Appendix D

Pilot Basin Study Interim Report
Booker Headwaters Subwatershed

Pilot Basin Study Report – Booker Headwaters Subwatershed

Booker Creek is a major stream in Chapel Hill, the largest stream which has its entire watershed within the Town's jurisdiction. Booker Creek discharges into Little Creek a little over a mile upstream of the Town's eastern boundary line. The portion of the Booker Creek watershed captured in Lake Ellen is referred to as Booker Headwaters (BL-6) in the Town's subwatershed GIS file and in the North Carolina Ecosystem Enhancement Program (EEP) report developed for Morgan and Little Creeks. An aerial photo of the subwatershed is shown in Figure D-1. The drainage area delineated for Booker Headwaters at the Lake Ellen dam covers an estimated 1.35 square miles. The 2008 Town of Chapel Hill GIS database for streams lists 5.3 miles of perennial streams in the subwatershed, encompassing the main stem of Booker Creek, plus portions of 11 tributaries.

Booker Creek is listed by NCDENR as impaired for biological integrity. The EEP assessment in the Morgan/Little Creek study lists Booker Headwaters as "fair" for stream condition and morphologic stability under the NCRS Stream Visual Assessment Protocol used to evaluate the streams in Chapel Hill. The subwatershed was recommended in the EEP study as a "second tier" subwatershed for focusing restoration, preservation and prevention efforts. The Booker Headwaters area lies within the Carolina Slate Belt, where streams are generally characterized by rocky substrates and narrow valleys. Roughly 70% of the soils in the subwatershed are classified as Hydrologic Soil Group B, allowing for relatively high rates of infiltration and low rates of runoff relative to many areas of the Piedmont.

Booker Headwaters is in a rapidly developing part of the Town. 1993 aerial imagery shows that very little of the area west of MLK Boulevard had been developed at that time. The single family neighborhoods around and north of Lake Ellen were developed earlier, as well as one other neighborhood north of Weaver Dairy Road, plus a few trailer parks. However, since 1993 several large residential developments have been constructed, along with a Town park and scattered commercial development. More projects are in the planning stages. As is also noted in the NCEEP report, development in the Booker Headwaters has high potential for causing significant impacts in terms of streambank erosion and water quality problems.
The Booker headwaters have been afforded a certain degree of protection with RCD corridors along the streams and BMPs controlling stormwater runoff from some of the newer developments. Road crossings, at least over the main stem, are relatively minimal. Additionally, the older neighborhoods within the subwatershed were developed with large lots and streets drained without curb and gutter. Much of the natural forest in that area has been preserved. Runoff from impervious surfaces in those neighborhoods has considerable opportunity for infiltration or treatment prior to entering Booker Creek.

