BOLIN CREEK WATERSHED

Geomorphic Analysis and Potential Site Identification for Stormwater Structures and Retrofits

TOWN OF CARRBORO
NORTH CAROLINA

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Project Summary
Bolin Creek Geomorphic Analysis

Introduction

Earth Tech provided services to the Town of Carrboro during the spring and summer of 2007 to evaluate the stability of the entire Bolin Creek Watershed. This project was performed as the first step of the Towns of Carrboro and Chapel Hill as partners in the Bolin Creek Watershed Restoration Team (BCWRT) to rehabilitate the watershed and to one day have its biological integrity improved to the extent that Bolin Creek can be removed from the Federal (303d) list of impaired streams. The ultimate goal of this project is for the findings of this study to aid in the decision making process to evaluate, prioritize and fund the individual projects which are presented herein. The funds for the project were provided by Clean Water Management Trust Fund (CWMTF) stormwater mini- grant #S-003, with matching funds provided by the Towns of Carrboro and Chapel Hill.

Previous studies in the Bolin Creek watershed have included a Watershed Restoration Plan (WRP) and a Local Watershed Plan (LWP). This project continues the process initiated by these efforts and provides supplemental information focusing on geomorphology of the streams within the watershed, and solutions addressing specific areas of stream instability.

Methods

The field work consisted of professionals from Earth Tech and the BCWRT performing a qualitative survey of all perennial and intermittent streams within the watershed. Ephemeral systems were surveyed when a specific geomorphic instability indicated that further investigation of the ephemeral system was necessary to fully understand the cause and magnitude of the problem. The survey was conducted between May 7th, 2007 and June 21st, 2007. Weather during the survey was generally dry and sunny, and no streams were observed during or immediately following a storm event. GIS data was used to create a field map atlas of 35 pages, and the streams on each page were systematically walked by the survey crews. Walks using these field maps were completed from the upper watershed to the lower watershed, so that the walk ended at the confluence of Bolin Creek with Booker Creek. Each field crew carried a sub-foot accuracy global positioning system (GPS) unit, a digital camera, field assessment forms, a set of field maps showing 2-foot topography, roads and streams, and a set of maps with high resolution aerial photography.

When specific areas of instability were identified, they were semi-quantitatively surveyed in order to fill out a field assessment form. The parameters which are recorded by the form are used to understand the channel dimension, cause of the problem, and stability of the reach at each location. In addition, at each location a sub-foot GPS coordinate was recorded, a photograph was taken, and notes were recorded in a field book and on field maps for later reference. The "Raw Data" for each of these locations was compiled together and provided to the BCWRT for their use in future evaluations of the watershed's condition. In the project site summaries contained in this report, each title page contains a "Raw Data Name" reference to a specific GPS point, and a reference to an Index Sheet, which were the 35 field maps used during the field evaluation. The index sheets and raw data maps showing the GPS points and notes for each observed stream reach, are contained in **Appendix D**.

After completion of the stream surveys, the sites was prioritized and approximately 50 sites were selected for consideration by Earth Tech and BCWRT as potential sites to be used as one of the final 30 project sites. To prioritize the sites, Earth Tech considered the input BCWRT members, along with professional judgment to give each site a qualitative score of 1 to 10. Because, at this point, pollutant loads and sediment export rates had not been calculated for any site, it was important to focus on the qualitative observations of geomorphic instability collected in the raw data. The most influential considerations in the ranking were the severity of the problem and the urgency of needing the problem fixed, as shown from the raw data, followed by ease of construction and opportunity for public involvement and education. Following the prioritization, 32 sites were selected for consideration by the Town of Carrboro and the Town of Chapel Hill as best management practice (BMP) installation or retrofit projects.

