PINE GUTTER BROOK ASSESSMENT AND RESTORATION PLAN

FINAL DRAFT

March 2005

MMI #2619-01

Prepared for:

Town of Branford
Parks and Open Space Authority
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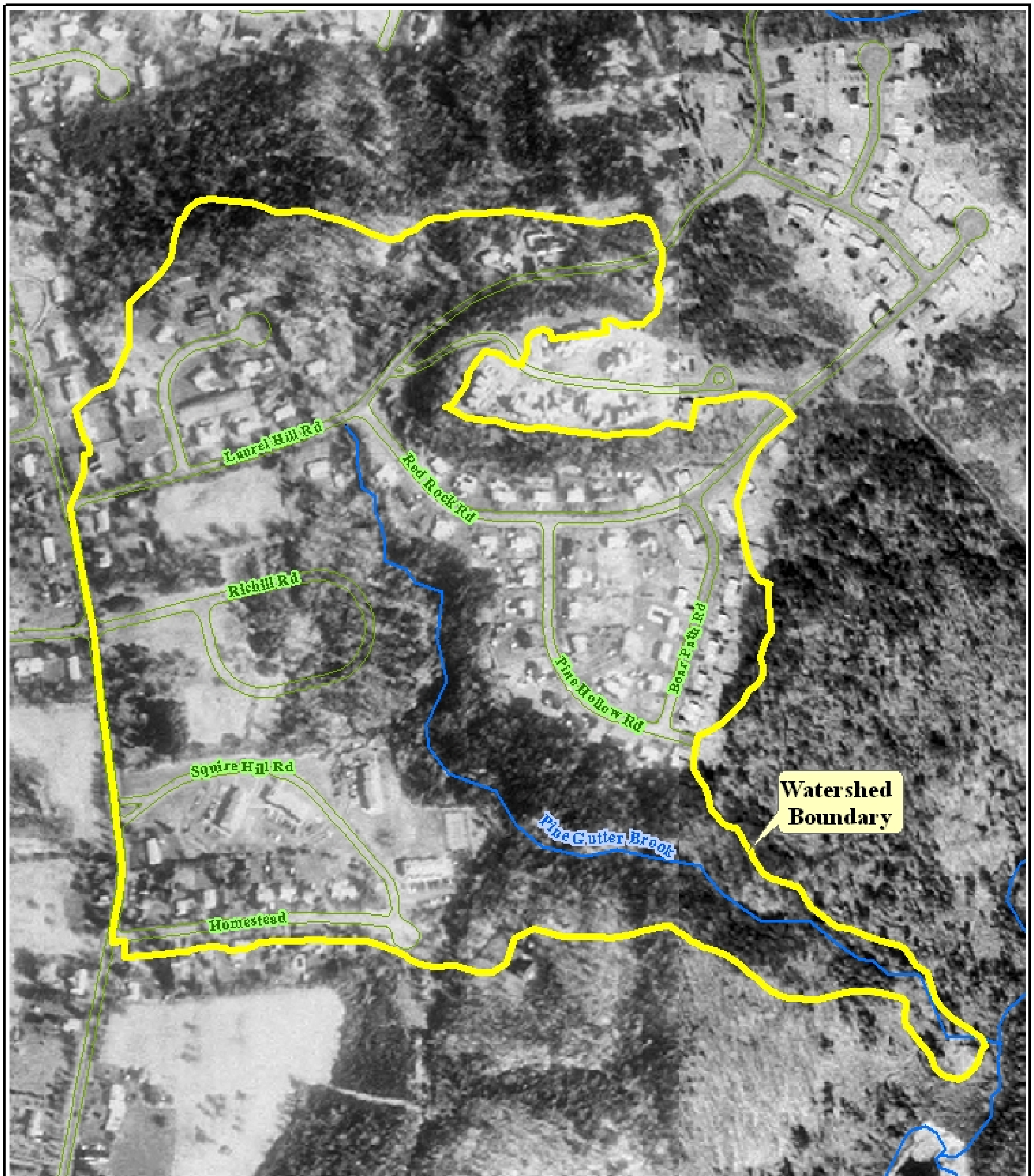
1.0 INTRODUCTION

1.1 Background and Purpose

The Town of Branford through its Parks and Open Space Authority retained Milone & MacBroom, Inc. (MMI) to evaluate Pine Gutter Brook and recommend methods for stabilizing its eroding banks. Since the channel incision that Pine Gutter Brook is experiencing is believed to be caused by poor watershed land management, a watershed assessment was also completed to identify potential watershed improvements to minimize future channel erosion. Figure 1 is a location map of the brook and its watershed.

Pine Gutter Brook is located in the north western portion of Branford. The brook discharges to Pisgah Brook (also known locally as Queach Brook), which in turn discharges through the Branford Supply Ponds to the Branford River. The Pine Gutter Brook channel suffers from severe bed and bank erosion that the Town has attempted to control by constructing a sediment basin at the outlet of the brook.

The Branford Supply Ponds were created around the turn of the 20th century when the Branford Electric Company constructed a dam for purposes of power generation. Eventually, the ponds were purchased by the New Haven Water Company and used for water supply. In the 1960's Branford purchased the ponds and approximately 359 acres of land from the water company for use as open space. Since that time, the Town has managed the original open space and added to it through the purchase of additional land. At the present time, the Town owns most of the length of the Pine Gutter Brook stream corridor.



Engineering, Landscape Architecture and Environmental Science MILONE & MACBROOM®	Pine Gutter Brook		LOCATION: Branford, CT	
716 South Main Street Cheshire, Connecticut 06410 (203) 271-1773 Fax: (203) 272-9733 www.miloneandmacbroom.com	MMI#: 2619-01 MXD: H:SiteLocationMap.mxd SOURCE: DEP Bulletin 37	N Site Location Map	DATE: 01/31/05 SCALE: 1" = 400'	SHEET: Figure 1

This report is organized in the following manner:

- Section 2 describes the existing conditions of the channel and watershed such as geologic setting of the area, as well as river processes that have shaped the channel.
- Section 3 is a detailed description of watershed hydrology and development patterns.
- Section 4 is a description of the channel hydraulics of Pine Gutter Brook including potential stabilization techniques.
- Section 5 presents information about the watershed, assesses existing storm drainage systems in the watershed and discusses watershed management techniques.
- Section 6 presents a master plan of improvements, associated permit requirements and potential funding sources.

1.2 Management Alternatives

There are many alternative techniques available to address channel incision and minimize its adverse impacts. In broad terms, these alternatives are:

Do Nothing – The no action alternative would allow the channel degradation to continue at its current pace towards a natural equilibrium. This can be a long process (on the order of 10 to 100 years) with several consequences, including downstream sediment loading, bank collapses, channel widening and land loss, and ground water recession. In some areas, this is acceptable and unavoidable.

Channel Linings – A traditional technique for minimizing channel incision is the use of continuous linings on the bed and/or banks to stop erosion. Common linings include concrete, stone riprap, stone filled gabions, precast concrete blocks, and revetments, as well as bio-mechanical plantings such as root wads, fascines, brush layers, and use of dormant cuttings or stakes. The placement of channel linings can result in significant ecologic and hydrologic impacts due to vegetation removal to regrade the bank, loss of habitat diversity, and aesthetics.

Bank Protection – Armoring the banks with retaining walls helps to protect private property by reducing channel widening. However, it does not address the source of the problem and can accelerate further incision. Similarly, the use of conventional plantings or bio-technical methods to reduce bank erosion is most effective if the channel width is already adequate for flood flows and the banks are regraded below the angle of repose.

Watershed Scale Measures – These are applied in situations where land use activities are deemed to be contributing to channel incision. Activities that stimulate incision could include deforestation, construction of buildings and paved surfaces, gravel mining or mineral extraction, wetland destruction or urbanization.

Flow Control – In watersheds subject to deforestation or urbanization, control of peak flood flows is essential to minimize downstream impacts. Higher or more frequent peak flows increase flow velocities and sediment transport that lead to channel bed or bank scour. Specific control techniques include dry storage dams, detention basins, and created wetlands.

Channel Slope Control – Incision can be minimized or contained by use of grade controls or drop structures. Various types of grade controls can be used, including low weirs, flush sills, boulder clusters, anchored logs, gabions, check dams, and rock ramps. It is important to recognize that some grade control structures on perennial streams obstruct fish passage. Visual inspection of Pine Gutter Brook revealed that woody debris accumulation has been very effective in controlling channel incision.

Velocity Control – Providing increased channel roughness with boulders and anchored logs or bank vegetation reduces flow velocity and subsequent bed erosion. However, extensive roughness may increase flood water levels and the frequency of overbank flows. In some instances, this is in conflict with regulatory programs such as those administered by the Federal Emergency Management Agency (FEMA).

Floodplain Connectivity – A fundamental problem with incised channels is that their increasing depth and flow capacity reduces the frequency and magnitude of overbank flow on their floodplains. As they erode and deepen, more and more of the flood flow is trapped in the channel, increasing velocity and shear stress and creating even more erosion. One approach to controlling this is to mimic a natural system by recreating a new floodplain at a lower grade to increase its usage and reduce velocities via a larger cross sectional area. These compound channels (low flow channel plus floodplain) can be complex to design, but are very effective if sufficient land is available.

Channel Fill – Occasionally refilling incised channels is suggested as a way to raise the bed elevation and allow floodplain flow again. However, in developed areas, this increases flood levels as well as hazards and is a regulated activity with significant ecological impact. MMI discourages this alternative.

Sediment Load – Channels become incised when sediment transport capacity exceeds their supply of sediment (this is explained in more detail later in the report). The Colorado River is a classic example where construction of large dams that trap sediment reduce downstream loads, leading to severe channel incision. Some European rivers are managed through increasing sediment loads to create an equilibrium condition. This is not desirable in many areas due to water supply intakes, water quality, and ecological concerns. One example of a measure to increase sediment loads include removing trees and woody debris that may alter downstream sediment migration.

Each of these alternatives are discussed in greater detail throughout this report, and their applicability for use at Pine Gutter Brook is also assessed.

2.0 EXISTING CONDITIONS

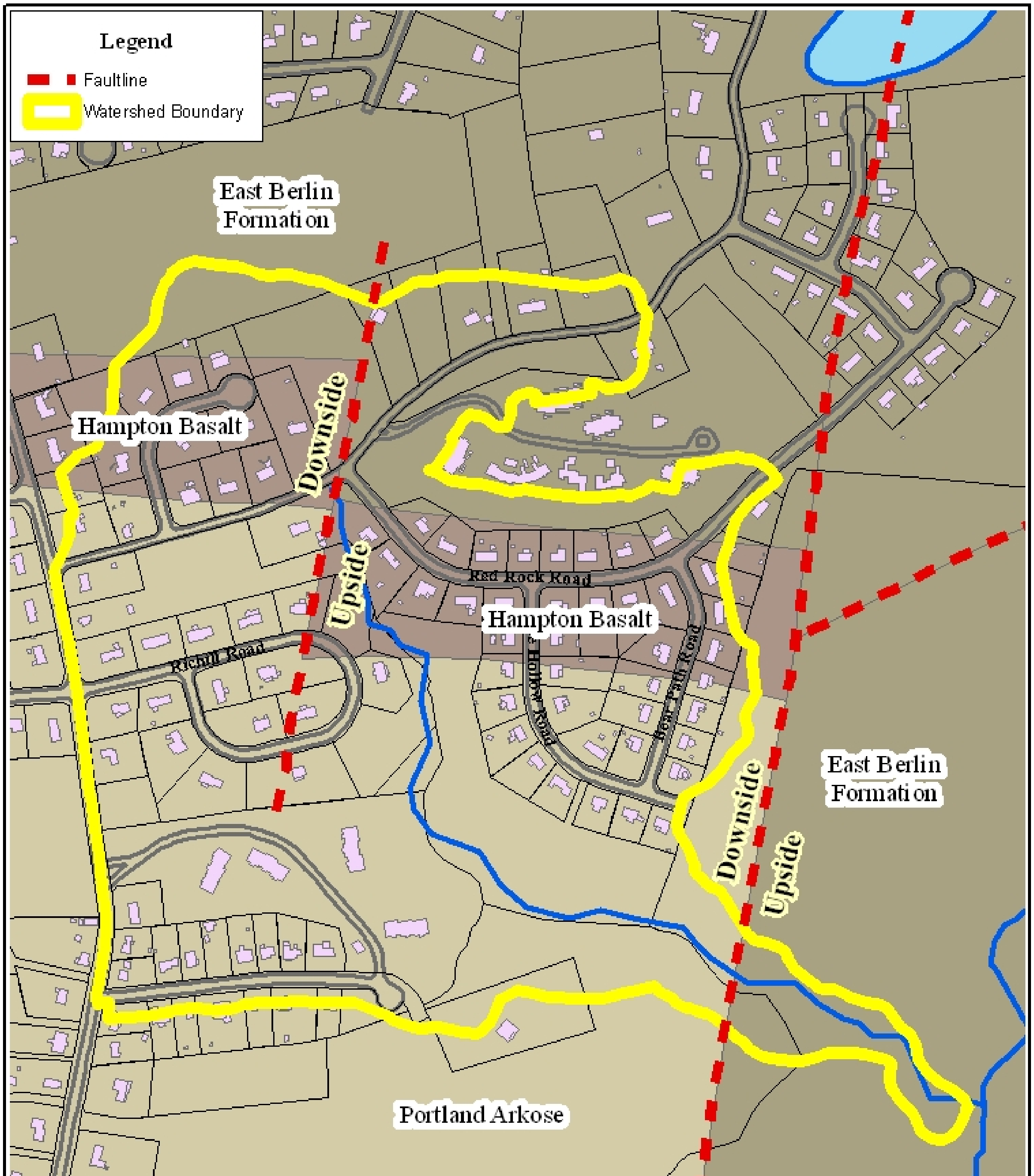
2.1 <u>Geology of Pine Gutter Brook</u>

Pine Gutter Brook is located at the eastern fringe of the Central Lowlands of Connecticut. Pisgah Brook (a.k.a. Queach Brook), downstream of its confluence with Pine Gutter Brook, and the Supply Ponds are located in the Eastern Highlands formation. The intersection of these two formations forms the Triassic Border fault. Figure 2 depicts the bedrock geology of the area.

Bedrock of the Central Lowlands near Pine Gutter Brook consists of sandstones, conglomerates, siltstone and shale – Triassic era formations of sedimentary and basaltic rocks. Two separate formations underlie Pine Gutter Brook – the East Berlin formation and the Portland formation.

The East Berlin formation underlies the bottom one-half of the Brook and its watershed. This formation consist of reddish brown silty shale. Shale is comprised of fine-grained layered sedimentary rocks. This material is erodible and would not be particularly resistant to the erosive forces of water.

The Portland Arkose formation underlies the upper half of the Pine Gutter Brook watershed. This formation consists of reddish brown arkose. Arkose, or brownstone as it is often called, consists of medium to coarse grained sandstone-like sedimentary rock containing quartz, feldspar and rock fragments. It is the most common type of sedimentary rock in the Central Lowlands.



