Town of Pembroke, North Carolina
and
University of North Carolina - Pembroke

Hydrologic Study Report

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EXECUTIVE SUMMARY

The Town of Pembroke and the University of North Carolina at Pembroke (UNC-P) have been plagued with consistent flooding issues for decades. Every few years the Town and UNC-P's campus experience moderate flood conditions that inundate roads and structures. Severe flooding in late 2016 caused by Hurricane Matthew and in 2018 by Hurricane Florence increased awareness for the need to take preventative action. The Town, located within the Bear Swamp Watershed and the Lumber River Watershed, consists of a stormwater conveyance infrastructure that is in need of analysis. MacConnell and Associates (M&A) has conducted this Hydrologic Study on a macro level that can be utilized as a basis for future detailed design and construction activities.

To address the frequent flooding events within the town and on the UNC-P campus, the project has been broken down into two phases. The short term phase addressed immediate concerns within the three main corridors that convey stormwater through the town, while the long term phase will address other parts of the town outside of the three main stormwater corridors.

M&A reviewed previous hydrologic reports for the area to identify any existing recommendations, note any changes to the stormwater infrastructure, and gather a snapshot of the condition of the drainage area. M&A reviewed topographic maps to delineate drainage areas that discharge through the town to determine the hydrologic study area boundaries. Site reconnaissance were then conducted to assess the condition of the conveyance measures throughout the town and on the UNC-P campus. An assessment of contaminated soil, groundwater, and surface water was conducted to ensure any recommendations do not provide conduits for further expansion of contaminated environmental media. The United States Fish and Wildlife Service was contacted to determine if habitats of threatened or endangered species are affected by current flooding events or recommended improvements.

Recommendations were then provided for the short term and long term portions of the project. Short term recommendations are provided under separate cover (see Hydrologic Study – Short Term Recommendations drawings prepared by M&A dated April 20, 2018). Short term and long term recommendations were designed to provide adequate conveyance of stormwater through the town and UNC-P for the 25-year storm without hydraulic gradient lines exceeding top of structures.

Long term recommendations include upsizing existing structures, removing conveyance impedances, and rerouting stormwater through new or existing conveyances.

1.0 INTRODUCTION

1.1 Town of Pembroke

Pembroke is a 2.3 square-mile town located in Robeson County in the southeast portion of North Carolina. The Town of Pembroke was established in 1895 and was named for the railroad official Pembroke Jones at the end of the 19th century. According to City-Data.com, the town has a population of approximately 3,011 (as of 2014). The town is the tribal seat of the state-recognized Lumbee Tribe with approximately 66% of its population identifying as part of the Native American tribe. Additionally, 16% of the town's population identify as White American, 14% as Black American, and 4% identified as another ethnicity. The Town of Pembroke has historically battled with poverty, with approximately 53% of its population below the poverty line (Census.gov) and a median household income of $17,147.

1.2 University of North Carolina at Pembroke

The Town of Pembroke is home to the University of North Carolina at Pembroke, (UNC-P). Founded in 1887, UNC-P is a public, co-educational, liberal arts university that is part of the 16-campus University of North Carolina System. Beginning as the "Croatan Normal School", offering elementary and secondary level education, it was moved to its present location in 1909. In 1972 the General Assembly established Pembroke State University, as one of the constituent institutions in the University of North Carolina System. On July 1, 1996, Pembroke State University officially became The University of North Carolina at Pembroke.

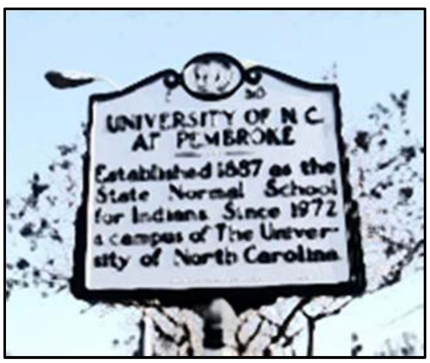


Figure 1: UNC-P Historical Marker on Old Main Road

As of the fall semester of the 2018 school year, UNC-P has set a new enrollment record of 7,137 students, up 14% from 2017 fall enrollment. UNC-P offers 41 undergraduate programs and 17 graduate programs and boasts a 16:1 student to faculty ratio. Composed of five residence halls, the campus is capable of housing approximately 1,460 students with much more off-campus housing close by. The athletic program at UNC-P offers six men's sports and eight women's sports and is part of the National Collegiate Athletic Association Division II Peach Belt Conference.