Each of these final sites were analyzed for feasibility, cost benefit, net reduction in loading of nutrients and suspended solids, anticipated reductions in runoff quantity and potential baseflow augmentation to the receiving channel. A second set of field visits were made to each of the 32 potential BMP sites, at which time additional notes, photographs and GPS data was collected. In particular, notes were made on constraints such as potential size restrictions, presence of existing utilities, and potential alternative treatments. A brief GIS analysis of each site was then undertaken, consisting of delineation of the site watersheds, analysis of land use in each watershed, and calculation of percent imperviousness. Areas of land use type were calculated using 1996 land cover data for Orange County available from the North Carolina Center for Geographic Information and Analysis. Because this data was out of date for several of the sites, the land use data was updated when necessary using 2005 aerial photography provided by the Towns of Carrboro and Chapel Hill. Percent imperviousness was calculated using GIS polygons representing roads, driveways, parking lots and other impervious features, which were provided by Carrboro and Chapel Hill. The inputs of drainage area, percent imperviousness, and land use type were used to estimate pollutant load rates for each watershed using the Simple Method (Schueler et. al., 2007). An annual rainfall depth of 46.2 inches was assumed for the calculation, based on Orange County rainfall data available from the National Oceanographic and Atmospheric Association.

For sites where sediment reduction through stabilization of streambanks was the primary focus, a modified BANCS model was used to estimate annual stream bank erosion rates (Rosgen, 2006). The BANCS model uses the combined inputs of Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) with a graph showing a relation between the two variables and stream bank erosion rates for a particular area. An estimate of BEHI was measured for each bank at each stream stabilization site for the length of the bank and then combined with a rough estimate of NBS to estimate stream bank erosion rates in tons per year using a North Carolina graph.

The results of this analysis, along with site descriptions and photos are found in the project specific reports that follow.

Construction costs were estimated using a combination of standard quantities and prices following North Carolina Department of Transportation (NCDOT) specifications, recent cost estimates for other projects calculated by professionals at Earth Tech, and equations that predict the cost of BMP construction as a function of potential storage volume (Schueler, et. al. 2007). Earth Tech first began by developing line item cost estimates using standard quanitites of materials for given areas and measurements. CADD software was relied upon to measure acreages and distances in order to calculate needed quantities of materials. These construction costs were then compared with equations that have been developed by several researchers to predict the cost of new and retrofit construction of different types of BMPs. In many cases, particularly with stormwater wetlands, the line item cost estimates were very similar to what research has shown as the actual cost of construction for a BMP. Where there was a discrepancy between the two, however, the equation-predicted figure was used. In addition, the contingency cost for each project was adjusted depending on site conditions. Sites that are harder to access or near utility right of ways were given a higher contingency cost.

Research has shown that maintenance costs for stormwater wetlands and wet detention ponds typically range from 3-5% of the base construction cost per year (Center for Watershed Protection, 2007). To err on the side of caution, the higher figure of 5% was used to estimate annual BMP maintenance costs for all the proposed BMP sites.

Data Summary

During the stream survey, a total of 115 GPS points were collected that specifically relate to an area of geomorphic instability, and are represented on a field form (See **Appendix C**). Other GPS points were taken that highlight notable features of concern or interest within the watershed, or that simply represent continuations of problem areas, but are not noted on a field form. **Table 1** provides a summary of the raw data recorded on the field form for each location, and shows the number of GPS points collected on Bolin Creek or its tributaries, the types of stream conditions present at each point and the observed type of problem at the point. Multiple indications of stream condition and multiple types of problems were observed at many of the points. Stream condition observations have been grouped into general stream observations (changes in stream dimension and stream profile), and observations of specific symptoms indicating stream change such as bed and bank scour, and bank failure.

Table 1. Summary of raw data collected during the stream survey

I. Location Within Watershed	
	# of GPS Points
Bolin Creek	14
Tributaries	101
II. Stream Condition Observations	
	# of GPS Points
Observations of Stream Dimension Change	
Aggrading	12
Downcutting	56
Widening	40
Total	108
Observations of Stream Profile Change	
Slope Failure	4
Headcutting	13
Total	17
Observations of Specific Symptoms of Instability	
Bed Scour	15
Bank Failure	35
Bank Scour	49
Sediment Depostion	6
Channelized	6
Total	111
III. Type of Problem	
	# of GPS Points
Pond Outfalls	25
Stream Crossings	29
Impacted Buffer	13
Utility impacts	23
Channel Modification	17
Confluence	4
Beaver Activity	1
Other	33

BMP Site Summary

A total of 32 potential BMP sites were identified during the course of this study. After evaluation of each site and its contributing watershed for pollutant loads, impervious surface and sediment contribution, and after completion of a conceptual-level cost estimate, the sites were prioritized according to a ranking system that is modeled on a similar system recommended by Schueler, et. al (2007). Four criteria were chosen to rank each site: "Cost per pollutant removed", "Project Visibility", "Construction Access", and "Critical Nature of Project".

