |  X |

## 5. Daylighting Stroubles Creek in Blacksburg, Virginia

Settlements in colonial and frontier days were often developed close to sources of water. This is true for Stroubles Creek, which was the historic water source that helped establish Blacksburg, Virginia. Springs and other sources of running water were important elements that helped structure the community, including the angle of the historic downtown grid. But development pressure surrounding Stroubles Creek, in the town proper as well as on the Virginia Tech campus, has threatened the health and function of this historic stream.

As awareness for the need to understand and manage water resources at watershed levels grows, so too does the possibility of implementing more radical approaches to restoring, protecting, and celebrating buried urban streams. The practice of stream daylighting is proposed as an alternative “green infrastructure” tool that can incorporate long-term land use planning, urban design, and stream restoration efforts together. The challenges and opportunities of this new technology will then be investigated by applying them to selected sections of Stroubles Creek.

### ***Watershed Location and Description***

The Stroubles Creek watershed is a small sub-watershed within the larger New River watershed in southwest Virginia. The watershed is oriented from east to west and drains Price Mountain and most of the town of Blacksburg (Alexander et al. 2000). The headwaters of Stroubles Creek itself are natural springs located on

the northern part of Blacksburg in Montgomery County, Virginia. Stroubles Creek is one of 35 tributaries of the New River in the Great Valley bioregion. It is formed from two main tributaries – Central Branch and Webb Branch – which flow into the Duck Pond on the Virginia Tech campus. The freshwater stream flows 9.2 miles before discharging into the New River. Along the way it travels through urban areas of town, the campus of Virginia Tech, and agricultural and rural sections (Figure 8).

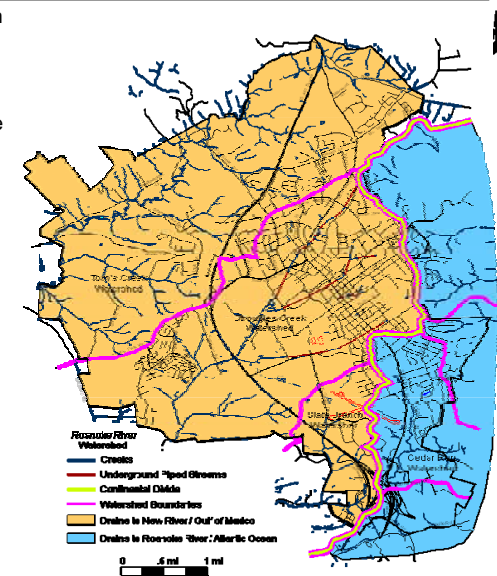


Figure 8. Stroubles Creek Watershed

The entire Stroubles Creek watershed encompasses 14,336 acres, most of which are composed of rolling agricultural hills mixed with deciduous forests on the steeper slopes and urban development in the flatter areas (Alexander et al. 2000). The Upper Stroubles Creek watershed is 24.8 km<sup>2</sup> (6,119 acres) and contains a large urban area associated with, or incorporated in, the Town of Blacksburg, and a majority of the main Virginia Tech campus (Benham et al. 2003). Stroubles Creek sits at an average elevation of 610 m above sea level, with the highest point in the watershed at 792 m and the lowest at 518 m above sea level (Alexander et al. 2004).

### Stream Morphology and Classification

Using the Montgomery and Buffington stream morphology system (Montgomery and Buffington 1997), Stroubles Creek can be categorized as a pool-riffle channel. It has a series of collecting pools and shallow running riffles contained within its stream banks. The deeper, cooler pools contain larger pieces of gravel and cobbles and allow fish to safely congregate in warm summer temperatures, while the faster-moving riffles filter out smaller particle sizes and facilitate their deposition along delta and point bars in the stream.

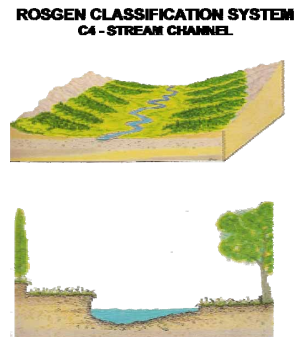


Figure 9. Rosgen Classification

Additional classification can be accomplished using the Rosgen classification system that assigns a letter/number combination to a given stream (Figure 9, Figure 10). Using this system, Stroubles Creek is classified as a C4 stream. It has relatively low slopes ( $< .02$ ), alluvial valleys, moderate meander widths and sinuosity, medium-depth pools, and is dominated by gravel beds along its stream bottom. Any stream restoration work or channel design/intervention must pay close attention to this information in order to avoid creating any further harm to the already-damaged stream system (Hession and Wynn 2006).

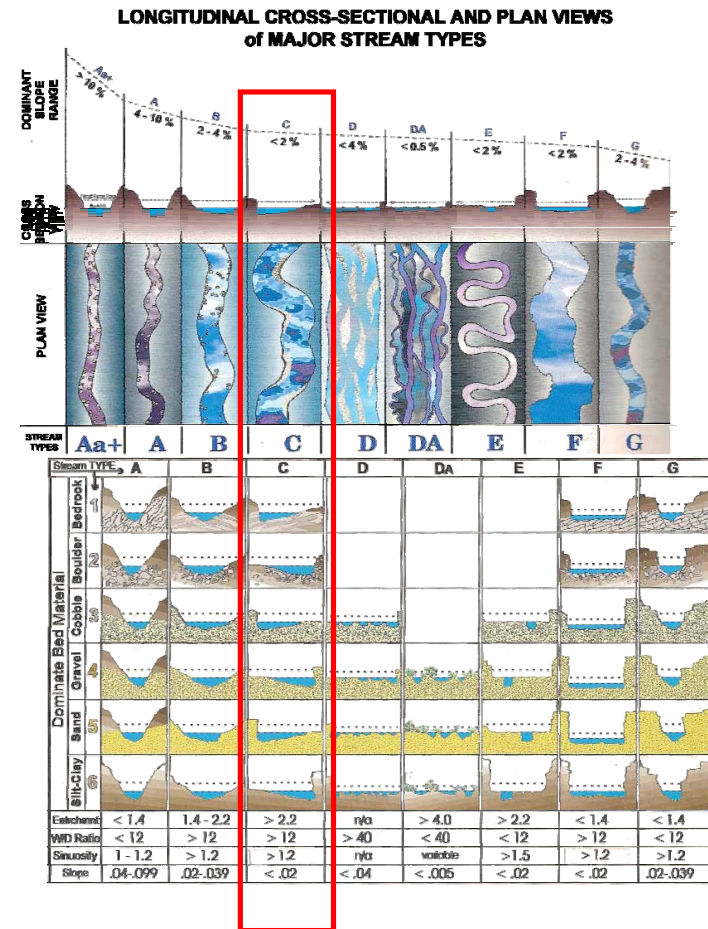


Figure 10. C4 Stream Type Characteristics

### ***A Brief History of Development and Land Use along Stroubles Creek***

Changes in land use throughout the Stroubles Creek watershed over time have had an important cumulative effect within its bounds. Some actions have altered the course of some of the watershed's streams, increased fine sediment and contaminants in its waterways, introduced cattle and crop production to the landscape, paved over large swaths of natural areas, and in the most extreme cases have buried streams underground to accommodate growth. Understanding these changes and their lasting impacts can help community leaders and residents anticipate future land use changes and devise better strategies for coping with them.

In 1671 a pioneer party led by Abraham Wood followed the "Trader's Path" connecting eastern and western Virginia, to explore unsettled land (Alexander et al. 2000). This path traveled along the Roanoke River to what is now Salem, crossed the Allegheny Ridge, and followed Stroubles Creek to Wood's River (now the New River). Originally a frontier settlement called Draper's Meadow, the town of Blacksburg was founded by William Black in 1798, due in large part to the presence of springs and streams in the area: "Black sent a petition to the General Assembly requesting that a town be established at a spot along Stroubles Creek" (Alexander et al. 2000).

In rural areas a homestead was often located near a spring. Three main springs were present in early Blacksburg: the Keister-Evans Spring, the Town Spring, and Spout Spring. Spout Spring feeds the Central Branch of Stroubles Creek which lies buried under much of the downtown area, including the university campus (Dunay 1986). Thus, springs and other sources of running water were important elements that helped structure the community. In fact, the line created by this particular stream bed "...determined not

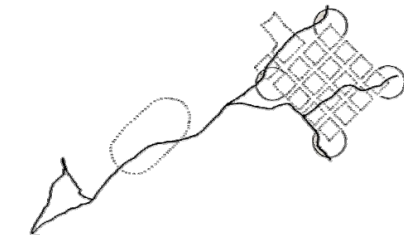


Figure 11. Orientation of Grid along Stroubles Creek

only the placement of Blacksburg but its peculiar 45-degree pitch as well" (fig. 11) (Dunay 1986).

Virginia Tech was established in 1872, and was originally called the Virginia Agricultural and Mechanical College (VAMC). For the next twenty years, what is now known as the Drill Field was covered with wheat and hay fields, orchards, gardens, and an agricultural experiment station (Figure 12). Stroubles Creek followed the edge of these fields.

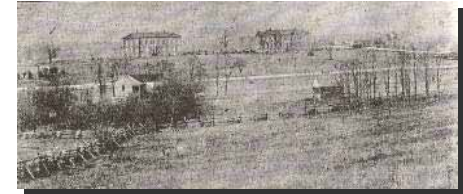


Figure 12. Virginia Tech campus circa 1887

"Between the years of 1892 and 1928, these cultivated fields were used as drilling fields for the cadets" (Younos 1999).

In 1914, Stroubles Creek itself was characterized as "surrounded by rough and hilly country, which gives to the creek numerous water-falls and rapids. The creek bed was characterized as having many rocks and riffles and water flowed through karst channels" (Younos 1999). But it was also known for its contamination: "...drainage into Stroubles Creek originated from pastures, cultivated fields, the town of Blacksburg and the college, and coal-mining activities. As Stroubles flowed through Blacksburg and Virginia Tech, town stables, privies, the VPI septic tank and other sources contaminated it" (Younos 1999).

Two main events directly impacted Stroubles Creek in the early 20<sup>th</sup> century. The first event, in 1928, occurred when Virginia Tech enlarged the drill field to the size that it is today (Alexander et al. 2000). According to a 1928 article in the Roanoke Times, it cost \$40,500 and involved removing 69,655 cubic feet of dirt and 1,800 cubic feet of rock. It also required re-directing the course of Stroubles Creek under the field by placing it in a culvert (Younos 1999). The second significant impact to the creek came with the creation of the Duck Pond. The pond was originally conceived as a recreational lake for ice skating and swimming, but it required damming a portion of Stroubles Creek to



create the necessary reservoir (Figure 13). Despite concerns that it would “eventually become a swamp and a mud-hole, due to run-off from Blacksburg” (Younos 1999), it was constructed in 1937 by the Works Progress Administrative Project.



Figure 13. Virginia Tech Duck Pond

Around 1900, urban land use was small since the town of Blacksburg only covered a few square blocks and the university was only a few buildings and experimental agricultural fields.

But urban land use increased significantly in the post-war population boom (Figure 14). After World War II, Blacksburg experienced growth “...on such a large scale that whole neighborhoods rather than individual dwelling units were being added to the town” (Dunay 1986). This was largely in response to demand of local soldiers seeking a college education.

The ever-increasing student population faced a critical lack of housing. As a result the new neighborhoods bore little semblance to the original historic town grid, choosing instead to replicate the newly-embraced suburban form of curving streets and larger lots. Apartment and townhouse complexes sprang up over the next thirty years or more, including Foxridge and Terrace View (Dunay 1986).

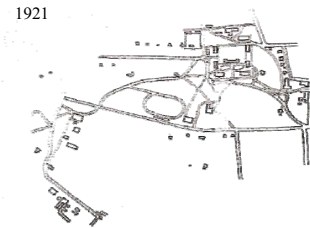
### ***Why Daylight Stroubles Creek?***

During the 20<sup>th</sup> and 21<sup>st</sup> centuries, rapid residential growth has remained the development norm, and future population projections indicate continuing challenges for Blacksburg and the Virginia Tech. Despite the existence of beautiful and significant water sources within the Stroubles Creek watershed, modern land use and development patterns have become a cause of serious concern. On one hand, a large portion of the watershed is used solely for agriculture, with its attendant issues related to nutrient management and riparian corridor protection. On the other hand, “there has been extensive development in the upper portions of the watershed. This development is significantly impacting water quality and influencing stormwater management efforts along those sections of the creek” (Alexander et al. 2000).

