Appendix C

Pilot Basin Study Interim Report
Ephesus Subwatershed

Pilot Basin Study Report – Ephesus Subwatershed

Tracy Branch, a tributary to Little Creek, drains the Ephesus subwatershed, designated as B-11 in the North Carolina Ecosystem Enhancement Program (EEP) report developed for Morgan and Little Creeks and in the Town's Geographic Information System (GIS) stormwater database. An aerial photo of the subwatershed is shown in Figure C-1. The drainage area delineated at the mouth of Tracy Branch at Little Creek covers approximately 1.0 square miles. The Town of Chapel Hill's 2008 GIS database for streams lists three miles of perennial streams in the watershed, with over 40% of the lengths either piped or in an artificially lined channel. The main stem up to Colony Lake, and portions of four tributaries, have been classified as perennial streams. The EEP assessment lists Tracy Branch as "poor" for stream condition and for morphologic stability in the Natural Resources Conservation Service (NRCS) Stream Visual Assessment Protocol used to evaluate the streams in Chapel Hill. The Ephesus subwatershed was recommended as a "second tier" subwatershed for focusing restoration, preservation and prevention efforts.

The land use in the Ephesus subwatershed is almost entirely residential, ranging from multi-family developments up to large homes on lots more than an acre in size. Development has occurred over several decades beginning in the 1960's. Few stormwater Best Management Practices (BMPs) were required or installed in conjunction with the development in Ephesus. The watershed includes several relatively long piped reaches of tributaries to Tracy Branch. The streams in this watershed have numerous crossings and relatively narrow riparian corridors. Roughly half of the main stem of Tracy Branch was enlarged and lined with concrete, apparently to prevent the channel erosion expected in response to increased volumes of runoff.

The subwatershed is almost completely built out. The Town of Chapel Hill owns a large tract of Little Creek floodplain and wetland area near the mouth of Tracy Branch, and also a 12-acre site north of Ephesus Church Road encompassing a portion of two of the Tracy Branch tributaries. Both sites remain undeveloped, except for tennis courts atop the hill on the Ephesus Church Road site. The American Legion also owns a large tract of forested land, mostly undeveloped, that is partially within the subwatershed.

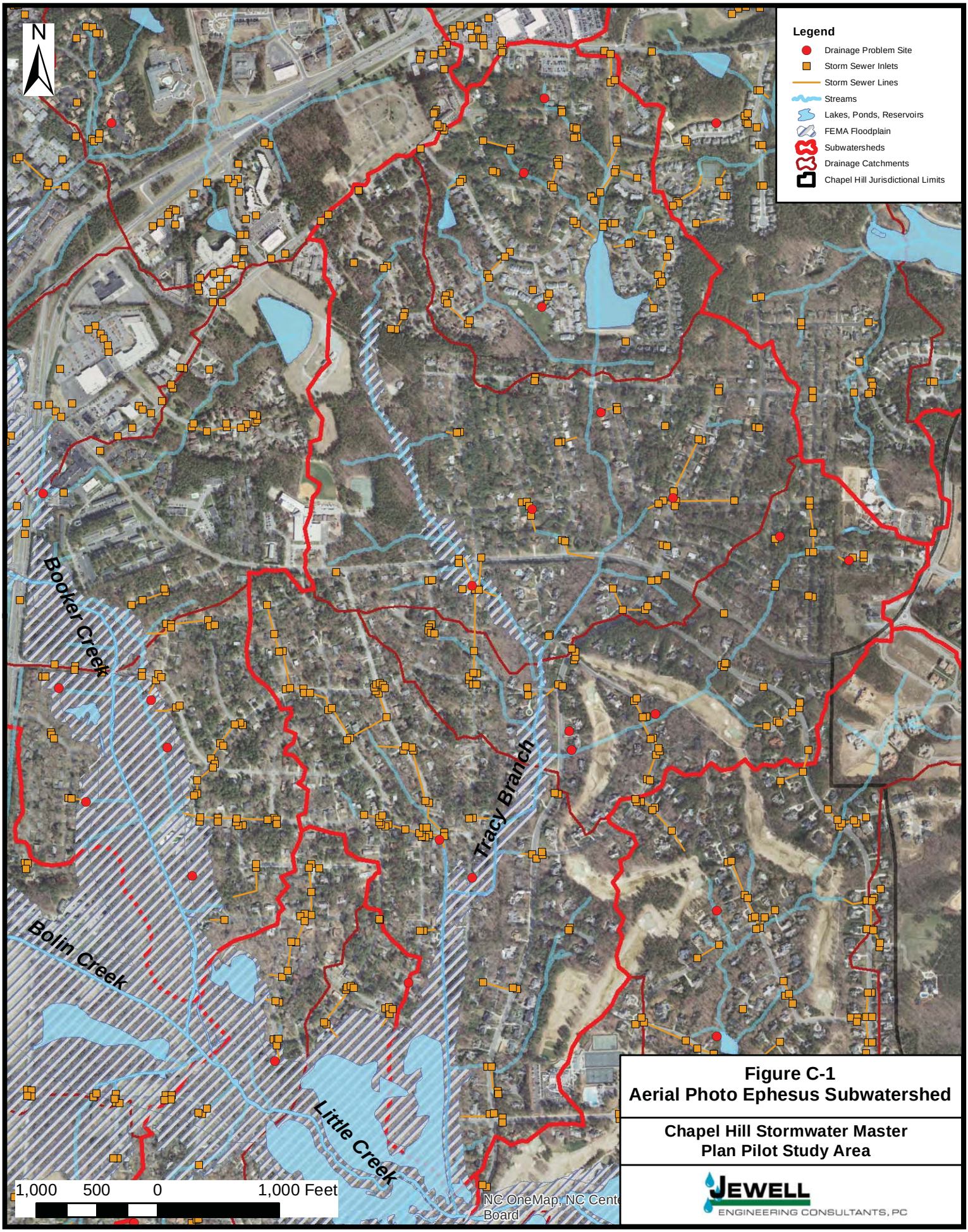

Figure C-1
Aerial Photo Ephesus Subwatershed

Chapel Hill Stormwater Master Plan Pilot Study Area

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Existing Stream Conditions

A relatively small eastern portion of Chapel Hill, including the Ephesus subwatershed, lies within the Triassic Basin geological region of North Carolina. Triassic Basin soils tend to have low permeability, such that less rainfall is infiltrated and more becomes runoff. Streams thus tend to have lower base flows, and are susceptible to becoming dry during drought spells. The basin soils are considered highly erodible and sedimentation is a concern for Triassic Basin streams.

To assess the stream conditions in the subwatershed and to identify potential stormwater BMP sites, staff from Jewell Engineering Consultants (JEC) and the TOCH Stormwater Division walked all of the perennial streams in the Ephesus subwatershed in December 2008, noting conditions and mapping the culverts and outlets. Additionally, complaints and comments from citizens residing in the watershed have been reviewed as a part of assessing the watershed problems.

Most of the Ephesus subwatershed stream reaches can be characterized as either artificial or severely degraded. There are at least twenty culvert crossings on perennial streams, as well as some long reaches of piped streams. In a few reaches the stream and floodplain remain connected and an adequate riparian corridor exists, but these are the exception. A number of Orange Water and Sewer Authority (OWASA) sanitary sewer line crossings are aerial pipelines over the streams, including several where the pipes are set atop steel beams. The following provides descriptions of the perennial stream corridors in the subwatershed. The main stem reaches and major tributaries are individually described, followed by a summary of conditions in the minor tributaries. Photographs are compiled as Exhibits at the end of the report. Figure C-2 shows the streams and crossings referenced in the descriptions, as well as the mapped Federal Emergency Management Agency (FEMA) 1% Annual Chance Floodplain.