The "Cost per pollutant removed" criterion was chosen out of a desire to compare the relative cost/benefit of each site, as the overarching goal of the Bolin Creek Watershed Restoration efforts is to reduce pollutants in the watershed, and thereby remove Bolin Creek from the 303(d) list. However, because of a lack of available information showing what specific pollutant is the primary cause of biological impairment in Bolin Creek, this criterion has been split into two separate criteria; cost per ton of sediment reduced, and cost per pound of nutrients reduced. Therefore, two separate prioritization tables have been produced: one for sites where the primary target is removal of nutrients and another for those sites where the primary target is sediment reduction through streambank stabilization. To compare the two different types of projects directly against one another was considered impractical without knowing the relative effects of the differing pollutants on the biological integrity of Bolin Creek.

The "project visibility" and "construction access" criteria were chosen because they were considered to be easy to judge based on site visits and available aerial photography and topographic GIS data. The final criterion of "Critical Nature of Project", was chosen to account for the potential for future exacerbation of the observed problem at each site, if action is not immediately taken. While this criterion reflects more qualitative engineering judgment than quantitative analysis, it was felt that it was important to give a higher ranking to sites where problems are expected to increase steadily or even exponentially in the future. The justification for each site rank in this criterion is listed below in **Table 4.**

The BMP Ranking criteria and the points allocated to each criteria are represented in **Table 2**.

Table 3 presents a summary of each BMP site, with scoring of each criterion and total scores for each site.

Table 5 shows the prioritization of the sediment reduction projects, while **Table 6** presents the prioritization of the nutrient reduction projects.

Table 2. BMP Ranking Criteria and Point Allocation

BMP Ranking Criteria (20 Total Points Possible)		Possible Points
1	**Cost/Ton of Sediment Reduced**	**5**
	Less than $50	[5]
	Between $50 and $200	[4]
	Between $200 and $300	[3]
	Between $300 and $500	[2]
	Greater than $500	[1]
2	**Cost/ lb of Nutrients Removed**	**5**
	Less than $9,500	[5]
	Between $9,500 and $23,000	[4]
	Between $23,000 and $50,000	[3]
	Between $50,000 and $80,000	[2]
	Greater than $80,000	[1]
3	**Project Visibility**	**5**
	Poor (site cannot be seen from street)	[1]
	Good (site adjacent to a street)	[3]
	Excellent (site adjacent to a highly traveled street or public property)	[5]
4	**Construction Access**	**5**
	Poor	[1]
	Good	[3]
	Excellent	[5]
5	**Critical Nature of Project**	**5**
	Critical (exponential increase of problem is expected if project is delayed; i.e. headcut causes channel incision which causes decades of channel instability and is order of magnitudes higher if you wait to repair)	[5]
	Very High (problem will increase in future at a steady rate)	[4]
	High (problem will increase, but range of future impact is limited)	[3]
	Medium (problem is severe but not expected to increase significantly)	[2]
	Low (problem is present, but stable, no expected increase)	[1]