1.3 Flooding Problems

The Town of Pembroke and UNC-P have been in need of flood mitigation for decades. The Town of Pembroke and UNC-P have had numerous flooding events that have inundated roads and structures from heavy rainfall. Often, stormwater backs up into the town and on-campus that shuts down roads, cancels UNC-P classes, closes businesses, and causes damages to private and public property due to elevated water levels. At the issuance of this report, the most recent flooding event reportedly occurred on May 17, 2018 when water inundated the Gough Street and 1st Street intersection, Barker Street at the stormwater channel crossing, Bonnie Road between 1st and Garden Streets, and the Vance and Second Streets intersection. These areas are the first areas to flood with the following areas within the Town of Pembroke and on the UNC-P campus also prone to inundation:

- Cypress Hall north parking lot;
- Braves Drive and University Drive
- Alumni Lane and Lot 12 parking lot;
- Vance Street and Clifton Street channel crossings;
- 604 Harry Lane West Extension;
- Maynor Manor neighborhood;
- Old Main Road and Lot 3 and Lot 4 parking lots;
- North Jones Street.

1.4 Hurricane Matthew Impact

Hurricane Matthew emphasized the need for flood mitigation by bringing rainfall amounts that caused floodwater elevations to rise higher than ever recorded. Hurricane Matthew traveled along the coast of North Carolina and brought heavy rainfall to the eastern portion of the state between October 8 and 9, 2016. 36-hour rainfall totals surpassed record rainfall amounts for the area at that time with Pembroke receiving more than 12 inches of rain during that timeframe. The region had already received heavy rainfall a week earlier that caused water levels in rivers and streams to swell and adequate time had not passed to allow these rivers and streams to return to normal conditions. The elevated water levels along with historic rainfall amounts caused rivers and streams to surpass historic water level records. The nearest river gauge stations to Pembroke are located upstream at NC Highway 710 on Lumber River, approximately one mile west of Pembroke town limits, and downstream in Lumberton on the Lumber River, approximately 7.2 miles east of the town limits. On October 11, 2016 the

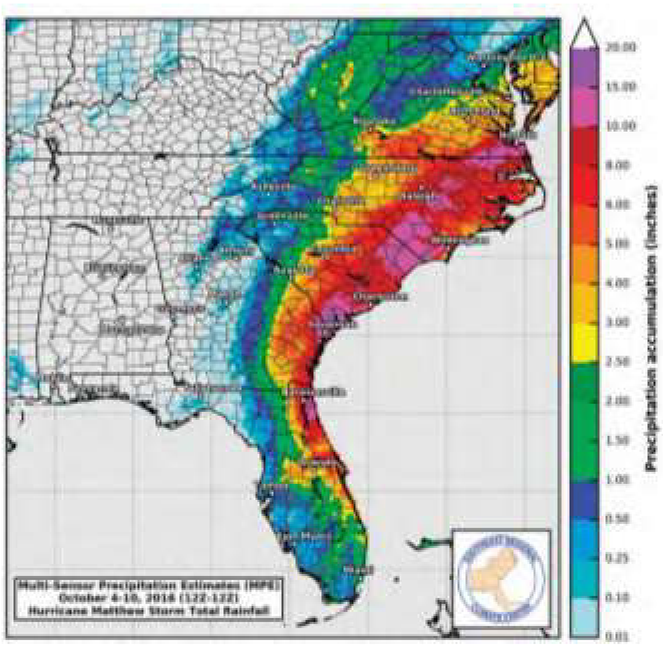


Figure 2: Accumulation of precipitation in the southeastern United States caused by Hurricane Matthew

upstream river gauge observed a record peak stage of 13.43 feet; 4.43 feet above action stage, 3.43 feet above flood stage, and 3.00 feet above its previous record peak stage observed September 10, 2008. On October 9, 2016 the downstream river gauge observed a record peak stage of 24.39 feet (preliminary); 12.39 feet above action stage, 11.39 feet above flood stage, and 3.91 feet above its previous record peak stage observed on September 11, 2004 (Hurricane Frances).