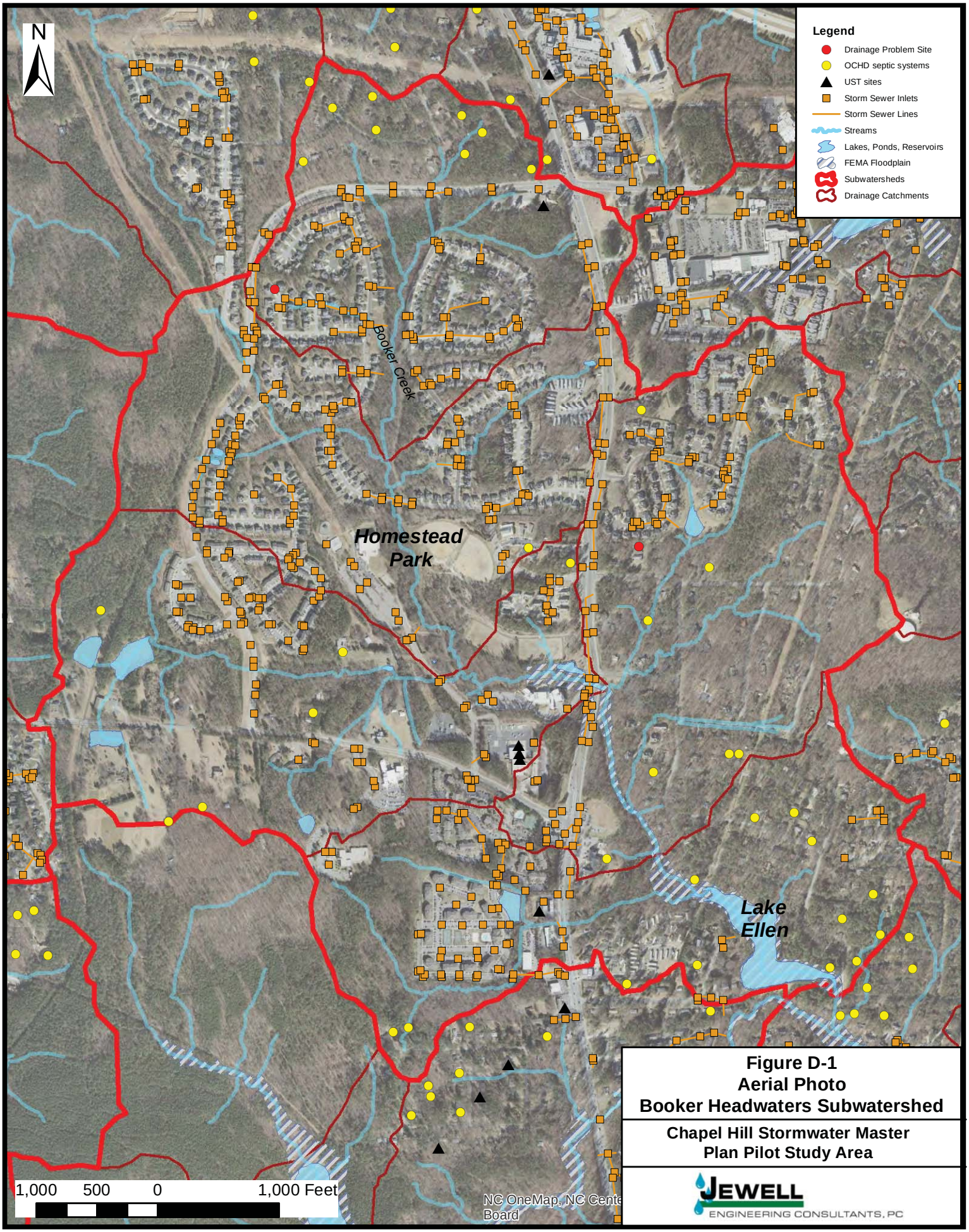

Figure D-1
Aerial Photo
Booker Headwaters Subwatershed

Chapel Hill Stormwater Master Plan Pilot Study Area

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Existing Stream Conditions

To assess the stream conditions in the subwatershed and to identify potential stormwater BMP sites, JEC and Town Stormwater Staff walked the perennial streams in the Booker Headwaters during the spring of 2009, 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.

A mix of stream conditions exists within the subwatershed. The grade in some stream reaches, including the downstream portion of the main stem, is controlled by bedrock. There are other reaches where, although bedrock grade control is not evident, the stream seems to have suffered very little impact from development. In contrast, there are also reaches with headcuts and a considerable degree of streambank erosion. Algae were present in numerous areas during the April streamwalks. The following provides descriptions of the perennial stream corridors in the subwatershed. Figure D-2 shows the streams and crossings referenced in the descriptions, as well as the mapped FEMA 1% Annual Chance Floodplain. The photographs taken during field reconnaissance are compiled as a set of Exhibits at the end of the report.

Riparian conditions are similarly mixed. Much of the forested riparian buffer along Booker Creek has been preserved. However, there are areas along some of the tributaries where pavement is within 20-30' of the stream. Other areas exhibit heavy growth of invasive species.

Main Stem of Booker Creek Headwaters

Reach A, the most downstream portion of Booker Creek in this subwatershed, includes the reach from MLK Boulevard to Lake Ellen. It flows through church properties, undeveloped parcels and large residential lots. The riparian areas are forested for almost the entire reach. Some photos of Reach A are shown in Exhibit D-1. There is sedimentation in the downstream portion of the reach in the transition to Lake Ellen. For much of the reach the grade is controlled by bedrock and the stream shows remarkably little sign of negative impacts due to the upstream development.

Reach B, the middle portion of the main stem, is located between New Parkside Drive and MLK Boulevard. Some photos of Reach B are shown in Exhibit D-2. Over half of Reach B flows through Homestead Park. Most of the downstream portion is on the United Church of Chapel Hill parcel, with a small area upstream of MLK Boulevard on a lot owned by NCDOT. The entire reach is crossed only by two trails within the park. The riparian areas are mostly wooded.

The stream condition through this reach is generally good, but is varied and shows early indications of degradation. Some downcutting of the bed seems to be occurring in the downstream portion of the reach, though incision thus far is relatively minimal. Erosion and incision are more pronounced in upper portions of the reach. Sedimentation is evident in some areas along this reach, possibly a result of the relatively recent construction of the park facilities.

A large BMP in Homestead Park on the east side of Booker Creek, apparently constructed as a stormwater wetland, is eutrophic and could be adding instead of removing nutrients. Fertilization of the baseball fields could also be a contributing factor. Algae were persistently evident in Reach B.