Table 3. Summary of Final BMP Sites and Scoring

Final Site Name	Type of Project	Cost of Construction	Location	Cost/ton of sediment		Cost/ lb nutrients Removed		Project Visibility		Construction Access		Critical Nature of Project*		Total Score Nutrient Projects	Total Score Sediment Projects
					(pts)		(pts)		(pts)		(pts)		(pts)		
1	Dam Retrofit	$30,964	Outside	$21.46	5			Poor	1	Excellent	5	High	3		**14**
2	BMP- Retrofit	$43,879	Carrboro			$8,200.78	5	Excellent	5	Excellent	5	Low	1	**16**	
3	Stream Bank Stabilization	$31,734	Outside	$197.53	4			Poor	1	Good	3	Critical	5		**13**
4	BMP- Retrofit	$73,509	Carrboro			$98,769.50	1	Poor	1	Poor	1	Medium	2	**5**	
5	BMP- Retrofit	$22,660	Carrboro			$10,031.09	4	Good	3	Excellent	5	High	3	**15**	
6	BMP- Retrofit	$34,578	Carrboro			$15,307.01	4	Good	3	Excellent	5	High	3	**15**	
7	BMP- Retrofit	$100,619	Carrboro			$44,542.49	3	Good	3	Excellent	5	Very High	4	**15**	
8	BMP- Retrofit	$19,017	Carrboro			$3,504.29	5	Good	3	Excellent	5	Medium	2	**15**	
9	Stream Bank Stabilization	$18,215	Carrboro	$191.92	4			Good	3	Good	3	Medium	2		**12**
10	BMP-New Construction	$48,336	Carrboro			$9,121.72	5	Poor	1	Good	3	Medium	2	**11**	
11	BMP- New Construction	$30,323	Chapel Hill			$28,285.41	3	Excellent	5	Excellent	5	Medium	2	**15**	
12	BMP- New Construction	$69,358	Chapel Hill			$22,467.50	4	Poor	1	Good	3	Medium	2	**10**	
13	BMP- New Construction	$25,688	Chapel Hill			$2,353.10	5	Poor	1	Poor	1	Medium	2	**9**	
14	BMP- New Construction	$25,688	Chapel Hill			$6,416.48	5	Good	3	Excellent	5	Medium	2	**15**	
15	BMP- Retrofit	$27,266	Chapel Hill			$23,281.67	4	Poor	1	Good	3	Very High	4	**12**	
16	Stream Bank Stabilization	$56,479	Carrboro	$282.81	3			Excellent	5	Poor	1	Medium	2		**11**
17	Stream Bank Stabilization	$66,649	Carrboro	$1,098.79	1			Poor	1	Poor	1	Very High	3		**6**
18	BMP- New Construction	$17,416	Chapel Hill			$14,828.54	4	Good	3	Good	3	Very High	4	**14**	
19	Stream Bank Stabilization	$8,884	Carrboro	$319.81	2			Excellent	5	Excellent	5	Medium	2		**14**
20	Stream Bank Stabilization	$49,479	Chapel Hill	$26.04	5			Excellent	5	Good	3	Very High	4		**17**
21	Stream Bank Stabilization	$52,104	Chapel Hill	$74.33	4			Good	3	Poor	1	Critical	5		**13**
22	Stream Bank Stabilization	$72,526	Chapel Hill	$38.42	5			Excellent	5	Excellent	5	Very High	4		**19**
23	BMP- Retrofit	$32,030	Chapel Hill			$65,099.01	2	Poor	1	Poor	1	Low	1	**5**	
24	BMP- New Construction	$107,541	Chapel Hill	$285.11	3	$49,502.23	3	Good	3	Poor	1	Critical	5	**12**	
25	BMP- New Construction	$84,571	Chapel Hill			$52,133.47	2	Poor	1	Poor	1	Low	1	**5**	
26	BMP- New Construction	$69,375	Chapel Hill			$83,059.38	1	Poor	1	Poor	1	Low	1	**4**	
27	BMP- New Construction	$38,554	Chapel Hill			$213,283.40	1	Poor	1	Poor	1	Low	1	**4**	
28	BMP- New Construction	$36,660	Chapel Hill			$22,209.33	4	Poor	1	Poor	1	Low	1	**7**	
29	BMP- New Construction	$81,218	Chapel Hill	$144.51	4	$40,728.87	3	Poor	1	Poor	1	Very High	4	**9**	
30	BMP- Retrofit	$28,501	Chapel Hill			$3,625.74	5	Poor	1	Poor	1	High	3	**10**	
31	BMP- New Construction	$20,130	Chapel Hill	$38.91	5	$15,809.47	4	Poor	1	Good	3	High	3	**11**	
32	Stream Restoration	$207,000	Chapel Hill	$3,522.80	1			Excellent	3	Poor	1	Low	1		**6**

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Table 4. Justification of Critical Nature criterion for each site.