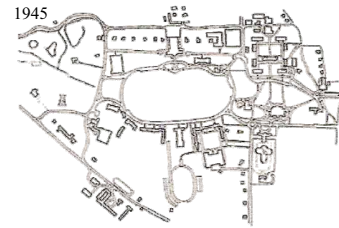
How does this development impact Stroubles Creek? First, as land uses change from naturalized areas to farmland to housing developments, construction practices directly impact nearby streams by disturbing the soil and sending it straight into waterways. Second, placing streams into culverts and pipes to get them out of the way of construction removes them from the rest of their natural processes and over time renders them incapable of performing their intended functions: supporting aquatic life, storing rainfall after storms, filtering pollutants, and carrying sediment effectively.

1921

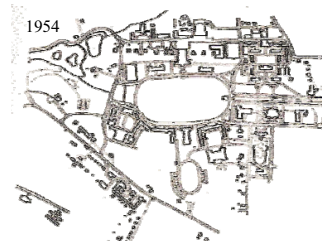
1921



1945



1954



1984



Figure 14. Historic progression of Virginia Tech campus

Problems with water quality, water quantity, and land use changes have emerged in Stroubles Creek as more and more of it gets surrounded by asphalt and concrete and placed underground. In response to this, stream daylighting is proposed as an alternative solution to expensive urban BMP (Best Management Practices) technologies. By removing the stream from its pipes and restoring it to its surface elevation, it is very likely that the system can recover its life-giving role in the natural environment and reclaim its proper place among the identifying features of Blacksburg. If future land use changes can be predicted and accommodated – including the composition of the urban fabric of Blacksburg and the Virginia Tech campus – then the face of Stroubles Creek can also be anticipated and included in those changes. Rather than erase the natural resource that made the community possible, it is time to consider planning for it and around it as part of the future of the entire watershed. Daylighting its buried pieces, and protecting what segments remain above ground, is the best course of action.

#### Water Quality

The Virginia Department of Environmental Quality (VDEQ) has been monitoring chemical water quality in the Stroubles Creek watershed since 1979. Biological monitoring has been conducted at station STE007.29 (Merrimac Road) on Stroubles Creek since 1994. Monitoring was conducted twice a year, when in 1998, 2000, and 2002 successive assessments indicated decreased numbers and diversity of organisms in the benthic macro-invertebrate populations in and around the stream bottom, leading to the designation of Stroubles Creek as being “impaired” (Figure 15) (Benham et al. 2003). A benthic impairment is “a condition whereby a stream is assessed as having chronic or recurring monitored violations of the state general standard as shown through biomonitoring results” (Benham et al. 2003).

An impairment in a stream segment usually stems from nonpoint sources of pollution found throughout all portions of an upstream area that drains down to the impaired segment. VDEQ listed nonpoint source agricultural and urban pollution as the

probable causes of the benthic impairment (Benham et al. 2003). The primary stressor was identified as sediment with additional contributions from nutrients and organic matter. A Total Maximum Daily Load (TMDL) study was conducted on Stroubles Creek from April 2002 through October 2003 and approved by the USEPA in 2004. The TMDL report was developed specifically for sediment and required reductions from the three main sediment sources: agriculture, urban development, and channel erosion (Benham et al. 2003). Approximately 27% of the sediment loading was attributed to stream bank erosion.

Excessive sediment loads are typically linked with increased urbanization. The means by which this occurs is that expanding housing and commercial development directly disturbs surface soil, which results in an increased supply of fine, loose sediment available for transport in nearby stream systems. Combined with larger

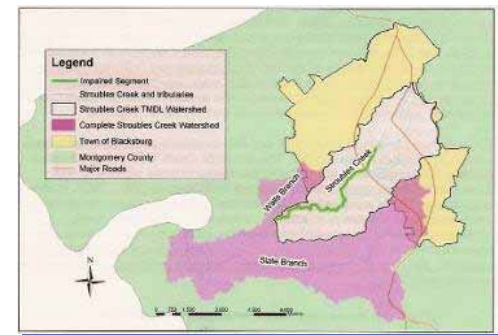


Figure 15. Location of impaired segment of Stroubles Creek

impervious surface area (rooftops, paving, etc.) that dramatically increases the rate and volume of stormwater runoff, the result is often stream bank erosion (Benedict and McMahon 2006). Even after development activities have ceased, the destabilized stream banks continue to further erode in an ongoing and natural effort to re-establish dynamic equilibrium within the disturbed system (Hession and Wynn 2006). As a result, the source of sediment loading shifts from damaging construction practices to the damaged streams themselves.



Research carried out by the Stroubles Creek Implementation Plan Development Team confirms that this is the case for the Stroubles Creek watershed: “Sediment is delivered to the impaired segment of Stroubles Creek through the processes of surface runoff, channel and streambank erosion, and from point source inputs, as well as from background geologic processes. During runoff events, sediment loading occurs from both pervious and impervious surfaces...Streambank erosion is caused by reduction in riparian cover...[and] animals grazing on pastures in riparian areas with access to streams...Transport of sediment is further increased by increasing areas of imperviousness...from urban growth and development” (Stroubles TMDL IP Study 2006). Of additional note is the fact that the Duck Pond, which is the receiving water body of upstream reaches of Stroubles Creek in the most urbanized portion of the watershed, has “had a history of sedimentation problems that led to dredging practices in 1950, 1960, and 1986” (Younos 1999). This indicates that sediment is a problem in the stream system before it ever leaves the Duck Pond and journeys to the New River.



Figure 16. Virginia Tech, 2006

In this light it is likely that the housing expansion experienced after World War II caused damage to the headwater reaches of the upper watershed, and unchecked construction practices and post-construction site management since then have continued to damage the system. More importantly, increased development is to be expected as both the Blacksburg community and Virginia Tech campus continue to expand (Figure 16). Town population growth is projected to increase from 35,972 people in 2000 and up to 56,660 by 2046 (Stroubles TMDL IP Study 2006). While the town is growing at a relatively slow rate (2.7%), the university is projected to “grow at a rate of five percent annually after 2020”, reaching an ultimate projection of 27,500 students by 2030 (Alexander et al. 2000). These figures suggest that enrollment will grow more than the overall town population during the same time period, which translates into the potential for more students living off-campus as

Virginia Tech does not currently have enough housing on campus to meet this future demand. The result: the need for more housing construction and the potential to further damage Stroubles Creek and its watershed.

#### Water Quantity

Compared to some urban communities that experienced such significant and frequent downtown flooding caused by streams housed in failing underground pipes (Kalamazoo, MI and Hutchison, KS), Blacksburg typically does not experience much flooding in its upper watershed. However, two types of events are worthy of mention regarding water quantity in Stroubles Creek. The first event was a flood in 1992 that damaged portions of downtown Blacksburg and caused an estimated \$4.5 million in damage to the Donaldson Brown building on campus (Figure 17).

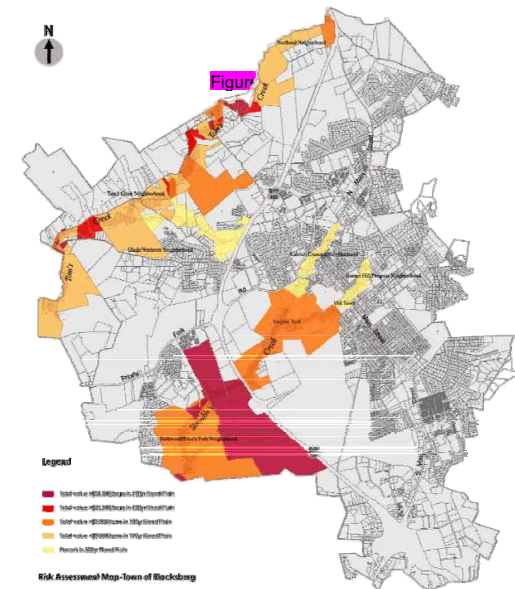


Figure 17. Parcels in 100-Year Floodplain

It is speculated that the primary cause of downtown flood damage was the inability of channelized portions of Stroubles Creek to effectively pass increased storm discharges.

The second type of event is known as a “bankfull” event, where a stream channel is filled with enough rainfall in a given storm to fill it up to the top of its stream banks. Normally, this type of event occurs approximately every 1.5 to 2 years on average, helping to form and maintain the average width and depth of the

channel over time. In the case of portions of Stroubles Creek in the lower watershed – in agricultural areas – bankfull events have occurred twice already in 2007, prior to and including the month of May. With heavier summer storms yet to come later in the season, the increased numbers of bankfull events could be an indication of growing water quantity problems starting in the upper, urbanized sections of the same watershed.

#### Land Use Changes

A map of land use within the Stroubles Creek watershed was digitized and classified by the Virginia Department of Conservation and Recreation from 1998 digital orthophoto quads (Figure 18). Land use within the Upper Stroubles Creek watershed, where the impaired segment of Stroubles Creek is located, is 46% urban, 28% forest, 21% pasture, and 5% cropland (Alexander et al. 2000). The urban and residential area is mainly in the northeastern section of the watershed; the forested area is mainly in the southwestern area; the agricultural area is in the middle (Benham et al. 2003). The town of Blacksburg is located within the large urban zone, encompassing approximately 19 square miles. This includes the main campus of Virginia Tech and the majority of residential neighborhoods. This is the location of the largest amount of impervious surface cover from roads, parking lots, and rooftops. It is also the location of the headwater springs of Stroubles Creek.

Further urbanization is expected in the entire Stroubles Creek watershed as population trends show that Blacksburg has been growing faster than the rest of the New River Valley. This leads to increased demand for new housing, labor, employment, and commercial/industrial development (Blacksburg 2046 Comprehensive Plan 2006). Though agricultural operations will still exist, and their effects will continue to have an impact, the urbanized areas will become the focal point of water quality and quantity. Future projections of population growth and land use indicate "...a virtual elimination of forested and agricultural land by 2046 within the Blacksburg portion of the watershed....the major trend from this analysis – that

agricultural land would be shifting to urban residential, commercial, and institutional uses – was consistent with that of a growing urban community such as the one found in the Upper Stroubles Creek watershed" (Table 1) (Stroubles TMDL IP Report, 2006).

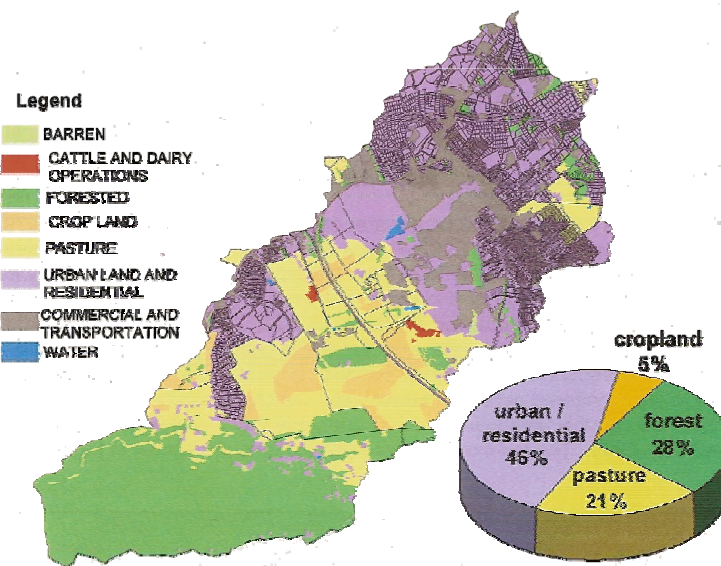


Figure 18. Land use distribution in the Stroubles Creek watershed

Table 1. Landuse Change Between Existing and Future Scenarios

|             | Existing | % Change | Future |
|-------------|----------|----------|--------|
| Agriculture | 25.7%    | -5.9%    | 19.8%  |
| Urban       | 46.6%    | 7.5%     | 54.1%  |
| Forest      | 27.7%    | -1.6%    | 26.1%  |

In anticipation of such drastic changes in the future, the town of Blacksburg has taken positive steps to initiate long-term strategies that will protect natural resources within its bounds, especially water resources. One of those strategies is called the “Creek Overlay Zone”. It is a connected system of buffers around streams that form the Tom’s Creek Basin west of Route 460 and is designated as a no-development zone (Figure 19). The intention is to prevent housing, commercial, or institutional construction from taking place within those buffers in order to protect the integrity of the existing streams found there. This is also meant to protect water quality and quantity in the overall Tom’s Creek watershed (Blacksburg 2046 Comprehensive Plan 2006).

Fundamentally this is a good start but the limitation rests in the fact that there is no such protective buffer planned for the headwater streams of Stroubles Creek east of Route 460. While it is imperative to protect waterways from development impacts, one stream system should not be selected for intervention over another. All of these streams combine at some point, sending their cumulative pollutants and stressors down the entire water system. The fact that one stream system is already surrounded by urban development does not exclude it from the same consideration as a rural system; the same ideology can be applied in both settings, using different means.