Main Stem Below Ephesus Church Road

Reach A, comprising 2000 feet at the downstream end of the main stem, is generally in good condition even though it was likely channelized at some point in the past. Most of the reach is within a wooded floodplain on Town property or on large residential lots with deep back yards. The stream exhibits little entrenchment, is beginning to re-establish some sinuosity, and has a forested floodplain relatively free of invasive species. Much of the reach is within the floodplain of Little Creek, with some wetland areas on either side of Tracy Branch. The right overbank floodplain on the most upstream portion of the reach has been cleared and is mowed up to the stream bank. There is slight incision at the upstream end of the reach. This portion of the stream is shown in Exhibit C-1.

Reach B covers the concrete-lined portion of the main stem of Tracy Branch, a distance of over 4000 feet from Reach A up to Ephesus Church Road. The channel has been enlarged, straightened and lined with a fabric-formed concrete liner, presumably for purposes of increasing conveyance capacity and maintaining a stable channel to accommodate increasing discharges

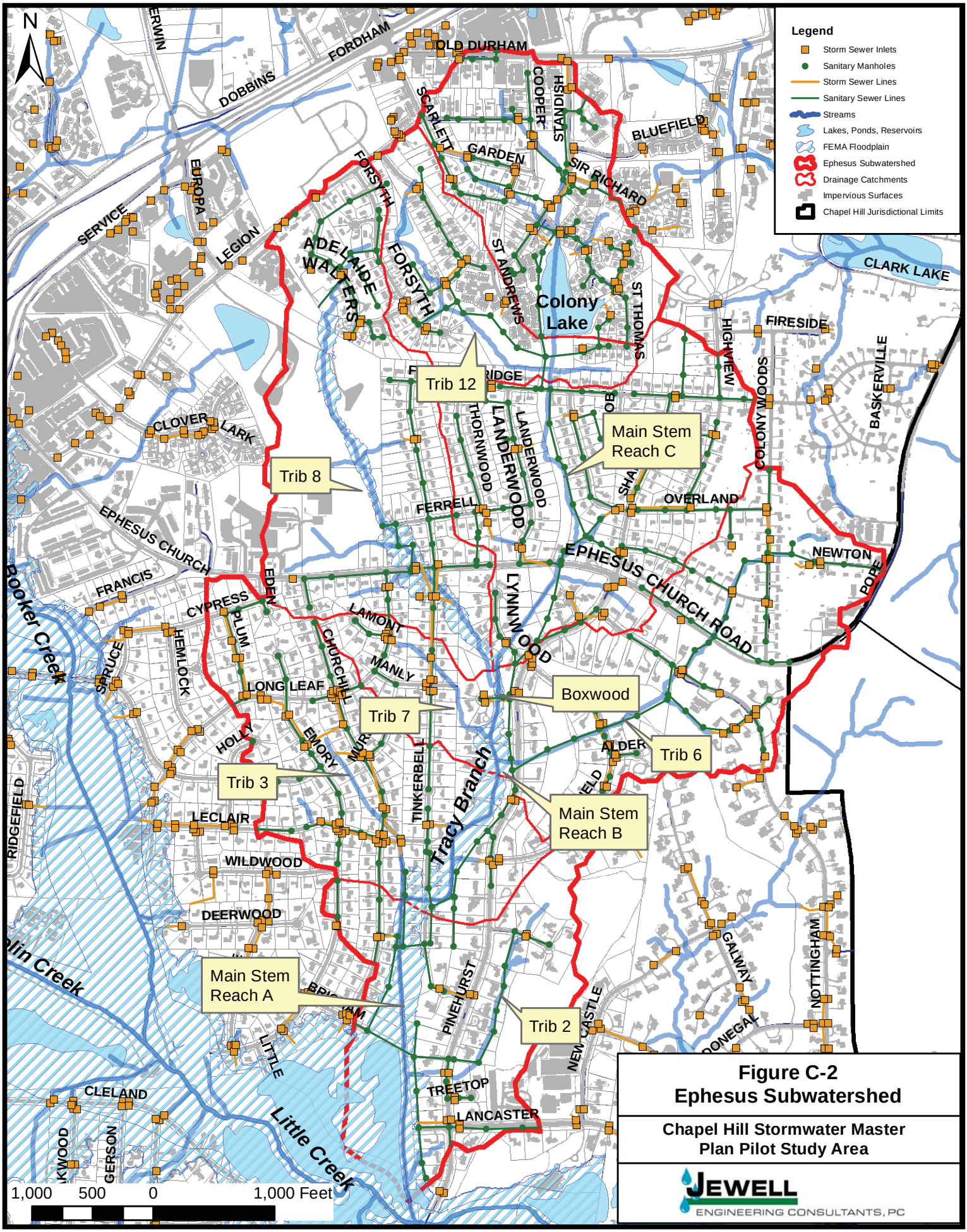

Figure C-2
Ephesus Subwatershed

Chapel Hill Stormwater Master Plan Pilot Study Area

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from residential development. The concrete was formed as an articulated mat, in a manner which allows for some permeability in the depressions. This construction method helps to limit buildup of hydrostatic pressure as the ground behind the concrete becomes saturated during rainfall events. Some photos of the concrete liner are shown in Exhibit C-2. A number of the culverts along the branch were apparently sized for extreme storm events, as indicated by significant sedimentation within some culverts and/or in the inlet and outlet areas, depicted in Exhibit C-3.

Portions of Reach B reach exhibit reasonably good morphology in spite of the artificial lining. The typical concrete channel cross-section has a 10-foot wide bottom and is about six to eight feet deep. The concrete typically lines the bank up to a height of two to two-and-a-half feet, allowing growth of a canopy on the upper banks in some areas. Sediment has been deposited on portions of the wide concrete channel bottom, forming an intermediate floodplain with a narrow, low flow channel meandering through it. In some areas, the concrete is only evident at the bottom of portions of the low flow channel and the stream looks like a natural stream. However, the concrete prevents the development of a hyporheic zone of exchange between surface water and ground water, which is critical for nitrogen processing and some types of aquatic life. Some photos of Reach B are shown in Exhibit C-4.

In contrast to most of the reach, the lower and upper ends of Reach B exhibit little to no sediment deposition. The lower portion may be periodically scoured out when water backs up behind a problematic OWASA sewer aerial. Based on survey data at culvert crossings, the upper portion of the reach, between Lynnwood Drive and Ephesus Road, is considerably steeper than the downstream reaches, such that velocities are probably too high to allow sediment to settle out.

Most of the concrete lining is in very good condition. However, it is buckling along the stream bottom in a few areas. There is one major failure of the bank lining just downstream of the confluence with Tributary 8. Photos of this area are shown in Exhibit C-5.

Nine homes along Reach B are mapped within the FEMA 1% annual chance floodplain. Downstream of Tinkerbell Road, the watershed surface elevations in a 1% annual chance flood are a function of the backwater from Little Creek. Six homes on the west side of Tinkerbell Road are estimated to be within the backwater floodplain for Little Creek, such that no improvements along Tracy Branch would be expected to reduce flooding affecting these homes in the 1% annual chance event. Three additional homes on the east side of Tinkerbell Road are also mapped within the 1% annual chance floodplain.

Besides the concrete channel lining, there are a number of other anthropogenic impacts in the Reach B segment of Tracy Branch. The stream flows through back and side yards of private residential properties, including some that are mowed right up to the channel bank. Four aerial sewer line OWASA crossings are located within a 1600 foot portion of Reach B at the lower end. In spite of the Resource Conservation District (RCD) designation along Reach B within The Oaks neighborhood, two homes and five culvert crossings were constructed in what was apparently mapped as RCD. There is a large growth of bamboo in one area of the floodplain.

There are a few roof drains piped directly to the stream along these reaches. Several other small discharge pipes, with unknown origins, were observed during the stream walks.

Main Stem Above Ephesus Church Road

Reach C is north of Ephesus Church Road and most of the reach is moderately to severely entrenched. The stream flows through a small town park and between relatively deep lots fronting along Landerwood and Overland Drives. Riparian areas generally are not maintained as part of the owners' back yards. Ivy and other invasive species are rampant in some areas. The park area, at the lower end of the reach, is a relatively wide and flat floodplain, and the stream is less entrenched there than in the upper portions. Moving upstream from the park, the stream gradually becomes more narrow and deep. Downstream of Fountain Ridge Road, the stream is almost 10 feet deep and only four to six feet wide at the bottom. Photos along the Reach C are shown in Exhibit C-6.