Justification of Critical Nature rankings for each site	
Site	**Reasoning**
1	The incised dam outfall is probably widening and the sediment problem will increase, but the extent of future impact upstream and downstream will be limited
2	The problem at this site is not worsening.
3	The headcut at this site will continue to work upstream, and incise a greater length of stream if not addressed.
4	Nothing imminent or critical at this site.
5	There is potential damage to adjacent streams from the current configuration of the BMP outlet.
6	There is potential damage to adjacent streams from the current configuration of the BMP outlet.
7	There is potential damage to adjacent streams from the current configuration of the BMP outlet.
8	Is presently stable, but there is some danger of damage to channel due to concentrated flows.
9	The extent of bank erosion is relatively small.
10	Due to headcut downstream of the site.
11	High nutrient contributions and potential for channel damage due to concentrated flows.
12	Some modest instability from discharges.
13	Some modest instability from discharges.
14	Some modest instability from discharges.
15	Active headcuts are present at this site.
16	The annual contribution is not expected to increase.
17	Bank wasting is likely increasing here.
18	The conditions at this site will likely get worse.
19	Sediment contribution is expected to be constant here.
20	Relatively high wasting banks, stream will continue to widen.
21	Stability of this hillside needs to happen.
22	Stability of this hillside needs to happen.
23	No expected increase in problem here.
24	Active increase in 3' headcut at this site.
25	No expected increase in problem here.
26	No expected increase in problem here.
27	No expected increase in problem here.
28	No expected increase in problem here.
29	At least three active headcuts on this channel will create an incised gulley over time, with expected increase in sediment contribution.
30	Hillside erosion is occuring here and will worsen, but extent of impact will likely be limited upstream and downstream.
31	Ditch in floodplain will continue to erode, but impact upstream and downstream will be limited.
32	Stream is channelized, but stable; no expected increase in sediment contributions.

Table 5. Prioritization of Sites Specifically Targeted at Nutrient Reduction

Final Site Name	Type of Project	Cost of Construction	Location	Total Score Nutrient Projects
2	BMP- Retrofit	$43,879	Carrboro	**16**
5	BMP- Retrofit	$22,660	Carrboro	**15**
6	BMP- Retrofit	$34,578	Carrboro	**15**
7	BMP- Retrofit	$100,619	Carrboro	**15**
8	BMP- Retrofit	$19,017	Carrboro	**15**
11	BMP- New Construction	$30,323	Chapel Hill	**15**
14	BMP- New Construction	$25,688	Chapel Hill	**15**
18	BMP- New Construction	$17,416	Chapel Hill	**14**
15	BMP- Retrofit	$27,266	Chapel Hill	**12**
24	BMP- New Construction	$107,541	Chapel Hill	**12**
10	BMP-New Construction	$48,336	Carrboro	**11**
31	BMP- New Construction	$20,130	Chapel Hill	**11**
12	BMP- New Construction	$69,358	Chapel Hill	**10**
30	BMP- Retrofit	$28,501	Chapel Hill	**10**
13	BMP- New Construction	$25,688	Chapel Hill	**9**
29	BMP- New Construction	$81,218	Chapel Hill	**9**
28	BMP- New Construction	$36,660	Chapel Hill	**7**
4	BMP- Retrofit	$73,509	Carrboro	**5**
23	BMP- Retrofit	$32,030	Chapel Hill	**5**
25	BMP- New Construction	$84,571	Chapel Hill	**5**
26	BMP- New Construction	$69,375	Chapel Hill	**4**
27	BMP- New Construction	$38,554	Chapel Hill	**4**

Table 6. Prioritization of Sites Specifically Targeted at Sediment Reduction

Final Site Name	Type of Project	Cost of Construction	Location	Total Score Sediment Projects
22	Stream Bank Stabilization	$72,526	Chapel Hill	**19**
20	Stream Bank Stabilization	$49,479	Chapel Hill	**17**
1	Dam Retrofit	$30,964	Outside	**14**
19	Stream Bank Stabilization	$8,884	Carrboro	**14**
3	Stream Bank Stabilization	$31,734	Outside	**13**
21	Stream Bank Stabilization	$52,104	Chapel Hill	**13**
9	Stream Bank Stabilization	$18,215	Carrboro	**12**
16	Stream Bank Stabilization	$56,479	Carrboro	**11**
17	Stream Bank Stabilization	$66,649	Carrboro	**6**
32	Stream Restoration	$207,000	Chapel Hill	**6**

Discussion of Specific Sources of Instability

The specific project sites address many of the water quality issues that Bolin Creek faces, however it is important to note that the projects in this report represent the types of projects that could be implemented throughout the watershed. A summary of key sources of instability and other observations made during the field investigation for the Bolin Creek Watershed follows:

1. Stream Channelization – Stream channelization is one of the most significant impacts that has occurred to the reaches in the Bolin Creek Watershed. Channelization was, at one time, a common means of dealing with a stream that was in the way, or that flooded neighboring properties. By deliberately lowering the stream elevation, overtopping of the banks would often be eliminated. The intentional carrying of higher flows within the channel is exactly opposite of natural processes where a stable stream will utilize access to a floodplain to dissipate the energy that is above the capacity of the stream channel. As a result, the higher flows which are now contained within the streambank are flows that greatly exceed the allowable shear stress of the channel. In the end, channelization results in steams that down cut to bedrock or saproilte and then begin to widen as exceedingly high shear stresses causes bank scour and thus a lateral movement of the streambank due to its erosion. The mass wasting of these banks is a significant cause of excess sediment in this watershed. Several of these selected projects are bank stabilization projects and the anticipated reductions in sediment loading indicate the magnitude of this problem.

   Another result of channelization is the loss of instream habitat and structure that can be found in the stable pool-riffle sequence of natural channel. Pools provide essential habitat and drought refuge areas for proper biological function. It should be noted that this is a problem on many reaches that are not a part of one of the proposed sites for stormwater BMPs included in this report.

2. Culverts and Channel Crossings - A significant amount of the instability in the Bolin Creek Watershed may have been started by the construction of stream crossings for roadways. The resulting channel contraction that occurs at most culverts may have caused the erosion on the downstream side that leads to a tail cut, and thus channel incision (no longer accessing the floodplain), a lowering of groundwater base, and continued instability that may exist for decades. Head-cuts can result from a depressed invert elevation, and work upstream until it hits some form of grade control. Overly wide crossings cause deposition of sediments when the wider channel becomes shallower in depth, thus reducing the shear stress needed to carry sediment. Backwater from floodplain encroachment of roadways

causes a loss of velocities, thus lowering shear stress, and a lack of sediment transport results.

It is difficult to have a road crossing and maintain a natural cross section, flood plain relief for proper sediment transport and flow capacity. Current DOT standards have improved with this regard and in the future, road crossings in this watershed should utilize floodplain culverts and main channel culverts that maintain a wider flow path with a base flow channel at the natural bed elevation.

3. Utility Impacts – The installation of sewer lines and other utilities within the floodplains of streams was the perceived cause of apparent channel relocations throughout the watershed. For the most part, these impacts occurred long ago and the remaining degradation is primarily in the form of channel instability from channelization, as mentioned in item #1. Current impacts were observed in several locations in the form of unstable channel crossings, culvert installations, and removal of woody riparian vegetation that is essential to channel stability. It will require a continued effort between the towns and the utility providers to minimize these future impacts, as well as to monitor them.

4. Bank Wasting – Streambank wasting is probably the largest cause of the degradation of the biological integrity of the streams within the Bolin Creek watershed, because of the large amount of sediment that is exported through bank wasting processes. There are very few streams in the watershed that do not possess mass wasting banks on outer meander bends and lower riffle sections. Any effort to manage stormwater in the future by reducing peak flow rates of runoff and total volume will aid in establishing stability in the watershed by reducing the shear stress experienced by these banks. Direct modification of all streams within the watershed is impractical, thus particular reaches that are identified as supplying the greatest amounts of sediment should be targeted and treated. While the Geormorphic Assessment identified the most unstable reaches within the watershed, an analysis of the estimated quantities of sediment produced by all unstable reaches within the watershed was beyond the scope of this effort. Notwithstanding this, many of the BMPs proposed in this report are targeted at treating what were observed to be the worst reaches.

5. Direct Discharges to the Channel – In many cases, a definite impact was observed at the location of stormwater outlets within, or very near the channel. This concentrated and sediment-starved stormwater causes channel instability in the form of mass wasting of banks and channel incision. Even when discharges occur onto the floodplain, but within 10-15 feet of the channel itself, mass wasting of downstream banks is present as well as a headcut through the stream bank up to the point of discharge.

The placement of BMP outlets in the floodplain, unfortunately, may also have the same effect. When possible, any discharge in a near-channel region should be diffused by use of level spreaders or substantial energy dissipation basins. Observations indicate that an "apron" at the outlet is grossly insufficient at energy dissipation and flow diffusion.