A second initiative underway by Blacksburg’s leaders is the development of a Greenway Master Plan (Figure 19). It is intended to extend walking trails throughout the community, linking open space with neighborhoods, downtown businesses and campus destinations (Blacksburg 2046 Comprehensive Plan 2006). It is anticipated that many of these new trails will follow several lengths of Stroubles Creek, simultaneously buffering the stream from development while offering an attractive park-like amenity to local residents and visitors. But the Greenway map itself does not visually indicate these

buffers or the stream lengths they will follow (especially those currently running in underground pipes), so it is unclear how true to this intention any future greenway construction will be. Simple dashed lines on a map of town are hopeful but unconvincing in terms of final implementation. Finally, the town’s Park map (Figure 19) does not include any visible lengths of Stroubles Creek, now or in the future. This is a discouraging observation.

But urban stream daylighting may be the answer to all of these concerns. The downtown Blacksburg master plan reiterates the historic importance of Stroubles Creek in the establishment of the town and states “Stormwater management is a critical issue in the downtown sector, which has a very high percentage of impervious surface....Opportunities to daylight this environmental asset should be explored to the east and west of the immediate downtown area, and maybe in the central core in future years if possible”).

Pulling branches of Stroubles Creek out of their pipes over time can be the tool by which the entire stream corridor is recovered and restored – and as a result possibly protected from future development as well. Related park space and urban forest canopy can actually be expanded by daylighting this stream, rather than lost to development. The proposed Greenway plan which includes planting trees, native shrubs, and seasonal grasses can help stabilize eroding stream banks while providing necessary wildlife habitat – linking human and natural communities alike. Rather than deeming urban land development as an inevitable destructive force of the future, strategies like stream daylighting can turn aspects of it into a positive outcome for the environment. As the urban fabric changes over time, so too, can the physical form of Blacksburg’s native streams. Perhaps revealing pieces of this critical system will prevent any further burial while allowing what exists to recover and reclaim its rightful presence in the entire community.

## FUTURE LAND USE & STREAM CORRIDOR OPPORTUNITIES - 2046

**Proposal:** Park System and Greenway Master Plan could be revised to include protection of the Stroubles Creek corridor within town limits.

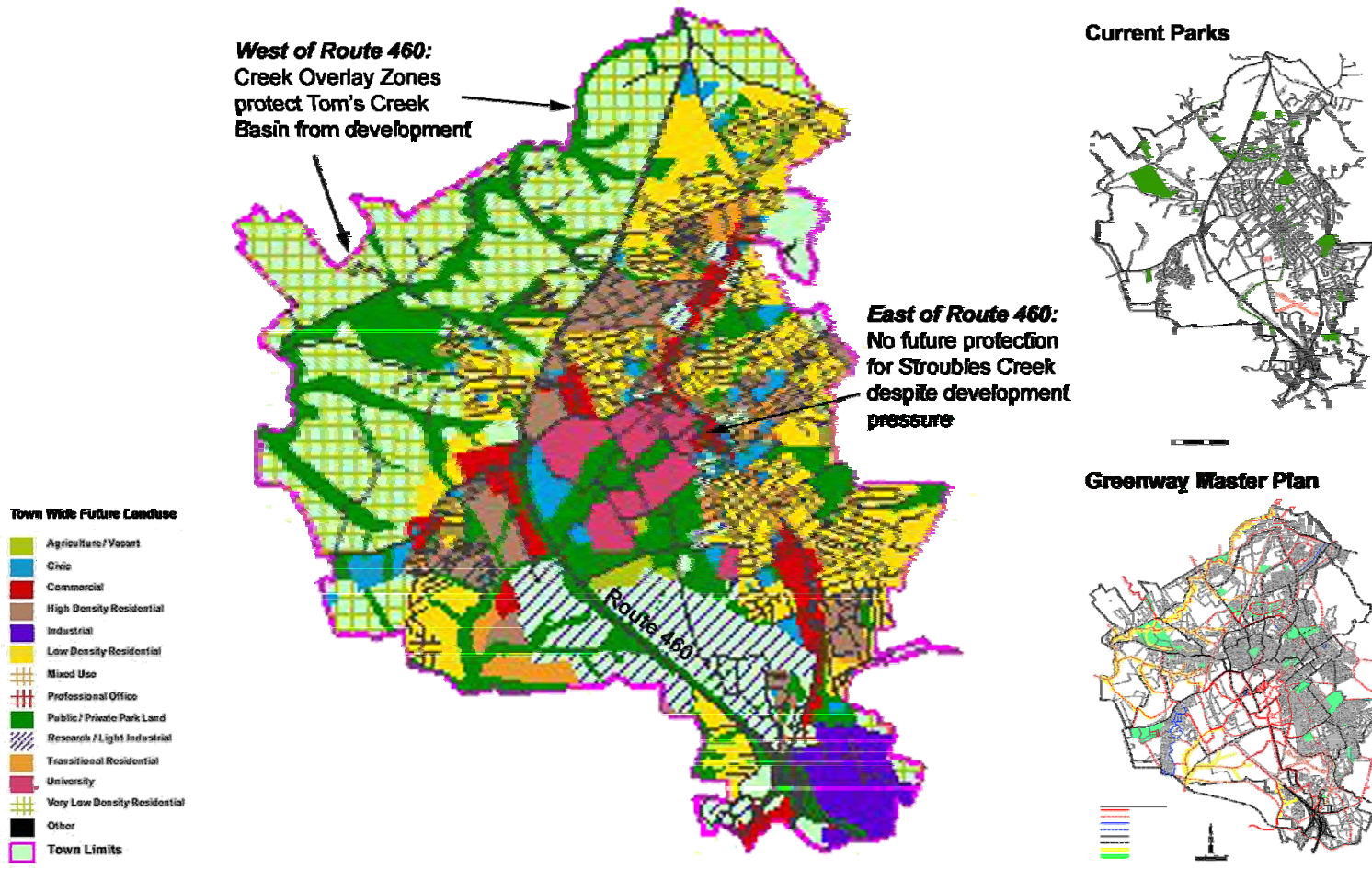
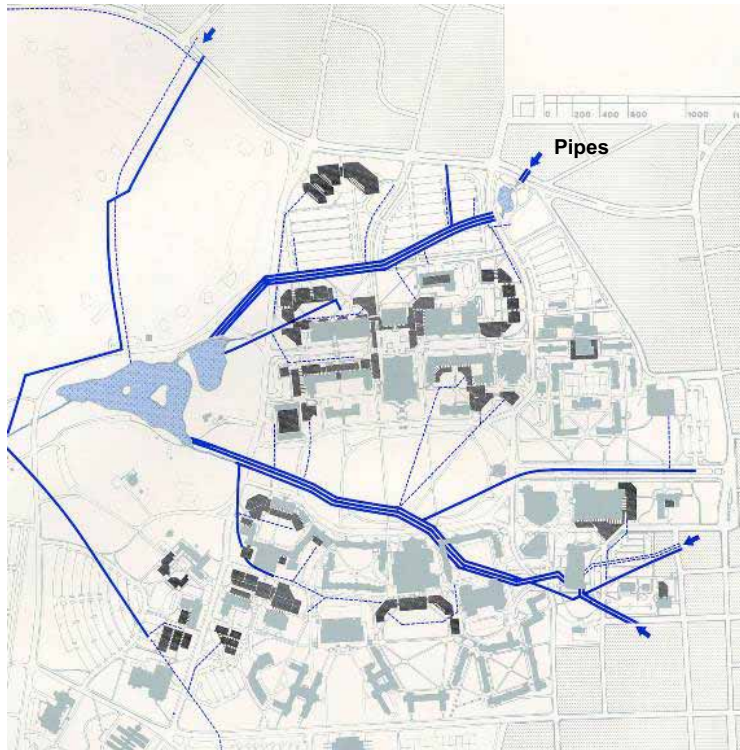


Figure 19. Creek Overlay Zone map; Town of Blacksburg Parks Map; Town of Blacksburg Greenways Master Plan  
Blacksburg 2046 Comprehensive Plan. 2006.



## DAYLIGHTING STROUBLES CREEK



**Existing Conditions:**  
Buried portions of Stroubles Creek on campus  
Source: Virginia Tech Campus Master Plan



**Early Concept:**  
The same corridor, only daylighted and buffered

### Where is Stroubles Creek Today?

It is extremely difficult – if not impossible – to detect any signs of Stroubles Creek while standing on the corner of College Avenue and Main Street in downtown Blacksburg. The stream system responsible for the original settlement of Draper's Meadow, and the angle and orientation of the historic 16-square grid, has vanished from the map. A few storm drains here and there are the only reminders that there is any natural water running nearby. Draper Aden Associates compiled a map of Blacksburg's "Historic Streams" and highlighted in red those segments that are now buried in underground pipes (Figure 21). All of them are located in the urbanized sections of town.

The progressive covering of these stream reaches is well-illustrated by Donna Dunay in her book, *Understanding a Virginia Town: Town Architecture*. Between the late-1800's and early 1900's, the stream system in town remains intact. But after World War II pieces of it begin to disappear, and continue to disappear well into the 1980's as the Virginia Tech campus expands (Figure 20).

Two branches of Stroubles Creek are candidates for daylighting. Webb Branch has a portion running underneath the Commuter Lot on campus. But it remains largely at surface elevation and has received enough attention through recent design proposals to not warrant investigation at this time. Central Branch, however, runs largely underground for much of its length and transects the downtown business district as well as large portions of the Virginia Tech campus. Its contribution to the 1992 flood was significant, and is a perfect candidate for various forms of daylighting.

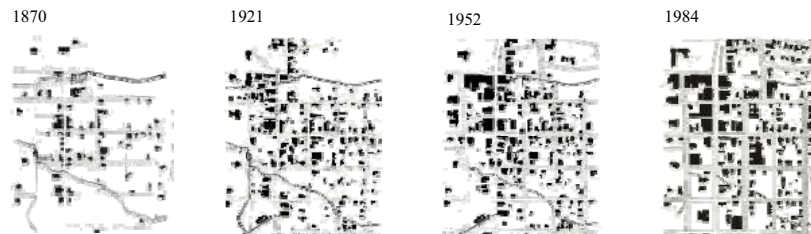


Figure 20. Historic progression of development in downtown Blacksburg (Note missing sections of branches of Stroubles Creek after 1921)