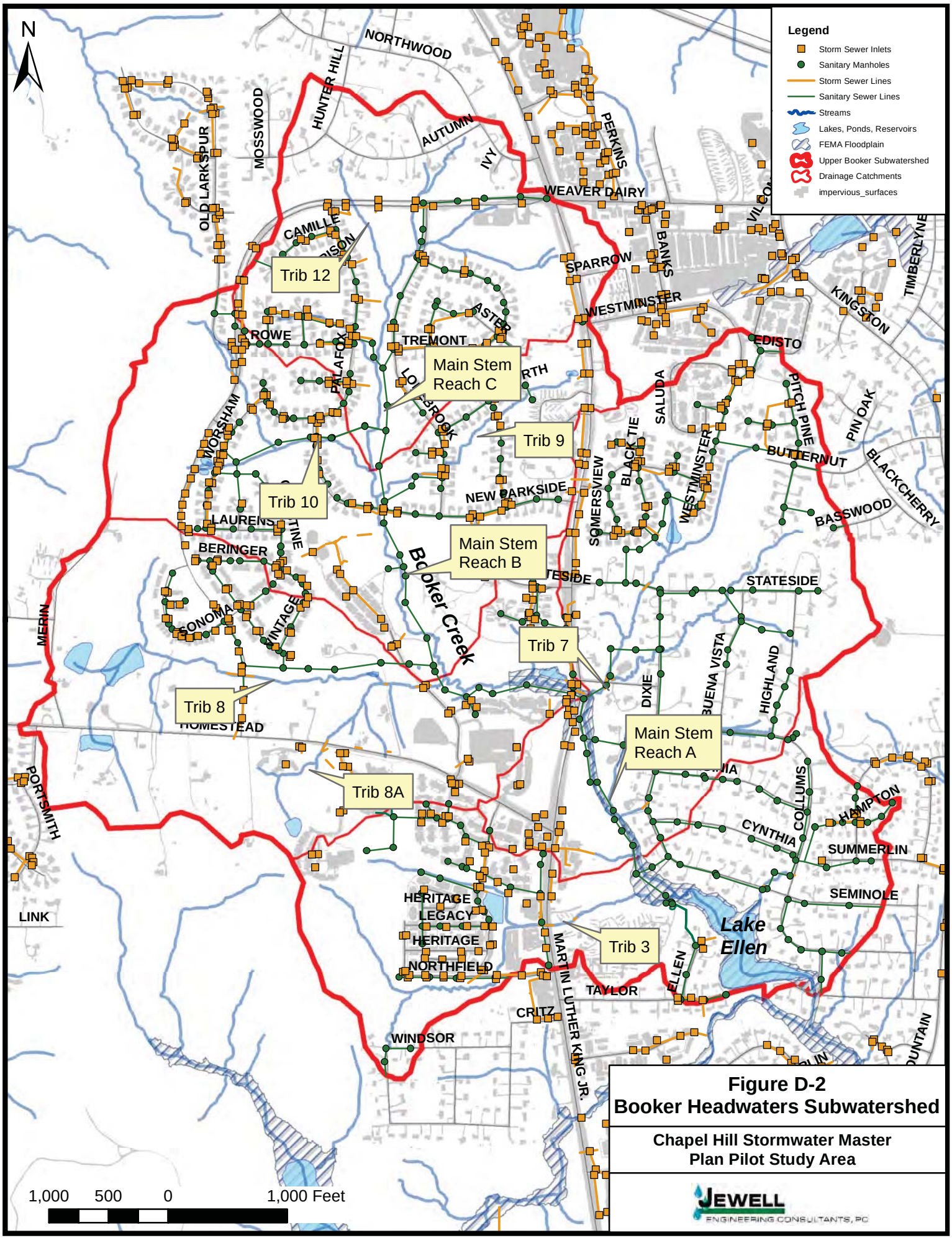

Figure D-2
Booker Headwaters Subwatershed

Chapel Hill Stormwater Master Plan Pilot Study Area

JEWELL ENGINEERING CONSULTANTS, PC

Several BMPs were constructed in conjunction with the park development. There is a large wet pond behind the aquatic center, which appears to be functioning as designed. The afore-mentioned wetland does not seem to be functioning as intended. There are also a couple of smaller BMPs in the watershed which have not been maintained and for which the design and intended function is not apparent. Pictures of a couple of BMPs are shown in Exhibit D-3.

Reach C, from Weaver Dairy Road to New Parkside Drive, is the most upstream reach of Booker Creek. Some photos along the reach are shown in Exhibit D-4. Development has occurred along the entire reach, drastically changing the hydrology and hydraulics of the catchments. A dozen pipe systems discharge into the RCD area along Reach C. Several tributaries have numerous road crossings and/or extensive pipe systems. However, RCD requirements have preserved a wooded buffer along Reach C that is at least 100 feet wide at all points. The only crossings along the main stem are OWASA pipeline aerials or access crossings.

Headcuts seem to be migrating upstream through a couple of relatively flat, shallow floodplain areas where there was little evidence of a single, low-flow channel at the time of the field observations in spring 2009. One of these locations is in the area of an OWASA crossing, where the main stream channel could not be discerned during the April visit. The entire crossing is grassed, with water flowing across in numerous shallow areas such that the location of the main low flow channel could not be definitely discerned. On the 1977 soil survey, this area is mapped as having two streams, with the longer reach discharging to what is now mapped as Tributary 9 and the shorter picking up the discharge from Tributary 10. It seems likely that the OWASA crossing, in combination with the line paralleling the creek, significantly altered the routing of flows through this area and has resulted in the observed instabilities. At some distance downstream of the crossing, there are multiple small drainage channels with headcuts. It is difficult to discern what the natural condition of the area would be without the crossing. A similar area exists further upstream where there is no OWASA crossing. In between the two flat areas, as well as upstream and downstream, there is clear evidence of ongoing channel incision. At one location, a homeowner had constructed a small dam in the creek to create a reservoir for pumping water to facilitate his backyard landscaping project. Reach C is unstable and is likely to experience continuing erosion until a new stream equilibrium is established.

Tributary 3

Tributary 3 flows into Booker Creek at the upstream end of Lake Ellen and drains 91 acres to the west of the confluence. Two perennial stream branches feed the tributary, joining together at a point about 200 feet upstream of MLK Boulevard. Several reaches appear to have been re-routed from the natural stream channel to the edges of developed properties. The drainage area for Tributary 3 is a mix of undeveloped wooded areas at the upstream ends, dense multi-family sites along the mid-reach and trailer parks in the downstream portion. This tributary has the worst floodplain encroachment in the Booker Headwaters subwatershed, with paving in close proximity to the banks upstream of MLK Boulevard. There are also several mobile homes located in very close proximity to the stream in the area immediately east (downstream) of MLK Boulevard. Some photos of the encroachments are shown in Exhibit D-5. A portion of the north branch of the tributary also has development immediately adjacent to the spring-fed perennial stream.

One of the apartment complexes in this area has a large bioretention BMP. The complex drains to a walled-in area encompassing about 7/10 acre, where runoff ponds and is infiltrated, partially collected in underdrain piping, and discharged through 2-36" pipes to the north branch of Tributary 3. The vegetation appears to be relatively sparse and the depth of the infiltration media is not known. The BMP is fenced and has a controlled access gate. The area is presumed to be accessible to residents of the complex. TOCH Stormwater staff requested from the property owners, but have not received, additional information on the design and function of the BMP. The BMP and the Tributary 3 reach downstream are shown in Exhibit D-6.