At the upper end of Reach C is a 4.5-acre lake owned and maintained by the Colony Lake Homeowners Association. The main outlet is a riser discharging through a 30" concrete pipe. The owners have constructed a rip-rap lined stilling basin to dissipate energy and slow velocities in an effort to stem the erosion occurring below the discharge point. An OWASA aerial crossing, mounted on a large beam at a point about forty feet downstream of the lake outlet, further exacerbates the channel stability problems in the reach between the discharge point and Fountain Ridge Road. The bottom of the corrugated metal pipe (CMP) culvert under Fountain Ridge Road observed during stream walks was eroded out and the channel bottom was a few inches below the pipe. The culvert was replaced in March 2010 as an emergency construction project due to failure of the road, caused by a non-functional subdrain system. Although the road failure in this case was not caused by the eroded pipe, the observed pipe condition is typical of many older CMPs, where the deterioration of structural integrity may represent a threat to public safety. Photos of the lake pipe outlet and the new Fountain Ridge culvert are shown in Exhibit C-7.

Tributary 2

Tributary 2 drains a portion of the Chapel Hill Country Club golf course and some of the homes and lots along Pinehurst Drive and Black Oak Court. (See Figure C-2.) Roughly half of the 2100 foot reach has been piped by the developer and/or by individual property owners. Most of the remaining stream is incised, less at the upstream end but down to bedrock at the downstream end. Erosion threatens to undermine a parallel OWASA sewer line. Eighteen small pipes, typically 4" corrugated HDPE roof drains discharging directly to the stream, were observed during the field reconnaissance.

Tributary 3

Severe entrenchment and bank erosion characterize the 370 feet of open channel at the downstream end of Tributary 3, which drains the area between Emory Drive and Churchill Drive above LeClair Street. The photos in Exhibit C-8 show the perched outlet at the culvert under LeClair Street and the erosion downstream. The tributary includes 1500 feet of open and piped

reaches that have been classified as perennial. All of the other drainage paths in the catchment also appear to have been enclosed in pipe.

Tributary 6

Tributary 6 is piped under six streets and two golf course holes, making it the one of the most segmented stream reaches in the subwatershed. Roughly a third of the 3300-foot stream reach flows in pipe, including much of the 2100 feet of perennial stream. The reach begins at a ditch behind homes along Colony Woods Drive and flows in a southwesterly direction to its confluence with Tracy Branch between 816 and 824 Pinehurst Drive. Generally, the open portions of the tributary have good floodplain access and some reaches also have reasonably adequate riparian buffers. The pipes vary greatly in their conveyance capacity, with the golf course pipes sized only to handle low flows, allowing for overland flow during significant rainfall events. Ephesus Church Road, probably the oldest street in the subwatershed, has a 42" RCP culvert draining roughly 35 acres of residential watershed. The pipe is estimated to pass the 2% annual chance storm event (50-yr flood) without overtopping the road, but a number of homes are within the area that is lower than the sag point in the road.

At the upstream end of Tributary 6, along Colony Woods Drive, residents have complained about flooding. Development of upstream areas (Newton Drive and the Montesorri School) apparently resulted in drainage flows that exceed the capacity of the drainage ditch running between 507 and 509 Colony Woods Drive. The Town constructed a culvert under Colony Woods Drive to help alleviate the flooding problem and portions of the channel have a low-flow concrete swale.

Tributary 8

Tributary 8 is the longest and largest of the tributaries to Tracy Branch, draining about 1/5 of the watershed and flowing a distance of about 4500 feet. The FEMA flooding mapping for Tracy Branch extends up this tributary instead of along the main stem. The neighborhoods along Forsyth and Adelaide Walters Drives drain to the upstream end of Tributary 8. From there the tributary flows south through the American Legion and Town of Chapel Hill properties towards Ephesus Church Road. Photos of the Tributary 8 stream conditions are shown in Exhibit C-9.

In spite of the undisturbed nature of the heavily forested land adjacent to the stream, the upstream reaches of Tributary 8 exhibit evidence of moderate to severe incision and bank erosion. Several knickpoints were observed and there are also reaches where the stream has aggraded. In one area, so much sediment has collected that the stream channel is no longer readily discernible. There are problems with minor trash dumping at the upstream end of Tributary 8, as well as some evidence of debris dumps and abandoned "campsites" along the reach in undeveloped properties.

The stream has two separate culvert systems under Ephesus Church Road and through downstream properties, with outlets from both systems located behind the home at 609 Tinkerbell Road. There is an older system handling the low flows, and a newer system with an inlet placed at a higher elevation upstream of Ephesus Church Road which was apparently

constructed to provide additional drainage capacity. Some photos of the culvert system are shown in Exhibit C-10 and C-11. Each culvert is roughly 500 feet long. No records of the pipe alignments were available for this study and the alignments could not be determined from surface observations. In spite of the upgrade, the culvert system nevertheless remains undersized, during field reconnaissance, one upstream homeowner described frequent problems with flooding. The flood history of homes in this area has not been documented, but twelve homes are at least partially mapped within the FEMA 1% annual chance floodplain. Additionally, the photos show evidence that the low flow system is possibly being undermined. Flow below the pipe invert elevation can be observed in one of the curb inlets along Tinkerbell. A complaint was received from the homeowner at 604 Tinkerbell in 2004 about deterioration of his driveway, presumably over the low flow culvert from Ephesus Church Road. The driveway appears to have been repaired by the homeowner and the property has changed ownership since then.

Stream conditions are mixed in the 600 feet of open channel on Tributary 8 downstream of the Ephesus Church Road/Tinkerbell Road culvert. The reach is moderately incised, but there is strong sinuosity and evidence of good riffle/pool sequences. However, one homeowner has reinforced the channel with riprap to stem erosion that is eating away his backyard. At least nine roof/unknown 4" to 6" drain pipes are discharging along this reach and there is a large infestation of bamboo in one area along the left bank.

The downstream end of this tributary is routed through a 62-foot length of 36" concrete pipe discharging directly to the bank of Tracy Branch. The only significant bank failure along the lined portion of Tracy Branch is just below the outlet for Tributary 8 (shown in Exhibit C-8) and appeared to have occurred not long before the stream reconnaissance in 2008. The culvert serves no obvious purpose (e.g.. road, driveway, etc.) and may have been installed as a grade control measure or under a construction access drive or staging area at some point. The tributary outlet is two to three feet above the streambed of Tracy Branch. Photos of the downstream reach and the discharge point are shown in Exhibit C-12.

Tributary 12

At the upstream end of the Ephesus subwatershed, Tributary 12 drains portions of the Forsyth and Colony Lake neighborhoods. The lower 1200 foot length is classified as perennial. About 350 feet of the downstream end of this tributary has been straightened and either was artificially deepened or has become severely incised over time. The banks are quite steep and there is evidence of bank failure at some points. Immediately upstream of the channelized reach is an area of multiple channels and knickpoints, indicating potential for a headcut to migrate upstream. There is no apparent control feature or debris jam blocking flows, so it is unclear why the channel becomes poorly defined in this area. The upstream 850 l.f. of perennial stream is well-connected to the floodplain and has good structure. A large bottomless culvert crossing at the upstream end of the perennial reach serves as a textbook example of a minimal-impact crossing. The width and vegetation of the riparian areas is mixed, with some portions mowed almost to the stream bank and others having a wide forested area adjacent to the stream. An old farm pond, pre-dating the surrounding development, is located at the upstream end.

Minor Tributaries

Observations of the minor tributaries are based on reviews of map data, aerial photography and, for some reaches, cursory field observations. (See Table C-2 for tributary locations.)