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Pine Gutter Brook

LOCATION: Branford, CT

MMI#: 2619-01
MXD: H:Geology.mxd
SOURCE: DEP Bulletin 37

Bedrock Geology Map

DATE: 01/31/05
SCALE: 1" = 400'

SHEET: Figure 2

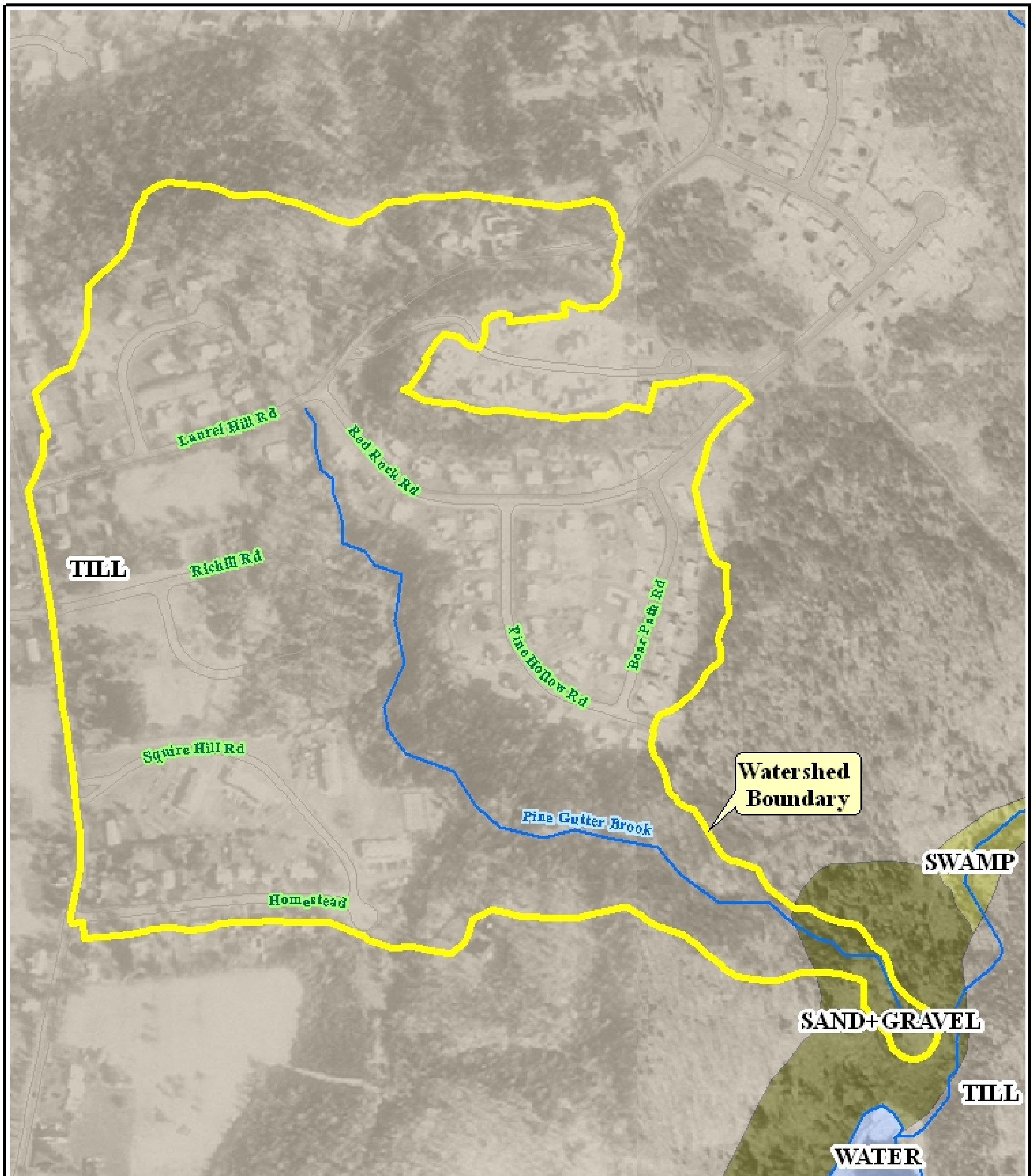
Also in the Pine Gutter Brook watershed are block areas of Hampton Basalt. This formation is traprock that would be resistant to erosion by stormwater. Hampton Basalt is generally characterized by steep slopes that are not typically deemed suitable for development. This formation underlies the western edge of the watershed and has been developed with residential homes.

Surficial materials in this area are characterized as glacial till, which is generally rocky and shallow to bedrock. This is characteristic of the upper reaches of Pine Gutter Brook, where steep slopes that support very little vegetation extend to the channel edge. Moving toward Pisgah Brook, overbank slopes become less steep and soils transition to excessively well drained material. Figure 3 depicts the surficial geology of the Pine Gutter Brook watershed.

2.2 Topography

The Central Lowland region is characterized by topography consisting of elongated ridges and valleys running in a northwest to southeasterly direction. The ridgelike hills that are often observed reflect the erodibility of the bedrock materials in the formation. Pine Gutter Brook follows this classic pattern of the Central Lowlands, with watershed elevations ranging from 230 feet based on the National Geodetic Vertical Datum of 1929 (NGVD 29) to 20 feet NGVD29 at the confluence of Pisgah Brook.

In the Eastern Highlands region underlying Pisgah Brook and the Supply Ponds, topographic features tend to have a more irregular form, with the hills appearing short and cliff-like.



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Pine Gutter Brook

LOCATION: Branford, CT

MMI#: 2619-01
MXD: H:SurficialGeolMap.mxd
SOURCE: DEP Bulletin 37

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Surficial Geology Map

DATE: 01/31/05
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2.3 Geomorphology

Geomorphology is the study of the earth's surface forms and the processes that shape those forms. In the study of rivers and streams (fluvial geomorphology), the primary geomorphologic processes are erosion, sediment transport and sediment deposition (USDA, 1998). Erosion is the detachment of soil particles; sediment transport is the movement of those particles in stream flow; and sediment deposition is the settling of soil particles to the bottom of a waterbody, such as occurs in the sediment basin at the downstream end of Pine Gutter Brook.

The geomorphologic characteristics of river channels vary depending on the topography, geology, level of watershed urbanization and rainfall patterns. The watershed and channel characteristics of Pine Gutter Brook are similar to those of incised and mountain streams, although in Pine Gutter they occur on a smaller scale. Mountain rivers are characterized by having a channel gradient in excess of 0.002 meters per meter or feet per foot (Wohl, 2000). Incised channels are characterized by bed lowering, usually to meet either the limiting geologic regime or a downstream control point. The downstream reaches of Pine Gutter Brook appear to be undergoing channel incision to meet the elevation of Pisgah Brook and the Supply Ponds. Erosion will stop when the channel gradient is flat enough to slow velocities to a level that prevents degradation.

The nature of channel erosion was defined by Lane in 1955 with the following equation:

$$Q\,S \approx Q_s\,d_{50}$$

Where Q is the channel forming discharge, S is the bed slope, Q_s is the bed material discharge and d_{50} is the median diameter of grain size material. When any one of these elements is out of balance then the other three parameters will fluctuate to maintain the proportionality. For instance, if the channel forming discharge, Q, increases due to anthropogenic impacts in the watershed, then the bed slope and bed material discharge rate will change to maintain the relationship – in other words, channel bed erosion is likely to occur.

Channel erosion and degradation is different from the process commonly called scour. Scour tends to occur in isolated areas of the channel at limited time periods. Channel degradation is a systematic bed lowering that occurs over a period of years.

2.3.1 Mountain Rivers

While one wouldn't often consider the presence of a "mountain" river in the coastal community of Branford, Pine Gutter does exhibit many of the characteristics of a mountain river such as: (1) Steep average channel gradient; (2) highly turbulent flow and stochastic sediment movement resulting from the steep channel gradient and limited sediment supply; and (3) the potential for high sediment loads over a period of a few years following watershed disturbances. These channels differ in fundamental ways from channels formed at lower gradients.

Figure 4. Example of bank "fall" in lower reaches of Pine Gutter Brook.

Because of the high discharge velocities that occur on the steep slopes of mountain streams mass downstream movement of bank and bed materials is prone to occur. The mass movement may occur as creeps, falls, slides or flows. Creeps are slow and can only be perceived over long periods of time. Falls involve the free fall of soils, usually in response to undercutting of the toe of the bank. This is the type of mechanism that occurs in the downstream reaches of Pine Gutter as shown in Figure 4. Slides occur when a mass of unconsolidated material moves along a discrete failure plane. Flows occur when material is liquefied enough to force internal deformation.

One important control process that occurs in mountain rivers is the presence of large woody debris. Inspection of Pine Gutter Brook found areas of woody debris jams as shown in Figure 5. The presence of this material is beneficial in preventing channel erosion by providing flow resistance and creating a stepped channel profile. In small streams like Pine Gutter Brook, this debris is not likely to become mobilized in high flow events. The narrow valley walls and steep side slopes also hinder the movement of debris once it is wedged in the channel. These debris jams also provide habitat value and instream diversity, adding to the overall health of the stream corridor. One disadvantage to debris jams is that they block fish passage on perennial streams.

Figure 5. Example of large woody debris in Pine Gutter Brook channel

Due to the steep terrain, mountain streams are sensitive to the impacts of watershed urbanization. The transition from wooded, undeveloped watershed to residential land use with impervious roadway systems dramatically impacts the rate of discharge in the channel, the overall volume of discharge and the sediment load from the watershed area. During construction, sediment yield can be greatly accelerated as land is cleared and graded. Following completion of construction, sediment yield from the watershed is reduced, often ending up lower than pre-development sediment yield rates (Wohl, 2000).

2.3.2 Incised Channels

Channel incision in its basic form is the most common method of channel creation. It becomes a major concern when it occurs in a channel that is out of equilibrium, resulting drastic environmental changes and excessive sediment production (Darby, 1999).

Incised channels have been classified into four categories based on their size and location by Schumm, et. al. (1984). Rills are small intermittent channels that result from erosion by overland flow on steep slopes. They are often destroyed seasonally by frost action.

Valley side gullies are small to intermediate size channels, generally with relatively high steep unvegetated banks, extending down the side of steep valley walls without a defined valley or watershed. The tributary channels to Pine Gutter Brook found between Laurel Hill Road and the sediment basin are classed as valley side gullies. Valley bottom gullies are found where intermittent or perennial flows have eroded a new steep sided channel across a valley base or floodplain to the valleys main stream. As a result of their position in the valley bottom, they often erode deeper to match the grade of an entrenched river or extend longer to reach a meandering river into which they discharge. Entrenched streams occur where a natural stream has become incised in its own valley and below the elevation of its floodplain. Entrenched channels may occur in bedrock or in surficial soils, or in earlier sediment deposits. The main stem of Pine Gutter Brook is an entrenched channel.

Ultimately, the depth of incision will be controlled by the presence of bedrock or a resistant alluvium material, the formation of armoring on the bed, a rise in the base level of the channel outlet or a change in river pattern. In the case of Pine Gutter, incision in the upper reaches is controlled by the presence of bedrock, which is preventing rapid down cutting. In the downstream reaches of the channel, incision is continuing to occur, with little evidence that bedrock or resistant alluvium material will be encountered soon.

Channel incision can have significant ecological impacts. The deep channels have increased flow capacity and thus have less frequent floodplain inundation. This reduces over-bank floodwater storage, leading to higher peak flows and less sediment deposition on the floodplains. Alluvial ground water levels, dependent on river stages, will decline. This tends to "dry up" or eliminate riparian wetlands. Table 1 lists some of the adverse impacts of channel incision.

TABLE 1
Adverse Impacts of Channel Incision

Natural	*Anthropogenic*
creates excess sediment	undermines bridges
banks erode, trees collapse	exposes utility pipes
lowers alluvial groundwater levels	reservoir sedimentation
creates unstable bed habitat	loss of riverbank land
reduces biological diversity	downstream flood damages
higher velocities occur	poor channel access
reduces floodwater storage	degrades water quality
increased peak flood flows	
knick points inhibit fish passage	
sediments fill downstream lakes	

2.4 Erosion Processes and Bank Failure

2.4.1 Streambed Erosion

Open channels with flowing water have the ability to transport sediment based upon their flow velocities, shear strength, flow rates, and flow duration. The first two parameters are related to channel slope, friction, width, and water depth. Steep and smooth channels can carry more sediment as compared to low gradient or rough high friction channels.

Under equilibrium conditions, the sediment load produced by a watershed is equal to the channel's sediment transport capacity. Rivers that can transport more sediment than is supplied to them will tend to scour any erodible bed or bank material, while rivers with a transport capacity that is lower than the watershed yield will tend to aggrade or deposit sediment on the bed or floodplain. The basic relationship is:

$$\Delta S = \Sigma Q_s - Y$$

where:

ΔS = change in channel sediment storage;

Q_s = channels sediment transport capacity; and
Y = watershed sediment yield.

Bed scour has occurred in the upstream reaches of Pine Gutter Brook, where the channel consists of exposed bedrock. Moving downstream, some bed erosion is occurring. However, the presence of woody debris in the channel is limiting erosion by creating a step pool system.

Channel erosion in steep gradient rivers is a self-perpetuating cycle. As shown by Schumm's (1984) model, first they erode the bed where the greatest shear stress exists, concentrating even more flood water in the channel. (Class II in Figure 6). Then the channel will incise vertically (Class III) until either the bed slope (and velocity) is reduced, or until the even higher banks collapse, (supplying fresh sediment). Eventually the new side slopes will collapse and channel widening will occur (Class IV) followed by aggradation of the bed (Class V). After decades or centuries the channel reaches a new equilibrium. In mountainous and shallow bedrock regions incision may cease when bedrock is reached or the riverbed becomes armored with natural rock fragments of cobbles or gravel.

Two types of erosion and sediment load can occur in a stream system. The first is called surface erosion and occurs in the contributing watershed to a stream. Surface erosion can occur at construction sites, where bare earth is exposed to the forces of stormwater. It can also occur as a result of agricultural practices. Sediment load can also be introduced to a river or stream through the application of road sand or through urbanization. The second type of erosion is bed or bank erosion, where the source of sediment is the stream bed or bank walls. While the latter form can be driven by land uses within the watershed, it cannot be controlled through best management practices commonly applied to construction sites, road sanding practices, and the like.