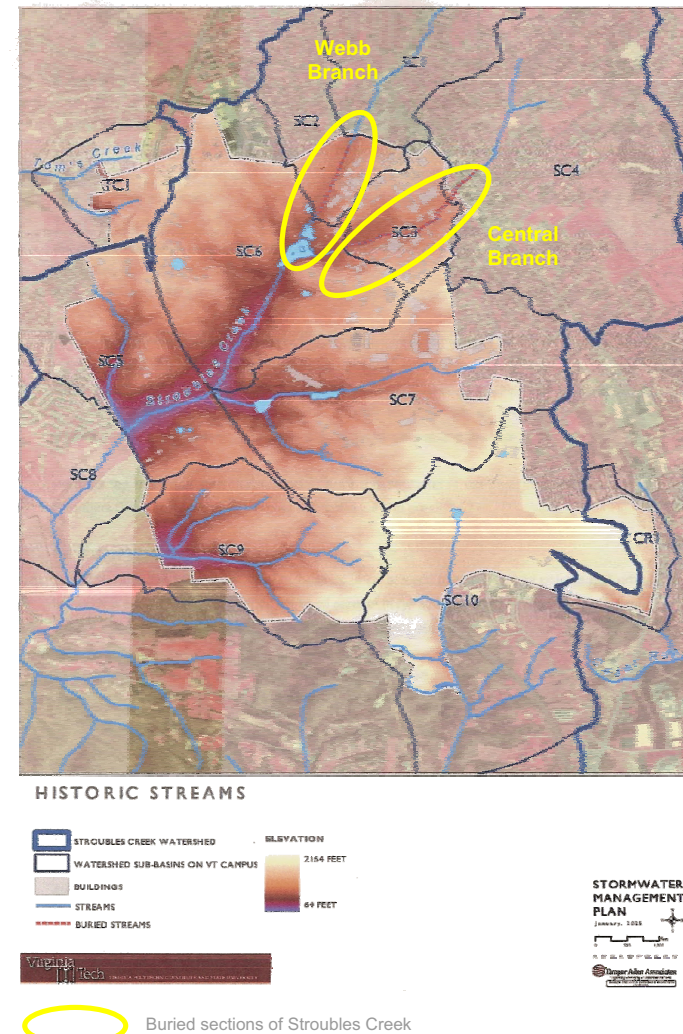
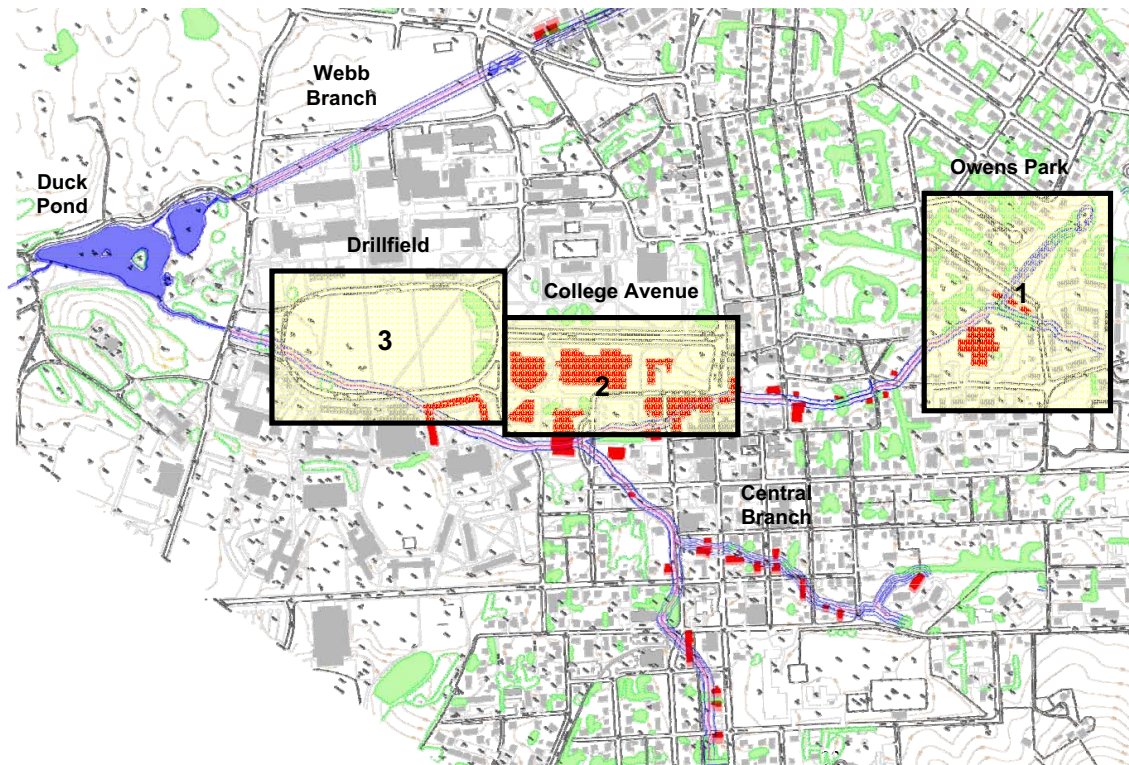
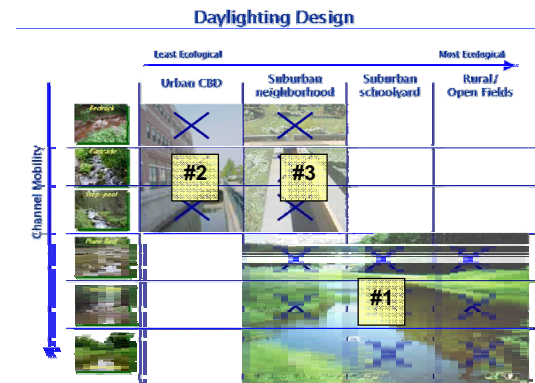


Figure 21. Map of Blacksburg's lost "Historic Streams"

### Applying the Matrix: Where to Daylight Stroubles Creek

To test the validity of the proposed Daylighting Design Matrix, three locations along the Central Branch of Stroubles Creek were selected based on landscape characteristics that matched, or were very similar to, those found in the matrix. In addition to site selection, the three daylighted stream typologies depicted in the matrix were explored for their design opportunities and challenges. Using these site selection characteristics and stream typologies, the ultimate goal was to create a complete stream corridor for Central Branch from its headwaters to its outfall point at the Duck Pond. This included restoring the upper reach that currently sits at surface elevation but is in poor condition, and daylighting the rest of the stream.



### Selected Sites

#### **Site #1: Owens Street Park**

*Location:* Large park / playing field

*Proposed Outcome:* 'Naturalized' stream

#### **Site #2: College Avenue**

*Location:* Edge of business district

*Proposed Outcome:* Artificial stream

#### **Site #3: The Drillfield**

*Location:* Multi-purpose university field

*Proposed Outcome:* Channelized stream



### Site #1: Owens Street Park – ‘Naturalized Stream’

Owens Street Park is located near the headwaters of the Central Branch of Stroubles Creek. The park – basically a large lawn with a small playground in it – is very close to Harding Elementary school and residential neighborhoods. The following site features made it a good candidate for basic stream restoration work to re-establish a naturalized stream channel.

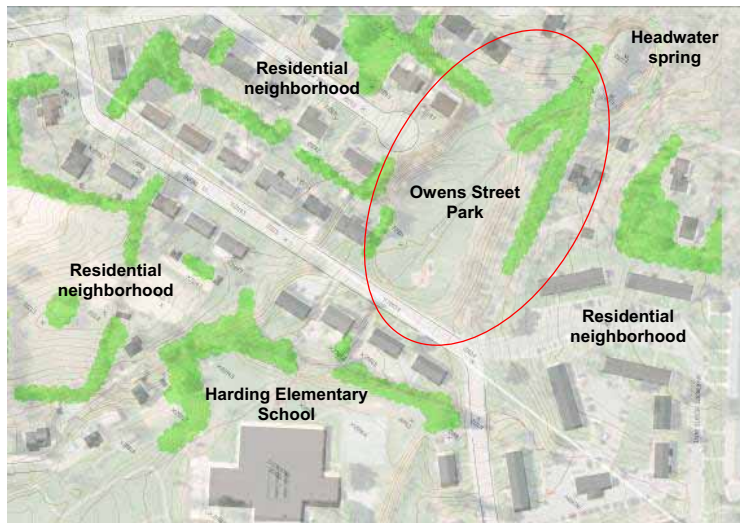
*Note:* this portion of the project does not directly involve daylighting *per se*.



Owens Street Park

### Factors in Site Selection

- Large area of open space without pavement, structures, or utilities
- Stream on surface but not protected with riparian buffers
- Straightened channel wrong form for stream type
- Outfall pipes old, wrong size, in poor condition; site flooding a problem
- Lots of lateral room for meandering and small storage / settling ponds
- Close to elementary school and residential area; place for children to play and exercise



### Precedent: Jolly Giant Creek Arcata, CA

**Size:** 160 linear feet daylighted;  
570 surface channel restored

**Dates:** 1991, 1995, 1997

**Budget:** \$120,000 for all three projects

**Purpose:** Outdoor Ecological Classroom

### Results

- Resident cutthroat trout have returned.
- Spawning redds observed.
- Juvenile Coho salmon and steelhead observed.

### Channel Design Features

- Sedimentation basin: 30 ft wide by 15 ft deep by 80 ft long. Meant to be dredged by backhoe.
- Curved pond roughly 75 feet long and 1/3 acre in size for aquatic plants and fish refuge.
- Sunken root wads added to pond.
- 75 feet of new stream channel downstream of pond.
- Upper floodplain built above the creek.



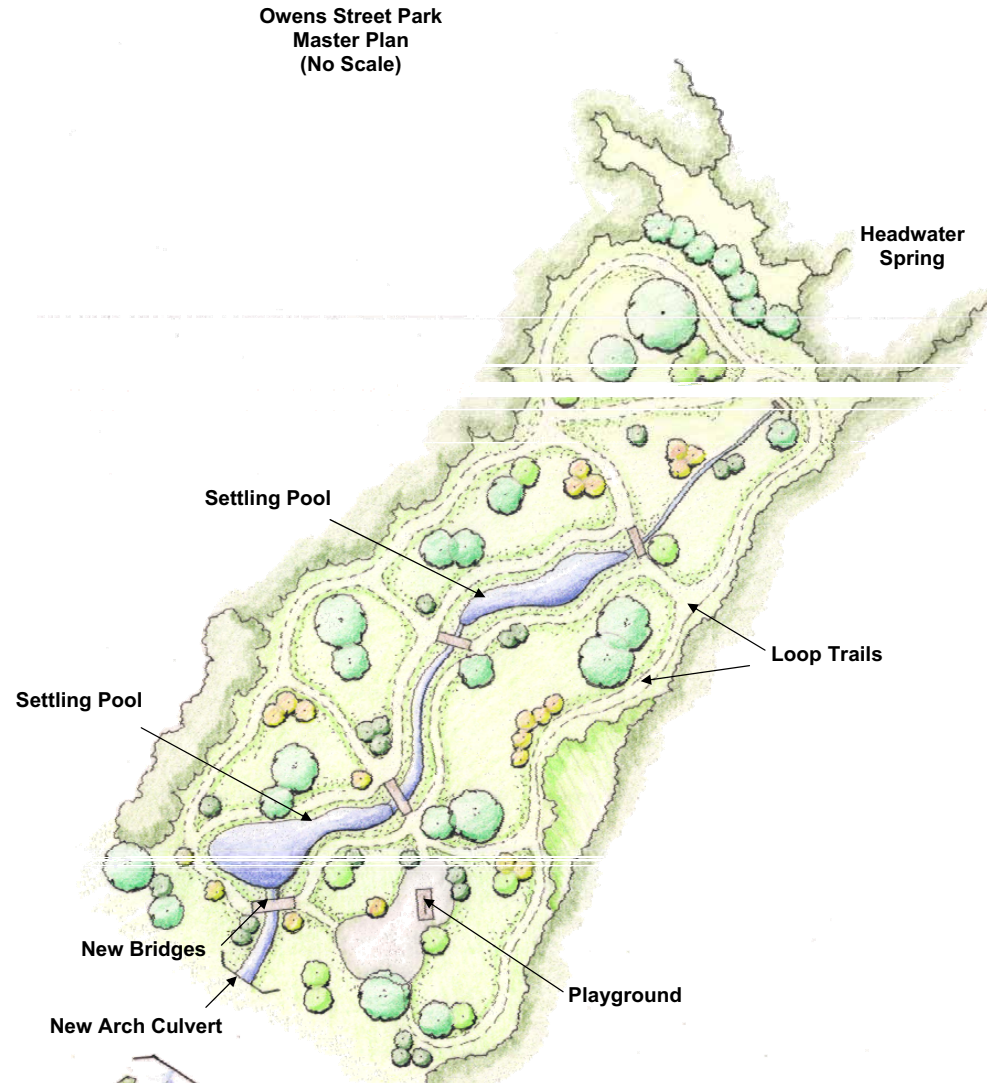


**Owens Street Park (aka Stroubles Park) Restored Stream Channel  
Concept Plan**



### **Design Features**

- Establish greater channel sinuosity consistent with C4 Rosgen classification
- Restored channel will be approx. 6 ft wide x 1 ft deep
- 2-year storm capacity calculated to be <150 cfs
- 10-year storm capacity calculated to be <300 cfs
- Protect pool-riffle bed structure to maximize pooling of water at headwater reach; do not remove cobbles or boulders found in the stream
- Stream banks to be made of earth and stabilized with riparian plantings
- Build two shallow settling pools to allow sediment from site to drop out of channel
- Build several 'loop trails' for different fitness levels
- Plant many more native trees and shrubs in clusters through the park and along the stream to increase canopy cover and shading
- Install new bridges near pools to connect to trails and provide an 'overlook' point for stream viewing
- Allow school to conduct outdoor classrooms and stream monitoring programs in park
- Remove old outfall pipes and replace with wider diameter arch culvert at road to prevent site flooding





## Site #2: College Avenue – ‘Artificial Stream’

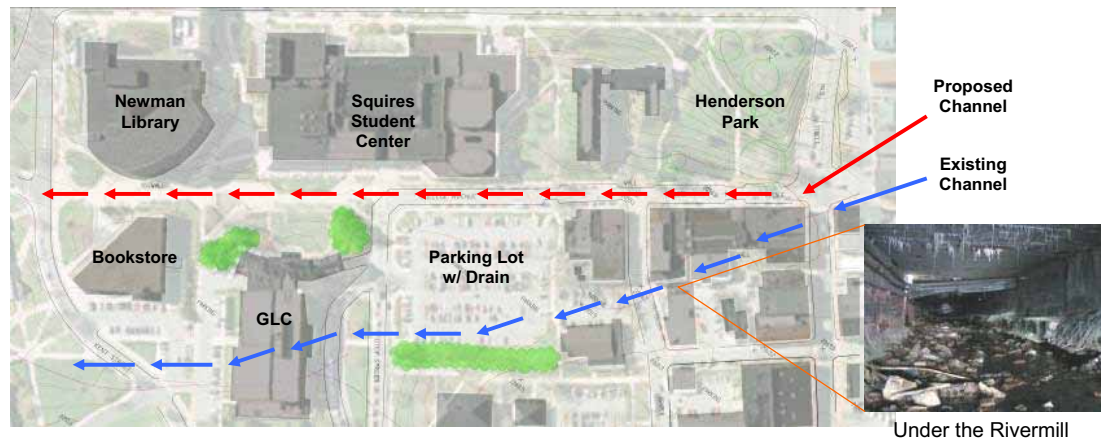
Stroubles Creek currently runs under several buildings in downtown Blacksburg and sometimes floods them under extreme storm events. The stream’s health is poor in these locations and deserves consideration as part of a total effort to repair water quality (and quantity) as per stated TMDL objectives. Its location between the town and the university campus makes it an ideal site to address the most challenging urban daylighting conditions. The fact that this is the location of one of the historic branches of Stroubles Creek cannot be overstated in terms of returning the stream to its deserved prominence within the human community.