- Tributary 1 is mapped as a 488-foot reach through wooded areas of two residential lots, with no contributing pipe outlets.
- Tributaries 4 and 5 are short, small ditches between storm drain outlets at Pinehurst Drive and Tinkerbell Road, respectively, and Tracy Branch.
- Tributary 7 is partially piped and partially open. The drainage routing is not clearly mapped, but approximately 18 acres of area in the vicinity of Manly Street and Tinkerbell Road drain to a 78-foot long 24" CMP on the lot at 712 Pinehurst Drive that discharges to Tracy Branch approximately 150 feet downstream. The culvert runs under an unpaved area that may be used for parking vehicles.
- Tributary 9 discharges to Tracy Branch just downstream of Ephesus Church Road, from a 90-foot pipe culvert apparently installed by OWASA to facilitate installation and/or maintenance of a sewer line.
- Tributary 10 joins the main stem in the area of Burlington Park, upstream of Ephesus Church Road. The 335 l.f. of open channel at the downstream end is deeply incised and has several exposed and/or aerial sewer crossings. The remainder of the catchment is apparently piped and discharges into the channel from an RCP culvert. There is a scoured area at the outlet and the pipe has separated at the last joint.
- Tributary 11 flows from the east and joins the main stem above Fountain Ridge Road as a relatively shallow open channel. The channel drains only yard areas and no pipes are known to discharge to this channel.

History of Citizen Complaints and Previous Assessments

A list of 22 drainage-related complaints within the Ephesus subwatershed was compiled from the Stormwater Division records. These complaints are listed in Table C-1, with a date, an address, a brief problem description, and a summary of the resolution. This information is taken from electronic records in the Town's stormwater management department.

The complaints date back to well before the Town established a Stormwater Utility. A number of the complaints were related to problems that did not involve any public drainage but were related to issues involving onsite and/or minor drainage areas. In some instances, property owners were complaining about ponding, erosion or other issues that result from natural shifts and processes associated with streams. Relatively few of the complaints were associated with drainage infrastructure in need of repair or improvements. Those are incorporated into the list of potential projects for the Ephesus subwatershed. Where residents have expressed concerns and made observations about streams, these are considered in development and prioritization of options for stream restoration or other improvements.

Table C-1. Drainage Complaints in Ephesus Subwatershed

Address	*Date*	*Complaint Summary*	*Resolution*
104/106 New Cooper Dr	12/2003	Crawl space flooding	Private property issue
221 Scarlet Drive	Before 9/2001	Eroding drainage swale	Private property issue – staff made recommendations
105 St. Andrews Place	Before 9/2001	Flooding concerns re: adjacent tailwater ditch	Private property issue – staff made recommendations
404 Overland Dr	08/2004	Owner requested clean-up of Tracy Branch	
214(?) Sharon Rd	2005 or earlier	Last section of 36" RCP is separating	Apparently not addressed (observed in 2009)
1922 Tryon Ct	2005 or earlier	No documentation except site map; possibly erosion at storm outlet	
57 Newton Dr	08/2007	Flooding	Staff rec'd waiting to ascertain effects of pending imp's by others
61 Newton Drive	11/2002	Sinkhole due to separated pipe	Repair completed under DAP
57 & 59 Colony Woods Dr	1983 and continuing	Crawl space flooding in Aug 2001	Improvements done by Town; rec's made to property owners
132 Sheffield Cir	05/2003	Ponding of water (natural wetland on Trib 6)	Staff explanation
1540 Ferrell Rd	10/2007	Erosion problems on Trib 8	Staff made recommendations to stabilize with vegetation
1605 Ferrell Rd	Before 9/2001	Pipe separation at transition from RCP to CMP	Private property issue – staff made recommendations
725 Pinehurst	08/2004 (?)	Water collecting on sidewalk	Streets issue
729 Pinehurst	Before 9/2001	Request for ditch improvement within an easement	
801 Churchill	08/2004 (?)	No documentation except site map	
823 Churchill	05/2004	Gutter paved over; drainage running down driveway	Streets issue
413 Tinkerbell Rd	01/2007	Standing water/saturated soils	Private property issue – staff made recommendations
604 Tinkerbell Rd	11/2004	Deteriorating driveway possibly related to storm drain	Staff recommended that owner verify drain carries public water; owner apparently made improvements
800 block of Tinkerbell Road	2004 (?)	No documentation, but presumed to be related to flooding	Record of 2005 work order for cleanout
1709 Fountain Ridge Rd	05/2007	Erosion; failing retaining wall on Trib 12	Staff made recommendations; problems attributable to natural processes
105 Lynwood Pl	03/2006	No written documentation; apparently stream erosion on Tributary 8	
Montessori School	11/2003	Downstream neighbors concerned	Addressed by Mayor's Montessori Committee

Potential Pollution Sources

The Ephesus subwatershed potential pollution sources are typical of suburban residential watersheds. A network of sanitary sewer lines has been constructed generally paralleling, and oftentimes crossing, the streams. Sewer lines in the vicinity of the streams may have potential for exfiltration into the streams. The numerous aerial crossings in the Ephesus subwatershed are indicative of sewer lines likey buried adjacent to streams at elevations above the stream bed. During field reconnaissance, one resident complained of a sewage smell above Nottingham Drive on Tributary 6. On this tributary, the sewer line crosses under the perennial stream five times and closely parallels for much of the reach.

As previously noted, there are a large number of small pipes, installed by private property owners, draining directly to the streams. Most of them appear to be connected to roof downspouts and are typically 4" HDPE. The origin of some of the pipes could not be determined. Although no dry weather flows were noted during the field reconnaissance, it is also possible that some of the pipes drain gray water from laundry or other washing operations. The direct discharges can contribute to stream bank erosion and prevent the filtering, settling and uptake of pollutants that could occur if the roof drainage flowed through yards before reaching the stream.

Some of the other frequently cited sources of urban stormwater pollution are largely absent from the Ephesus subwatershed. Orange County does not list any septic systems within the area. There are also no records of underground storage tanks or old landfills.

Some studies have cited golf courses and more upscale residential areas, such as are evident in parts of the subwatershed, as possible sources of higher nutrient loadings to streams because of frequent and sometimes excessive use of fertilizers. No water quality monitoring sites are located within the Ephesus subwatershed, so the nutrient concentrations relative to other parts of the Town is unknown.

Of particular concern in this subwatershed are the number and the size of some of the sanitary sewer aerial crossings. Although the aerials are only a pollution source if they leak or burst, they have potential to significantly impact channel morphology and in some instances can also increase flooding. OWASA policy allows for the option of supporting an aerial crossing on a steel beam instead of with pier supports.Two particularly problematic crossings of this type are located on Tracy Branch. The southern one, located near the downstream end of the concrete lining, potentially causes considerable hindrance to channel flows in major storm events and lies a few hundred feet downstream of one of the more floodprone areas in the watershed. The northern crossing, about 80 feet downstream of the outlet from Colony Lake, also affects channel flow in larger storms and possibly exacerbates the ongoing erosion along that reach. Photos of these aerial crossings are shown in Exhibit C-13.

Watershed Analyses

The pilot basin study effort included development of hydrologic and hydraulic models, as well as some projections of nutrient loads and some limited geomorphological assessments. Hydrologic and hydraulic models were developed for use in assessing potential flooding problems and solutions. Stream assessments utilized Rosgen classifications and erosion indices to characterize channel morphology. The Jordan/Falls Lake Stormwater Load Accounting Tool (JFLSLAT) was used as a basis for estimates of nutrient export loads from the Ephesus subwatershed.

Hydrologic Analysis

The Corps of Engineers HEC-HMS software was used as the platform for development of hydrologic models for the pilot basin study. NRCS methodology for rainfall-runoff and unit hydrograph computations formed the basis for the basin model. Estimates for the 50%, 20%, 10%, 4%, 2% and 1% annual chance floods were developed. For the Ephesus subwatershed, the 1.0 square mile area was divided into seven subbasins for the analysis. Subbasins were delineated for Tributary 8 and for Colony Lake. The other subbasins were delineated along the main stem to correspond with the crossing at Fountain Ridge Road, and the confluence points of Tributaries 3, 6 and 8.