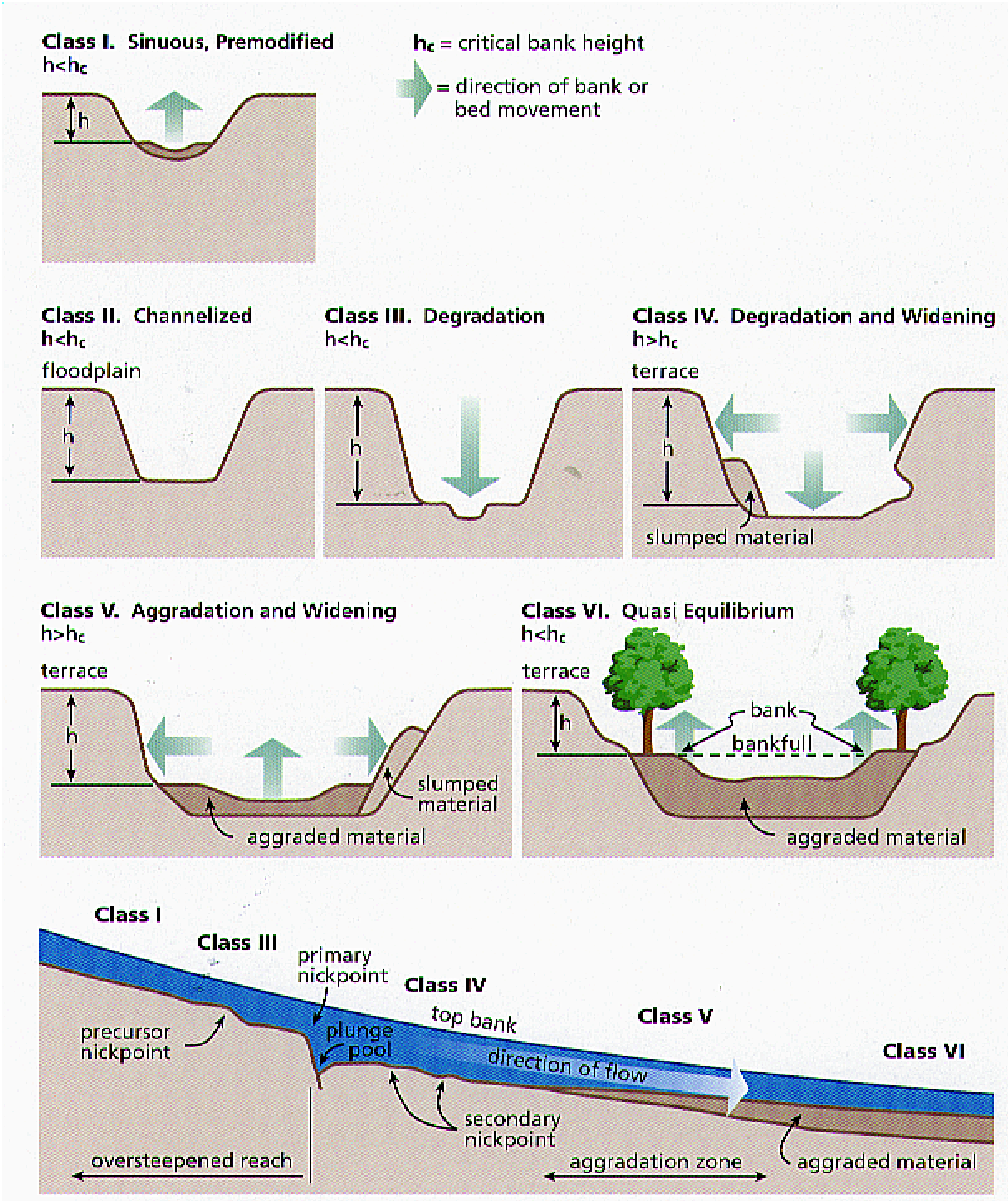


Figure 6. Channel Evolution Model of Incised Channels (Schumm. 1984).

In recent years, local planning and zoning ordinances, as well as state legislation, has focused on erosion control practices for land development, often accomplished through the use of haybales, silt fences, and sediment basins. Non-point pollution controls have also been the focus of much attention in recent years, with stormwater management treatment and best management practices becoming commonplace. However, when much of the development in the Pine Gutter Brook watershed occurred, stormwater management controls were not commonplace. Therefore, many of the developments within the watershed do not have sediment control structures or detention basins to control peak flow.

Hills and uplands form as the result of tectonic forces that warp the earth's crust. Plutonic rock masses can also push up through the crust, forming mountain ranges such as the Sierra Nevada. These mountainous areas and uplands in turn are subject to degradation and wear by the twin processes of surficial erosion and mass movement. Made-made slopes are subject to the same degradation processes. In order to control or prevent this wearing or wasting away of the earth's surface, it is first necessary to understand these two processes of degradation and the factors that affect them (Gray & Sotir, 1996).

Surficial erosion is the detachment and transport of the surface layers of soil by wind, water, and ice. Common forms of surficial erosion include rainfall and wind erosion. This type of erosion is most notable at poorly managed construction sites on exposed steep slopes. However, erosion can also occur along stream banks, where high velocities erode vulnerable banks.

As has been observed at Pine Gutter Brook, eroding banks can contribute large volumes of sediment to downstream receiving waters. When the receiving waters are of critical value, it is important to minimize the transport of sediment to them in order to maintain water quality. This often entails using biotechnical techniques to regrade and replant the channel banks.

Stream banks may erode and/or collapse due to many different causes and may undergo various types of failures. The potential factors involved in bank failure include watershed hydrology, river flow hydraulics, sediment transport, geology, soils, groundwater hydrology, and vegetation cover. The specific factors in any particular case depend on the type of failure that is occurring.

Surface erosion along stream banks can result in soil loss and bank undercutting. That situation can result in an eventual mass failure, in which the soil slumps or slides as a unit. While bank protection can address the underlying cause of the problem (i.e. surface erosion), the potential for mass failure also needs to be addressed on a location-specific basis. In general, bank failure can be attributed to mass failure or surface erosion.

2.4.2 Gully Erosion

Pine Gutter Brook is also characterized by a number lateral gullies that contribute runoff to the channel. These gullies are intermittent watercourses with steep side slopes. Wetlands were delineated in a few of these locations, but mostly they act as intermittent streams that carry stormwater. A few of the gullies originate at storm drainage outfalls, while others have formed through natural processes.

One significant gully was identified near the Squire Hill apartment complex. While the gully appears to have existed before the development occurred, storm drainage piping does discharge at the top of the gully. The storm drainage has resulted in some erosion of the gully. Aside from the storm drainage piping and its erosion, the apartment complex dumpster is also located at the top of the embankment for this gully. Due to poor housekeeping around the dumpster, garbage, ranging from plastic bottles and cans to ovens and other appliances, has accumulated in the gully and in Pine Gutter Brook.

The gullies observed along the Pine Gutter Brook channel appeared steeper than the main channel and are capable of supporting limited vegetation along the banks. Stabilizing these gullies using bioengineering and vegetation will not be possible. Therefore, some gullies may warrant structural stabilization work as part of the overall plan for the brook.

2.4.3 Bank Failure

Numerous types of mass soil failures can occur on steep slopes as summarized in Table 2 below.

TABLE 2
Types of Mass Soil Failures

Shallow Soil Slides	Occurs on steep low cohesion soils, often-coarse grain material. Has thin slide layers parallel to the surface.
Circular Plane Failures	Deep seated circular failure planes, common on strongly cohesive soils.
Slab or Wedge Failures	Occur on steep moderately cohesive soils. The slabs crack along the top and tip outward with near vertical upper slopes.
Cantilever Failures	Due to the collapse of an undercut block of soil, often due to erosion at the base of the slope.
Granular Flow	An avalanche type failure of dry cohesionless soils on steep slopes, creating a loose layer of debris in a fan pattern.
Saturated Flow	Saturated soils loose their strength and become plastic, often follows heavy rain or high water levels.
Seepage Failure	Caused by saturation of the lower slope, creating a "semi-moon" shaped pop-out cavity in the lower bank.

In the lower reaches of Pine Gutter Brook the failure mechanism appears to be granular flow. Debris was not observed in a fan pattern at the base of the slopes because it has been washed downstream and into the sediment basin.

The analysis of mass bank failures is a geotechnical evaluation that compares the weight of the soil mass (usually saturated) versus the shear strength of the potential failure plane. Quantitative assessment shows that higher and steeper banks are more failure prone and that failures decrease as the slope is reduced by past failures building up a berm of debris at the base of the bank. A stable bank may have gradual erosion of individual particles over a long period of time, while an unstable bank is one with frequent mass block failures every few years.

The banks at Pine Gutter were observed to be medium density sand with an estimated angle of repose of 35 degrees. The stable slope of any soil is defined as the tangent of the angle of repose. Since, the tangent of 35 degrees is equal to 0.7, we can estimate the stable soil slope for the unvegetated banks of Pine Gutter Brook to be approximately 1 horizontal to 1.5 vertical. This means that any stabilization work completed should result in channel banks of this slope or less steep.

3.0 WATERSHED HYDROLOGY

3.1 Watershed Description

The Pine Gutter Brook watershed is approximately 96 acres in area at the present time, extending from Pisgah Brook north to Crestwood Road. The western limit of the watershed is Brushy Plain Road and the eastern limit is Bear Path Road. Land use in the watershed has evolved since the 1960's from undeveloped woodlands to suburban lands developed with single family houses and apartment buildings. The amount of impervious surface in a watershed has been documented to impact rivers and streams, both by degrading the quality of water discharging to the channel, and by increasing the quantity of water discharging. Increases in quantity lead to higher velocities, which can result in bank erosion.

It has been assumed that the bank erosion occurring along Pine Gutter Brook is the result of land development activities within the watershed. Based on the information presented in Section 2 of this report, MMI believes that some bank erosion would be occurring, even if no development had occurred in the watershed. However, we suspect that anthropogenic activities have increased the rate of erosion.

3.2 Hydrologic Modeling

In recent years, land use in the Pine Gutter Brook watershed has transitioned to suburban single family and apartment style developments. Stream corridor impacts from this type of land use result during construction, when runoff from exposed soils carries excessive amounts of vegetation. After construction sites are stabilized, stream impacts continue to occur as runoff rates and volumes increase due to discharge from impervious surfaces, water temperatures increase as a result of runoff from summer storm events, and sediment loading increases due to wintertime road sanding operations.

Hydrologic modeling of the watershed was completed under both current development conditions, and assuming that no development had occurred in the watershed. Modeling was completed using the Army Corps of Engineer's Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS).

The physical representation of watersheds is configured in the HEC-HMS model using subbasin and junction elements. The Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, curve number method was used to estimate runoff rates from each subwatershed. The curve numbers were calculated based on land use conditions and the percentage of impervious area for the sub-watersheds.

3.2.1 Existing Conditions

Mapping of the watershed was obtained from the Town of Branford Geographic Information System (GIS) database. Information presented on this mapping included topography, storm drainage systems, roadways and buildings. Watershed and subwatershed boundaries were delineated based on topography and field verified to reflect changes in the watershed areas due to the presence of storm drains. Field inspection was performed by MMI staff to verify and supplement the storm drain information presented in the GIS.

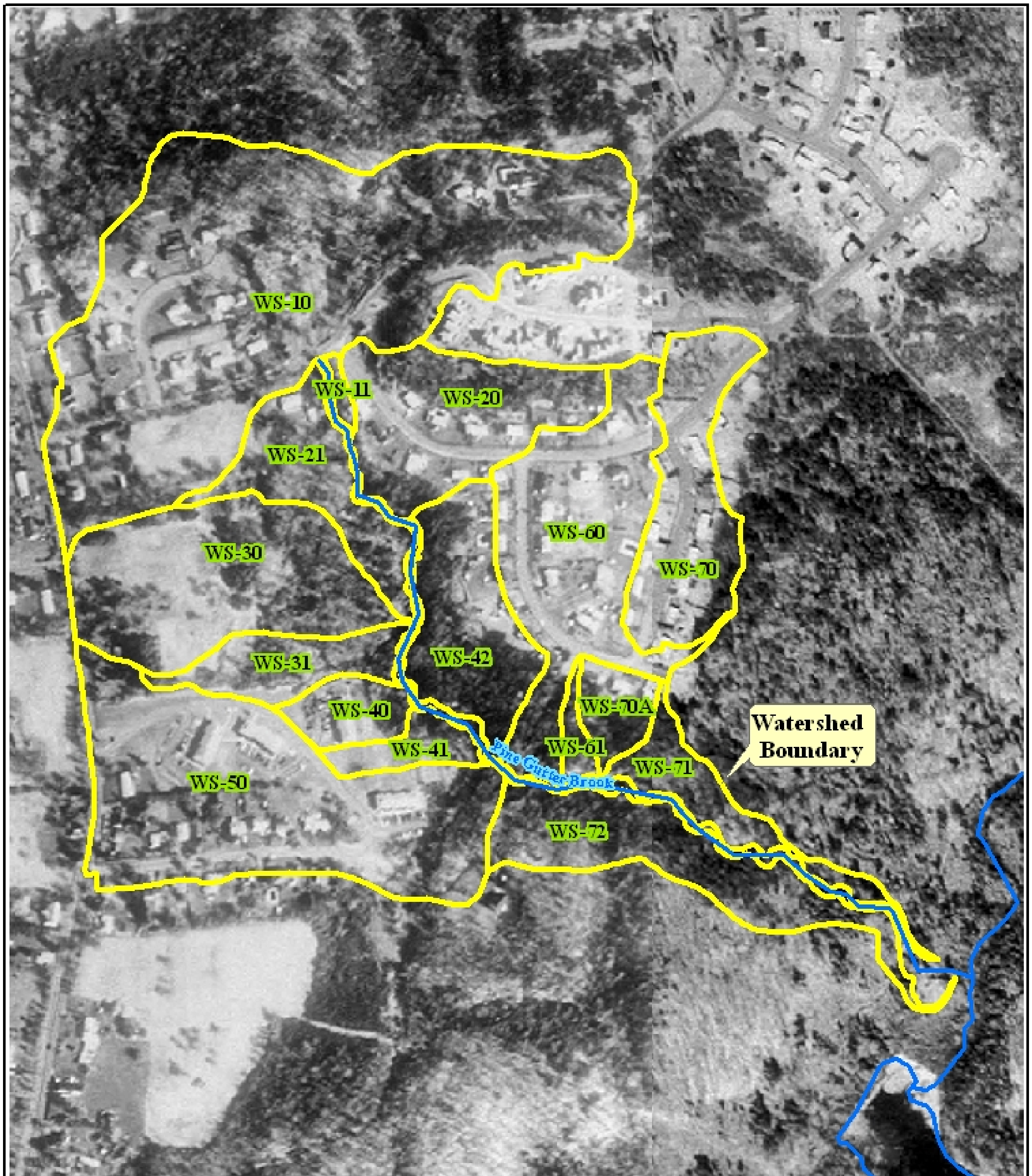
Land use under existing conditions was determined from the GIS mapping. Land use in the watershed was classified as dense or sparse forested, open space, building, parking lots and impervious (paved) cover. Soil types in the watershed were determined from the Connecticut Department of Environmental Protection GIS database of the NRCS soil survey for New Haven County, Connecticut. The NRCS divides soils into four groups A, B, C or D depending on their infiltration capacity and ability absorb water. Group A soils have the highest infiltration capacity. Group D soils have the lowest infiltration capacity and hence, generate the highest runoff rates. Watershed soils were determined to be hydrologic soil type 'B', and soil type 'C' as classified by the NRCS. Hydrologic group B soils have moderate infiltration capacity and consist of moderately well to well drained soils. Group C soils have low infiltration rates and consist of soils with a layer that hinders the downward movement of water.

The curve numbers used for this analysis were developed by Milone & MacBroom, Inc. specifically for use in Connecticut. The standard curve numbers presented in the SCS data are based on average information for all areas of the country, and were originally developed for use in agricultural lands. These numbers generally overestimate runoff rates from sub-watershed when applied to Connecticut sites. In response, MMI has developed curve numbers more appropriate for Connecticut and their use has been authorized by the SCS.

The time of concentration for each watershed, defined as the time it takes a drop of water to travel from the most hydrologically distant point in the watershed to the watershed outlet, was also determined for each subwatershed. A minimum of 10 minutes was assumed for the time of concentration of the small sub-watersheds of Pine Gutter Brook.

Rainfall data for the analysis was taken from the United States Weather Bureau's Technical Paper-40, published in 1961. Twenty-four hour rainfall rates for the 1, 2, 5, 10, 25, 50 and 100-year return frequency storm events were used. Control specifications were set up with a time interval of 3 minutes to obtain a hydrograph for each subwatershed.

The watershed was divided into 16 sub-watersheds based on the residential area and storm outlets to Pine Gutter Brook. The sub-watersheds were numbered WS-10 to WS-72 from the upstream to the downstream side of the flow. Sub-watersheds 10, 20, 30, 40, 50, 60 and 70 have a direct discharge to the channel from storm drainage piping. These watersheds are described in more detail in Section 5. Figure 7 shows the existing conditions sub-watersheds. The area, curve number, time of concentration and the percent impervious area of each sub-watershed are given in Table 3. Backup data on this information is presented in Appendix A.