Stream condition along most of the observed reaches is good. However, a couple of reaches are so overgrown with invasive species that they are barely accessible. Downstream of MLK Boulevard, the channel is incised and the stream is approximately as deep as it is wide. Severely undercut banks were also observed downstream of MLK. Upstream of MLK, at least in areas where the streams can be observed, problems with erosion and sedimentation are relatively minimal.

Tributary 7

Tributary 7 is also referred to as Dixie Branch. This tributary joins Booker Creek just east of MLK Boulevard and south of Dixie Lane. Just north of Dixie Lane is the confluence of East Branch with Dixie Branch. East Branch has over 2000 linear feet of perennial stream and Dixie Branch has been mapped as a perennial stream up to Stateside Drive, a distance of over 800 feet. The two branches drain about 136 acres. The large wooded lots of the Lake Ellen neighborhoods cover almost all of the drainage area for East Branch and the lower portion of the drainage area for Dixie Branch. A more dense residential development is located in the upstream area of Dixie Branch. Most of the runoff from that neighborhood is routed to a pond that pre-existed the development, but may have been modified with the construction of the neighborhood.

All reaches observed on Tributary 7 and its subtributaries exhibit good geomorphological conditions, with the exception of some encroachments in residential areas, such as a footbridge, driveway and road crossings and a few riparian areas cleared for grass or gardening. Very little incision has occurred and the streams are generally shallow and well-connected to adjacent floodplain areas. Some photos on Tributary 7 are shown in Exhibit D-7.

Tributary 8

Tributary 8 drains about 156 acres to the west of Homestead Park. This catchment is undergoing rapid development, including the relatively recent construction of several multi-family complexes and the extension of Weaver Dairy Road. Multiple ponds are located at the upper ends of the catchment area, including one on property acquired a few years ago by the Town. Besides the road crossings at Weaver Dairy and Homestead Park Roads, at least three other culvert crossings were observed at driveways and/or old trails.

Stream conditions along Tributary 8 are mixed. A few portions of the stream are somewhat incised, while most reaches seem to have retained a good connection with the surrounding floodplain area. The conditions at the upstream end of the Weaver Dairy Road culvert are particularly odd. Silt fence has been left in place about six to ten feet upstream of the culvert entrance. Sediment and large gravel have accumulated in the area between the fence and culvert

and there is no defined channel there. Photos along Tributary 8 are shown in Exhibits D-8 and D-9.

Tributary 8A

One branch of Tributary 8 drains about 32 acres of area along Homestead Road. Both headcutting and channel incision were observed along this sub-tributary. Immediately downstream of the culvert under Homestead Road, the channel is narrow and relatively deep, roughly two feet deep and two feet wide. A little further downstream, however, the stream branches into several multiple, poorly defined channels. The area at the confluence with Tributary 8, immediately upstream of a driveway crossing with an undersized culvert, exhibits extensive ponding and poor channel definition.

The Homestead Road culvert outlet is perched well above the stream bed and is clearly part an older section of pipe than what is in place on the upstream end, where there is a flared end section at the inlet. Apparently the previously existing pipe was retained and extended upstream when a turn lane was added for a new driveway. There is rip-rap at the outlet, but no scour hole has formed. The culvert outlet may have been somewhat perched when it was installed, but the condition has been aggravated by the channel incision. Photos of the culvert and the incised downstream reach are shown in Exhibit D-10.

Tributary 9

Tributary 9 drains an area of about 33 acres, beginning as a storm drain collection system on MLK Boulevard and running through the Parkside neighborhood, discharging into an unstable area of Reach C downstream of an OWASA crossing. The reach is mostly open channel along property lines or in backyards of single family residences, but includes a 500 foot reach of culvert in the area of Lonebrook Drive. The stream crosses an OWASA easement just upstream of where it discharges into Booker Creek. The stream is completely "mushed out" through the OWASA easement and there is no defined channel. Photos of the stream through the easement and in the wooded area just upstream are shown in Exhibit D-11.

Tributary 10

At the upper end of the catchment area for Tributary 10 are wooded areas on undeveloped properties west of Weaver Dairy Road. Two branches of the tributary flow in culverts under Weaver Dairy Road and Worsham Drive, converging in Town-owned RCD at a point about 400 feet east of Worsham Drive. Photos of Tributary 10 are shown in Exhibit D-12. The downstream reach of Tributary 10 is somewhat incised, but the upper reaches are still well-connected to the surrounding floodplain and have very minimal erosion.

Encroachments into the RCD area were noted during the field observations along this tributary. A property owner had cleared trees and extended his garden well into the RCD area and had also placed a small dam in the stream to facilitate pumping water to his garden. Bamboo had been planted along the stream in the vicinity of this property. Town staff followed up with the property owner to address the encroachment issues.

Tributary 11

Tributary 11 drains roughly 48 acres in the northeast corner of the subwatershed, including areas north of Weaver Dairy Road and a small area east of MLK Boulevard. Upstream of the culvert under Lonebrook Drive, the stream is steeply sloped and there is some evidence of headcutting beginning to move upstream. The headcutting may have been triggered by hydrologic changes due to development or could have been caused by construction of the culvert at a lower invert elevation than the original stream bed. Photos of this area are shown in Exhibit D-13.

Minor Tributaries

Observations of the minor tributaries are based on review of map data, aerial photography and, for some reaches, cursory field observations.

Tributary 1 is a 700-foot reach of intermittent stream draining into the lower end of Lake Ellen.

Tributary 2 is a short, spring-fed stream discharging directly to Lake Ellen. It drains the large, wooded single family area around the lake and is in good condition.