Reports of flooding in Pembroke started late in the morning of October 8 and floodwaters stayed for several days. Buildings and roads were inundated, power outages were reported, and countless homes, cars, and structures were damaged. High water levels were observed reaching the tops of road signs, tops of cars, and up to the roofs of some buildings. The University of North Carolina at Pembroke closed its campus on October 10, 2016 and students were strongly encouraged to go home. Power was restored to the area days later and classes did not resume until more than a week after the hurricane passed.

Figure 3: Main Street during Hurricane Matthew

Figure 4: Barker Street and First Street one day after Hurricane Matthew

Figure 5: North Jones Street during Hurricane Matthew

1530 individual assistance claims were filed to FEMA from Pembroke citizens following the flooding. Pembroke was only a small portion of the total damages caused by Hurricane Matthew. The majority of the population that obtained damages to personal property were not insured with flood insurance. Following the hurricane, North Carolina and the Federal government passed legislature to provide financial assistance to those who obtained property damages that were not insured. The Town of Pembroke was awarded a grant by the Golden LEAF Foundation to provide upgrades to the Town's stormwater drainage system to aid in the conveyance of stormwater through the Town in an attempt to mitigate flooding from lesser storm events. A summary of the upgrades is discussed in Section 1.4.

1.5 Hurricane Florence

Less than two years after Hurricane Matthew, the Town of Pembroke experienced another hurricane that brought torrential rainfall totals that caused severe flooding throughout the Town. Hurricane Florence first began affecting the Town on September 13 as it approached the coast of North Carolina from the southeast and turned west off the coast of Wilmington. As the hurricane approached land, the movement slowed down and brought heavy rainfall for an extended period of time. The eye of the hurricane made landfall near Wrightsville Beach, NC at 7:15 am on September 15, 2018. There the hurricane moved at approximately three miles per hour and rained for more than three days. Preliminary rainfall totals estimate the area received higher total rainfall depths than experienced during Hurricane Florence.

2.0 HYDROLOGY AND HYDRAULICS

2.1 The Hydrologic Cycle

The hydrologic (water) cycle illustrates how water travels between the oceans, the atmosphere, and land by utilizing its physical, chemical, and biological phases. There are many different paths water can take within the hydrologic cyclic such as; being trapped within polar ice caps for millions of years, it may flow into river and streams and eventually back to the ocean, it may be absorbed by vegetation and transpire into the atmosphere, it may infiltrate and percolate through porous soil surfaces into ground water reservoirs. During these different phases people tap into these reservoirs to use water for farming, electrical uses, consumption, common house hold needs, commercial/ industrial business uses, and for various other uses. However, after usage the water quality, if not treated, can cause water contamination downstream. Within the scope of this projects M&A used the process of the hydrologic cycle to determine the appropriate amount of water that flows through the Town.

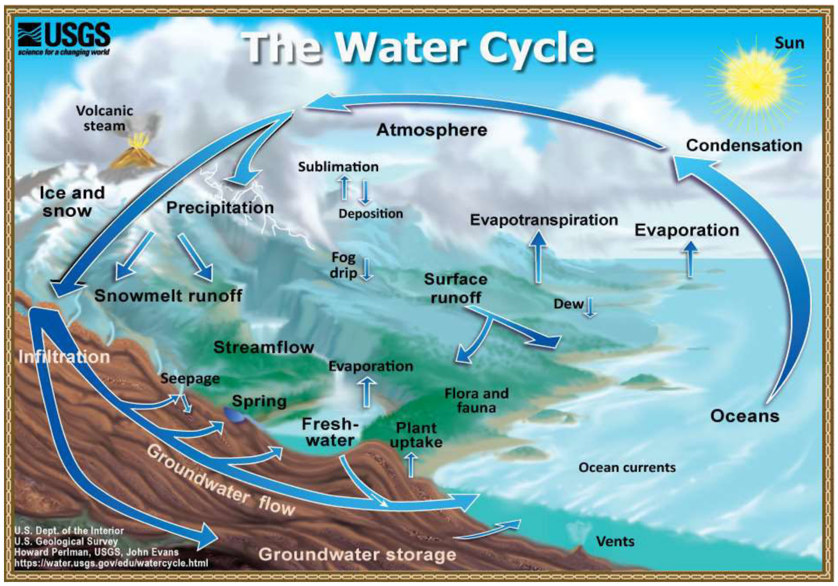


Figure 6: The Hydrologic Cycle

Runoff

Stormwater that does not infiltrate into the ground will flow overland exits the watershed. When quantifying runoff, volume and peak flow rates are the two main considerations for flood condition identification. A large volume of runoff may flow through a stormwater system without creating flood conditions if the system can adequately convey the peak flow rate. If the stormwater system does not allow the peak runoff flow rate to travel through the system, then a small volume of runoff may create flood conditions.