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716 South Main Street Cheshire, Connecticut 06410 (203) 271-1773 Fax: (203) 272-9733 www.miloneandmacbroom.com	MMI#: 2619-01 MXD: H:Watersheds-Existing.mxd SOURCE: DEP Bulletin 37	N Existing Conditions Sub-watersheds	DATE: 01/31/05 SCALE: 1" = 400'	SHEET: Figure 7

TABLE 3
Hydrologic Input Data – Existing Conditions

Sub-watershed	Area (acres)	Curve Number (CN)	Time of Concentration (Tc in hours)	Percent Impervious Area (%)
WS-10	26.39	70	0.204	17.92
WS-11	0.25	66	0.167	4.03
WS-20	6.32	76	0.167	30.78
WS-21	3.88	71	0.167	17.05
WS-30	8.77	81	0.381	38.91
WS-31	2.56	63	0.285	4.30
WS-40	1.56	73	0.167	18.35
WS-41	1.22	67	0.167	88.97
WS-42	4.95	66	0.167	8.13
WS-50	14.06	76	0.312	28.66
WS-60	9.03	77	0.215	32.93
WS-61	0.53	61	0.167	0.00
WS-70	5.46	80	0.268	42.01
WS-70A	1.36	69	0.167	13.79
WS-71	2.45	57	0.167	0.00
WS-72	5.55	58	0.222	0.00

It is interesting to note the extremely high levels of impervious area in watersheds WS-20, WS-30, WS-41, WS-60 and WS-70. The watershed Impervious Cover Model (ICM) developed by Schuler documents stream channel and corridor impacts at levels of watershed imperviousness in excess of 25 percent. Impairment of streams begins at impervious levels of 10 percent. See Section 5 for more information about watershed management and the ICM.

3.2.2 Undeveloped Conditions

A second analysis was completed to evaluate hydrologic conditions of the watershed if no development had occurred. For this analysis the Pine Gutter Brook watershed was divided into seven sub-watersheds based on the topography of the area. Figure 8 shows the sub-watershed areas under undeveloped conditions. The area, curve number, time of concentration and the percent impervious area of each sub-watershed are given in Table 4. Land use was considered dense forest for undeveloped conditions.

TABLE 4
Hydrologic Input Data – Undeveloped Conditions

Sub-watershed	Area (acres)	Curve Number (CN)	Time of Concentration (Tc in hours)	Percent Impervious Area (%)
WS-10	26.85	60	0.502	0.00
WS-20	12.86	60	0.719	0.00
WS-30	17.95	60	0.738	0.00
WS-40	19.20	60	0.505	0.00
WS-50	11.38	60	0.478	0.00
WS-60	2.40	57	0.167	0.00
WS-70	5.55	58	0.222	0.00

The total watershed area under undeveloped conditions is approximately two acres larger than under existing conditions. This is due to the fact that a storm drainage system in a development off of Laurel Hill Road was designed such that stormwater discharges to the northeast and out of the Pine Gutter Brook watershed.

3.2.3 Results of Hydrologic Analysis

Watershed peak discharges under both scenarios was determined from the HEC-HMS model. Table 5 presents peak flow rates at the Laurel Hill Road culvert (WS-10). Table 6 presents peak flow rates at the Pine Gutter Brook outlet at Pisgah Brook.

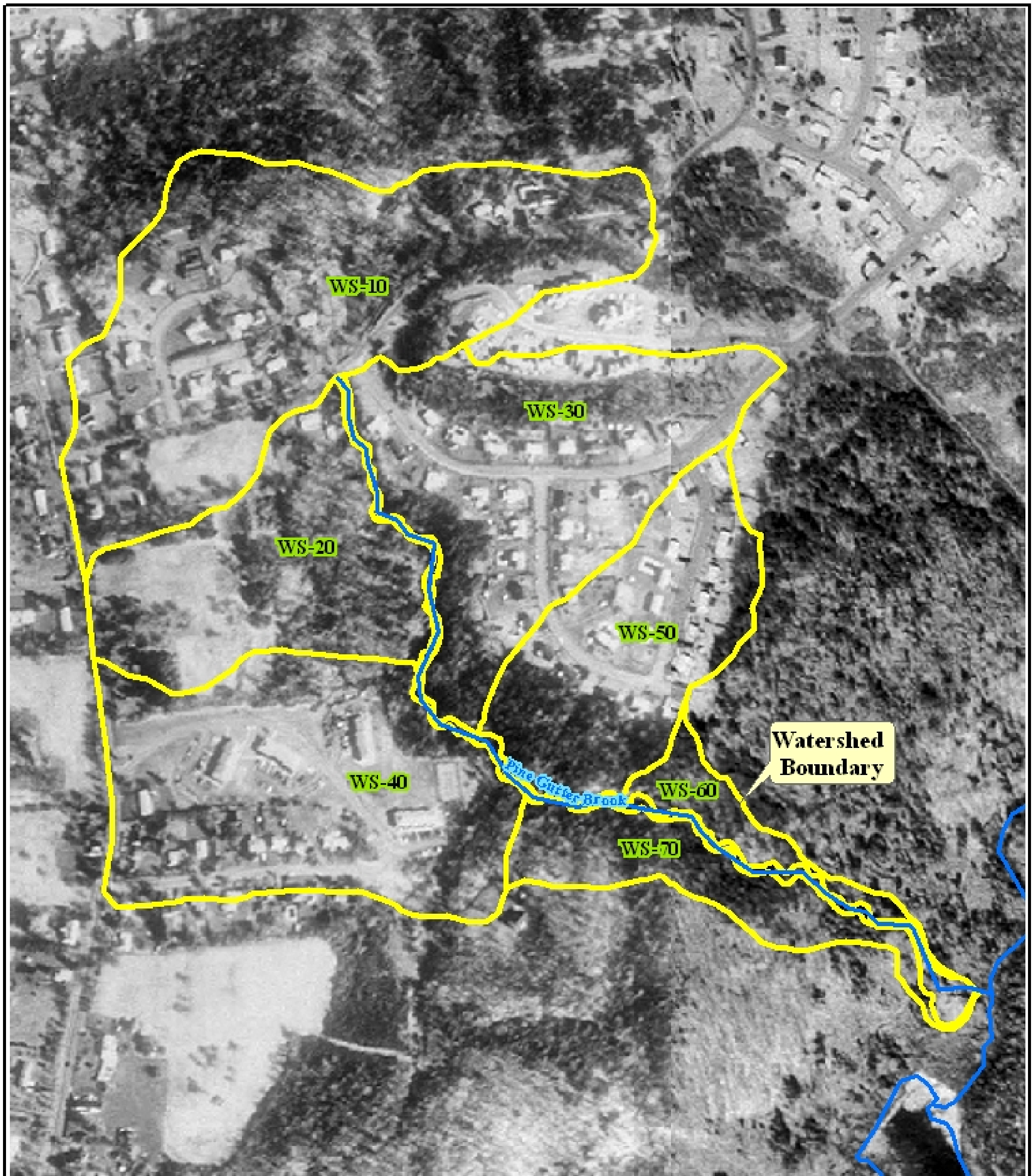

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TABLE 5
Predicted Peak Discharge Rates from WS-10
(Laurel Hill Road Culvert)

Flood Frequency (years)	Peak Discharge Undeveloped Conditions (cfs)	Peak Flows Existing Conditions(cfs)	Flow Increase (cfs)	Percentage Increase (%)
1	8.88	23.65	14.77	166
2	13.81	32.99	19.18	139
5	22.50	48.31	25.81	115
10	31.24	62.88	31.64	101
25	38.29	74.24	35.95	94
50	46.97	87.82	40.85	87
100	57.37	103.77	46.40	81

Notes: cfs = cubic feet per second

TABLE 6
Predicted Peak Discharge Rates at Watershed Outlet

Flood Frequency (years)	Peak Discharge Undeveloped Conditions (cfs)	Peak Flows Existing Conditions(cfs)	Flow Increase (cfs)	Percentage Increase (%)
1	28.82	87.96	59.14	205
2	44.84	121.07	76.23	170
5	72.95	174.83	101.88	140
10	101.21	225.49	124.28	123
25	124.13	264.76	140.63	113
50	152.41	311.60	159.19	105
100	186.36	366.14	179.78	96

Notes: cfs = cubic feet per second

Discharge rates from the Pine Gutter Brook watershed were higher than expected, even under undeveloped conditions. Based on gauge data information collected from the United States Geological Survey, streams in Connecticut typically demonstrate an annual flood (1-year storm event) discharge of 40 to 60 cubic feet per second per square mile of watershed. The Pine Gutter Brook watershed is approximately 95 acres (0.15 square miles), indicating the one-year flood would be expected to generate a peak runoff of six to nine cubic feet per second. The peak runoff rates estimate for Pine Gutter Brook were significantly higher, in part due to the long, narrow watershed shape, and in part due to the steep topography of the watershed.

Data presented in Tables 5 and 6 indicates that discharge rates from the Pine Gutter Brook watershed have increased due to development. In response to the increases in flow, the cross sectional area of the channel is increasing, as evidenced by the bank and bed erosion observed. It is important to understand that bed and bank erosion would likely be occurring in this system, even if no development had occurred in the watershed. This is due to erodibility of the soils and steep channel slope.

4.0 CHANNEL HYDRAULICS

4.1 Stream Reach Descriptions

On November 15, 2004, Milone & MacBroom, Inc. staff evaluated the Pine Gutter Brook stream corridor. During that site visit, the overall condition of the brook and its tributaries were evaluated and observations were made with regard to bank height, condition, vegetation and channel bed material. During this investigation the channel was divided into six reaches based on channel conditions. Each reach is described in Table 7 below and is depicted on the channel profile in Appendix B.

TABLE 7
Summary of Stream Reach Designations

Reach	Description of Geographic Limits	Length (feet)
1	Confluence with Pisgah Brook to end of broad floodplain (station 8+50)	515
2	End of broad floodplain to start of confined channel (station 16+60)	1,235
3	Start of confined channel to 20 feet upstream of apartment gully	230
4	From 20 feet upstream of apartment gully to sewer pump station	675
5	From sewer pump station to behind house at 26 Richhill Road	400
6	From behind house at 26 Richill Road to Laurel Hill Road culvert	405

Reach 1 extends from the confluence with Pisgah Brook upstream to the end of the broad floodplain area, includes the sediment pond and footbridge and is characterized by severely eroding banks. This reach is largely within the East Berlin formation (see Bedrock Geology in Section 2) as opposed to the Portland Arkose and Hampton Basalt that underlies the upstream reaches. The change in geology to the East Berlin Formation is evident in the field, as the channel through this reach is down cutting and widening in an effort to meet the elevation of Pisgah Brook. The down cutting is causing undermining of the channel banks, hence the severely eroded banks observed in the field. The soil materials are not resistant to erosion and bedrock has not been encountered by the down cutting. Channel erosion in this reach appears controlled by the elevation of Pisgah Brook and it is unlikely that down cutting of the bed will continue until bedrock is encountered unless bed lowering occurs in Pisgah Brook. The channel in Reach 1 is three to four feet wide with a flow depth during the site visit of approximately 10 inches. The bank full width and depth were estimated at 10 feet and two feet, respectively. The bank full discharge of a channel is that which occurs as the channel overtops its banks into the floodplain. The bank full dimensions are those associated with the bank full discharge.

Figure 9. Channel banks in Reach 2 showed evidence of river bed cobbles, indicating previous channel bed locations and elevations.

Reach 2 is characterized by the upstream limit of the broad floodplain (when viewing the channel downstream to upstream). The silty bed material encountered here indicates that water velocities are low. The channel is actively meandering through this reach and floodplain erosion is occurring as a result. Viewing the banks of the channel in this reach, old channel bed material, as evidenced by river bed cobbles and gravel materials, was observed as shown in Figure 9. This reach overlies the Portland Arkose formation and is eroding to the depth of the shallow bedrock that is characteristic of this formation. The channel depth in this reach was approximately six inches, with a bank full depth of two to three feet. Channel width was estimated at six feet, with a bank full width of 15 feet.

In Reach 3 the channel begins to transition to a bedrock substrate with an overlay of three to four inches of sediment. As with reach 2, the shallow bedrock Portland Arkose that underlies this formation will serve as the ultimate boundary for the bed erosion. In some areas the channel bed has down cut into bedrock already. Storm drainage discharges were observed in this reach, from both the apartment complex and from Bear Path and Pine Hollow Roads. The storm drain from Pine Hollow Road discharges perpendicular to the flow path directly at the edge of the channel. Concrete armoring has been placed in the channel bed at this location, presumably in response to scour at the outlet of the drain. The channel downstream of the outlet is undercutting the bed armoring, giving the appearance of a head cut formation.

Reach 4 is represented as a semi-confined bedrock channel with sand and sediment bars forming. A bedrock flume was observed in this channel reach upstream of the apartment complex. The source of the sediment was assumed to be upstream bank erosion. A perched storm drainage pipe (see Figure 10), located downstream of the sewer siphon, was observed in this reach. Riprap had been placed at the pipe outlet to protect from bank scour. However, the outlet is still set above the elevation of the riprap. The resulting drop that occurs during discharge will result in erosion of the bank material. The channel through this reach is approximately four feet wide, with a bank full width estimated at 12 feet. Channel depth was three to six inches with a bank full depth estimated at 18 inches.

Figure 10. Perched storm drainage discharge in Reach 4.

Reach 5 is a confined bedrock channel that appears to erode more to the right (when facing downstream) than to the left, likely due to its proximity to the Hampton Basalt fault in the area and the bedrock strike and dip angle (see Figure 2). The Hampton Basalt fault is depicted to the west of the channel on the bedrock geology mapping; however, the bedrock mapping is approximate, so the fault may in fact be closer to the channel. Channel width in this reach is estimated at one foot, with a flow depth of two to three inches. Bank full width is estimated at six to eight feet and bank full depth at four feet.

Reach 6 is at the upstream limit of the channel and consists of an approximately six inch deep confined channel with cobble substrate. This channel reach is also underlain by the Hampton Basalt and so would be resistant to erosion and down cutting.

Table 8 presents a summary of which sub-watersheds (described in Section 3) enter the channel in each stream segment described above.

TABLE 8
Correlations of Subwatersheds to Stream Segments

Segment Number	Description of Geographic Limits	Existing Conditions Contributing Subwatersheds	Undeveloped Conditions Contributing Subwatersheds
1	Confluence with Pisgah Brook to end of broad floodplain (station 5+15)	WS-71*; WS-72*	WS-60*; WS-70*
2	End of broad floodplain to start of confined channel (station 17+50)	WS-61*; WS-70; WS-70A; WS-71*; WS-72*	WS-50*; WS-60*; WS-70*
3	Start of confined channel to 20 feet upstream of apartment gully	WS-50; WS-42*; WS-60; WS-61*	WS-40*; WS-50*; WS-70*
4	From 20 feet upstream of apartment gully to sewer pump station	WS-40; WS-41; WS-42	WS-30*; WS-40; WS-50
5	From sewer pump station to behind house at __ Richhill Road	WS-21*; WS-30; WS-31; WS-42*;	WS-20*; WS-30*
6	From behind house at ___ Richill Road to Laurel Hill Road culvert	WS-10; WS-11; WS-20; WS-42*	WS-10; WS-20*; WS-30*

*Indicates that only a portion of the watershed drains into the stream reach.