College Avenue

### Factors in Site Selection:

- Stroubles Creek runs under many buildings, flooding them
- Street has enough room for a partial concrete channel and natural stream banks and stream bed
- Edge of business district is better than center of district
- Rather than demolish several historic buildings to place stream and buffer in current location, re-direct channel down the street
- Location of historic branch of stream; restore local identity
- Link to Henderson Park can add needed dimension to streetscape
- Presence of large amounts of impervious surface add to sedimentation and pollutant loading of stream; removal may improve downstream water quality



Under the Rivermill

## Precedent: Arcadia Creek Kalamazoo, MI

**Size:** 1,550 linear feet (5 city blocks)

**Dates:** 1995

**Budget:** \$7.5 million

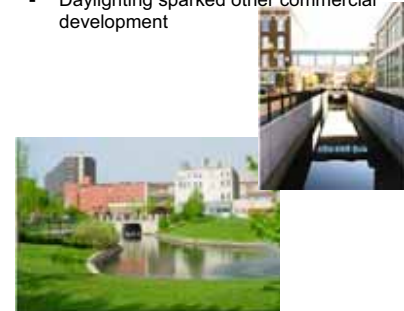
**Purpose:** Prevent urban flooding  
Economic Redevelopment

### Channel Design Features

- Three city blocks of concrete channel built: 20 ft wide by 12 ft deep
- Six weirs approximately 1.5 feet deep installed in channel
- Two blocks at end of channel became stormwater pond
- Existing culvert kept in place
- Second culvert constructed downstream to increase storm capacity

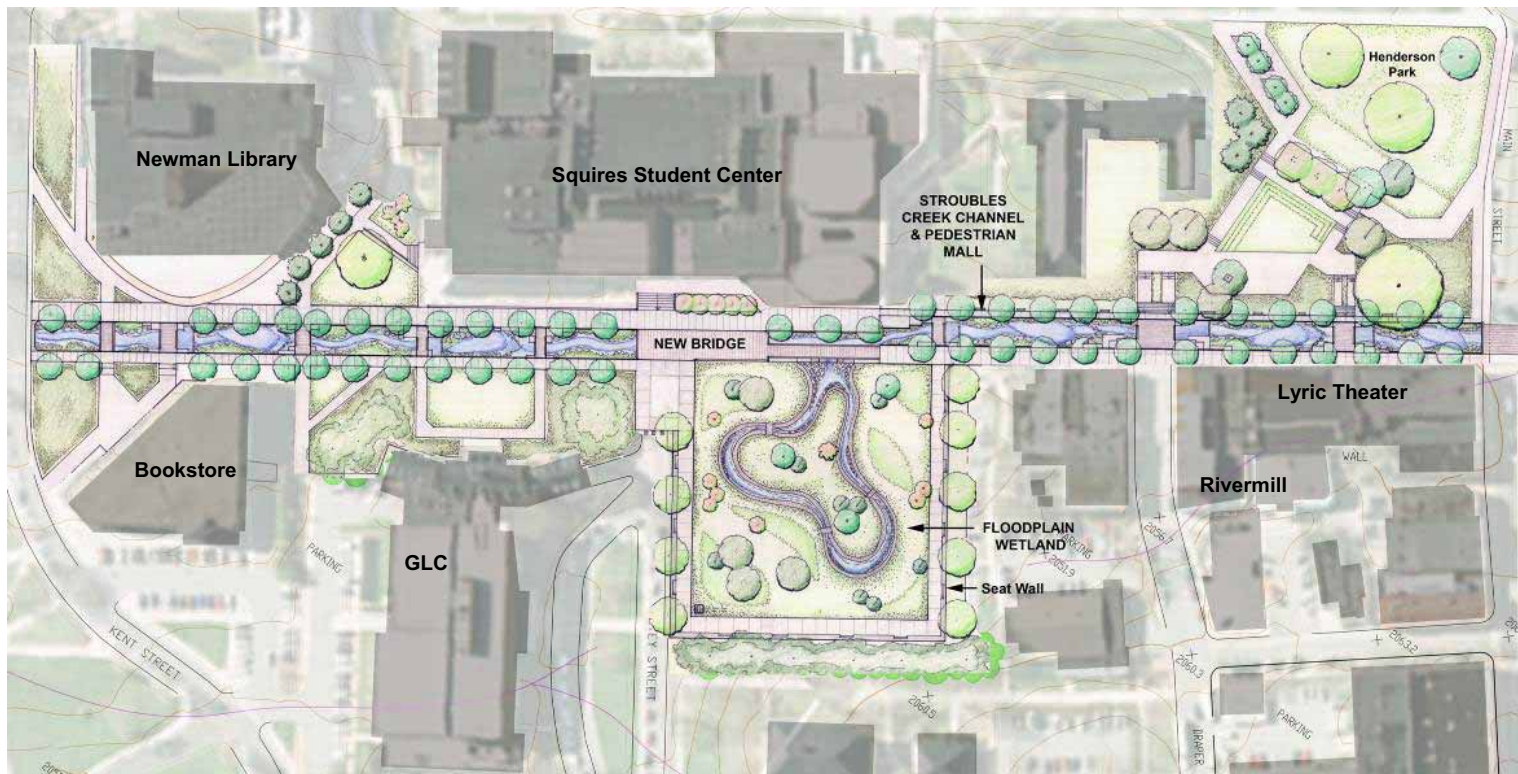
### Result

- Kalamazoo has protection from 500-year flood event
- Local floodplain maps have been redrawn
- Downtown properties no longer pay flood insurance
- Activity and concert fees at the new site generate \$12 million / year
- Daylighting sparked other commercial development

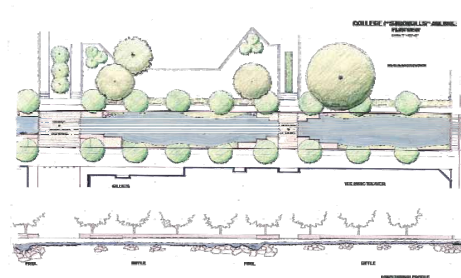
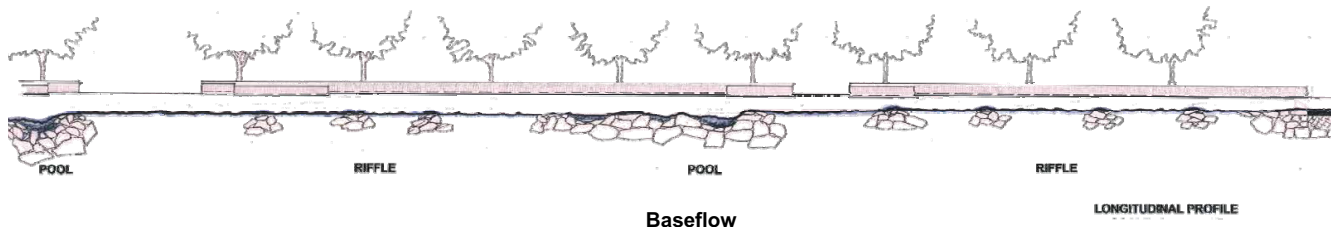
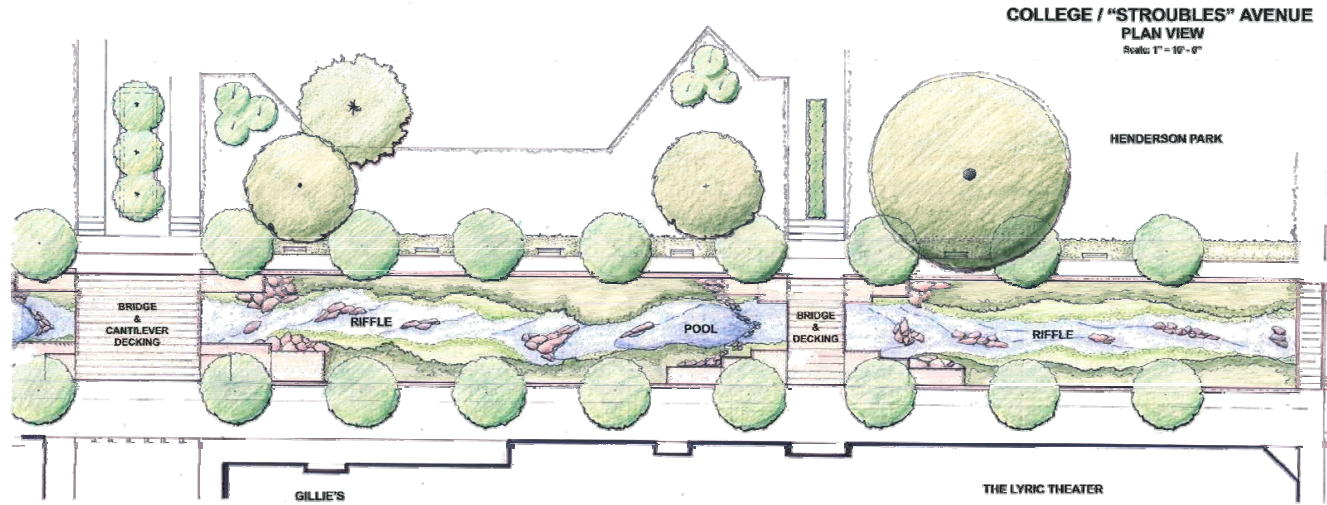


**Key Design Features:**

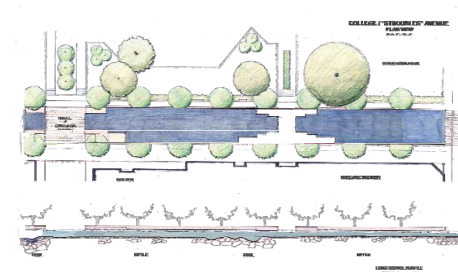
- New channel is 30 ft wide x 4 ft deep at inlet pipe
- Sides of channel are 2-ft thick concrete walls faced in architectural stone
- Stream bed is native clay found beneath the street
- D50 particle size is 8.9 mm (gravel); boulders and cobbles added to stabilize in-stream banks and pool-riffle structure
- Distance between pools and riffles is approximately 100 feet (distance between pools is approx. 200 feet)
- Cantilevered decks or 'piers' built next to bridges to accommodate local residents, shoppers, and students
- Brick and iron fence removed from Henderson Park
- Sidewalks offset to be wider along merchant side of College Avenue and narrower on Henderson Park side
- Regular spacing of street trees every 40 feet to provide shade
- Floodplain wetland park doubles as new student / community park and storm overflow basin in large rainfall events. Channel allowed to dry between storms.
- When channel travels through Newman Plaza, sidewalk is offset to be wider for Squires Student center and Newman Library.
- Vehicular traffic is blocked just passed the GLC and the Rivermill; fire access to Squires to be provided via Draper Road bridge