The main factors that contribute to the amount of runoff that will be generated from a rainfall event are rainfall intensity, land cover, and watershed area. Rainfall intensity affects runoff volume in that an intense storm event that introduces a large amount of stormwater to the watershed in a short period of time and soils may not allow infiltration at the rate of rainfall; therefore, increasing runoff. Land cover controls the infiltration rate of stormwater into the ground. Impervious areas have a very high runoff rate since stormwater cannot infiltrate the ground. Wooded areas have a low runoff rate because underbrush and leaf litter slow water flow across the land surface and allow for higher rates of infiltration. These two characteristics combined form the quantity of rainfall per area of watershed. The larger the watershed, the higher the volume of runoff from the watershed.

Infiltration

Infiltration is the key process in maintaining good hydrologic conditions. Most rainfall infiltrates into the ground, recharging soil water and bringing it up to field capacity (amount of moisture content held in soil). Following infiltration and soil recharge, the water moves down through the soil into groundwater, where it is available for use. Once the soil is fully saturated (has reached full moisture capacity), the remaining rainfall conveys as runoff into the applicable stream. This is referred to as "base flow". A significant decrease in infiltration results in an increase in surface runoff, increasing erosion of soils and flooding due to an increase in "peak flow".

There are four types of stream flow responses to rainfall. A "Type 0" response is one in which there is low antecedent soil moisture and low rainfall intensity, thus the soil absorbs the entire amount of the rainfall and no response occurs. A "Type 1" response describes an infiltration rate which is high and a moderate intensity of rainfall, thus all of the rainfall infiltrates and moves as interflow or groundwater flow into the stream to create the hydrograph peak (the base flow increases after the event). A "Type 2" response describes a low infiltration capacity and a high rainfall intensity, thus the majority of the rainfall travels as overland flow. A "Type 3" response is a combination of a Type 1 and 2.

The slope of the land can control the amount of time the stormwater has to infiltrate into the ground. In general, steeper slopes contribute more runoff than shallow slopes because stormwater will travel across the land surface faster, allowing less time for infiltration.

Hydrologic Soil Groups

Soils are classified into four major categories: A, B, C, and D. Category A has highly permeable soils with a water infiltration rate of greater than 0.30 in/hr. Typical soils textures for Category A are classified as sand, loamy sand, or silt. Category B has moderately permeable soils with a water infiltration rate of 0.15-0.30 in/hr. Typical soil textures for Category B are classified as sandy loam or silty loam. Category C has low permeable soils with a water infiltration rate of 0.05-0.15 in/hr. Typical soil textures for Category C are classified as sandy clay, clay loam, silty clay loam, sandy clay loam, and loam. Category D has very low permeability and high runoff potential, consisting with a water transmission of 0-0.05 in/hr. Typical soils are classified as clay or silty clay. The typical hydrologic soil groups for the United States is located in Appendix A. For this project the web soil survey website was used to determine the accurate soil groups within the Town. The runoff CN for urban areas is listed in Appendix A.

Land Cover Type

Cover type refers to all the different types of surfaces associated within the drainage area, such as wooded vegetation, bare grass, bare soil, and impervious areas such as sidewalks and roads. Two tables corresponding the urban cover type and its related curve number can be found in Appendix A.

Hydrologic Condition

Hydrologic condition refers to how the cover type and treatment can affect runoff. Typically, this is defined by the density of vegetation. The USDA recommends the following factors to consider when estimating hydrologic conditions: "(a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year-round cover; (c) amount of grass or close-seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness."

Runoff Coefficient

The runoff coefficient is a dimensionless value that represents the amount of runoff for a given drainage area. The value considers the characterization of the soil and land use (see Appendix; Table 1). To determine the runoff coefficient each drainage area was divided into groups which were based on the usage of the land. The final runoff coefficient was determined by averaging the runoff coefficient for each group. For areas with mixed land use, the appropriate runoff coefficient was determined with the aid of aerial images site visits.