4.2 Stream Dynamics

The movement of sediments through a river system is a complex process, often made up of many cycles of scour, movement, transport and deposition. Sediment movement occurs when water flow exerts sufficient force to overcome the resistance produced by the weight of individual particles, their cohesion to similar particles, and their friction with the streambed. Most sediment is transported during periods of high water flows and high velocities. High flow velocities are able to erode and transport larger particles and so accelerate erosion. Similarly, long-duration floods can cause more erosion and sediment transport as compared to short-duration floods. The sediment concentrations in river water and long-term sediment loads depend on the availability of erodible soil and the ability of a river to transport it.

Aggradation is the general increase in elevation of a long reach of a riverbed over a long period. This process occurs when sediment is continually added to the riverbed, or even the floodplain, and the river does not have the necessary slope, velocity or flow rate to wash away the sediment. Therefore, the riverbed will rise, increasing the slope in relation to the segment farther downstream. This increased slope accelerates erosion, until sediment transport is equal to the sediment supply rate and equilibrium is achieved.

In contrast, degradation is the general lowering of the streambed. This occurs where the slope, discharge and flow velocity combine to transport more sediment than is supplied to a river section. As a result, the riverbed will erode until the slope and velocity are reduced to a point of equilibrium. Natural degradation can result from an uplift of the land, climatic changes, or even an increase in vegetation. Humans can cause or accelerate degradation through watershed development that increases surface runoff and flow rates. Dams on alluvial rivers (i.e. those that are dynamic, whose beds and banks can erode and change course over time) encourage degradation by trapping sediment that would normally be carried downstream.

An entrenched channel is one that has degraded so much that its flood flow is unable to spread across its floodplain. Such channels are confined by well-defined banks that are higher than the mean annual flood level, thereby preventing inundation. Entrenched meanders occur when the channel's original pattern was preserved as the channel degraded, such as in the Grand Canyon. In other words, entrenched meanders are those that have eroded vertically but not laterally. They have steep valley walls on both sides of the meander bends.

Incised meanders occur where the channel has eroded both vertically and laterally. They move downstream by eroding the outside of the bends. They are characterized by steep valley walls on the outside of bends, with mild sloping walls on the inside. Active meandering channels often occur where the river flows through highly erodible sediments, common where glacial lakes occupied the land.

4.3 Hydraulic Modeling and Sediment Transport Analysis

Milone & MacBroom, Inc. developed a hydraulic model of Pine Gutter Brook using the Army Corps of Engineer's Hydraulic Engineering Center River Analysis System (HEC-RAS). This program estimates water velocities and water depth under a variety of flow scenarios based on information developed in the HEC-HMS hydrologic model. HEC-RAS was also used to estimate the sediment transport capacity of the channel system. Both the hydraulic analysis and the sediment transport analysis were completed for exiting watershed conditions as well as undeveloped.

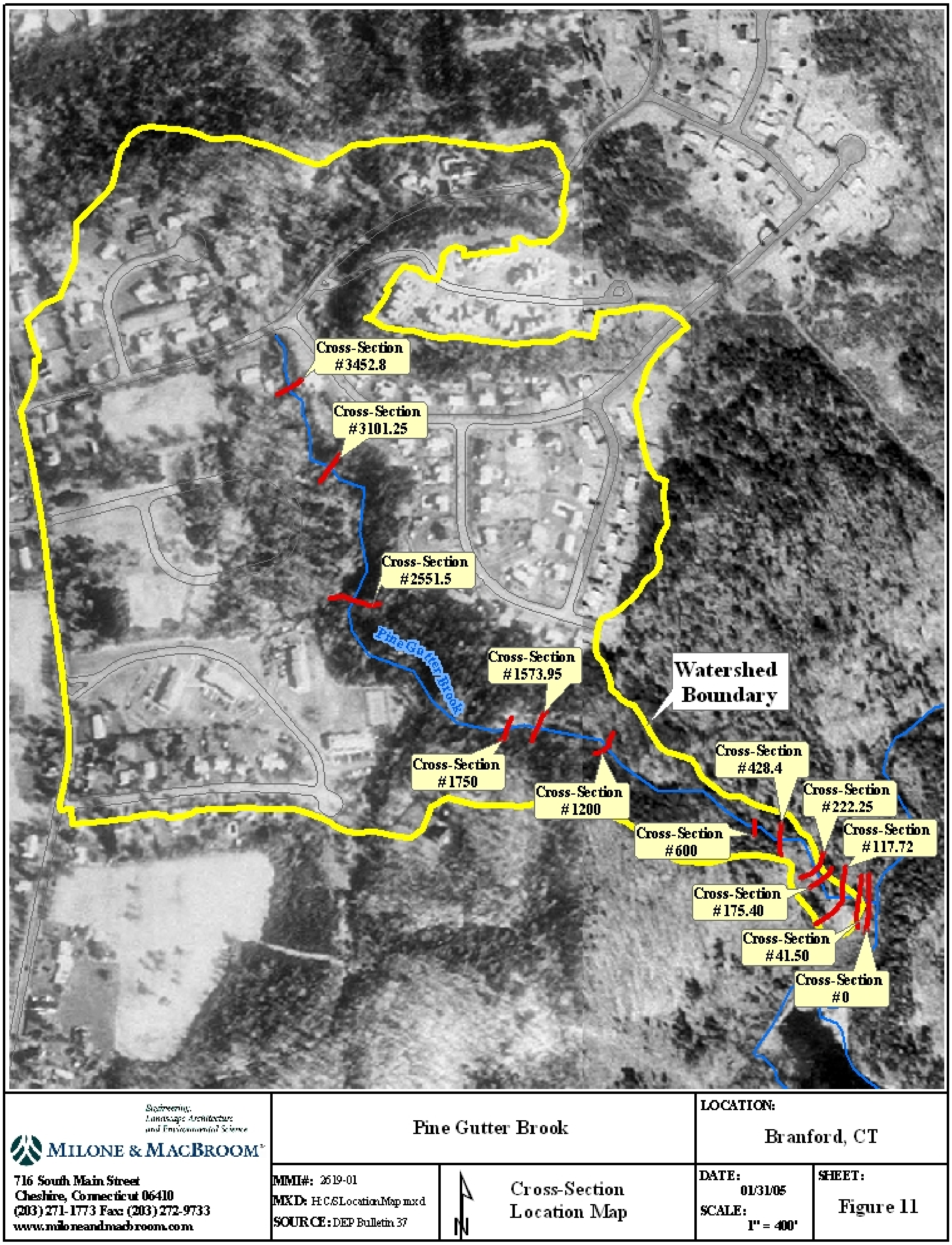
4.3.1 Hydraulic Analysis

HEC-RAS is used to compute water surface profiles for one-dimensional, steady state and gradually varied flow. This program can accommodate a full network of channels, a dendritic system, or a single river reach. HEC-RAS is capable of modeling water surface profiles under subcritical, supercritical, and mixed-flow conditions.

The basic computational procedure of HEC-RAS is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's Equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is used in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations, hydraulics of dams and bridges, and evaluating profiles at a river confluence.

Channel cross section data for the model was developed based on survey completed by Milone & MacBroom, Inc. in December 2004. Figure 11 shows the location of cross-sections in the study area. The upstream and downstream boundary conditions were evaluated with the normal depth method. A model run was completed for both existing conditions and undeveloped conditions. The flow data obtained from the HEC-HMS model was used as model input for the HEC-RAS analysis. The model was run for the mixed flow conditions to obtain the water surface elevations and the flow velocities.

Complete results and model output from HEC-RAS model is presented in Appendix C. Tables 9 and 10 presents predicted water velocities and depths for the undeveloped and developed conditions at cross-section 428.4, located 428 feet upstream of the confluence with Pisgah Brook. Cross sections downstream of 428.4 reflect the topography and velocities within the sediment basin and so do not provide an accurate representation of the flow conditions causing scour along the channel.


Cross-Section #3452.8
Cross-Section #3101.25
Cross-Section #2551.5
Pine Gutter Brook
Cross-Section #1573.95
Cross-Section #1750
Cross-Section #1200
Watershed Boundary
Cross-Section #428.4
Cross-Section #222.25
Cross-Section #117.72
Cross-Section #600
Cross-Section #175.40
Cross-Section #41.50
Cross-Section #0
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LOCATION:
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MXD: H:C/S Location Map.mxd
SOURCE: DEP Bulletin 37
N
Cross-Section Location Map
DATE: 01/31/05
SCALE: 1" = 400'
SHEET:
Figure 11

TABLE 9
Predicted Channel Velocity at Cross Section 428.4

Flood Frequency (years)	Channel Velocity Undeveloped Conditions (ft/sec)	Channel Velocity Developed Conditions (ft/sec)	Increase in Velocity (ft/sec)	Percent Increase (%)
1	4.25	6.06	1.81	43
2	4.82	6.68	1.86	39
5	5.66	7.50	1.84	33
10	6.28	8.13	1.85	29
25	6.69	9.73	3.04	45
50	7.16	9.82	2.66	37
100	7.64	9.90	2.26	30

TABLE 10
Predicted Water Depth at Cross Section 428.4

Flood Frequency (years)	Water Depth Undeveloped Conditions (ft)	Water Depth Developed Conditions (ft)	Increase in Water Depth (ft)	Percent Increase (%)
1	0.667	1.284	0.617	93
2	0.862	1.548	0.686	80
5	1.133	1.921	0.788	70
10	1.373	2.230	0.857	62
25	1.552	2.189	0.637	41
50	1.749	2.500	0.751	43
100	1.971	2.852	0.881	45

The channel velocities predicted in the HEC-RAS model are high enough to cause scour both under undeveloped and existing conditions. Given the soil materials observed in the bank and bed of Pine Gutter Brook (D_{50} = 0.8 mm), erosion would be expected to occur at velocities over one cubic foot per second. Therefore, bank and bed erosion is expected to be occurring in this system regardless of the level of the upstream development. However, Table 9 does clearly indicate that water velocities have increased in this system due to upstream development – a fact that is accelerating the erosion process.

Tables 11 and 12 provide the same data (velocity and water depth) at cross section 2551.5. This cross section is located upstream of the Squire Hill Apartments, upstream of many of the storm drainage inlets to the system. As would be expected, velocities are slightly lower in this area, although they are still high enough to cause bed and bank scour,

TABLE 11
Predicted Channel Velocity at Cross Section 2551.5

Flood Frequency (years)	Channel Velocity Undeveloped Conditions (ft/sec)	Channel Velocity Developed Conditions (ft/sec)	Increase in Velocity (ft/sec)	Percent Increase (%)
1	3.88	5.60	1.72	44
2	4.61	6.30	1.69	37
5	5.55	7.20	1.65	30
10	6.27	7.88	1.61	26
25	6.76	8.34	1.58	23
50	7.28	8.81	1.53	21
100	7.81	9.31	1.50	19

TABLE 12
Predicted Water Depth at Cross Section 2551.5

Flood Frequency (years)	Water Depth Undeveloped Conditions (ft)	Water Depth Developed Conditions (ft)	Increase in Water Depth (ft)	Percent Increase (%)
1	0.662	0.972	0.310	47
2	0.784	1.118	0.334	43
5	0.962	1.319	0.357	37
10	1.111	1.484	0.373	34
25	1.218	1.601	0.383	31
50	1.338	1.731	0.393	29
100	1.469	1.872	0.403	27

4.3.2 Sediment Transport Analysis

An advanced version of the HEC-RAS model was used to evaluate the sediment transport capacity of Pine Gutter Brook. The model used Yang's Method of total sediment discharge to estimate the sediment load of Pine Gutter Brook. The assessment is based on the following factors: average velocity, hydraulic depth, stream width, energy gradient of the channel, kinematic viscosity and the median bed material size. The analysis computes the sediment carrying capacity of each reach, comparing the channel's ability to transport material with the volume of material that is available. This is a practical application of Lane's channel erosion equation that was presented in Section 2, which states that a channel will always attain equilibrium between sediment discharge, sediment particle size, bed slope and flood discharge.

Samples were collected from various bed and bank locations along Pine Gutter Brook during the November 15, 2004 site inspection. Four samples were then submitted to Connecticut Testing Laboratory of Meriden, Connecticut for grain size analysis using a sieve. Results of the sieve analyses are presented in Appendix D.

The results of the HEC-RAS evaluation indicate that the mid section of the channel (Reaches 3 and 4) has a greater sediment transport capacity than the upper reaches (Reaches 5 and 6), but a lower transport capacity than Reaches 1 and 2. This means that in the middle reaches, the channel is "hungry" for sediment because only a limited amount is being supplied from Reaches 5 and 6. To "feed" its need for sediment, the channel is "eating" its bed and banks through the middle reaches. Since Reach 1 provides enough sediment to "feed" its sediment demand, material transported from Reaches 2, 3, and 4, deposits in Reach 1. Figure 12 depicts the results of this analysis. It is important to understand that the results of this analysis are theoretical and do not represent an actual estimated sediment yield on a daily or annualized basis. The results do provide a general measure and indication of the ability of each channel reach to move sediment.

Figure 12

The intent of the improvements proposed as part of this study is to control the erosion in Reaches 2, 3 and 4. Ultimately this will be done by reducing the bed slope to reduce water velocities and by stabilizing the banks in some areas to control future sediment migration.

4.4 Bank Stabilization

Many methods of stabilizing riverbanks can be employed, each with their own advantages and disadvantages. MMI has classified available methods into categories based upon two primary functions, mass failure protection and surface soil erosion protection. A single project site may often use multiple stabilization methods depending on site, soil and slope conditions. In addition, the type of treatment may vary based on its position on the slope and frequency or duration of inundation.

Two types of strategies can be applied to protect a bank undergoing surface erosion from a river. One is in-stream modification of the river's flow patterns to decrease the attack on the bank, and the other is modification of the bank itself to strengthen its ability to resist the erosive forces. In cases where the velocities of the water, rather than the alignment of the river, are causing erosion, modification of the bank is appropriate.

The approach to bank stabilization can be "soft" or "hard." The softest approach relies primarily on vegetation for bank strengthening. This type of approach typically provides instream and riparian habitat value that is superior to the harder methods; however it may not provide the level of stability required to decrease the erosion to acceptable levels. The harder approach relies primarily on structural methods, such as large riprap or concrete, to armor the riverbank. A balance of both soft and hard methods is often required, where some hard structural components are used and combined with softer habitat features to create a stable and attractive bank that provides both instream and riparian habitat.

A single project site may use multiple methods of stabilization depending on site, soil and slope conditions. In addition, the type of treatment utilized may vary based on its position on the bank slope and the frequency and/or duration of inundation at the site.

The splash zone is between the normal low water and normal high water levels. This is a high stress area, exposed to frequent saturation and drying. Only inert materials or plants tolerant to wet and dry conditions are suitable here. Remediation options such as log revetments and J-Vanes are often incorporated here to reduce localized velocities and redirect water away from an unstable bank.

The main bank zone is normally above high water levels except during floods. Both woody and herbaceous plants are common in this zone. The upper bank is rarely, if ever, flooded but can consist of less stable sediments that are subject to failure if unprotected. Deep-rooted vegetation is often desirable in this zone to help stabilize the slope. Depending on bank slopes, a lattice network may also be necessary to provide a stable substrate from where vegetation may grow.

Table 13 summarizes some available methods of bank stabilization, categorized by location along the vertical bank face.