College Avenue Daylighted Stream Channel  
Plan View



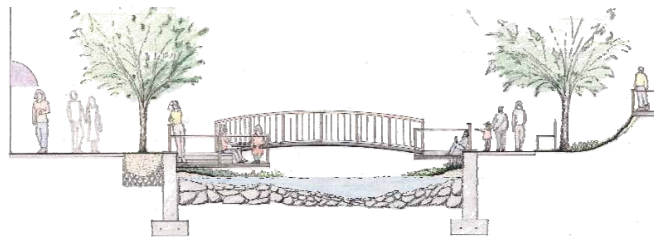
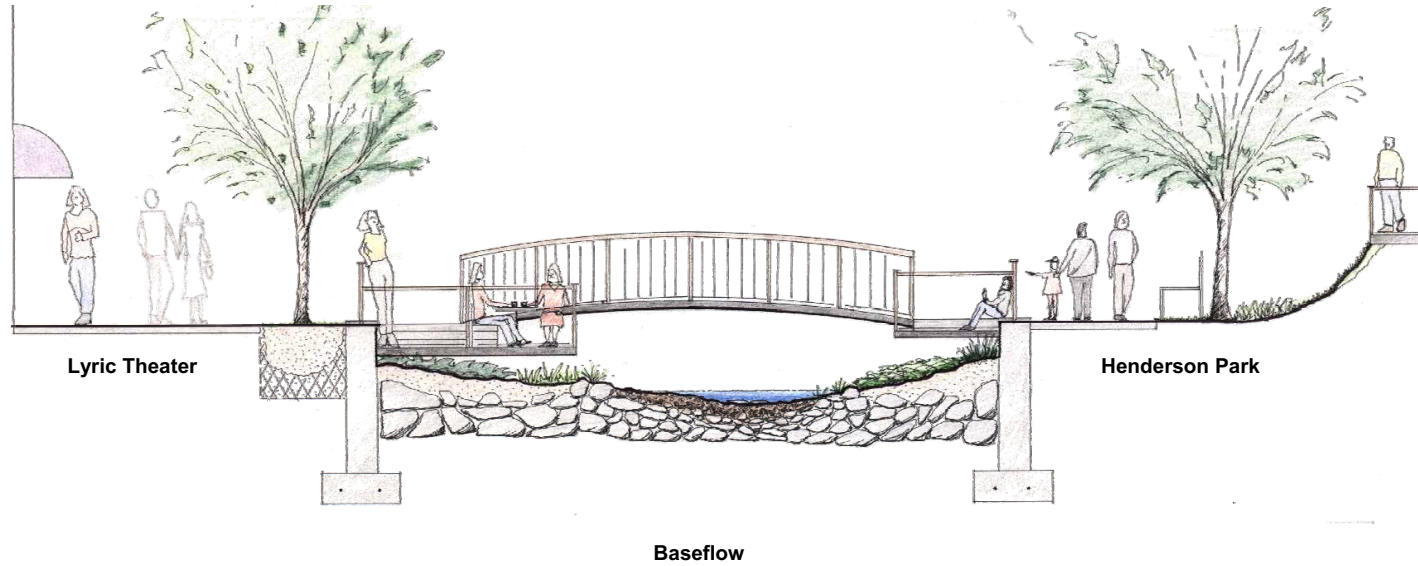
2-Year Storm Event  
(approximately 150 cfs)



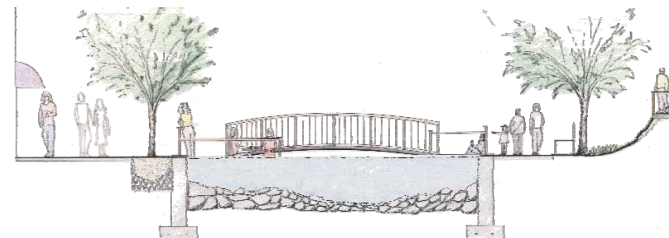
10-Year Storm Event  
(approximately 300 cfs)



College Avenue Daylighted Stream Channel  
Cross Section



2-Year Storm Event  
(approximately 150 cfs)



10-Year Storm Event  
(approximately 300 cfs)

**CONCEPTUAL SKETCH**



**College Avenue - Before**



**College Avenue - After**



**CONCEPTUAL SKETCH**



**Newman Library Plaza - Before**



**Newman Library Plaza - After**

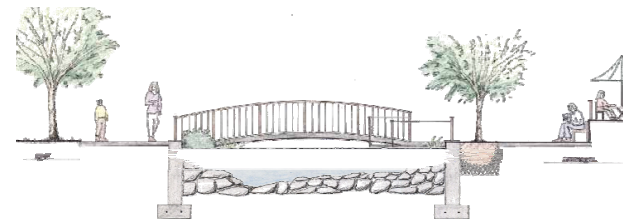
**Newman Library Plaza Daylighted Stream Channel  
Cross Section**



**Baseflow**



**2-Year Storm Event  
(approximately 150 cfs)**



**10-Year Storm Event  
(approximately 300 cfs)**



**CONCEPTUAL SKETCH**



**Squires Floodplain Wetland Park - Before**



**Squires Floodplain Wetland Park - After**

### Site #3: Drillfield – ‘Channelized Stream’

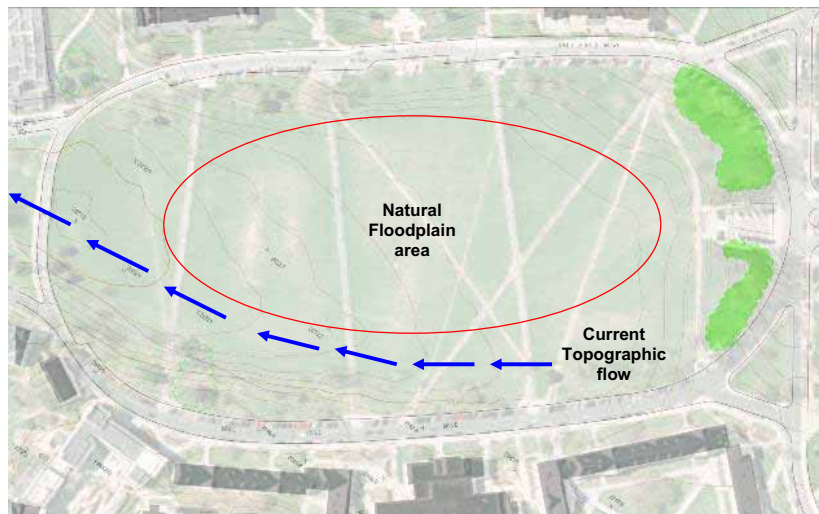
The Drillfield on the campus of Virginia Tech is a very large area of land under which runs one of the original channels of Stroubles Creek. It has few overhead or underground obstructions, and electric utilities are easily moved. Its natural topography and width provide an excellent location for a semi-natural, semi-controlled stream channel that flows directly to the Duck Pond without adding settling ponds in this location. It also has enough room to accommodate the greenway system of walking trails proposed by the town.



The Drillfield

#### Factors in Site Selection:

- Large area with room to establish meandering stream banks and earthen stream bottom
- Need to respect multi-purpose use of Drillfield; control stream banks to prevent excessive soil erosion on sloped sides of the field
- Location of original stream channel prior to enlargement of Drillfield
- Naturally depressed topographic area flows to Duck Pond; excellent ‘floodplain’
- Annual addition of trees for graduating classes can be incorporated into greenway trail plantings
- Good link between neighborhoods, campus, and downtown district



#### Precedent: The Dell Charlottesville, VA

|                 |                                                         |
|-----------------|---------------------------------------------------------|
| <b>Size:</b>    | 1200 linear feet daylighted<br>New sediment basin built |
| <b>Dates:</b>   | 2002-2004                                               |
| <b>Budget:</b>  | ~\$700,000                                              |
| <b>Purpose:</b> | Mitigate downstream development<br>Campus Amenity       |

#### Results

- Native wildflowers and volunteer vegetation have reappeared
- Tadpoles observed in the new stream

#### Channel Design Features

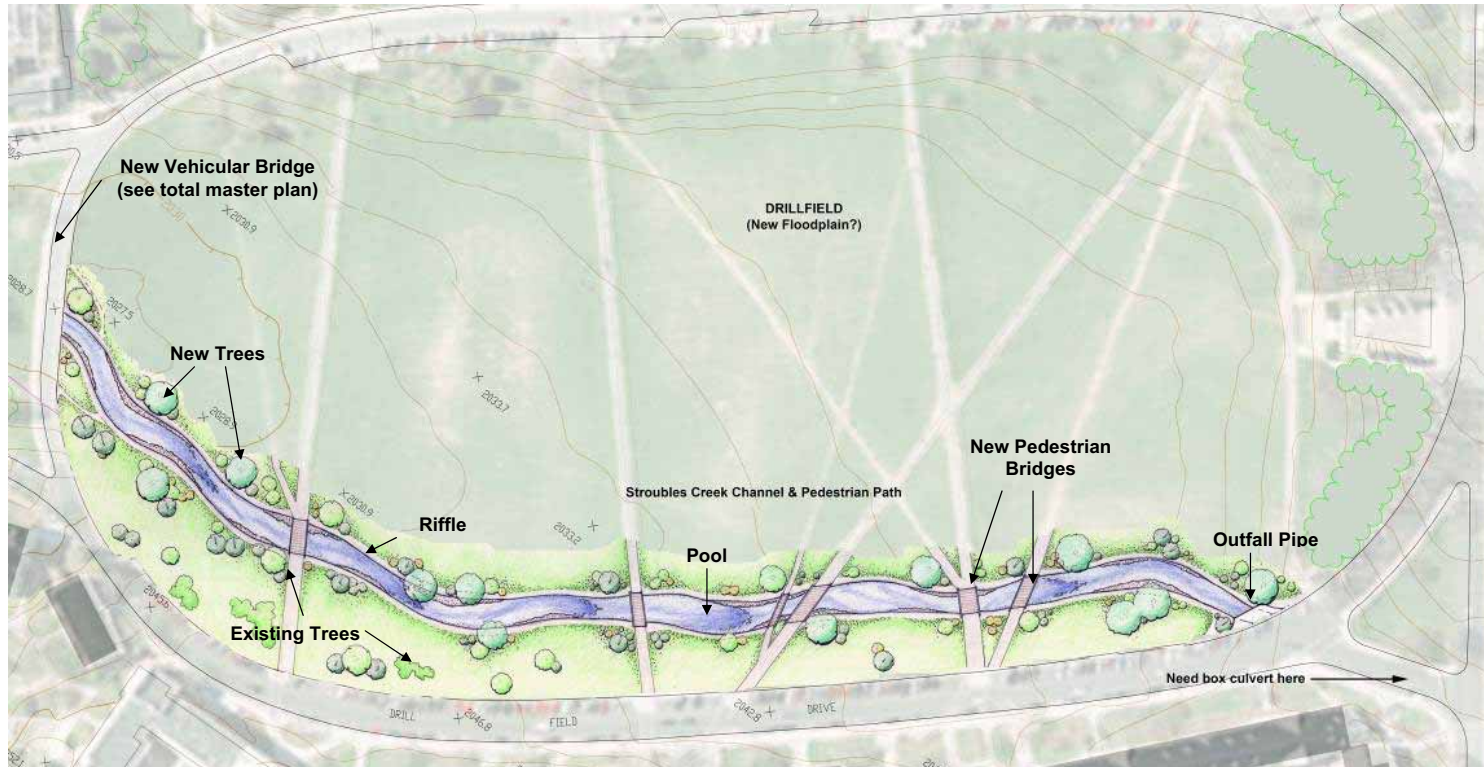
- Low stream banks allow adjacent fields and courts to be flooded
- Two infiltration rain gardens built on either side of existing tennis court
- In-stream riffles constructed using median particle size that is too large to be easily transported by average flow (1.25 cfs)
- Small boulders added to toe of bank slope to control lateral migration
- Log vanes used to direct flow at meander bends
- Forebay at stream's outfall point was built to be dredged over time
- Stone weir acts as a resting/viewing spot for the public while tying into underground pipe system