Tributary 4 is classified as ephemeral. Most runoff in the catchment area is collected in a storm sewer system that discharges from the Orange Methodist Church and drains to the 400 foot reach of stream channel.

Tributary 5 is a 200-foot long reach connecting a culvert under Dixie Drive to Booker Creek. Whether the reach was originally a natural stream or was constructed to accommodate the culvert is difficult to tell. It is classified as ephemeral.

Tributary 6 drains approximately 28 acres in the neighborhood north of Lake Ellen, including the ditches along Collums Road. The stream is currently classified as intermittent, but has been tagged for re-evaluation as a possible perennial stream.

Lake Ellen

All areas of the Booker Headwaters subwatershed drain to Lake Ellen. The lake and dam are owned and maintained by the Lake Ellen Homeowners Association. The dam is listed by NC Dam Safety as a high hazard dam.

Lake Ellen has a surface area of about six acres, and is listed by Dam Safety as having a maximum impoundment volume of 120 acre-feet. The topography and soils in the area surrounding the dam seem to indicate that the original stream channel flow path through the lake and dam was approximately due south, joining Crow Branch in the bend at its most northerly point. However, the discharge from Lake Ellen appears to have been re-routed, either at the time of original construction or at a later date, to discharge at the east end of the lake beyond the actual dam. The channel conveying the outflows from Lake Ellen may have once been the downstream end of a small tributary to Booker Creek.

This re-routing of flow has resulted in very severe erosion downstream of the lake. The size of a natural stream is developed over time in response to the overall regime of flows experienced. The dynamics of the adjustment are driven by an energy balance of flows, sediment loads and channel slope. Thus, the increased flows have resulted in channel incision, along with ongoing

stream bank erosion. The channel has cut down to bedrock along most of the reach in a series of natural drops. However, it remains a very steeply sloped channel such that it is unlikely to retain sediment and rebuild a floodplain within the enlarged channel, as would a more typical urban stream. Velocities will remain high, even with the widened channel, and bank erosion is likely to continue. Banks are very steep and as high as 20 feet in some areas. Although the stream is not a candidate for restoration, bank stabilization could be considered if the two property owners involved are amenable to such improvements, including the excavation that would be required to adequately slope back the banks and provide energy dissipation drops and pools along the reach. Some photos of this reach are shown in Exhibit D-13.

The outlet structure for Lake Ellen is a simple concrete weir, approximately 40 feet wide according to the information in the FEMA model. Immediately downstream of the weir, the channel is not eroded and the bed is not incised. The erosion begins at a point between the outlet and the bridge downstream and is extensive in the area of the bridge, even though the bridge structure itself does not appear to be compromised. The outlet structure could be replaced with one that facilitates some degree of extended detention and also incorporates energy dissipation.

In the summer of 2001, the Lake Ellen Homeowners Association petitioned the Town to address concerns about upstream contributions to ongoing sedimentation of the lake. The residents had noted increased sediment accumulation in the lake, particularly over the previous 10 years or so. Several neighborhoods in the contributing watershed were under construction at the time. Town staff investigated the issues and presented a subsequent report to the Town Council, concluding that the sedimentation and erosion control program in place at the time was effective and that the construction activities were being conducted in compliance with the program. Staff also suggested that the HOA establish a lake management program and offered to provide preliminary technical assistance. The HOA again contacted the Town officials and stormwater staff again regarding concerns about sedimentation in the lake during development of the Stormwater Master Plan.

Some precedence in the handling of issues and concerns regarding a private lake in Chapel Hill has been established by the Lake Forest Homeowners Association, who have ownership and maintenance responsibilities for Eastwood Lake. In 2003, they undertook a major renovation project to repair the dam, improve recreational facilities, remove accumulated sediment, and construct forebays to facilitate future sediment removal. Project costs were covered by property assessments on the order of $10,000 to $20,000 per home, with properties adjacent to the lake assessed a higher portion of costs. The forebays were constructed to minimize the sediment carried into the lake and facilitate periodic cleanout of deposited sediments at a relatively low cost. One forebay was cleaned out in the summer of 2009.

History of Citizen Complaints and Previous Assessments

As part of the assessment of the basin, available information from citizen complaints and previous studies was reviewed. The Town of Chapel Hill collected and analyzed monthly water quality samples from Booker Creek downstream of MLK Boulevard from 1995 through 2010. Citizen complaint records have been documented and retained for the past fifteen years or so. The Booker Headwaters drainage area was included in the EEP Morgan/Little Creek study.

Relatively few drainage complaints have been recorded for properties in the Booker Headwaters subwatershed. Most of the construction is either "low-impact" for the streams or was developed with buffers and design storms adequate to prevent flooding problems. Two homeowners, in different areas, complained of offsite drainage ponding in their backyards. Both problems seem to have resulted from drainage patterns that were altered by re-grading associated with residential construction, without adequate planning for relatively small flows that could be adequately handled by grassed swales.

Field measurements for temperature, specific conductivity, dissolved oxygen and turbidity are made when the Town's water quality samples were collected. Monthly analyses included TSS, TDS, fecal coliform and ammonia. Nutrient concentrations were analyzed quarterly. Lead, zinc and copper concentrations were checked twice a year. Table D-1 summarizes the average and maximum concentrations as compared to NCDENR water quality standards. Although too small to be officially listed as an impaired stream at this location, the headwaters likely contribute to the problems causing the downstream reaches to be listed as impaired for aquatic habitat.