For each subbasin, the total drainage area, the hydrologic soil groups and the percentage of impervious area were determined based on GIS data. The initial subbasin delineation was provided by TOCH Stormwater staff. Additional subdivisions of drainage areas were mapped visually based on TOCH contour mapping. Hydrologic soil group GIS data was downloaded from NRCS. Percentage of impervious cover was computed, based on the impervious cover GIS database maintained by the TOCH Stormwater staff. Large wooded tracts were delineated based on aerial photography obtained from TOCH in 2007. Pervious areas were characterized as either "woods – good condition" or "mixed use" of grassed open areas or partially wooded areas typical of residential lots.

NRCS TR-55 methodology was used to compute a composite curve number for each subbasin, based on the soil group, the vegetative cover, and percentage of impervious area, with differentiation between impervious areas directly or indirectly connected to the drainage system. The estimates of directly connected areas were based on the percent of impervious cover located within rights-of-way as well as field observations, aerial mapping and GIS databases of the storm drain system.

Colony Lake was modeled as a reservoir in HMS, based on estimated stage-storage and stage-discharge curves. The pipe outlet and the lake water surface elevation were surveyed. Stage-storage curves were estimated from topographic mapping provided by the Town of Chapel Hill. The stage-discharge curve was developed for a 30" RCP on a 3% slope with a 6-foot diameter riser barrel. Conveyance in an overflow channel was estimated from the point elevations in LIDAR data downloaded from the NCFMP website. For this model, the discharge from the lake during storm events is largely based on the conveyance capacity of the discharge pipe when flowing full. Because the slope of the pipe is unknown, the lake discharge is a "best-guess" estimate. According to the model results, the lake provides adequate storage capacity for the 100-year flood.

The Modified Puls method was used for computing flows through the stream reaches. Storages were estimated from HEC-RAS data for the range of modeled flows. A second iteration of the estimates was then done to further refine the storage-discharge curves for the reaches. Eight reaches were modeled: two for Tributary 8 and six sections along the main stem with breaks at the confluence for Tributary 2, Tinkerbell Road, the middle of three driveways along Pinehurst Drive, Boxwood Drive, and Ephesus Church Road.

Precipitation was modeled using SCS 24-hour Type II storms, with totals for RDU, N.C. rainfall from Table 2-A-2 of the Town of Chapel Hill Design Manual.

Hydraulic Analysis

The currently effective FEMA hydraulic model for Little Creek Tributary 3 is the basis of the floodplain delineation in the Flood Insurance Rate Map (FIRM) covering the Ephesus subwatershed. The model was developed under the guidelines for "limited detailed study" in the restudy covering Chapel Hill, with the FIS and FIRMs published in February 2007. For a limited detailed study, no survey work or field observations were done by FEMA as part of the re-study, although possibly surveys done in conjunction with previous modeling efforts were incorporated into the 2007 hydraulic model. The model covers Tributary 8 and the lower portion of the main stem of Tracy Branch. Tributary 8 was modeled instead of the upper portion of the main stem, possibly because of the flooding problems along the tributary. The FEMA model for the Ephesus subwatershed is deficient in that several driveway crossings were omitted and the Tinkerbell-Ephesus Church Road culvert system was not appropriately modeled. Dimensions used in the model for the concrete-lined channel were not consistent with measurements taken by JEC and Town staff during field observations.

The TOCH HEC-RAS model for the Ephesus subwatershed, developed as part of the pilot basin study, includes floodplain determination for the main stem of Tracy Branch up to Fountain Ridge Road and for Tributary 8 up to the limit of the existing FEMA floodplain mapping. Additional cross-sections were cut as needed on LIDAR downloaded from NCFMP in 2008. TOCH staff provided surveys of the major culverts in the subwatershed. Thalweg elevations between culvert surveys were interpolated. At some cross-sections, a typical section for the channel was superimposed in the GIS cut data in cases where the LIDAR data did not adequately pick up the channel section.

On the main stem of the stream, road crossings were surveyed and modeled at Tinkerbell Road, one of the driveways along Pinehurst Drive, Boxwood Circle, Lynnwood Drive, Ephesus Road, and Fountain Ridge Road. The Ephesus Church Road/Tinkerbell Road crossing on Tributary 8 was also surveyed at the upstream and downstream ends. However, both the low flow and overflow culverts have several bends and junctions. The HEC-RAS calculations for culverts assume a straight alignment and do not account for energy losses due to bends. Smoking the lines to better determine connections and alignments would need to be done prior to initiation of design for a culvert replacement or upgrade.

The FEMA input data for the unpaved driveway on the American Legion property was retained and no survey data was taken at that crossing. Sewer aerials and a couple of minor footbridges

and driveways were not included in the FEMA model or the TOCH model. Of these crossings, only one, a sewer aerial supported on a steel beam, is likely to impact 1% Annual Chance Flood WSEL's in an area where structures are threatened by flooding. The sewer aerial, however, is located on a reach where the 1% Annual Chance WSEL for backwater from Little Creek is higher than the projected Tracy Branch WSEL.

Results of Quantity Modeling

Two of the three CMP arches at the Tinkerbell Road crossing and three of the four RCP's at Boxwood Drive were modeled as partially blocked based on measurements taken in the field. The HEC-RAS model was also run for cleared culverts to assess the potential benefit of routine cleanouts. At Tinkerbell Road, a cleanout is projected to lower water surface elevations by less than 0.1 foot in storms with potential to flood nearby structures. The 1% annual chance flood would be expected to drop only 0.04 foot. However, in the 50% annual chance flood, the water surface levels are projected to drop by 0.6 foot for few hundred feet upstream. At Boxwood, greater benefits are projected from a cleanout of the culverts, with the 10% annual chance storm expected to drop by one foot and other storms by lesser amounts ranging from 0.3 to 0.8 foot. However, no structures appear to be threatened by flooding in the reaches upstream of Boxwood Drive.

The TOCH models generally predict higher flows and WSEL's than were estimated for the effective FEMA model. Table C-2 on the following page provides a comparison of flows and WSEL's for the two models.

The differences in results are attributable to a number of factors. The FEMA discharges were based on regression equations generally applicable to developed watersheds in the North Carolina Piedmont. The TOCH discharges are based on information specific to the Ephesus subwatershed, but the accuracy of the estimates is also a function of the applicability and validity of the NRCS methodology. THE TOCH models incorporated survey data, as well as field observations and measurements. Neither the FEMA nor the TOCH model has been calibrated and validated for the Ephesus subwatershed.

The finished floor elevations for 23 homes mapped within the FEMA 1% Annual Chance Floodplain were compared to estimated flood levels from both the FEMA and TOCH models. Thirteen of the surveyed homes could potentially be inundated in the 1% Annual Chance Flood, nine in the vicinity of the Ephesus Church Road/Tinkerbell Road crossing and four in the area of the 3-CMP arch culvert crossing in the 800 block of Tinkerbell Road. The FEMA and TOCH models both indicate inundation of the same structures.

Table C-2. Comparison of FEMA and TOCH Flood Model Results

Location	FEMA 1% Annual Chance Discharge (cfs)	TOCH 1% Annual Chance Discharge (cfs)	FEMA WSEL (feet)	TOCH WSEL (feet)	Road Elevation (feet)
Downstream end of concrete channel	1180	1725	253.21	252.32	
Upstream of Tinkerbell Rd	1060	1552	255.09	255.51	253.56 survey 254.12 FEMA
Upstream of Boxwood Dr	840	1071	262.27	264.91	265.71 survey at culvert; 263.07 estimated at sag (LIDAR)
Upstream of Ephesus Church Rd	n/a	816	n/a	278.81	279.11 survey at culvert; 277.93 estimated at sag (LIDAR)
Upstream of Fountain Ridge Rd	n/a	274	n/a	287.89	287.23 survey at culvert
Trib 8 Upstream of Ephesus Church Rd	414	480	279.18	279.50	278.45

Two of the four homes at-risk homes in the 800 block of Tinkerbell Road are projected to flood due to backwater from Little Creek, regardless of any potential improvements within the Ephesus subwatershed. Floodproofing of the four at-risk homes in the 800 block is the least-cost method for limiting flood damages in that area. The TOCH and FEMA models project widespread inundation in the area during a 1% Annual Chance Flood, but water depths will be relatively shallow and most of the structures within the inundated area are high enough to avoid flooding of the living areas even in an extreme event. The area is flood-prone because much of it was the natural floodplain for the stream before the neighborhood was developed and the channel was re-routed, straightened and lined with concrete.