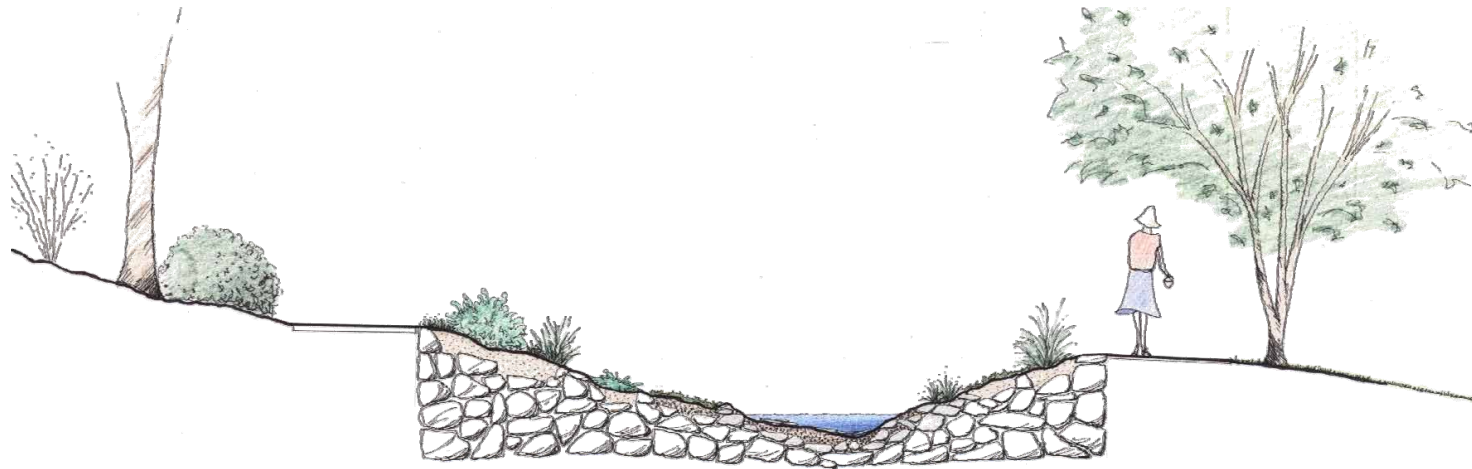


**Key Design Features:**

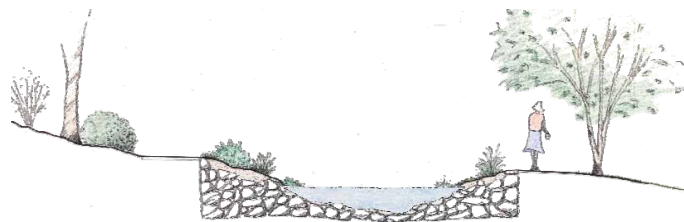
- New channel is 30 ft wide x 5 ft deep at inlet pipe; 2-year event calculated at 150 cfs; 10-year event calculated at 300 cfs
- Sides of channel are earthen berms lined with large boulders and cobbles
- Stream bed is native clay found beneath on site
- D50 particle size is 8.9 mm (gravel); boulders and cobbles added to stabilize stream banks, beds, and pool-riffle structure
- Distance between pools and riffles is approximately 100 feet (distance between pools is approx. 200 feet)
- New pedestrian bridges installed to accommodate student activity
- Existing trees protected during construction; new trees for graduating classes added along paths to provide stream shading; more trees added over time
- Greenway paths added to both sides of stream corridor
- Drillfield doubles as an overflow floodplain during large storm events
- Left end of circular drive elevated as a new bridge; greenway and stream continue to Duck Pond unimpeded



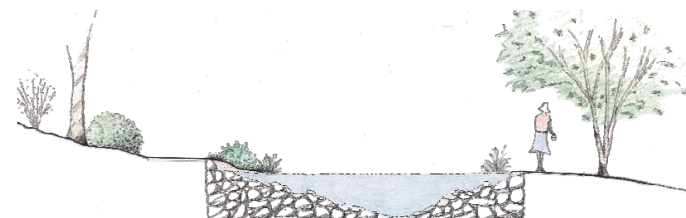
**Drillfield Daylighted Stream Channel  
Cross Section**



**Baseflow**



**2-Year Storm Event  
(approximately 150 cfs)**



**10-Year Storm Event  
(approximately 300 cfs)**



# CONCEPTUAL SKETCH



The Drillfield - Before



The Drillfield - After

## **Outcome**

### *Total Corridor Master Plan*

One of the most important goals was to protect and restore Stroubles Creek as a living ecosystem along the entire Central Branch. Rather than treat the new channel as urban drainage or an aesthetic amenity – putting human interests first – the primary objective was to honor the natural system and adapt humans around it. A major component of the “design” of this project was the stream itself, and to carry that sensitivity throughout the entire corridor. The result is a consistent channel geometry and morphology that honors the pool-riffle dynamics naturally found therein and preserves the most naturalized stream banks and beds possible, even in the most urban portion of the project.

Smaller parcels of land were utilized in the project to obtain the desired “total corridor” design, and included private land between Harding Elementary and the downtown Firestation, the parking lot at the Nerv (where Stroubles ran above ground until the 1980’s), and a small lawn area between the lower portion of the Drillfield and Duck Pond. All were treated with the same 30-foot wide buffer except for the Nerv, which would actually perform better if the controlled channel proposed for College Avenue were extended into the parking area. The total corridor master plan can be seen on page 48 and a scaled copy of the plan with base map is included with this document.

In the end, the daylighting proposal successfully applied all three stream typologies along the entire corridor. A ‘greenway’ system based on the newly daylighted lengths provides a cohesive linear park between residential areas, the downtown district, and the university campus. Bridges at key locations traverse the stream to connect each side of the waterway and provide the chance to explore architectural vernacular through their design. Note: bridge design details were never a part of this thesis project.

## **Challenges and Opportunities on Each Site**

### *Owens Street Park*

The goal at Owens Street Park was to re-establish a more meandering stream channel to match typical C4 streams. Additional objectives were to provide greater riparian buffering, shading, and ponds to prevent downstream flooding, stream bank erosion, and sedimentation problems. The width of the park site allowed for slight relocation of the channel to accommodate more sinuosity and larger pools, but the location of the outfall pipe had to remain the same so as not to cut off the park from the stream system across the street.

So much wide open space offered a clean design slate from which to work, but it also meant that shade tree canopy was non-existent and would require either patience as new trees grew or a larger planting budget to purchase larger trees. Otherwise, this was an ideal site for the most naturalized of stream designs. Since it was already a neighborhood park with a stream running through it, local support for its restoration is likely to be high. It was also a great location in which to conduct stream bank construction: equipment could be kept away from new stream edges and erosion control measures would be more likely to succeed if installed properly.

### *College Avenue*

For College Avenue, a whole new channel was designed where none currently existed. The challenge was to introduce a pool-riffle system with contained edges to prevent flooding of adjacent buildings. The channel had to be designed at an appropriate width and depth, with correct spacing between pools and riffles, to allow the alluvial stream to form itself over time while remaining capable of holding 2-year and 10-year storm events. The deliberate introduction of in-stream “banks” replete with gravel bars, cobbles, boulders, and plantings was intended to make the stream system more visually appealing to the human community, but also to bring life back to that particular stream length.

The challenge, of course, was virtually everything. The presence of historic buildings and a popular commercial street with much-needed parking rendered this the most daunting intervention. Digging up an asphalt road is tough enough, let alone digging it up in a narrow corridor without damaging structures or compromising the soil structure intended to hold the new stream bed. Overhead and underground utilities must be relocated, temporarily and permanently, and vehicular traffic would be eliminated from College Avenue for good. Bridge and culvert construction at the intersection of College Avenue and Main Street would be a minor nightmare for some time and would require long-term traffic detours. It is assumed that public support for this portion of the project would be difficult to obtain.

This channel was also tricky because it necessitated the careful incorporation of people into its design. Whereas park spaces are often wide enough to allow for unstructured human activity therein, a stream channel in the middle of a street doesn't provide the same degree of flexibility. People are relegated to one side or the other, and bridges and piers become the dominant spatial design options. Pedestrians must be prevented from falling into the stream, and from throwing trash into it. Design is found in the details of this corridor – from varying sidewalk widths to fences, railings, seats, and stone work –and establish a local vernacular for the new 'streamscape'.

The actual stream channel remained remarkably 'naturalized', which was not expected given the tight spatial constraints of the street. Engineering calculations and existing data on the reach revealed that typical baseflow conditions would not exceed 7 feet wide by 6 inches deep on average. Therefore, vegetated stream banks and boulders, cobbles, and natural gravel would be visible in the channel most of the time. During larger storm events, the vertical containment walls were found to be wide enough and tall enough to hold up to 300 cfs (possibly more) of stormwater, thus protecting the

business district and downstream reaches from excessive erosion and velocity.

The offline floodplain wetland park doubles as community outdoor space and still holds storm overflows, allowing sediment to drop out of that section of the system as per stated TMDL goals. However, if it works, dredging under the proposed boardwalks may become an issue, and they may need to be removable pieces. A degree of engineering comfort was achieved in this park by keeping a large overflow drain in place on the site. This allows water entering from the primary channel to continue to flow through the park rather than pond in the channel. It helps the channel clean itself and reduces any problems caused by high volume or velocity further downstream. It also teaches visitors about seasonal and storm event variability as water levels rise and fall in the basin.

#### *The Drillfield*

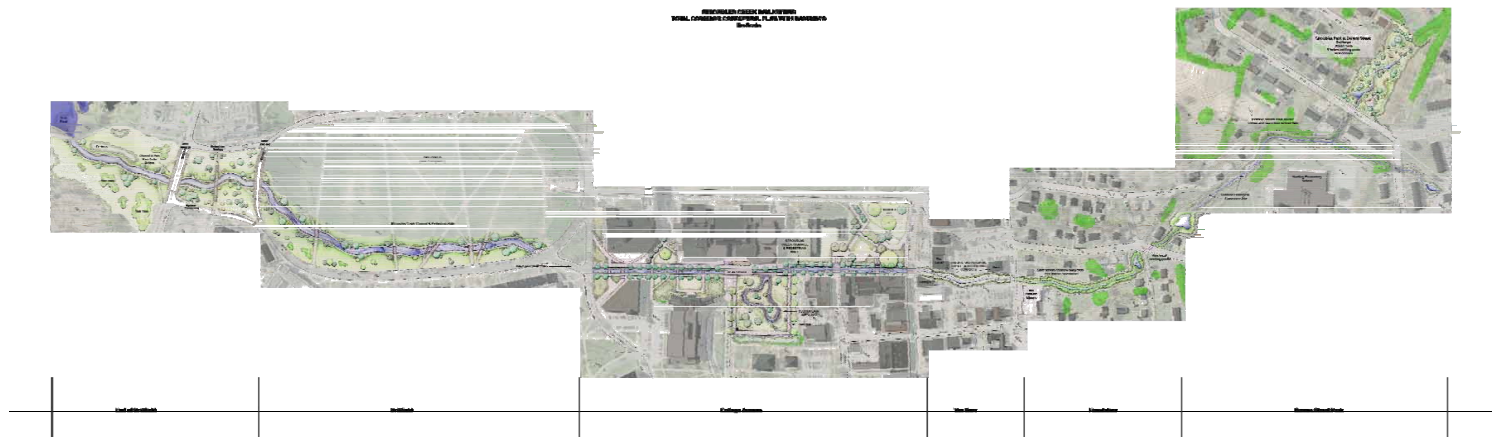
The Drillfield design kept the looser meander of the upper stream reach at Owens Street Park but kept semi-hard control of the stream banks with boulder edges. It removed the vertical walls needed on College Avenue and re-established a more park-like setting along its route. However, the idea of daylighting here may prove to be an equally hard "sell" to the university as the College Avenue concept, as this is *the* open space that defines the campus and is not likely to change easily.

While it works perfectly as a continuation of the total corridor/greenway concept, it also requires a long box culvert between the end of the College Avenue channel and the proposed outfall point on the Drillfield. It entails building several pedestrian bridges along the way, not to mention two large vehicular bridges at the lower end of the field and at West Campus Drive. The location of the channel may necessitate some tree relocation as well to protect existing trees along the southern edge of the field. Some of the trees are quite large, so the channel may need to be repositioned prior to construction to save them.