TABLE 13
Protection Approaches for Specific Vertical Riverbank Regions

Splash Zone	Above Water
Log Revetments	Vegetated Geogrids
Root Wads	Brush Layers
J-Vanes	Live Slope Grating
Bendway Weirs	Branch Packing
	Live Stakes, Tublings, Rooted Plants

4.5 River Bed Stabilization

In addition to bank scour, Pine Gutter Brook is undergoing bed erosion and down cutting as described earlier. In order to stabilize the channel and prevent further bank erosion, the channel bed erosion must be controlled and stabilized. In the upper reaches (4, 5 and 6) the channel has eroded to the basalt layer, and bed stabilization is not necessary. However, in Reach 1 and Reach 2, bed stabilization is an important consideration and will be necessary to prevent further bank erosion. The bed lowering is causing the stream banks to undermine and fail, so bank stabilization without bed stabilization will not be successful in the long term.

The area below water, or the submergence zone, is the lowest part of the riverbank and is almost always below water and subject to scour. Terrestrial plants cannot be used in this zone, nor can materials subject to rapid corrosion or decomposition. Structural components, such as boulders, riprap, log revetments or concrete block, are usually necessary to stabilize the bank in this zone. In Pine Gutter Brook the flow zone is typically less than 12 inches high, so bed stabilization would extend only 12 to 18 inches above grade. Given the steep bed slope along reaches 2 and 3 of Pine Gutter Brook, the use of log revetments placed perpendicular to the flow direction may also be appropriate. The purpose of this would be to create a step-pool channel bed configuration which would lower velocities and minimize scour.

4.6 Assessment and Recommendations by Stream Segment

The review and analysis of Pine Gutter Brook has resulted in development of the following stabilization strategy:

- Allow the natural erosion process to continue in reaches 5 and 6. The channel bed through these reaches is bedrock, so rapid down cutting is not anticipated. Some bank erosion may occur in isolated areas, but this is a natural process and not harmful to the stream health.

- Stabilize the channel bed and banks in selected areas of the lower reaches by minimizing bed lowering and widening. Reduce the overall channel slope to reduce flow velocities and minimize scour.

Following are specific strategies to be pursued in each reach. Construction details for the recommended structures are presented in Appendix E. The channel will benefit from an overall reduction in peak flow and cleaning of the household wastes located along its lengths. Reductions in peak flow may be achieved through watershed management techniques as presented in Section 5.

4.6.1 Reach # 1

In Reach 1, the overall goal is to control the elevation of the channel bed. Figure 13 is a concept plan of the improvements described here. Since the down cutting has undercut the channel banks, resulting in bank slope failure, minimizing the rate of future down cutting will also arrest bank collapse. The channel bed in this reach is approximately three percent under existing conditions. Proposed restoration includes the use of woody debris or rock placement to force sediment accumulations and provide a step-pool profile for the channel configuration.

The placement of log or rock revetment in the submerged zone along the most steeply eroded sections of bank is proposed to stabilize the bank areas and prevent further undercutting. In areas where the eroded banks are greater than five feet, it will be necessary to cut back the bank above the revetment to provide a stable slope. In areas where the eroded banks are less than 5 feet then the bank area above the revetment can remain as is, with natural re-vegetation occurring over time. Since the bank erosion in this area appears to be the result of undercutting due to bed erosion, halting the rapid bed erosion will stop the rapid bank degradation that is occurring.

Figure 13

It is recommended that the sediment basin be maintained. It is expected that once the proposed improvements are implemented, maintenance of the sediment basin will no longer be necessary and it can be allowed to fill in over time.

4.6.2 Reach # 2

The proposed restoration in Reach 2 is similar to that proposed in Reach 1. The channel bed in this reach is approximately 2.5 percent under existing conditions. The goal of restoration is to reduce the overall bed slope using woody debris or rock placement to force sediment accumulations. Figure 14 is a concept plan of the improvements described here.

Bank stabilization is not recommended in this reach. Since the bank erosion appears to be the result of undercutting due to bed erosion, halting the rapid bed erosion will stop the rapid bank degradation that is occurring. Eventually, the currently degraded banks will revegetate and stabilize.

Another issue to be addressed in this reach is the undercutting of tree root systems along the bank (see Figure 15). Trees should be evaluated on a case by case basis, with earth and rock fill material placed under the tree roots to provide support. In areas where this is not possible, then the tree should be removed and the bank cut back to meet the channel width.

Figure 15. Tree root systems undercut by channel erosion. Place fill material under tree to stabilize, or remove tree and cut back bank.

Figure 14

4.6.3 Reach # 3

The channel bed in this reach 3 is approximately 3.3 percent under existing conditions. The goal of restoration is to reduce the overall bed slope by using woody debris or rock placement to force sediment accumulations. As with Reaches 1 and 2, bank stabilization is not proposed here. Figure 16 is a concept plan of the improvements described here.

The gully from Squire Hill Apartments should be stabilized and the debris removed to protect water quality. It is recommended that stabilization of the gully be completed by placing stop log structures in the channel perpendicular to flow. This will prevent eroded gully material from being discharged to the main channel. Prior to constructing any structure, the accumulated debris and garbage in the channel should be removed and disposed of in accordance with proper requirements.

The storm drain discharge from Pine Hollow Road should be realigned to eliminate the discharge perpendicular to flow. The concrete and rock channel armor should also be removed following realignment of the discharge pipe to allow natural channel erosion to occur.

4.6.4 Reach # 4

Gully stabilization is the primary goal of Reach 4. Although many gullies do not appear to suffer from severe erosion at this time, the potential for erosion in these intermittent channels is high. Small control structures could be placed in each of these gullies to minimize migration of material into Pine Gutter Brook.

The perched storm drainage outlet located downstream of the sewer siphon should be replaced to discharge at the brook water surface elevation. The current configuration has the potential to result in significant erosion along the stream bank.

Figure 16

The channel bed in this reach begins to transition to bedrock, so rapid bed erosion is not occurring here. However, the placement of debris or rock jams at selected locations may be appropriate in this reach.

Figure 16 depicts the location of the recommended improvements.

4.6.5 Reach # 5

Recommendations in this reach are similar to Reach 4. Flow control measures should be introduced in the gullies and household debris should be removed from the channel. Figure 17 shows the location of the gullies in this reach that may require stabilization.

4.6.6 Reach # 6

As with Reaches 4 and 5, recommendations for Reach 6 focus on controlling discharge from the gullies. Household waste was also identified in this reach and should be removed.

Figure 17

5.0 WATERSHED ASSESSMENT

In addition to the stream corridor evaluation presented in Section 4, Milone & MacBroom, Inc. performed a watershed assessment of the Pine Gutter Brook Watershed. The purpose of this assessment was to evaluate watershed development patterns and identify how those patterns may impact the Brook. A total of seven drainage systems were identified in the watershed with direct discharges to Pine Gutter Brook. Each of these systems was evaluated to estimate peak discharge rates and velocities and management strategies for each subwatershed were evaluated.

5.1 Principles of Watershed Management

Many factors require that river management efforts extend beyond the banks that contain flowing water. For some river systems, management issues result from upstream land use, runoff, and sources of pollution. This appears to be the case in Pine Gutter Brook, where over 25 percent of the watershed consists of impervious cover materials. In other areas issues arise because of floodplain encroachments, inadequate riparian buffers, or loss of wetlands. The evolving methods of river management emphasize a holistic approach, addressing the watershed and stream corridor in addition to the actual channel. This holistic approach is being pursued for Pine Gutter Brook.

Watershed management has evolved in response to the need for a broad approach that considers rivers and streams to be important natural resources with many, often competing uses. It is essential to recognize that, besides conveying storm runoff, streams serve many other ecological, economic and social functions, and the planning and design of management systems must consider water supply needs, recreational uses, wildlife, aesthetics, and the cost and maintenance of the management measures that are implemented.

The concept of watershed management has been in existence for many years. The practical application of the watershed management approach is constantly evolving as new technologies are developed. An effective watershed management program should be based on scientific and engineering guidance, but also needs to be communicated to and implemented by the stakeholders of the watershed in a complementary and coordinated effort.

Effective watershed protection involves a multi-faceted approach that encompasses land use (past, present, and future); stream and wetland buffers; responsible development through adequate site selection, design, and maintenance; stormwater best management practices; control of non-stormwater discharges; and control of destructive and unnatural erosion and sedimentation.

The increased industrialization and urban growth after the Civil War was followed by the rapid growth of suburbs dependent on automobile transportation. Urban and suburban areas both increase the area of impervious surfaces and use artificial drainage systems to collect runoff. The prevailing stormwater management philosophy for 100 years or more, was to convey the runoff to rivers as rapidly as possible. This reduces infiltration and evapotranspiration, increasing the volume of runoff and raising peak flow rates in rivers. In recent years that philosophy has changed, with more attention given to detention and infiltration of stormwater.

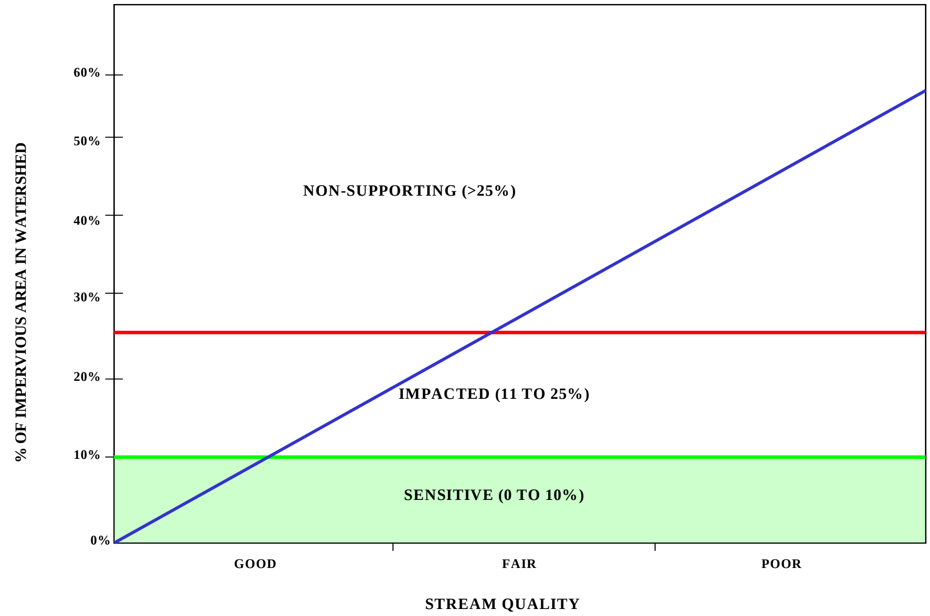
In addition to raising peak flows, urbanization reduces riverine base flows that are necessary for aquatic life, recreation, and water supply in dry weather. The percentage of a watershed that is covered with impervious surfaces is one of the key parameters affecting urban runoff. Increased runoff into a river's channel and floodplain affect the river's hydraulics, altering its flow depth, velocities, flood frequency, scour, and sediments. Channel and floodplain encroachments, such as fill material, buildings, bridges, and culverts, can also reduce flow capacity of a river and increase peak flow rates and velocities.

Changes in land use result in hydrologic changes that affect the shape, size, and form of stream channels, as has been observed in Pine Gutter Brook. The higher flow velocities and more frequent floods scour the channel, enlarging the flow area. Unless lateral erosion is contained by soil and vegetative conditions, urban rivers will generally erode their banks and increase in width. Lateral erosion leads to steeper, less stable banks that tend to be undercut and then collapse into the channel, adding more sediment directly to the river. Urban streams are also known to erode their channel beds, causing degradation, especially in uniform soils, such as silts and clays.

Aside from impacts to watershed hydrology and riverine hydraulics, land use can have a marked impact on stream water quality, temperatures, and sedimentation and erosion. With increased impervious surfaces come higher peak rates of stormwater runoff, greater transport of contaminants, higher stream velocities, and often degraded water quality due to increased temperatures and an influx of pollutants.

Based on the Impervious Cover Model (ICM) developed by Schueler, water quality degradation begins to occur when 10 percent of the watershed is covered in impervious surfaces. Degradation at this stage consists of a loss of the most sensitive aquatic organisms. Streams with 10 to 25 percent impervious cover usually are impacted with erosion channel deterioration, unstable banks, reduced habitat, reduced biodiversity, and declining water quality. Streams within watersheds of over 25 percent impervious cover tend to be flood prone, highly unstable, with poor water quality and limited aquatic life. Figure __ illustrates the relationship between impervious cover and stream quality.

Figure 18
Relationship of Imperviousness to Water Quality



Source: Schueler & Claytor, 1996 ASCE

Apse, et. al reported in their 1999 study that the Pine Gutter Brook watershed is 27.3% impervious. Table 14 provide the imperviousness of each existing subwatershed as estimated by MMI based on available GIS mapping.

TABLE 14
Levels of Subwatershed Imperviousness

Sub-watershed	Total Subwatershed Area (acres)	Percent Impervious Area (%)
WS-10	26.39	17.92
WS-11	0.25	4.03
WS-20	6.32	30.78
WS-21	3.88	17.05
WS-30	8.77	38.91
WS-31	2.56	4.30
WS-40	1.56	18.35
WS-41	1.22	88.97
WS-42	4.95	8.13
WS-50	14.06	28.66
WS-60	9.03	32.93
WS-61	0.53	0.00
WS-70	5.46	42.01
WS-70A	1.36	13.79
WS-71	2.45	0.00
WS-72	5.55	0.00

In the subwatershed delineations, WS-10, 20, 30, 40, 50, 60 and 70 each include a direct storm drainage discharge to Pine Gutter Brook. The presence of a direct stormwater discharge provides the opportunity for making drainage system improvements that can control peak discharge rates and velocities and improve water quality. Stormwater from other subwatersheds discharges by overland flow directly to the brook.

5.2 Management Practices

Milone & MacBroom, Inc. inspected and reviewed various watershed management practices that have been (or could be) applied to minimize flooding, erosion, and sediment problems in the Pine Gutter Brook watershed. The specific interest was to identify the performance of individual practices with regard to short- and long-term objectives.

Watershed management measures can be classified by primary functional groups as listed in Table 15. Typical measures are tabulated below by primary function.

TABLE 15
Primary Watershed Management Functional Groups

Hydrology	***Hydraulics***	***Surface Erosion Control***
detention basins	channel clearing	vegetation ground cover
infiltration systems	channel enlargement	rill/gully controls
created wetlands	bridge improvements	Mulch
flood control dams	channel alignment	bio-fabrics
low impact development	floodways	silt fence barriers
Channel Stabilization	***Sediment Control***	***Water Quality***
vegetation	upland sediment basins	catch basins sumps
bio-technical	in-stream silt basins	hooded outlets
stone riprap	vegetative buffers	vegetated buffers
log revetments	diversions	oil traps
geomorphic design	bio-filters	grit chambers
retaining walls		

<u>Hydrologic measures</u> are intended to reduce the volume or peak rate of runoff and ideally attempt to mimic natural conditions. <u>Hydraulic measures</u> are traditionally used to lower flood water levels, reduce flood damages to natural or community assets, or modify flow velocities. <u>Surface erosion controls</u> are used to limit upland erosion on the ground surface to reduce production of sediment, such as at construction sites and agricultural fields. Many types of <u>channel stabilization</u> are in use throughout the country, ranging from simple use of vegetation and stone to geomorphic design process to reshape channels. Section 4.0 of this report generally addressed channel hydraulics and stabilization.