The situation is somewhat similar upstream on Tributary 8 where the culvert system at Ephesus Church/Tinkerbell Road was constructed to carry low flows and the natural stream was completely obliterated. Homes were built atop what used to be the stream and now some of them are at risk of flooding. The undersized culvert also causes Ephesus Church Road to function as a dam, backing up water onto upstream properties. The original CMP was later supplemented with a larger RCP that provides some relief. However, the combined capacity of the two culverts is estimated in HEC-RAS to only be about 110 cfs, and the models project that Ephesus Church Road could potentially be overtopped in the 20% Annual Chance Flood. In the 1% Annual Chance Flood, about 390 cfs would flow over Ephesus Church Road at a depth of as much as 15 inches, spreading across the yards and eventually re-entering the downstream channel. Specific flood elevations between Ephesus Church Road and the downstream channel are difficult to estimate since there is no well-defined flow path. However, it is expected that

five of the homes south of Ephesus Church Road could be flooded in the 1% Annual Chance Flood. North of Ephesus Church Road, there are another four homes at risk of flooding due to backwater from the road crossing. The Town records reviewed as part of this study regarding stormwater complaints did not include any about overtopping at this location on Ephesus Church Road.

The area upstream of Ephesus Church Road presently serves as somewhat of a storage reservoir for stormwater during significant rainfall events. Increases to the capacity of the culvert system would reduce the frequency of flooding in the upstream area and overtopping of the road, but rare storm events would still have the potential to cause flood damage to homes. Some of the at-risk homes were built on or in close proximity to the former natural drainage path and are at elevations that make it infeasible to provide protection for them in the 1% Annual Chance Flood. Analyses of potential improvements to the Ephesus Church Road crossing over Tributary 8 are described later in this report.

The HEC-RAS analysis for the main stem of Tracy Branch projects that Ephesus Church Road at the main stem crossing would be overtopped in a 4% Annual Chance Event (25-yr Storm). Because the upstream area is a neighborhood park, the road overtopping would not be expected to cause any flooding of structures. Other minor roads are also projected to overtop in storms as frequent as the 10% Annual Chance Flood. Driveways may overtop in the 50% Annual Chance Flood.

In addition to the culverts included in the HEC-RAS analysis, the 42" RCP under Ephesus Church Road on Tributary 6 was also assessed. Like the Ephesus Church Road crossing over Tributary 8, this one also serves as a dam during major storm events such that the limited discharge combined with the flood storage upstream of the road provides significant reduction of downstream peak flows in some storm events. When the upstream area is modeled as a reservoir, based on the volume of runoff potentially stored before Ephesus Church Road would be overtopped, the culvert passes the 50-year storm without overtopping. No survey was done of finished floor elevations in this area, but five homes are within the potential backwater area for this crossing, with one home projected to be completely surrounded by floodwaters in the event of roadway overtopping.

The planning and neighborhood development policies and practices of an earlier era, lacking in stream protection and stormwater management strategies, are largely to blame for the flooding problems within the Ephesus subwatershed. Most of the area was developed prior to implementation of newer regulations that require flood controls and stream buffers. A number of the structures at risk of inundation during extreme storm events were constructed in areas that were once part of the natural floodplain. Although urbanization may have contributed to larger volumes of runoff and higher peak flows, the more significant factor in this watershed is the layout of the homes in relation to the streams. Current TOCH requirements for RCDs would have prohibited the types of development patterns prevalent in the older Ephesus neighborhoods.

In spite of the FEMA mapping and the model projections regarding potential for extensive flooding in several areas of the Ephesus subwatershed, the official record of drainage complaints includes only a few about flooding, and those were related to minor drainage channels in the

upper reaches of the watershed and were limited to yard or crawl space flooding. The stormwater records included in the electronic files compiled for the master planning project do not include any reports of inundated structures along the perennial streams in the Ephesus subwatershed.

Stream Morphology/Stability Assessment

Another aspect of the pilot basin study was to assess the geomorphological condition of the streams, in particular noting which streams are stable and which have become unstable such that relatively excessive erosion and/or aggradation should be expected. The following describes quantitative measures used to supplement the qualitative information and photo-documentation of stream conditions observed during the field reconnaissance. In order to better assess the stream morphology and stability and to facilitate future comparisons to present conditions, permanent cross-sections were established at three sites in the subwatershed: one on Reach A on the main stem downstream of the concrete channel, one on Reach C and one on Tributary 8. The sections were surveyed such that the channel dimensions could be computed. Channel slope and sinuosity was estimated from aerial photos, GIS information and elevations from the culvert surveys. No substrate sampling was done. The Rosgen classification system, a methodology for classifying different types of rivers and streams, was used for categorizing the streams. Reach A is classified as E6, although sinuosity is very low because the stream was previously channelized. The other reaches have very low width-to-depth ratios, entrenchment ratios lower than 1.4 and are classified as G6c. This classification is typical of an urban stream that has become incised and is in the processing of re-equilibrating to a changed hydrological regime. Key section measurements and characteristics are listed in Table C-3. Some gravel can be seen in the stream beds in the upper reaches, along with rip rap that has been transported, but the bed material in the vicinity of the permanent sections is predominantly silt and clay.

Table C-3. Geomorphic Classification and Stability Measures at Permanent Cross-Sections

	Reach A	Reach C	Trib 8
Entrenchment Ratio	15.7	1.5	1.4
Width-to-Depth Ratio	9.8	5.8	6.2
Bank Height Ratio	1.0	3.1	1.6
Estimated Slope	0.003	0.007	0.015
Sinuosity	Low (probably has been straightened)	Low to moderate	Low to moderate
Rosgen Classification	E6*	G6c	G6c
BEHI Rating	moderate	high to very high	high

**the low sinuosity is not consistent with this classification*

Estimates of Bank Hazard Erosion Indicator (BEHI) ratings were made at each of the sections, based on observations of the ratio of the bankfull depth to the bank height, the bank slopes and estimates of root depth and density. The downstream reach has a moderate BEHI rating. The BEHI rating at the upstream section is estimated on the borderline between high and very high. The Tributary 8 reach has a high BEHI rating. The BEHI ratings indicate that bank erosion is likely to continue in the reaches and contribute significant amounts of sediment to downstream reaches, unless measures are undertaken to restore the streams and stabilize the banks.

In the Ephesus subwatershed, all of Reach B has been lined with concrete and is no longer a natural stream. Although sediment is still being transported through the reach and some aspects of natural stream function have been restored, the channel profile and dimensions are constrained by the concrete liner. Whereas a stable natural channel has conveyance capacity for roughly a 50% Annual Chance Flood within the channel, the artificial channel was probably sized to carry at least a 10% Annual Chance Flood. Thus, the channel banks are more rarely overtopped and the channel-to-floodplain connection typical of a natural stream has been disrupted. The option of restoring the concrete-lined channel as a natural stream was considered as part of the pilot basin study. The potential restorability, however, is greatly constrained by the development of the adjacent floodplain and the need to protect homes and property from increased flooding. Establishing a naturally stable channel profile and geometry would require a considerably wider corridor than the present channel requires, since a secondary floodplain with sufficient conveyance capacity would need to be excavated. The restoration project would require essentially 100% support from the homeowners all along either side of the concrete channel. Even though the aquatic habitat conditions within the reach are poor and the nutrient processing typical of a natural stream is either absent or greatly diminished, the reach is relatively stable in its present condition. Because the benefits of restoration in this case are relatively low and the constraints and the costs are high, restoration of the concrete-lined portion of Tracy Branch is not recommended for the planning horizon of the Stormwater Master Plan.