Rainfall Intensity

The rainfall intensity is derived using historic rainfall data, as well as using rainfall trends to determine the average intensity for a specific area. Rainfall intensity is given in inches per hour and is associated with a predetermined time of concentration. For this project the National Oceanic and Atmospheric Administration (NOAA) was used to determine the time of concentration for the Town. See Appendix A for the point precipitation frequency estimates from NOAA.

Drainage Area Delineation

Drainage areas were defined for every major drop inlet using AutoCAD Civil 3D. Several considerations were taken into account while delineating the drainage areas such as: streets, ditches, and man-made developments, and natural topography. By taking these factors into account a drainage area was created to show the watershed extent to each discharge point (i.e. drop inlets). The majority of drop inlets within the three corridors were delineated with drainage area for the most accurate modeling. However, larger drainage areas were developed for areas outside of the Town since their effects on the drop inlets were minimal.

2.2 Hydraulics

Hydraulics is defined in Merriam-Webster's dictionary as "a branch of science that deals with practical applications (such as the transmission of energy or the effects of flow) of liquid (such as water) in motion." During natural processes such as rainfall, water that is unable to permeate naturally into the ground, often referred to as stormwater runoff, makes its way into the natural or manmade conveyance systems. This volume of water is then measured to determine a discharge rate. The determined discharge rate is the main factor used to properly size new conveyance systems so as to be sure they are capable of handling the volumes of water that accumulate during natural events. The calculations used to design these conveyance systems are only concerned with the surface runoff portion of the hydrological cycle as it is the major result of manmade developments which prevent water from permeating into the ground naturally. Thus, in evaluating surface runoff, it is necessary to first evaluate the topography of the area in order to ascertain where surface runoff collects and is subsequently conveyed.

Manning's Equation

Manning's equation is an empirical equation, hence the experimentally-derived roughness coefficient, that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope. It is possible to ascertain an optimal channel geometry based on this equation:

$$Q = VA = A\frac{1.49R^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$

Where: Q = Flow Rate, (ft^3/s)
V = Velocity, (ft/s)
A = Flow Area, (ft^2)
n = Manning's Roughness Coefficient
R = Hydraulic Radius, (ft)
S = Channel Slope, (ft/ft)

Time of Concentration

The time of concentration is the time required for a drop of water to travel from its furthest hydraulic point to the discharge point. The time of concentration varies typically as a function of the topography of the land, the arrangement of any conveyance system, and depending on the type of flow characterizing the stormwater runoff (sheet, shallow concentration, open channel, and pipe flow). There are two methods for deciding the time of concentration; the NRCS method and the velocity method.

The velocity method was primarily used for this, which was developed by the National Resources Conservation Services (NRCS). The velocity method is the summation of travel times based on three parameters; sheet flow, shallow concentrated flow, and open channel flow. This relation is described in the following equation:

$$Tc = T_{t1} + T_{t2} + T_{t3} + \cdots + T_{tn}$$

Where: Tc = time of concentration, (h)
$T_{t(n)}$ = travel time of a segment n, (h)
n = number of segments comprising the total hydraulic length

The travel time is a ratio between a length of the flow path to its velocity, as described in the following equation:

$$T_t = \frac{L}{3600V}$$

Sheet Flow

Sheet flow consists of stormwater that travels in a sheet-like pattern over the land surface. Sheet flow is defined by USDA as "flow over plane surfaces. It usually occurs in the headwater of streams." Manning's roughness coefficient (friction value) for sheet flow is shown in Table 2 in Appendix A. Sheet flow is limited to a maximum of 300 linear feet before it becomes shallow concentrated flow. The following equation defines sheet flow:

$$T_t = \frac{0.007(nl)^{0.8}}{(P_2)^{0.5}S^{0.4}}$$

Where: Tt = travel time, (h)
n = Manning's roughness coefficient (see Table B-2)
l = sheet flow length, (ft) when l < 300 ft.
P_2 = 2-year, 24-hour rainfall, (in)

S = slope of land surface, (ft/ft)

Shallow Concentration Flow

As sheet flow continues across the land surface rivulets begin to form as stormwater droplets naturally choose preferential pathways of least resistance. As these rivulets form and multiple rivulets begin to converge, a shallow-concentrated flow is created. The different types of shallow concentration flows as well as their corresponding velocity equations are described in Appendix A.