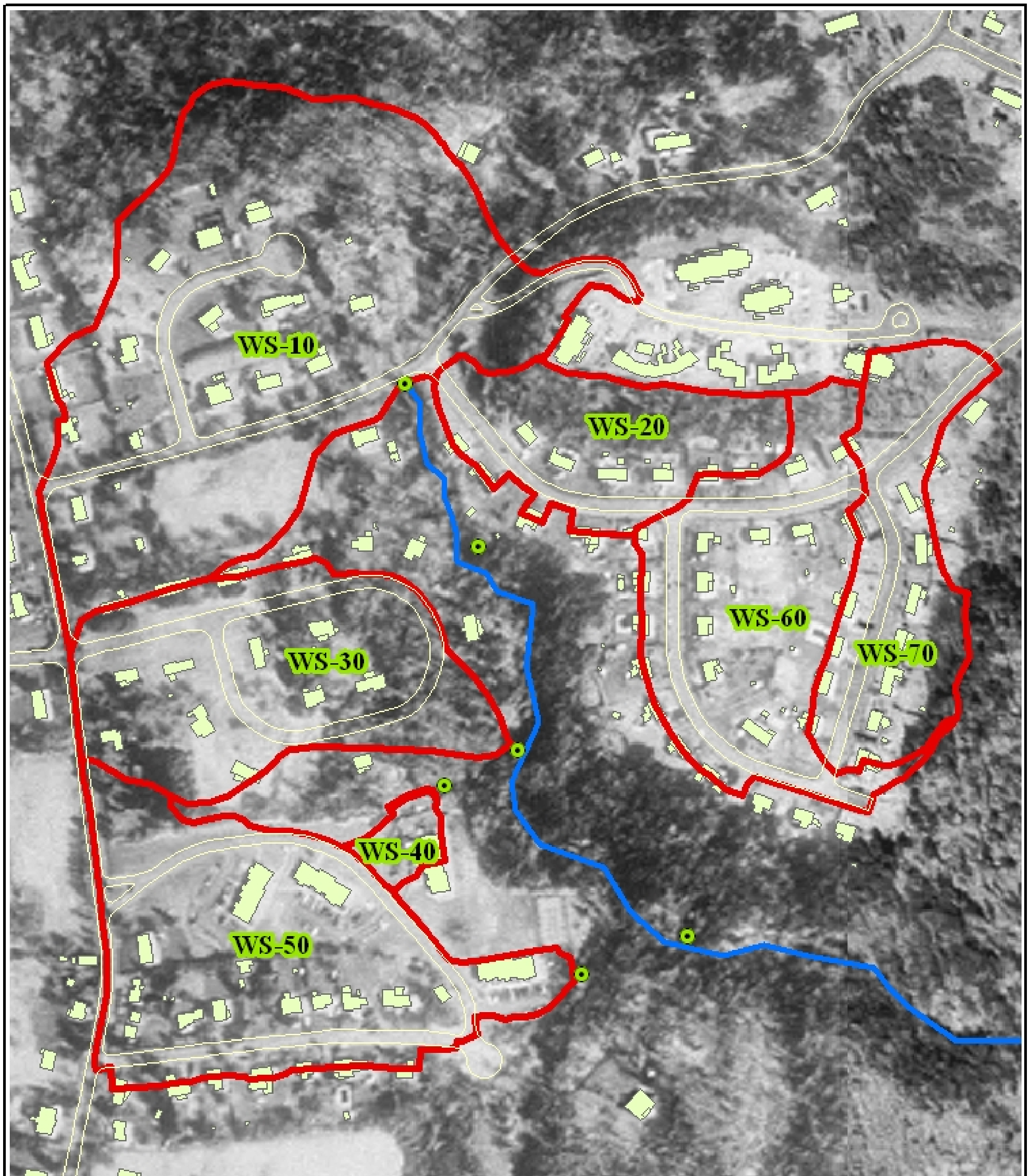
In some cases, a reactive strategy is implemented to <u>control sediments</u> that have already been eroded from the earth. In these instances, suspended sediment is captured downstream of its source and is subsequently settled by gravity or is treated through other physical or mechanical mechanisms. This has historically been the primary methods of managing Pine Gutter Brook.

Water quality controls and improvements have not historically been incorporated into the developments in the Pine Gutter Brook watershed. This is due to the fact that most watershed development occurred before water quality was a consideration.

5.3 Sub-Watershed Delineation and Analysis

Field evaluation of the storm drainage systems was completed by MMI personnel on February 8, 2005. Approximate watersheds of the storm drainage systems have been drawn based on the stormwater mapping obtained from the Town of Branford and supplemented by field investigation. Town mapping depicts the storm drainage network, catch basins, buildings, approximate parcel limits and roads. Seven storm drainage systems in the Pine Gutter Brook watershed were identified and evaluated. The watersheds were named WS-10 through WS-70 from the upstream to the downstream of the Pine Gutter Brook. Figure 19 presents the limits of each subwatershed. Storm drainage mapping for each sub-watershed is presented in Appendix F. The subwatersheds delineated for this analysis vary from those delineated for the HEC-HMS analysis presented in Section 3.0 of this report. That is because the watershed limits presented in this analysis are those areas that discharge to the drainage system, with not accounting for areas that may discharge to the brook via overland flow.

Field evaluation involved identifying the size, material of construction and flow direction of piping between the catch basins. The location and structural condition of the storm outlets was noted. Storm drainage piping observed in the field generally matched the existing storm drainage mapping obtained from the Town with the exception of four-, six- and eight-inch diameter polyvinyl chloride (PVC) pipes connected from buildings to catch basins at some locations. It is presumed that these pipes are for roof and/or footing



Engineering, Landscape Architecture and Environmental Science MILONE & MACBROOM® 716 South Main Street Cheshire, Connecticut 06410 (203) 271-1773 Fax: (203) 272-9733 www.miloneandmacbroom.com	Pine Gutter Brook		LOCATION: Branford, CT	
	MMI#: 2619-01 MXD: H:RationalMethod.mxd SOURCE: DEP Bulletin 37	N Rational Method Sub-watersheds	DATE: 03/31/05 SCALE: 1" = 300'	SHEET: Figure 19

drains. However, the Town should consider investigating this further during implementation of the General Permit for Discharge of Stormwater from Municipal Separate Storm Sewer Systems.

5.3.1 Sub-Watershed Delineation

The following is a summary of each subwatershed that was studied as part of this evaluation:

Figure 20. Culvert under Laurel Hill Road at Pine Gutter headwaters.

Watershed 10: Watershed 10 (designated as WS-10) consists of the headwaters of Pine Gutter Brook. The storm outlet for this watershed consists of a 30-inch reinforced concrete pipe under Laurel Hill Road (see Figure 20). Watershed land use consists of residential lots, with forested cover in the northeastern part of the watershed. A pond approximately 1/4 acre in area is located north of the intersection of Laurel Hill Road with Red Rock Road and discharge from this impoundment appears to serve as the source of Pine Gutter Brook.

Figure 21. Discharge location of WS-20.

Watershed 20: Watershed 20 (designated as WS-20) is on the east side of Pine Gutter Brook and includes Red Rock Road from its intersection with Laurel Hill Road to Pine Hollow Road. The storm drainage network in this watershed consists of two catch basins with a 15-inch reinforced concrete pipe outlet with flared end section as shown in Figure 21. The outlet is located approximately 60 feet from the edge of Pine Gutter Brook, with discharge traveling by overland flow to the brook. This watershed consists of residential lots and impervious roads and some woods in the northern part of the watershed.

Watershed 30: Watershed 30 (designated as WS-30) is located on the west side of Pine Gutter Brook and includes all of Richill Road. The storm drainage network from the Richill Road area discharges fro a catchbasin on the southeast side of the road though an 18-inch reinforced concrete pipe. The flow path of the 18-inch pipe could not be determined, but it is believed that this system connects to a catch basin located on the north side of the access road to the sanitary sewer siphon. A channel carrying overland flow also enters into this catchbasin. Discharge from this catchbasin then flows to a 36-inch diameter reinforced concrete pipe with flared end section. The outlet from this pipe is perched as shown in Figure 22, with riprap at the outlet to prevent scour of the adjacent bank.

Figure 22. Discharge location of WS-30. Pipe is perched above grade.

Watershed 40: Watershed 40 (WS-40) is a small watershed on the west side of Pine Gutter Brook that collects runoff from the northern portion of the Square Hill Apartment Complex on Squire Hill Road. The storm outlet consists of a 12-inch diameter reinforced concrete pipe in good condition. Figure 23 depicts the headwall where this discharge pipe is located. The discharge point for WS-40 is located on the left side of this picture. A second pipe (12-inch diameter corrugated metal pipe) is located in this headwall as well as shown in Figure 23. No discharge was observed from the 12-inch CMP and its source could not be identified through field observation. Discharge from this pipe flows overland for a short distance

Figure 23. Discharge location of WS-40 is left of this CMP

to a culvert under the access road to the sanitary sewer siphon. The outlet of this culvert was identified on the south side of the access road, and stormwater discharges to Pine Gutter Brook via a gully. The gully enters the brook approximately 60 feet downstream of the outlet from WS-30.

Figure 24. Discharge location of WS-50. Perched pipe discharge to gully.

Watershed 50: Watershed 50 (WS-50) consists of storm drainage network around Squire Hill and Homestead Roads. The watershed consists of single family residential development and a portion of the Squire Hill Apartment Complex. A 36-inch reinforced concrete pipe with flared end section forms the outlet of the watershed as shown in Figure 24. The discharge location is at a gully east of the existing dumpster of the Squire Hill Apartment Complex. Stormwater flows approximately 180 feet in this gully before entering Pine Gutter Brook. This gully contains household debris and garbage due to its location near the dumpster. Downstream of the outlet, the gully is severely eroded and the drainage outlet is perched above the gully bed. Bedrock was observed in the Pine Gutter Brook channel at the gully outlet, indicating the future bed lowering of Pine Gutter Brook at this location is not likely. However, gully erosion may continue until the elevation of Pine gutter Brook is reached – a condition that is expected to occur over many years given the intermittent discharge of the gully.

Figure 25. Discharge location of WS-60. 30" RCP with concrete and riprap bed armor.

Watershed 60: Watershed 60 (WS-60) consists of residential area around Pine Hollow Road.

Watershed land use consists of residential development and roadways. The outlet is a 30-inch diameter reinforced concrete pipe with flared end section in good condition. The outlet is located at elevation 66, approximately 70 feet below the elevation of Pine Hollow Road. A drop manhole structure, which serves to control velocity in the pipe system, was identified approximately 30 feet upgradient from the outlet. The channel at the outlet of the 30-inch diameter pipe has been reinforced with riprap and concrete See figure 25), presumably to prevent scour of the channel bed.

<u>Watershed 70</u>: Watershed 70 (WS-70) is located on the west side of Pine Gutter Brook and consists of residential lots along the Bear Path Road. An 18-inch reinforced concrete pipe was found leaving a catchbasin on Bear Path Road in the direction of Pine Gutter Brook; however, the outlet of this pipe could not be located. It is suspected that the outlet is buried under existing wood and brush but, no flow was visible from snow melt. It may be possible that this 18-inch pipe is tied into the 30-inch diameter pipe at the outlet of Watershed 60.

5.3.2 Sub-Watershed Hydrology

The Rational Method was used to calculate the peak discharges from each of the outlet pipes. Please note that the watershed areas calculated for this Rational Method analysis differ slightly from those areas developed for the HEC-HMS analysis. This is due to the fact that not all watershed area is directly connected to the catchbasin and pipe system and so would be excluded from the Rational Method discharge estimates.

Peak discharges were calculated based on the average intensity of rainfall, drainage area and the runoff coefficient. The average rainfall intensity was obtained from the rainfall frequency-intensity-duration chart for the New Haven area. The intensity is determined from this chart based on the time of concentration. The time of concentration is the estimated time required for runoff to flow from the most remote part of the area under consideration to the outlet and is calculated as the total time for overland sheet flow, open channel flow and pipe flow. The runoff coefficient is an empirical coefficient representing a relationship between rainfall and runoff. A composite runoff coefficient was calculated based on the land use conditions such as impervious pavements/buildings, grass/open space and woods. Peak discharges for the 2-, 5-, 10- and 25- year storm events were calculated for the present study.

Discharge velocity in each outlet channel was calculated using Manning's formula. Velocity calculations for the 2-, 5-, 10-, and 25- year storms were calculated based on different hydraulic conditions of the channel.

A Manning's roughness coefficient of 0.09 was assumed based on silty soil conditions and some pebbles in the channel. The longitudinal slope of each channel was estimated based on the available topographic mapping. Table 16 presents the results of this analysis. Calculations are presented in Appendix G.

TABLE 16
Results of Rational Method Analysis

Storm Event	2 -year	5-year	10-year	25-year
WS-10				
Watershed Discharge (cfs)	23	32	37	42
Downstream Channel Velocity (fps)	3.1	3.4	3.6	3.7
Normal Depth (ft)	1.5	1.7	1.8	1.9
WS-20				
Watershed Discharge (cfs)	9	12	14	16
Downstream Channel Velocity (fps)	4.6	5.0	5.2	5.4
Normal Depth (ft)	0.8	0.9	0.9	1.0
WS-30				
Watershed Discharge (cfs)	12	15	18	21
Downstream Channel Velocity (fps)	5.0	5.5	5.7	5.8
Normal Depth (ft)	0.8	0.9	1.0	1.0
WS-40				
Watershed Discharge (cfs)	1.5	2	2.5	3
Downstream Channel Velocity (fps)	2.5	2.7	2.9	3.0
Normal Depth (ft)	0.5	0.6	0.6	0.6
WS-50				
Watershed Discharge (cfs)	15	20	24	27
Downstream Channel Velocity (fps)	6.0	6.4	6.7	6.9
Normal Depth (ft)	1.6	1.8	1.9	2.0
WS-60				
Watershed Discharge (cfs)	12	17	20	23
Downstream Channel Velocity (fps)	3.9	4.3	4.4	4.6
Normal Depth (ft)	0.8	0.9	1.0	1.0
WS-70[1]				
Watershed Discharge (cfs.)	8	11	13	15
Downstream Channel Velocity (fps)	N/A	N/A	N/A	N/A
Normal Depth (ft)	N/A	N/A	N/A	N/A

Notes: cfs = cubic feet per second; fps = feet per second; ft = feet; N/A = Not applicable

1. Outlet pipe of WS-70 could not be located in field.

Discharge rates and velocities are an important consideration in designing stabilization measures for the gullies. Velocities over five feet per second generally have the potential to cause erosion. The information presented in Table 16 explains why the "apartment gully" (WS-50) is severely eroded. The steep channel slope, combined with the high discharge flow rates result in excessively high velocities in that gully. The sediment stop proposed in this channel will help prevent the discharge of sediment from the gully; however, other stabilization measures may be needed along the banks of the gully. The creation of step-pool type channel formation in this gully would help slow velocities. Construction of a step-pool could be achieved by moving the existing rocks along the channel to create pools in the gully. While this won't eliminate all erosion, it would slow velocities and reduce the volume of erosion.

The high velocities from the discharge at WS-50 also support the need for implementing watershed management controls or detention at the apartment complex. Currently, a tennis court is located at the east side of the complex, not far from the outlet pipe from WS-50. the fencing around the court is in disrepair and it does not seem the courts are used frequently. This would be a possible location for a detention basin, given the flat topography, and proximity to the outlet pipe.

Velocities at the discharge from WS-30 are also high enough to create erosion. The fact that the outlet is adjacent to the channel, is directed parallel to the flow of the channel and that riprap at the channel outlet all combine to prevent excessive erosion from occurring at this location.

The gully downstream of the outlet from WS-20 should be monitored for erosion. Channel velocities appear to be high enough during large rain events to cause erosion. Placement of a sediment stop in this gully will slow velocities, but the condition should continue to be monitored.