Water Quality Analysis

The biggest stressors for water quality in Ephesus streams are the ongoing erosion in the upper reaches of Tracy Branch and Tributary 8 and the significant lengths of culverts and artificially lined channel. The stream bank erosion contributes to downstream sedimentation problems in Tracy Branch, Little Creek and possibly further downstream. The piped and artificially lined channels restrict the nitrogen processing that would otherwise be occurring in a natural stream channel, likely resulting in higher nutrient loading to Jordan Lake. The lack of benthic habitat restricts the biodiversity in the stream. The Town began a benthic monitoring program in 2011, but no suitable location for sampling could be located on Tracy Branch.

The Jordan/Falls Lake Stormwater Load Accounting Tool has been designated by DENR as the basis for computations of nutrient load estimates from proposed development sites. The JFLSLAT also incorporates updated research results and methodology for estimating the reductions in nutrient discharge loads facilitated by various types of BMPs. A separate report has been developed to estimate the overall nutrient discharge load from the Ephesus subwatershed, along with a scenario of BMPs and associated costs from meeting the 8% nitrogen reduction target for areas of existing development, currently a part of the Stage 2 Jordan rules.

Potential Stormwater Projects

The stormwater issues within this subwatershed include extensive flooding concerns and stream degradation problems. Most of the potential projects listed below are aimed at addressing these issues. Opportunities for increasing nitrogen reduction within this subwatershed are also identified as potential projects. Several repairs to infrastructure are noted. Projects are classified as flooding/infrastructure or water quality. Lastly, non-structural BMP's specifically appropriate for the Ephesus subwatershed are proposed. Additional non-structural BMP's, applicable to both of the pilot basin subwatersheds, are described in a separate section, along with issues relating to meeting the Jordan Lake rules nutrient reduction targets. Conceptual plans and cost estimates for projects will be integrated into Infrastructure and Water Quality CIPs or added to the Small Maintenance Projects Program. Non-structural BMPs will be addressed as part of the Public Education Program.

Flooding/Infrastructure

1. Repair failed area of concrete lining on Tracy Branch right bank below confluence of Tributary 8. A localized repair could be done with concrete, but a more comprehensive approach would be to replace the failing concrete with gabion mattress for the entire reach from Lynnwood to Boxwood. The project would also have some limited water quality benefits by allowing surface water/groundwater exchange in the channel bottom. The channel is located on private property.

2. Replace or upgrade culvert on Tributary 8 at Ephesus Church and Tinkerbell Roads. The existing low flow culvert is eroding and should be replaced with a larger culvert. Partial daylighting could be considered in conjunction with buyout of 605 Tinkerbell Road, where the basement level is at risk of flooding. Restoration of the downstream portion of the stream could also be incorporated into this project. Unless a 1% annual chance design storm is used for the culvert sizing, upstream homes may still be at risk of flooding when Ephesus Church Road is overtopped. Results of a rudimentary analysis of the impacts of replacing the existing 30" CMP with a 48" RCP are shown in Tables C-4 and C-5. Additional survey and an adequate determination of the alignment of the existing system would have to be undertaken at the design phase in order to more comprehensively analyze and project the impacts of a proposed improvement. Replacement of the culvert would require dedication of easements from several private property owners.

Table C-4. Tributary 8 at Ephesus Church Road – Upstream Water Surface Elevations

Annual Chance Flood	Upstream WSEL w/ Existing Pipes (ft)	Upstream WSEL w/ New 48" RCP (ft)	Difference (ft)
50%	276.9	275.4	-1.5
20%	278.2	276.7	-1.5
10%	278.8	277.5	-1.3
4%	279.2	278.5	-0.7
2%	279.4	278.9	-0.5
1%	279.6	279.2	-0.4

Table C-5. Tributary 8 at Ephesus Church Road – Downstream Flows

Annual Chance Flood	Peak Flows Immediately Downstream of Culvert			Peak Flows at Confluence w/ Tracy Branch		
	Existing Pipes (cfs)	48" RCP Low Flow Pipe (cfs)	% Change	Existing Pipes (cfs)	48" RCP Low Flow Pipe (cfs)	% Change
50%	95	143	50%	335	372	11%
20%	128	189	48%	504	571	13%
10%	177	213	20%	598	640	7%
4%	296	247	-17%	735	693	-6%
2%	381	333	-12%	926	880	-5%
1%	469	424	-10%	1094	1054	-4%

The results indicate that significant flood level reductions upstream are projected for storms likely to occur several times over a ten-year period, but they are somewhat offset by some projected increases in downstream flows. Little benefit is projected for the more extreme storm events.

3. Remove sewer aerial near the end of the concrete reach, replace beam with pier supports or concrete blocks buried in the bank, or encase pipe in steel. The objective is to reduce the obstruction to flows caused by the existing structure and associated vegetation. Channel is located on private property and sewer line is owned by OWASA.

4. Purchase one of the flood-prone homes on Colony Woods Drive in the area of previous drainage complaints in order to construct an appropriately sized channel to accommodate stormwater through the reach. A BMP sufficiently sized for the upstream drainage area could be incorporated with the project.

Water Quality/Stream Stability

1. Construct an energy dissipator for the outlet of Tributary 3 downstream of LeClair Street and restore 370 l.f. of stream by cutting back the banks and providing a vegetated buffer. This project would impact eight property owners. Aquatic habitat improvement would be very limited unless restoration of the concrete-lined downstream reach is also undertaken.

2. Restore 1800 l.f. of stream on Tracy Branch from Fountain Ridge Road to Ephesus Church Road. The entire length has approximately a 90-foot wide strip along the stream that appears from GIS mapping to be Town-owned. Some grading and re-vegetation would likely extend onto private property, at least in areas where the stream is not located within the publicly-owned land. Restoration would arrest the ongoing stream bank erosion on this reach, but may offer only limited improvements to aquatic life because of the long reach of concrete channel separating this reach from the downstream end of Tracy Branch.

3. Establish grade control structures on Tributary 8 on property owned by Town of Chapel Hill and American Legion. Grade control features, aimed at arresting the ongoing

streambed incision along this reach, should be constructed. Stream restoration is not warranted at this point, especially in light of potential future development.

4. Establish grade control structures and restore a short reach at the downstream end of Tributary 12 and on the main stem between Colony Lake and Fountain Ridge Road. Project would require easements from three property owners, as well as the Colony Lake Homeowners Association. Coordination would be required with OWASA to address issues regarding two aerial sewer crossings.

5. Reforest a vegetated stream buffer along an area on Reach A of the main stem in conjunction with slight lowering of floodplain. Project would impact four properties. The back yards are quite deep, such that owners may be amenable to reforestation along the stream.

6. Remove concrete channel and restore 800 l.f. of stream on Tracy Branch below confluence with Tributary 3. Work with homeowners, especially on the flood prone east side, to lower the floodplain and construct a meandering natural stream. This would extend the natural stream approximately 800 feet further upstream and would impact four property owners on each side of the stream.

7. Repair broken culvert on Tributary 10, construct an energy dissipator and restore 300 l.f. of downstream reach. This effort would require coordination with OWASA to eliminate or alter the two aerial crossings and one exposed sanitary sewer pipe near the stream bed on this reach. The Town owns most of the affected property. Regrading of the stream banks to incorporate a lower floodplain is probably only feasible on the north side of the tributary.

8. Modify Colony Lake to incorporate additional treatment and to gain credit for nutrient removal. Floating wetland islands may provide a feasible option. The lake could be improved to incorporate an extended detention zone, but this may alter the 1% Annual Chance discharge. Stream restoration of downstream reaches could offset impacts due to higher lake discharges. Current BMP manual design requirements include: addition of forebays, a 2-5 day drawdown period for WQ volume, a 10-ft littoral shelf (probably not practical, could seek a variance), and a spreader for the outlet (definitely needed, may be tough to engineer). A preferred option may include a slight lowering of permanent pool and incorporation of an extended detention WQ volume. Obstacles include private ownership/future maintenance issues, avoidance of flooding for numerous structures abutting the lake and liability concerns for the Town for changes perceived to impact flood risks. Possible incentives for Colony Lake HOA could include stormwater utility fee credits and Town takeover of or participation in maintenance of the lake.