Open Channel Flow

The velocity follows Manning's Velocity which is a function of the slope and flow type. When the flow travels through a defined channel it is considered open channel flow. The following equation defines how to determine the velocity through an open channel:

$$V = \frac{1.49 R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \qquad R = \frac{a}{P_w}$$

Where: V = average velocity, (ft/s)
R = hydraulic radius, (ft)
A = cross-sectional flow area, (ft^2)
P_w = wetted perimeter, (ft)
S = slope of hydraulic grade line (channel slope), (ft/ft)
n = Manning's n value for open channel flow

Pipe Flow

Another form of flow that stormwater runoff typically goes through is pipe flow. Similarly to open-channel flow, water flowing in a pipe will experience friction losses that ultimately affect the flow velocity. When there are multiple pipes in series with bends and changes in elevation, friction losses may accumulate and have a reasonable effect of the overall flow rate. For this analysis, the Hazen-Williams method was used in order to determine the proper flows in this project.

The Rational Method

The Rational method is one of the two methods commonly used to determine the peak flow through a particular drainage area using the following equation. The empirical runoff coefficient, C, is a tabulated value designated in the table following this equation, and is designated based on a given area's "land use":

$$Q = CIA = \left(\sum CA\right) I$$

Where: Q = Flow Rate, (ft3/s)
C = runoff coefficient
I = rainfall intensity (inches/hour)
A = drainage area (acres)

NRCS Runoff Curve Number Method (SCS, or TR-55 Method)

While the rational method is meant for smaller watersheds, the NRCS runoff curve number (CN) method is used to determine runoff from larger watersheds. The NRCS method is also commonly referred to as the SCS or TR-55 Method. The following equation is used to determine the NRCS runoff method:

$$Q = \frac{(P - 0.2S)}{(P + 0.8S)}$$

$$S = \frac{1000}{CN} - 10$$

Where: Q = runoff, (in)
S = potential maximum retention after runoff begins, (in)
P = precipitation, (in)
CN = NRCS curve number (see Appendix A)

The NRCS curve number (see Appendix A) is determined using the hydrologic soil groups (HSG), cover type, treatment, hydrologic conditions, and antecedent runoff conditions (ARC).

Potential Maximum Retention After Runoff

The potential maximum retention after runoff is a storage factor calculated for each soil type as a function of the established curve number for each area. This refers to the amount of water a soil type can retain in a rainfall scenario before the majority, or all of the rainfall begins going directly toward runoff as opposed to infiltration.

2.3 Computer Modeling

AutoCAD Civil 3D, Storm and Sanitary Analysis (SSA), and HEC-RAS were used to aid with the stormwater analysis for the Town. These programs were used to map out the storm drainage system, and to conduct the hydrological and hydraulics calculations.

AutoCAD Civil 3D provides a platform to create and analyze topographic data. By incorporating the latest QL2 LiDAR data, we were able to obtain the most accurate topographic data for the Town. AutoCAD Civil 3D also allows the users to model the stormwater pipe network. This was developed using aerial imagery, survey information, and site visits. Civil 3D incorporates the Rational Method in order to determine the drainage area, C values, and time of concentration. The information Civil 3D is then transferred over to SSA in order conduct the hydraulics calculations.

SSA takes the information from Civil 3D and using the Rational Method, determines the capacity of each conveyance measure (pipes, ditches, etc.). Multiple iterations can be run to simulate either the 1-year, 5-year, 10-year, 25-year, 50-year, or 100-year storm events. The results are then analyzed to show areas of concern.

HEC-RAS is a program that was designed by the U.S. Army Corps of Engineers. It is a river analysis system software to perform one-dimensional steady flow and un-steady flow river hydraulics calculations. HEC-RAS is used by the Federal Emergency Management Agency (FEMA) in order to create flood maps. In this project HEC-RAS was used to investigate culvert crossings along Bear Swamp and the effects of the 25-year and 100-year storms within the Town.

<u>New Survey Information</u>
M&A contracted Johnny W. Nobles & Associates to obtain survey information at points of interest within the Town. The survey included pipe sizes, pipe type, invert elevations, and cross sections of ditches. The survey data provided was used as control points to determine the remaining inverts within the pipe network.