Table D-1. Water Quality Sampling Results on Booker Creek at MLK Blvd from 2000 to 2008

Pollutant	Average 2000 to 2008	Max (or Min) 2000 to 2008	NC Freshwater AQ Standard	Jordan Rules wastewater discharge limits
pH	7.17	5.97	6.0 to 9.0	
Dissolved Oxygen	6.60 mg/l	0.01 mg/l	≥5.0 mg/l	
Turbidity	22.57 NTU	2.50 NTU	25 NTU	
Total Suspended Solids	11.77 mg/l	178 mg/l	*regulated as % removal from development sites*	
Fecal Coliform	129.21 per 100 ml	6000 per 100 ml	200 per 100 ml*	
Total Phosphorus	0.11 mg/l	2.14 mg/l		0.18 mg/l
Total Nitrogen	0.65 mg/l	3.60 mg/l		3.0 mg/l
Copper	<10 µg/l		7 µg/l	
Lead	<10 µg/l	40 µg/l	25 µg/l	
Zinc	<10 µg/l	27 µg/l	50 µg/l	

Potential Pollution Sources

In addition to the pollution associated with runoff from developed areas, several potential underground sources of stormwater and/or groundwater pollution are evident within the Booker Headwaters subwatershed. According to Orange County's database, about 30 septic systems are operating within the area. There are no sewer lines in the residential area north of Weaver Dairy Road and 8 septic systems are located in that area within the subwatershed. The neighborhoods around Lake Ellen have sewer service available, but a number of the residents have apparentaly opted to continue to use septic systems. A few septic systems are also scattered at other locations in the subwatershed, typically at older large-lot residences.

The OWASA sewer system in the Booker Headwaters subwatershed is generally newer than in other parts of the Town and thus may be less prone to problems with infiltration or exfiltration. However, there are several mobile home parks in the subwatershed, some with privately installed and maintained sewer collection systems. These are likely to be more susceptible to failures, with a lower probability of prompt attention and correction.

Developed properties within the subwatershed include several with potential to contribute particular pollutants to the nearby streams. A car wash is operated in close proximity to Tributary 3. A large automobile repair facility is operated in the same vicinity, with roughly 50 cars parked there at any given time, many of them apparently junked or stored long term. A training area for the Town's fire department is located near Tributary 12. Improperly routed or managed runoff from these types of facilities can result in pollutant discharges to adjacent streams.

During field reconnaissance, a few areas of significant stream and riparian disturbance by adjacent property owners were noted. In a couple of locations, homeowners had dammed the stream adjacent to their property and were pumping water for use in backyard gardens. There were also instances of over-enthusiastic gardening adjacent to streams and one or two small footbridge crossings. Bamboo had been planted in one area. However, very few roof downspout connections were observed in this subwatershed.

Algae problems were noted in this subwatershed, an indication of a nutrient overload. Sewer or septic system leaks can be a source of additional nutrient loading in a stream. Fertilizer is another oft-cited source. It is possible that fertilizer use is more prevalent in newer neighborhoods where homeowners are trying to establish and maintain lawns, often in soils that were stripped of organic material and heavily compacted during construction.

Existing Stormwater BMPs

Installation of stormwater BMPs have been required in conjunction with the more recent development projects in the subwatershed. Six BMPs were observed during field observations, but it is likely that others have also been constructed. For several existing ponds, it is unclear whether they were constructed as BMPs or simply as stormwater detention ponds.

There are many unknowns regarding the BMPs observed during the pilot basin field reconnaissance. What standards were used in the designs? Were they constructed as designed? Are they functioning as intended? Is the existing vegetation effective for filtration and uptake or have undesirable species taken hold in the pond, wetland or bioretention area?

The present stormwater management program in TOCH, as well as in most NC cities, lacks a comprehensive component to ensure the ongoing effectiveness of stormwater BMPs. Developers are now required to submit as-built's of the BMPs and staff have recently begun inspecting the BMPs to ensure compliance with the designs prior to the Town's issuance of a Certificate of Occupancy (CO). Staff have also begun an effort to set up a database of BMPs as a beginning step in an ongoing effort to ensure periodic inspections and proper maintenance. Enforcement options in the event of a failure to maintain are a particularly critical and thorny concern.

Watershed Analyses

The pilot basin study effort included development of water quantity and quality models, as well as 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. Water quality models were developed to assess the available methodology and make some initial projections of potential nutrient loading from the Ephesus subwatershed. The models developed within the scope of the pilot basin study are referred to as Town of Chapel Hill (TOCH) models, in contrast to models developed by state or federal agencies.

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%, 5%, 2% and 1% annual chance floods were developed. For the Booker Headwater subwatershed, the 1.35 square mile area was divided into eleven subbasins for the analysis. Subbasins were delineated for Tributaries 3, 7 and 8. The other subbasins were delineated along the main stem to correspond with the crossings at New Parkside Drive, MLK Boulevard and some of the confluences with tributaries. Lake Ellen was modeled as the outlet for the subbasin, but was not specifically analyzed as a reservoir.

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 delineated manually based on TOCH contour mapping. Hydrologic soil group GIS data was downloaded from NCRS. The TOCH maintains a mapping of impervious areas and this analysis is based on 2008 data. 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 based on the soil group, the vegetative cover, and percentage of impervious area. AN estimate was also made of the percentage of impervious cover directly connected to the drainage system, based on the amounts located within rights-of-way as well as field observations, aerial mapping and GIS databases of the storm drain system. The input for the HMS subbasins is summarized in Appendix C.

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, MLK Boulevard, the confluence of Tributary 8, Parkside Drive and the confluence of Tributary 10.

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 Booker Creek is the basis of the floodplain delineation in the Flood Insurance Rate Map (FIRM) covering the Ephesus subwatershed. The model was developed as a detailed study in the FEMA restudy for Chapel Hill streams, with the FIS and FIRMs published in February 2007. The model includes Booker Creek up to a point about 500 feet upstream of MLK Boulevard.