9. The small existing impoundment draining roughly 8.0 acres of the upper end of Tributary 12 may have potential as a retrofit BMP. It is located on property owned by Forsyth HOA.

10. The Colony Lake HOA property may also offer possible locations for BMP retrofits. There is at least one existing BMP at the southwest corner near Tributary 12 that seems to be performing poorly.

11. Instead of or in addition to Colony Lake improvements, there are possible opportunities for smaller BMP's on private lots or on TOCH property upgradient of the lake (i.e. reduced drainage areas, but possibly more feasible implementation).

12. A retrofit BMP could possibly be located on an empty lot on Nottingham (third lot owned by adjacent owner of large home on two lots) as an overflow constructed wetland area for Tributary 6.

13. Non-structural BMP: Develop education/cooperation efforts with Chapel Hill Country Club regarding fertilizer practices, possible daylighting of pipes, use of filter strips, etc. to improve water quality.

14. Non-structural BMP: Target a stream clean-up effort at the upstream end of Tributary 8, accompanied by possible signage and/or public education efforts aimed at curtailing further dumping in the area.

15. Non-Structural BMP: Target some of the neighborhoods in the Ephesus subwatershed in a campaign to educate and encourage homeowners in regarding to disconnecting roof drain downspouts from direct flow into streams.

Exhibits

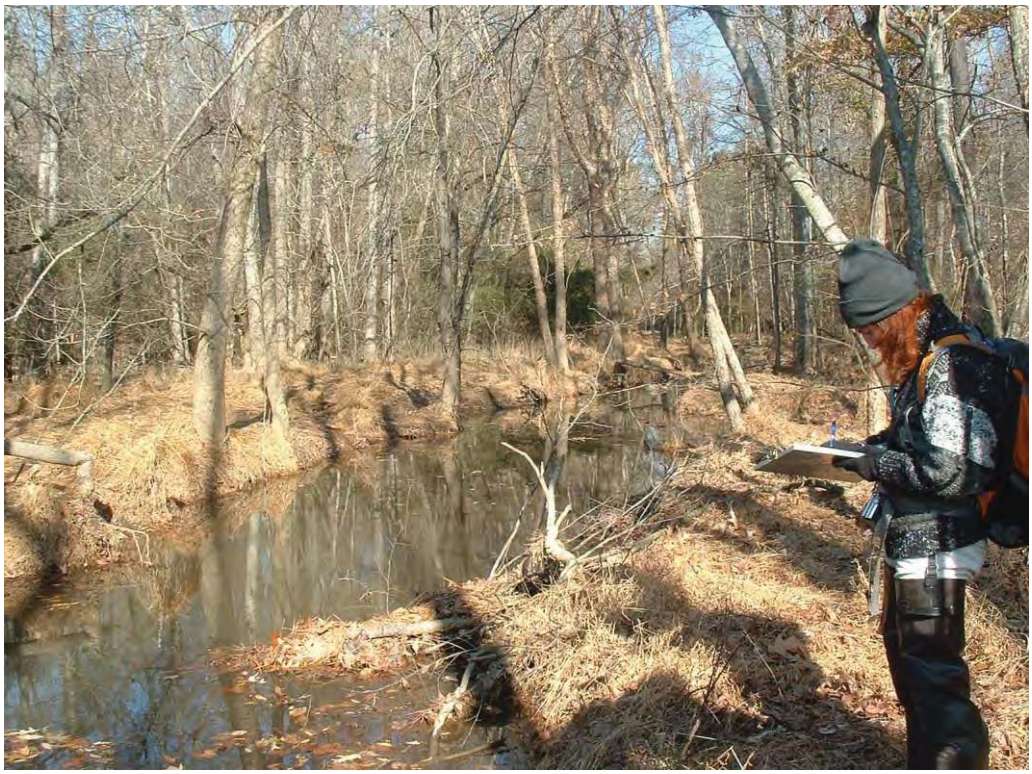

Exhibit C-1. Photos of Reach A

looking upstream from downstream end of concrete lined reach

Exhibit C-2. Photos of Concrete Channel Lining

Exhibit C-3. Photos of Sedimentation at Culverts

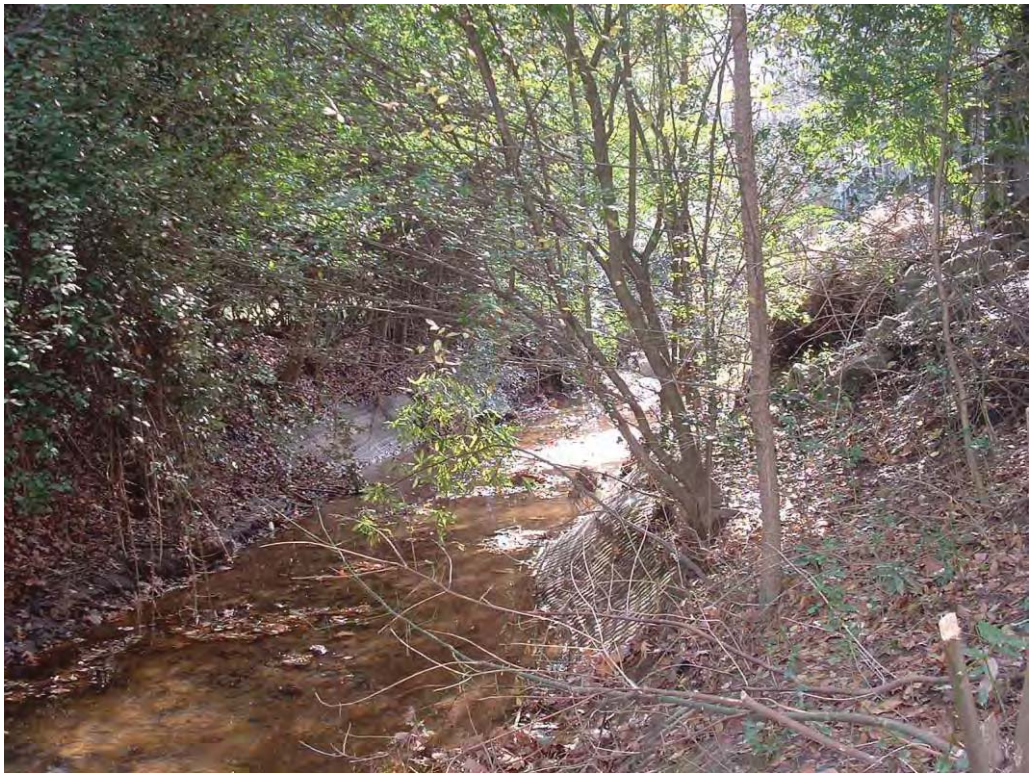

Exhibit C-4. Photos of Reach B Concrete Lined Channel

Exhibit C-5. Photos of Failing Sections of Channel Lining

Exhibit C-6. Photos along Reach C

Exhibit C-7. Photos of Colony Lake Outlet and Replaced Fountain Ridge Culvert

Erosion on Tributary 3; Looking downstream from culvert outlet

Perched outlet for culvert under LeClair Street

Exhibit C-8. Photos of Tributary 3

Exhibit C-9. Photos of Tributary 8

Exhibit C-10. Photos of Tributary 8 Culverts at Ephesus Church Road

deterioration in culvert

Exhibit C-11. Photos of Tributary 8 Low Flow Culvert at Ephesus Church Rd

streambank reinforced by homeowner

discharge from Tributary 8 into Tracy Branch (prior to concrete failure)

Exhibit C-12. Photos of Tributary 8 Downstream Reach and Discharge Point

aerial crossing on Reach B

aerial crossing on Reach C

Exhibit C-13. Photos of Aerial Sewer Line Crossings Along Tracy Branch