<u>M&A Site Investigation</u>
M&A took several site visits to the Town to determine the pipe network, size of ditches, and the overall flow path of the stormwater. The finding and results were then incorporated within the SSA modeling.

3.0 DRAINAGE ANALYSIS

3.1 Flood Zones

The Federal Emergency Management Agency (FEMA) partners with states and communities to provide Flood Insurance Rate Maps (FIRM) that identify flood zones along hydrologic features to provide flood hazard and risk data. These maps identify areas that have a 1% annual chance and a 0.2% annual chance of experiencing flooding conditions that pertain to a minimum of 1-foot inundation (flooding) that would occur once every 100 or 500 years respectively. These events are referred to as 100-year and 500-year storms, each with correlating flood zones. These maps are used to provide property owner's guidance on the need for flood insurance and establishes flood insurance requirements and regulations.

It should be noted that the FIRM maps provide two forms of flood data; the Effective and the Preliminary flood maps. The Effective FIRM maps provide flood data that has been recorded and approved historical flood data. The Preliminary FIRM flood maps provide more up to date flood data that has yet to be approved.

Effective FIRM maps available for the Town of Pembroke indicates there is an approximately 0.04-acre area that is located in the 100-year flood zone and an additional 0.84 acres located in the 500-year flood zone. Preliminary FIRM maps indicate that the 100-year flood zone has expanded in this area to be approximately 7.25 acres with approximately 0.84 acres located within the 500-year flood zone, indicating that areas once thought to be outside of 100-year flood zone are now inside. Fortunately, only one residential structure is located within the Preliminary 100-year flood zone. A map of the 100-year and 500-year flood zones within the town limits and on UNC-P's campus are located shown in Appendix A.

This area is located in the northern portion of the town at the Bear Swamp outfall of the stormwater corridor adjacent to the north-south railroad. This zone of flooding is caused by insufficient culvert capacity at the north-south railroad and Bear Swamp crossing. What the FIRM map does not show is that the stormwater channel discharging into this 100-year flood zone actually serves as a conduit for floodwaters to enter developed portions of the town that are not identified as being within the 100-year flood zone. This flood zone is further discussed in Section 7.0, Recommendation #7.

Additional areas within the Town of Pembroke are located within the 1% and 0.2% annual chance of flooding zones on the FIRM map, but are generally encompassed within the stream buffer of Bear Swamp or the Lumber River.

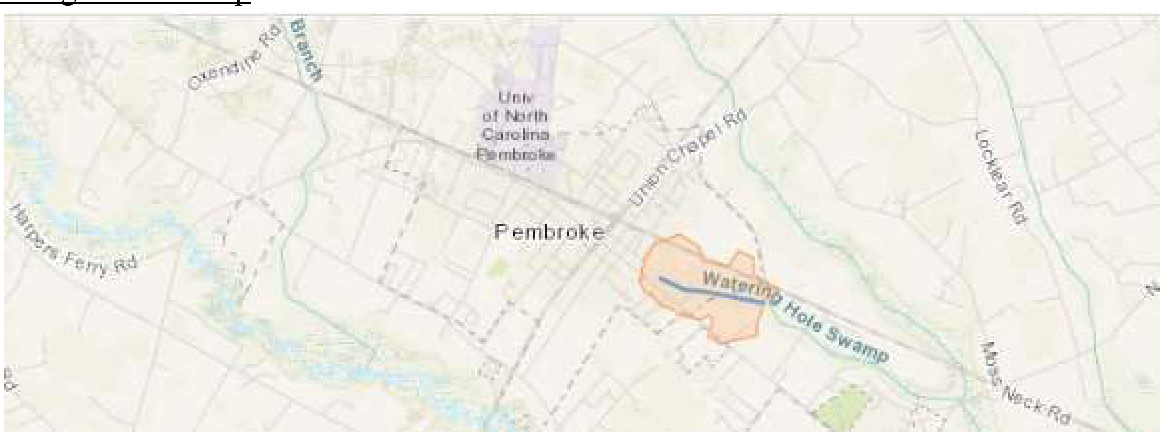
3.2 Watersheds

The Town and UNCP are located within the Bear Swamp Watershed, Lumber River Watershed, and Watering Hole Swamp Watershed. Information pertaining to these watersheds were obtained from National Hydrography Dataset Plus (NHDPlus). NHDPlus is a suite of geospatial products built upon and extend the capabilities of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), and the Watershed Boundary Dataset (WBD), developed and maintained by the U.S. Environmental Protection Agency (EPA) in partnership with U.S. Geologic Survey (USGS) efforts.