For the TOCH HEC-RAS model, the Booker Creek FEMA model was extended up to a point about 1800 feet upstream of New Parkside Drive, at a confluence of two branches. Tributary 8 was also modeled as a separate reach, from the confluence with Booker Creek up to Weaver Dairy Road. Additional cross-sections were cut as needed on LIDAR downloaded from NCFMP in 2008. Upstream and downstream surveys were done at most of the modeled culverts. 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 MLK Boulevard, Parkside Drive, Weaver Dairy over Tributary 8 and a driveway over Tributary 8.

Results of Quantity Modeling

The TOCH models predict higher flows and somewhat higher elevations in the area around Lake Ellen. The projections for the crossing at MLK Boulevard correspond closely with the FEMA model, predicting overtopping in the 1% annual chance flood, but passing all of the more frequent storm events through the culvert without overtopping. The extended HEC-RAS model indicates the other road crossings included in the subwatershed model are not expected to be overtopped. Neither the FEMA nor the TOCH models have been calibrated and validated for the Booker Headwaters subwatershed.

Table D-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)
Lake Ellen	1210	1532	434.01	435.16
MLK (Airport) Road	1010	1028	478.93	478.84
Parkside Drive	Not modeled	611	n/a	492.34
Trib 8 Weaver Dairy Rd	Not modeled	217	n/a	501.69

The HEC-HMS model projects significant attenuation of floods in the natural floodplains on Tributary 8 and on Booker Creek north of Parkside Drive. The Booker Creek floodplain areas are preserved in Town-owned park or RCD area. However, Tributary 8 is undergoing development and does not have a FEMA-regulated floodplain. If placement of fill is permitted in floodplain areas outside of the RCD, some of the storage capacity could be lost and downstream areas may experience some impacts.

Culverts for perennial streams under MLK Boulevard, Homestead Road and Weaver Dairy Road were checked for hydraulic adequacy. The Weaver Dairy Road culverts are all newer and seem to have been sized for build-out conditions. The 48" RCP culvert on Tributary 3 under MLK Boulevard is undersized and is projected to slightly overtop in a 25-year storm. Backwater would inundate a parking lot full of stored vehicles at a repair shop. Additional upstream development could further increase the risk of overtopping. The 36" RCP on Tributary 8A under Homestead Road passes the 50-year for existing conditions, but most of the upstream area is still undeveloped. Further development of the contributing watershed for either of these culverts could increase frequency of flooding on the roadways.

Stream Morphology/Stability Assessment

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 B on the main stem in Homestead Park, one on Reach C and one on Tributary 8. Specific characterizations of stream bed materials were not done. Sand and silt were the most prominent materials in the stream bed at the three locations, but likely result from an oversupply of sediment to the stream and are not representative of natural bed materials. Key section measurements and characteristics are listed in Table D-3. In spite of the relatively low entrenchment ratios, a number of the streams in the Booker Headwaters seem to be unstable and show early signs of the typical evolution that has come to be expected in streams responding to the hydrological changes associated with urbanization. Both sections on the main steam have banks which are undercut at the bottom. Perched culverts, often indicative of downcutting of the channel bed, were observed on some of the tributaries.

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

Parameter	Reach B	Reach C	Trib 8
Entrenchment Ratio	10.1	4.6	23.2
Width-to-Depth Ratio	6.8	7.8	4.2
Bank Height Ratio	1.0	1.9	1.1
Estimated Slope	0.007	Less than 2%	0.007
Sinuosity	Moderate to High	Moderate to High	Low to Moderate
BEHI Rating	25-36	17-22	18-25

Bank Erosion Hazard Indices for the subwatershed range from moderate for Reach B and Tributary 8 to high for Reach C. Numerical BEHI ratings are listed in Table D-3. Inhibiting downcutting of the stream beds may be a sufficient measure to limit the extent of further stream degradation in the subwatershed.

Potential Stormwater Projects

Within the Booker Headwaters subwatershed, the targeted stormwater management priorities should be inhibiting stream degradation and improving water quality. The structural projects proposed herein are aimed at establishing grade control in areas where the streams are beginning to downcut, maximizing the effectiveness of BMPs already in place and installing retrofit opportunities at location where it is most cost effective to do so. Although there are some indications of stream degradation within the subwatershed, stream restoration is not warranted and should not be undertaken in areas still undergoing rapid development. No culvert replacements are proposed for the subwatershed, although developers should be required to assess the adequacy of downstream culverts in light of proposed projects and replace as needed. Conceptual plans and cost estimates for projects will be integrated into Infrastructure and Water Quality CIPs or added to the Small Maintenance Projects Program.

Water Quality/Stream Stability

1. Install grade control structures at intermediate points along the main stem and tributary 8 to limit downcutting of the stream bed and minimize bank erosion. The structures could be constructed of concrete, gabions, boulders or a combination of materials. Consideration should be given to establishing these points at OWASA crossings and constructing them in a manner acceptable both to OWASA and to TOCH Stormwater Management Division. Grade control structures need to be constructed such that they will remain stable as drop structures should erosion occur on the downstream side. The structures could be installed with Town forces, under a construction contract for a larger project, or as separate projects for a number of structures at different locations. Portions of the stream reaches are within private properties, but much of the stream length requiring grade control is within park and RCD areas owned by the Town.