6. Railroads and Streams- The team observed multiple direct impacts from stormwater systems of railway lines. There is no treatment of the stormwater that is collected by the ditches associated with the fill and cut of the railway grade. This concentrated flow could be treated before discharging it to an ephemeral, intermittent, or perennial stream in a variety of ways, including retrofit of BMPs alongside the railway lines.

7. Recreation Impacts – Greenway trails, paved and unpaved, and recreational activities are causing a substantial impact to the reaches within the Bolin Creek watershed. Bolin Creek itself is suffering multiple locations of instability that are created simply by the foot traffic on the banks. Trails and greenways that are located close to the channel affect the vegetation along the streambank and cause mass wasting to occur. Paved greenways do not typically have stormwater treatment and therefore cause a concentration of flows from the impervious surface and associated grading. This concentration flow typically outfalls onto the floodplain or streambank at low points in the trail and causes instability. Paved greenways trails should be constructed in a manner that acknowledges the risk of placing an impervious surface in the riparian zone. Level spreaders, dissipater basins, etc. should be used to handle the stormwater that collects from these surfaces. It is recommended that any future greenway plans include strategies for education and outreach as part of the greenway development.

   Unpaved trails result in a compacted soil that behaves in a similar manner to an impervious surface except that the trail is normally a concaved depression. This depression and resistance to percolation results in concentration of flows down these paths and erosion of the trail. The sediment from the trails is often discharged directly into the channel at a low point.

   Individuals using these trails and riparian areas are normally there to enjoy the stream, not harm it. "Education and outreach" would dramatically improve many of the impacts that were observed. Stream crossings can be designated and stabilized, trails kept away from the streambank, etc. and the citizens of these communities would most likely be very receptive to the suggestions. Information kiosks at strategic locations could start this process at a relatively low cost.

8. Stormwater Runoff – As with any urban watershed, the development in the Bolin Creek watershed has caused an increase in the peak flow rates and total runoff volume that reaches the receiving channels. It is evident that increases and the concentration of runoff are the major problem in the watershed. However, specific observations, such as a headcut in an intermittent channel, are indicators that the instability created by stream crossings or direct alterations of the channel may be the more significant catalyst for channel instability in many cases. Increased stormwater flows that are "trapped" down inside a channel and not allowed to dissipate energy via a floodplain only serve to exacerbate the instability of an incised channel. Earth Tech strongly believes that our field experiences and completed restoration projects indicate that the increase in stormwater flows can be accommodated by reconnection with the floodplain and proper bank stabilization practices. Earth Tech encourages the use of these practices to stabilize problematic reaches where the sediment contributions are degrading the biological integrity of the system.

   In other cases, especially with ephemeral channels, increased stormwater flows are the perceived cause of instability in the form of channel scour. There are many ephemeral channels in the Bolin Creek watershed which are suffering from scour. These upper slope positions in less developed parts of the watershed can be observed to have no significant debris scour of significance, much less erosion of soil beneath the leaf litter. After investigating the cause of the scour in the ephemeral reaches, Earth Tech made the conclusion that concentration of storm flows from drainage networks were the prevailing cause of this instability. These ephemeral channels offer a location for dissipation of energy from the concentrated and increased flows from development. There are many opportunities in the Bolin Creek Watershed to reduce peak flows, nutrient contributions, and directly eliminate erosion by using BMPs within these reaches.

   Increases in nutrient export via stormwater runoff are also a likely cause of biological degradation of the streams in the watershed. Although the geomorphic assessment can not pinpoint the most severe cases of this problem within the watershed, direct pipe discharges and the observation that the majority of this watershed has development with no water quality treatment, indicates that a significant amount of nutrient loading is occurring in this watershed.

   Increases in water temperature are another expected cause of biological degradation within this watershed. Increases in impervious areas are usually associated with warmer stormwater runoff temperatures. This study has not addressed this issue. However, many of the BMPs that are outlined in this report are known to reduce this problem.

The BMPs outlined in the 32 conceptual projects address the various causes of instability that were observed. By using these projects as a guide, the BCWRT should be able to conceive and implement other projects to improve the biological integrity of Bolin Creek in the years to come.

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