5.4 Watershed Management Methodologies

Of the six groups of watershed management programs described above in Section 5.2, hydraulics, channel stabilization and sediment control were addressed in previous report sections. Watershed management measures must focus on the remaining three: hydrology, surface erosion and water quality. Of these three, hydrology is the most critical, as it deals with the volume of water generated by and flowing through the Pine Gutter Brook system. However, sediment control and water quality are important considerations for any watershed.

5.4.1 Managing Watershed Hydrology

Since the mid-1990's there has been a movement to minimize the hydrologic and hydraulic impact that development activities have on riverine systems. These so called "low impact development" techniques also serve to improve water quality. Most development of the Pine Gutter Brook watershed occurred long before low impact development was a consideration for most communities. In fact. Much of the development likely occurred before stormwater detention was required for controlling peak flow. As a result, development in the watershed followed the standard paradigm of moving water away from homes and streets as quickly as possible. The result is the accelerated bank and bed erosion that is occurring in Pine Gutter Brook. As previously mentioned, the erosion would likely be occurring even if no development had occurred, but at a slower rate than currently observed.

The steep slopes of both the channel bed and the channel valley make the construction of detention basins to control peak discharge at the storm drainage outlets very difficult. For example, there is no are within watershed WS-60 to construct a detention basin. The slope from Pine Hollow Road to the channel is too steep to support construction of such a facility and the watershed is full developed with residential homes, leaving no room for a detention facility. Detention may be feasible in WS-40 and WS-50; however, the owner of the Squire Hill Apartments would need to provide land area for this use. The construction of detention facilities at Squire Hill Apartment would be beneficial to Pine Gutter Brook both be reducing the discharge velocities in the gullies downstream of the discharge pipes and by reducing the peak flow in Pine Gutter Brook itself. Since Squire

Hill is the largest single landowner in the watershed, this complex represents the best opportunity for construction of a "large scale" improvement to manage stormwater.

Despite the level of development that has occurred in the watershed, it is possible to make small scale improvements that will to reduce the impact on Pine Gutter Brook. The overriding goal of any improvements should be to restore the natural hydrology of the watershed by disconnecting impervious surfaces from the storm drainage system to the extent possible. This can be done on a lot by lot basis through the use of what are frequently called Integrated Management Practices (IMP's) Prince George's County, 1999). These are controls that are implemented near the source of the impacts. Examples of IMP's that may be suitable for implementation in the Pine Gutter Brook watershed are:

- Rain gardens
- Rain barrels
- Grass swales
- Convert sidewalks to pervious materials

Three of these four IMP's are appropriate implementation by residential property owners. The fourth IMP, converting sidewalks to pervious materials could be undertaken by the Town. While other IMP's, such as infiltration trenches or dry wells, can effectively reduce runoff, the soil conditions in the watershed do not appear to be suitable for this type of control measure. A determination can be made on a lot by lot basis regarding the use of infiltration measures.

Figure 26. Residential rain garden

Rain gardens manage and treat stormwater runoff from rooftops by discharging water to a landscape area planted with native vegetation. The garden fills with a few inches of water after a rain storm and the water is then discharged by a combination of plant uptake and filtering into the ground slowly. Figure 26 is a photograph of a rain garden.

Rain barrels are a low cost device that can be used to provide retention of rooftop runoff. The barrel is typically sized to provide storage of a specific volume of water (e.g., the first inch of runoff from a rooftop area). This water can them be used for lawn and plant watering through a hose hook-up included near the bottom of the barrel. The barrels are placed at the bottom of downspouts so that water is discharged to the barrel instead of grass areas or piped directly to the roadway drainage system. A number of properties in the Pine Gutter Brook watershed were observed to have downspouts discharging directly to nearby driveways or into the drainage system as shown in Figure 27.

Figure 27. Downspouts at Squire Hill Apartment Complex are connected directly to the storm drainage system. This condition was observed at many residential properties in the watershed

Grass swales can be used in some instances in lieu of tradition pipe drainage systems. Swales that are dry except during storm event also provide some detention of rainwater. The swale concept is actually being used at the discharge of existing piped systems. Unfortunately, these discharges are located at the top of steep slopes and the swales have eroded gullies to the main channel of Pine Gutter Brook. Swales should be constructed on a maximum slope of six percent to prevent erosion. There appears to be limited area available in the Pine Gutter Brook watershed to construction grass swales. However, if appropriate locations can be identified, they are a viable stormwater management alternative.

Sidewalks were observed along some streets in the watershed and throughout the Squire Hill Apartment Complex. One way to reduce the overall imperviousness of the watershed is to replace old concrete and bituminous (i.e., asphalt) sidewalks with stone dust or with pervious pavement material. On some streets it may be possible to eliminate the sidewalks, although this decision needs to be made based on traffic patterns and speed limits.

5.4.2 Sediment Control

Much of the sediment collected in the sediment basin at the confluence of Pisgah Brook and Pine Gutter Brook is generated by bed and bank erosion along the channel. However, the introduction of new sediment to the river system from construction and earth moving activities should be avoided. This can be accomplished through the implementation and maintenance of proper sediment and erosion controls at construction sites. Figure 28 depicts a construction site near the north end of the Pine Gutter watershed where limited sediment and erosion controls were observed.

Figure 28. Construction site on Laurel Hill Road near watershed limit.

A sediment and erosion control plan must be developed for any site where more than one acre of disturbance is proposed. The plan should depict the location of proposed controls, a construction sequence and details of the proposed controls. The plan should comply with the requirements of the 2002 Connecticut Guidelines for Soil Erosion and Sediment Control. Development of a sediment and erosion control plan is critical to successful implementation by site contractors. Review of this plan should occur during the Planning and Zoning Site Plan review process. Based on the fact that zoning through much the Pine Gutter Brook watershed is ½-acre residential, future development is expected to be limited to single building lots associated with historic subdivisions. Sediment and erosion control at these lots should be considered carefully.

Following approval of a plan, inspection of sites by Town staff is necessary to ensure proper implementation. No silt fence or haybales were observed at the site on Laurel Hill Road depicted in Figure 28. Another concerns is that the full site area was disturbed at one time, without regard to the ability to vegetate the area. Town staff have limited resources to police such matters and enforce sediment and erosion control requirements, but proper construction site management can be very effective at reducing sediment loading in rivers and streams.

5.4.3 Water Quality

Pine Gutter Brook is not known to have water quality problems at this time; however, water quality could become a problem if existing land use is not managed effectively. The Town has already done one of the best things it can to protect water quality by purchasing and deeding as open space land area immediately adjacent to the stream. The Town's ownership does not include areas behind Richhill Road and does not extend to Laurel Hill Road. As a result, houses in the upper portion of the watershed are much closer the stream than in the lower portion. Nonetheless, a healthy riparian corridor has been maintained along much of the length of the brook.

Housekeeping is another way to improve water quality in the brook. Household garbage was observed in the channel on every site visit made during this study. Items observed ranged from appliances to tires to children's toys. A number of items were observed near the Squire Hill Apartment Complex and in the gullies behind this facility.

Other water quality measures that may be suitable include: (a) catchbasin inserts to remove oil and grease and debris from roadway and parking lot runoff; (b) hooded catchbasin outlet to trap floatable debris in catchbasins; and (c) implementation of a regular street sweeping and catchbasin cleaning program.

5.5 Public Outreach

Given the nature of existing development in the Pine Gutter Brook watershed, improvements to system hydrology and water quality will require the participation of individual households. This will require the Open Space Authority to develop and implement a public participation program designed to educate homeowners about the brook and things they can do to improve its condition.

The Town is required per the requirements of the Stormwater *General Permit for the Discharge of Stormwater from Municipal Separate Storm Sewer Systems* (administered by DEP) is required to develop a public education and outreach program to educate residents and businesses about stormwater management. In most communities, this permit is administered by the Public Works or Engineering Departments. In Branford's case, coordination between Public Works or Engineering and the Open Space Authority may be beneficial.

The objective of the public outreach program for Pine Gutter Brook should be to educate residents and property owners about the brook, its watershed, ongoing problems, and possible solutions. Outreach materials must make clear the Pine Gutter Brook is an important resource for the Town and an integral part of its open space. Since the majority of land use throughout the watershed is residential, materials developed for Pine Gutter Brook should relate directly to ways for homeowners to act. Since Squire Hill Apartment Complex is the only non-single family residential use observed in the watershed, it would be prudent to approach the owner of this complex directly, rather than develop outreach materials.

Reaching homeowners in the watershed can be accomplished directly through a mass mailing. It is estimated (based on GIS mapping) that there are less than 100 homes in the watershed, and possibly 150 households assuming Squire Hill maintains 50 apartments. Given the limited distribution required, annual or semi-annual direct mailings to each homeowner may be a feasible cost for the Town to assume. Other possible avenues to reach residents may include the Town web site (which currently doesn't appear to contain information relating to the Supply Ponds or Pine Gutter Brook) and placing brochures in the Town Hall and the public library.

Outreach and education materials can range from professionally produced brochures to one page fact sheets. One page fact sheets are more likely to be read by homeowners than a lengthy brochure. However, if materials are to be placed in public areas such as the Town Hall or the library, then colorful images may draw people to read the material.

As a starting point the town might consider using public information material that has been developed by other entities. While the development of Pine Gutter Brook specific materials is important, materials will take time and resources to develop. Using existing materials may provide a way to reach homeowners in the short term.

Aside from public education materials, the development of public involvement programs would serve to teach residents about the watershed. These activities may range from nature ad/or history tours of the Supply Ponds area to river clean-up days to remove trash from Pine Gutter Brook.

The Town may also want to consider constructing a "pilot project" rain garden in the watershed. If a willing homeowner can be identified, then it may be feasible to construct the rain garden in the watershed. If a willing homeowner cannot be identified then other public lands in Town can be considered, although it is recommended the location be highly visible. Construction of a pilot rain garden would serve to educate homeowners on the advantage of these systems, and also provide and example of aesthetics of the constructed project.

6.0 IMPLEMENTATION STRATEGY

6.1 Master Plan for Improvements

A number of improvements, both in channel and in the watershed, have been presented in this report. Presented below is a summary of the activities and the ideal chronology of implementation. The actual order of implementation of the improvements may be (and should be) driven by the availability of funding. The activities have been split into two "tracks": watershed management and streambank stabilization. We recommend that both tracks can be implemented concurrently.

TABLE 17
Master Plan of Improvements

Streambank Stabilization Activities	Watershed Management Activities
1. Construct log and debris jams as called for on project plans.	1. Develop and implement public education and campaign for watershed improvements
2. Construct j-vanes as called for on project plans.	2. Contact owners of Squire Hill Apartments to discuss possible detention and stormwater management changes
3. Construct log or stone revetment as called for on project plans.	3. Construct "pilot" project rain garden
4. Construct sediment stops in gullies.	
5. Realign and/or reset storm drainage outlet for WS-60.	

6.1.1 Project Permit Needs

The streambank stabilization plan that has been proposed is expected to require permits from the Branford Wetlands Commission, Connecticut DEP and the Army Corps of Engineers (Corps). It is anticipated that the project will require a 401 Water Quality Certification from DEP and a Section 404 wetlands permit from the Corps.

DEP and the Army Corps will consider all proposed activities along the channel reach to be one project for permitting purposes. Both agencies would review the application concurrently and in coordination with each other. One application would be submitted on forms provided by DEP. The following attachments will also be required:

- Executive Summary;
- USGS Location Map;
- Project Plans;
- Hydraulic Analysis of the Proposed Improvements (to verify that the project will not cause up or downstream flooding);
- Flood Contingency Plan (to address possible high flows during construction);
- Soil Scientists Report (to document wetland type and quality);
- Environmental Report (to document potential impacts of the project on wetlands, etc);
- Mitigation Report (to document any mitigation to compensate for wetland filling); and
- Alternatives Assessment (to justify need for project).

These application materials are submitted to DEP and the Corps for review. The permit process is expected to take nine to twelve months depending on the backlog of pending permit applications at the time the application is submitted. The permit expiration will need to be monitored to ensure it does not expire before all activities are completed. Permit extensions can be requested from both the DEP and the Corps. It may also be possible to request a longer permit period during the application process.

Local wetlands permitting is also expected to be required for the stabilization activities. The project could be presented to the Commission as a master plan, with a permit requested for all proposed activities. As with state and federal permits, the expiration of the date of the permit will need to be monitored and extension requests submitted as necessary.

The watershed management activities that have been proposed may require permits on a case by case basis. These activities are not expected to require state or federal permitting, but may require local wetlands approval depending on the location of the proposed activity.

6.2 Cost Opinion for Recommended Improvements

To assist the Town in implementing the improvements recommended in this report, MMI has developed an opinion of probable cost for both stream channel and watershed improvements. Table 18 is a summary of recommended improvements and an opinion of cost. Stream channel improvement costs are presented on a reach by reach basis.

Add data here

6.3 Funding Options for Watershed Management and Stream Restoration

Milone & MacBroom, Inc. researched potential funding sources that may be available to assist the Town in implementing an improvement program at Pine Gutter Brook. It is important to understand that funding allocations change from year to year based on state and federal budget allocations. In some years, select programs may not receive any funding. Following is a description of programs that MMI identified. Additional information is presented in Appendix F.

Non-Point Source Management Grant Program (319 Grants): The so called 319 grants are federally funds that are administered by the Connecticut DEP. Funds are available to any Connecticut organization for projects intended to correct problems created by non-point source pollutants and/or improve water quality. In determining award of funds consideration is given to projects that may help improve water resources that are listed on the *List of Connecticut Waterbodies Not Meeting Water Quality Standards* as published bi-annually by DEP. The 2004 list includes Pine Gutter Brook and Pisgah Brook as impaired water bodies due to turbidity and siltation caused by erosion and sedimentation. The deadline for applications for funding in fiscal year 2006 is expected to be in June 2005. A 40 percent matching grant from the applicant is required for eligibility.

Targeted Watershed Grants: These grants are administered by the United States Environmental Protection Agency to support community based watershed management intended to reduce or eliminate pollution. Matching funds of at least 25 percent of the project cost must be provided.

Watershed Protection and Flood Prevention Program: This program, also known as the Small Watershed Program," is administered by the United States Department of Agriculture. Funding is available to government entities for projects intended to protect and restore watersheds less than 390 square miles in area that have been damaged by erosion. In Connecticut, this program is administered by the Natural Resources Conservation Service. It is not clear, based on the information obtained from NRCS if funding is available only to develop watershed management plans, or to implement plans developed by third parties.

National Fish and Wildlife Foundation Matching Grants Program: The National Fish and Wildlife Foundation is a non-profit agency established by Congress to conserve fish and wildlife, as well as their habitat. Pine Gutter Brook is listed on the Connecticut 303(d) list as impaired for aquatic life support, meaning it is unable to adequately sustain the habitat necessary for health aquatic species. This is a matching fund grant that requires a 2:1 match by the project sponsor.

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APPENDIX A
HEC-HMS INPUT AND OUTPUT

PINE GUTTER BROOK CHANNEL ASSESSMENT
BRANFORD, CONNECTICUT

APPENDIX B
CHANNEL PROFILE

PINE GUTTER BROOK CHANNEL ASSESSMENT
BRANFORD, CONNECTICUT

APPENDIX C
HEC-RAS OUTPUT DATA

PINE GUTTER BROOK CHANNEL ASSESSMENT
BRANFORD, CONNECTICUT

APPENDIX D
RESULTS OF SIEVE ANALYSIS

PINE GUTTER BROOK CHANNEL ASSESSMENT
BRANFORD, CONNECTICUT

APPENDIX E
DETAILS OF STREAM CORRIDOR IMPROVEMENTS

PINE GUTTER BROOK CHANNEL ASSESSMENT
BRANFORD, CONNECTICUT