2. Monitor several large existing BMPs and upgrade as needed. TOCH should consider seeking grant funding to monitor and potentially upgrade up to four relatively large BMPs in this subwatershed: the large bioretention facility at the apartment complex on Tributary 3, the stormwater wetland draining the baseball field in Homestead Park, the wet pond draining the aquatic center and parking area in Homestead Park and the wetland draining the apartment complex on Tributary 8. The additional assessment of these facilities in regard to nutrient removal would enhance the Town's (and the State's) knowledge of how well recently designed and installed BMPs are functioning relative to the Jordan rules. Monitoring from several storms over the course of the year should provide sufficient information on which to base plans for improvements to the BMPs and/or changes to ordinances or design guidance. Improvements to the BMPs should be undertaken if the data indicates that inadequate nutrient removal. Changes may include soil media replacement, vegetation changes, grading changes and replacement of outlet structures. For the privately owned BMPs, the Town would have to fund the desired improvements and would have to obtain agreements from property owners and possibly also easements.

3. Restore and enhance the existing farm pond on Town property along Tributary 8. The dam for the pond has some seepage and is overgrown with bamboo. The pond is proposed to be cleaned out and retrofitted as a stormwater management facility, possibly

utilizing funds from developers upgradient who could mitigate their impacts with the pond upgrade. The dam and outlet structure should be replaced and the accumulated sediment removed. Other possible options include enlargement of the lake, incorporation of extended detention, wetland islands, forebays and a littoral shelf.

4. Install BMPs at discharge points to Booker Creek north of Parkside Drive where enhancement of pollutant removal is projected to be cost effective. Some pollutant removal at these outlets is already occurring through filtration and sedimentation. Space may not be adequate to establish a maximally effective BMP.

5. Install NCEEP-recommended BMPs along MLK Boulevard. The NCEEP report included conceptual plans for four small BMPs in this area.

6. Improve the water quality function of Lake Ellen. As with virtually any wet pond, Lake Ellen already provides some water quality improvement to the downstream area. The observations and complaints of nearby residents confirm that the lake traps sediments and it likely captures other pollutants as well. There are three possible courses of action for consideration:

   The "do-nothing" option is for the Town to continue to allow the privately owned lake to serve its somewhat unintended water quality functions. If and when the residents become dissatisfied with the state of the lake and decide to take action at their own expense, the Town has regulatory oversight and can ensure that the cleanout and any proposed improvements are done in a manner consistent with overall Town goals. Option 1 follows the Eastwood Lake precedent. Lake Ellen would remain a private access facility and no enhancements to the water quality functions are likely to be undertaken.

   As has been offered by the Town, the HOA could opt to allow the lake to become a public facility and turn over ownership and maintenance to the Town. The Town would then have the responsibility of seeking to maximize the public benefit of the lake, including pollutant removal as one factor to be considered. A littoral shelf, an improved outlet structure, forebays and extended detention are some of the features that could be considered for possible improvements in the function of the lake.

   A third option would be some type of public-private partnership arrangement, under which the HOA funds their own cleanout work and any enhancements done for their own benefit (e.g. forebays). The Town could offer to fund enhancements undertaken for public benefit, such as a new outlet structure to facilitate extended detention and incorporate energy dissipation.

7. Stabilize the banks downstream of the Lake Ellen outlet in order to prevent further streambank erosion and downstream transport of the associated sediments. Improvements to the reach downstream of Lake Ellen should only be undertaken in conjunction with or subsequent to resolution of issues related to maintenance and enhancement options regarding the lake itself. The primary benefit of restoring this

reach would be the stabilization of the banks and the prevention of continuing movement of sediment for the banks into Booker Creek. However, it is expected that costs for improvements will be high relative to the potential benefits. The ongoing capture of sediment in the forebay of Eastwood Lake is likely a more cost effective measure than incorporating bank stabilization in this reach, as long as no structures are expected to be threatened by the ongoing erosion.

Flooding/Infrastructure

Replace undersized culvert on Tributary 3 under MLK Boulevard to reduce frequency of overtopping and flooding in backwater areas.

Exhibits

Downstream end of Reach A

Upstream end of Reach A

Exhibit D-1. Photos of Reach A, Booker Headwaters

Exhibit D-2. Photos of Reach B in Homestead Park

Wet pond behind aquatic center

Stormwater wetland near baseball fields

Exhibit D-3. Photos of BMPs at Homestead Park

Exhibit D-4. Photos of Reach C, Booker Headwaters

Mobile home close to the bank of Trib 3

Carwash with paving to the bank of Trib 3

Exhibit D-5. Photos of Floodplain Encroachments on Tributary 3

Bioretention BMP

BMP discharge area

Exhibit D-6. Photos of BMP on Tributary 3

Exhibit D-7. Photos of Stream Reaches on Tributary 7

Tributary 8 reach between Homestead Park Road and driveway crossing

Area on Tributary 8 upstream of driveway crossing and Tributary 8A confluence

Exhibit D-8. Photos of Downstream Reaches on Tributary 8

Tributary 8 downstream of Weaver Dairy Road

Tributary 8 upstream of Weaver Dairy Road

Exhibit D-9. Photos of Upstream Reaches on Tributary 8

Downstream of Homestead Road on Trib 8A

Downstream end of Homestead Road Culvert

Exhibit D-10. Photos of Stream Reaches on Tributary 8A

OWASA crossing on Tribuary 9

Looking upstream from OWASA crossing

Exhibit D-11. Photos of Stream Reaches on Tributary 9

one of the upstream reaches

downstream of Parkside Drive

Exhibit D-12. Photos of Stream Reaches on Tributary 10

downstream of Lonebrook Drive

upstream of Lonebrook Drive

Exhibit D-13. Photos of Tributary 11

Exhibit D-14. Photos of Reach Downstream of Lake Ellen