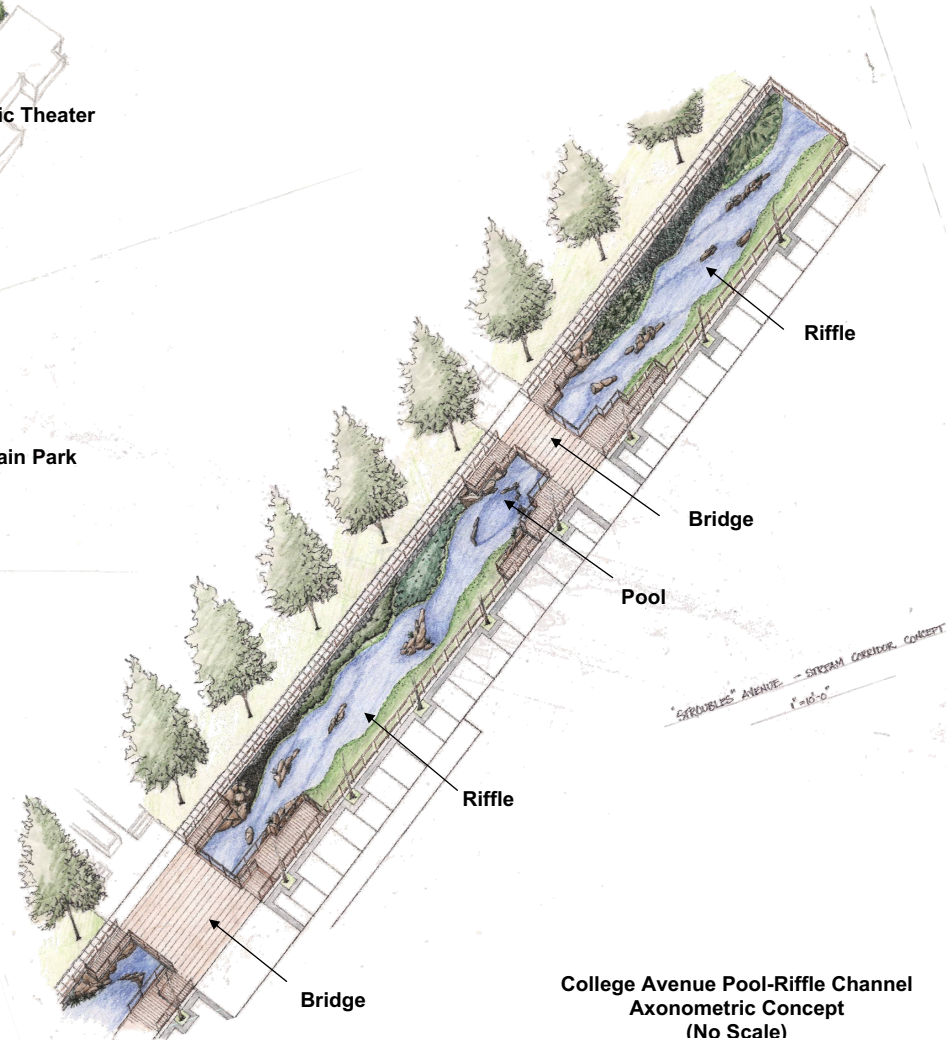
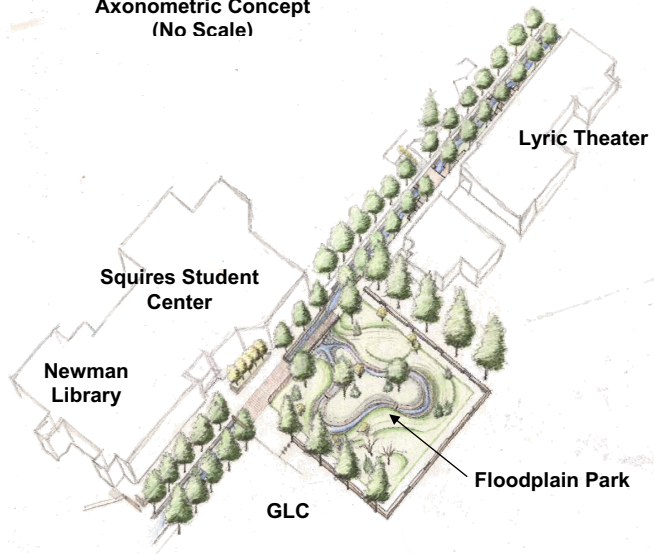
### Total Corridor Concept Plan – Without Basemap



### Total Corridor Concept Plan – With Basemap



College Avenue/Squires Park Basin Corridor  
Axonometric Concept  
(No Scale)



College Avenue Pool-Riffle Channel  
Axonometric Concept  
(No Scale)



## 6. Conclusions

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### *General Conclusions about Daylighting*

The case study reviews revealed the following key facts:

- Most projects are *not* undertaken primarily to restore stream health, ecology, function, or habitat
- Most projects are initiated to provide public parks for human use
- Ecological restoration efforts vary widely, although they tend to want to improve in-stream habitat and fish passage
- Projects that are undertaken to restore some sort of ecological function often do not engage in scientific monitoring to evaluate whether or not this goal was obtained over time
- Approximately one-quarter of all projects used some form of mathematical hydrologic study to estimate current stream conditions as well as the effects of building a new stream; the rest of the projects were designed by “trial and error”
- Stream daylighting seems to provide significant flood protection and sedimentation control
- Stream daylighting has been very successful in promoting outdoor education on school campuses

The act of rendering a buried and forgotten waterway visible again has a profound impact on the human psyche. Case studies demonstrated that although the preferred outcome of many daylighting projects was to improve the environment, the reality was that most efforts focused attention on aesthetic appeal and public enjoyment of the new waterway. These were considered by far the most popular and “successful” projects according to the literature. Thus, by revealing pieces of the system that have been covered over, daylighting projects to date have displayed greater potential to improve human understanding and awareness of larger systems in the environment rather than improving the environment *per se*.

In terms of “green infrastructure” function, it appears that all projects undertaken to reduce urban flooding problems succeeded in achieving that goal. New stream channels and/or larger open water canals that replaced failing culverts and deteriorating pipes greatly minimized or removed any previous stormwater overflows and damage. The time frame when these results became apparent is not directly known, but is presumed to have been noticed after the first significant post-project rainfall event.

The issue of cost-effectiveness is an important one, but can be hard to determine. Perhaps a better term for consideration is “affordability”. In some specific examples, daylighting was less expensive than traditional pipe engineering. In the case of Darbee Brook, which cost \$9,000 for a length of 330 linear feet, daylighting proved to be far more *affordable* than installing a new culvert (estimated at \$45,000 - \$50,000). Cow Creek in Hutchinson, KS was rerouted and daylighted because it was a more *affordable* option than building a new bridge and redirecting traffic for three years. The city of Kalamazoo, Michigan decided to daylight Arcadia Creek despite the \$7.5 million price tag because long-term flood damage to its downtown business district was far more costly. The new park associated with the daylighted stream generates \$12 million each year in concert and activity fees, more than paying for project costs (Pinkham 2000). In these and other cases reviewed, daylighting definitely helped revitalize neighborhoods, increase property values, and benefited nearby businesses, thus justifying the money spent.

Stream daylighting can be an expensive endeavor due to a range of technical and physical realities. Experienced practitioners estimate the costs of daylighting to range from \$300 - \$1,000 per linear foot (Pinkham 2000). Overall, the case studies examined in this research revealed certain cost trends depending upon length of stream daylighted. These trends are depicted in Table 2.

Table 2. Stream Daylighting Average Cost Breakdowns by Length

| Small Scale = < 250 linear feet |              |
|---------------------------------|--------------|
| Average length                  | 144 lin. ft. |
| Average cost                    | \$9,800      |
| Cost/lin. foot                  | \$68.05      |

| Medium Scale = 250 - 1,000 linear feet |              |
|----------------------------------------|--------------|
| Average length                         | 480 lin. ft. |
| Average cost                           | \$48,250     |
| Cost/lin. foot                         | \$100.50     |

| Large Scale = > 1,000 linear feet |                |
|-----------------------------------|----------------|
| Average length                    | 2,287 lin. ft. |
| Average cost                      | \$1,857,250    |
| Cost/lin. foot                    | \$812.09       |

In general, the longer the length daylighted, the higher the costs. Also, the more urban the location, the more expensive the project became. This was often due to significant physical constraints such as the need to purchase and/or demolish existing property and to construction costs associated with structures like concrete channels to contain the new stream near building foundations. The most expensive project completed to date was Arcadia Creek at \$7.5 million and 1,550 linear feet, while the least expensive project was West Ox Pasture Brook at \$1,200 and 85 linear feet.

Currently, there is little information available to facilitate a cost comparison between maintaining a pipe and maintaining a new stream. One way it can be determined is to compare daylighting costs with the costs of replacing pipes and culverts, which is at best an indirect and incomplete comparison. Average costs of some individual stormwater system components are listed in Table 3. It is harder still to compare daylighting with the unknown costs of damaging complex aquatic ecosystems. In the end, daylighting projects can be expensive, but many have been completed at lower costs due to donations of services, materials, and volunteer labor (Pinkham 2000).

Table 3. Costs of Stormwater Pipeline Components (USEPA 1999)

| Material                                          | Cost               |
|---------------------------------------------------|--------------------|
| Median diam. 24 inch corrugated metal pipe        | \$30.10 / lin. ft. |
| Median diam. 36 inch reinforced concrete pipe     | \$74.40 / lin. ft. |
| Excavation of clay soil trench at 1:1 ft ratio    | \$7.09 / cu.yd.    |
| Bedding costs for trench 24 in. diam.x 4 ft. wide | \$8.52 / ft.       |
| Manhole 4 ft. diam. x 4 ft. deep                  | \$1,860.00 / ft.   |
| Paving Costs:                                     |                    |
| Prepare and roll subbase > 2500 sq.yd.            | \$ 0.88 / sq. yd.  |
| Base course (3 in. crushed stone)                 | \$3.39 / sq.yd.    |
| Asphalt pavement (3 in. binder course)            | \$5.91 / sq.yd.    |
| Asphalt pavement (2 in. wearing course)           | \$4.52 / sq.yd.    |
| Curb and gutter (24 in. diam. concrete)           | \$6.95 / lin. ft.  |

Project longevity is an important factor when comparing the two methods. The material used to build underground pipes decays over time and in contact with water; as a result, pipes need to be replaced periodically. In contrast, it can be argued that daylighting a stream – and incurring the associated costs - will take place only once. An additional justification for stream daylighting is that it has the real potential to reduce costs associated with flood damage because the new stream will store and convey rain water levels better than a traditional pipe (Pinkham 2000). Also, any miscalculations of surface stream size can be recognized and fixed more readily than they can be for an underground, out-of-sight pipe.

The aspect of time has another facet worth considering. Once a stream is placed into a pipe underground and the final layer of paving is applied, the project is complete and the objective is immediately met. But what is the average length of time it takes for daylighted streams to meet their objectives? Available literature provides no definite timeline for these results. From the nineteen case studies reviewed, the average year of completion was 1994. The dominant literature source for the case studies was published by the Rocky Mountain Institute in September, 2000. Thus, subtracting the publication year (2000) from the average daylighting year (1994) results in a mean length of six years before outcomes can be observed and recorded.

Richard Pinkham asserts that “Daylighting can provide multiple benefits—tangible and intangible—for every dollar expended” (Pinkham 2000). In the end, most experts agree that daylighting can be cost effective compared to the expense of repairing a failing culvert, even if direct proof of such effectiveness is elusive.

## 7. Recommendations for Future Research

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In light of the proposed Daylighting Decision Matrix, a high priority for future research is to track existing stream daylighting projects and determine how many have resulted in either a naturalized, channelized, or artificial stream and under what site circumstances. Assessing the prevalence of certain types of stream outcomes based on available corridor width could help establish baseline standards of intervention to best protect newly uncovered urban streams. Imminent demonstrations worth following will be Indian Creek in Caldwell, Idaho (a very urban site on the verge of daylighting as of 2006), and Rocky Branch Creek on the campus of North Carolina State University in Raleigh, NC (daylighting is part of a larger campus greenway and stream restoration project).

On the opposite end of the recommendation is the desire to find non-standardized ways of daylighting streams. The fundamental conclusion is that the decision matrix is effective in initial site and stream typology selection, but does little else to generate unique physical forms for new streams. Efforts must be made to document unusual and innovative strategies that still protect stream health while allowing designers more creative room.

If the proposed daylighting design for Stroubles Creek were ever to be implemented, it is highly recommended that additional calculations be performed to ensure its flood stage capacities. Tests should also be conducted to determine if the new channel and floodplain will reduce sediment input into stream as required by the TMDL Implementation Plan. Strategic signage can serve to educate the public about the intent of the newly daylighted stream, as well as the plight of other buried streams around them.

The issue of cost effectiveness is a critical component when undertaking any daylighting project. Future investigations, especially of Stroubles Creek, could facilitate greater understanding of the true costs by comparing the design and

installation expenses of each proposed daylighting segment to the costs of the 1992 flood damage and projected costs of future floods.

Ultimately, the ideal scenario is to prevent streams from being buried in the first place. A number of communities have stream protection ordinances that discourage the culverting of open waterways and these initiatives warrant further examination (Pinkham 2000). In the most proactive case, the city council of Seattle, WA has drafted legislation to ban construction that interferes with streams that have the potential to be daylighted on the site. Proponents of the bill "...want to preserve the option to daylight in the future by ensuring that a developer cannot place a building on top of a creek, whether that creek is temporarily in a culvert or not" (Stiffler 2006).

A similar measure worth exploring closer to home is Blacksburg's "Creek Overlay Zones". These zones outline buffers around local streams beyond which no development is allowed to take place. There are important questions about the popularity and efficacy of such requirements, and whether or not they can be retrofitted over streams that have already been put underground in anticipation of future restoration. Monitoring how strictly the zones will be enforced may prove instrumental in promoting future daylighting: if the stream system they would like to protect winds up infringed upon by development pressures and lax enforcement, then will daylighting become an even better option in town?

Finally, a priority list of land parcel acquisitions and buildings to demolish can be prepared in anticipation of Stroubles Creek returning to a complete stream corridor at its original surface elevation. Planning for the future of this historic stream can directly benefit the built urban fabric surrounding it.

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