Bear Swamp Creek

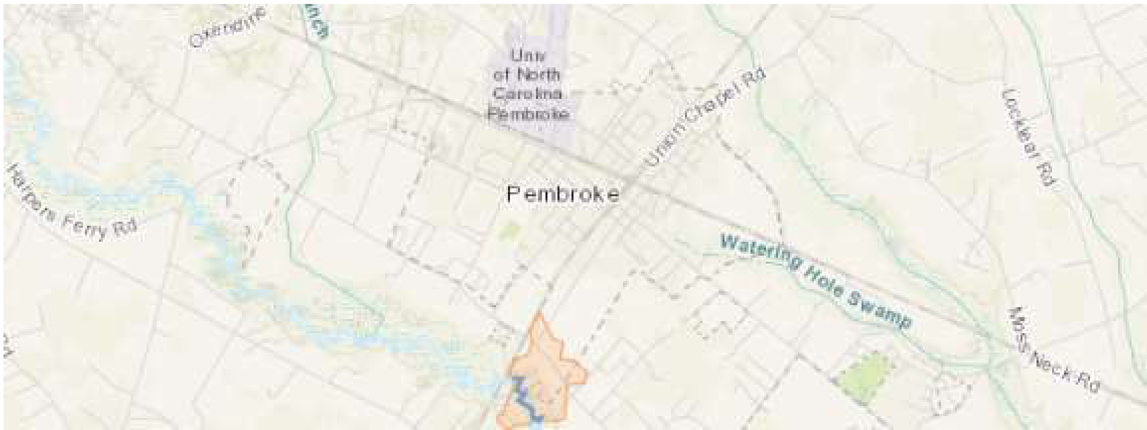
The Bear Swamp Creek Watershed is the primary watershed focused upon in this hydrologic study, as it has the most significant stormwater impact on the Town and UNC-P, North of E Railroad Street. The watershed covers a total area of 5,676 acres and has a variety of soils and land cover. Soils in this catchment contain; 50% sand, 27% clay, and 0.66% organic matter. The mean permeability of these soils is 2.6 in/hr. The mean depth to bedrock is 5 feet and the mean of all seasonal water table depth of soils is 2 feet 4 inches. The land cover found in the Bear Swamp Watershed consists of; woody wetland (47.9%), developed (12.9%) shrub/scrub (11.5%), evergreen forest (6.34%), grassland (4%), herbaceous wetland (0.89%), open water (0.1%), deciduous forest (0.02%).

Watering Hole Swamp



Mean annual flow of 0.27 ft^3/s and velocity of 0.56 ft/s.
Watershed area is 180.4 acres.
Land cover as follows; low intensity residential (6.2%), commercial (7.93%), other (85.87%).
Mean surface soil erodibility factor is 0.19.
Soils: clay (26.6%), sand (50%), organics (0.6%).

Lumber River



Mean annual flow of 512 ft^3/s and velocity of 1.47 ft/s.
Watershed area is 103.8 acres.
Land cover as follows; low intensity residential (6.2%), other (93.8%).
Mean surface soil erodibility factor is 0.17.
Soils: clay (23.9%), sand (53.4%), organics (1%).

3.3 Corridors

There are three main corridors that convey stormwater through the town:

- Corridor along 1st Street from N. Odum Street to the west side of railroad track and northeast until Bear Swamp (approximately 7,910 ft);
- Corridor from 1st Street crossing Union Chapel Road to Jones Street and then across railroad to E. 3rd Street, releasing into Watering Hole Swamp (approximately 2,902 ft);
- Corridor from Jones Street to northeast adjacent to a residential area and agricultural area and releasing into Bear Swamp (approximately 3,265 ft).

See Appendix A for images of these corridors.

4.0 SITE RECONNAISSANCE

The scope of work of the short-term tasks included an initial site walk through to identify specific conveyance corridors and all conveyance measures utilized in these corridors. Factors that must be taken into consideration while observing theses conveyance systems include:

- Conveyance system structural intactness and proper installation (Images 1A-D)
- Vegetation that hinders the effectiveness of the conveyance (Images 2A-D)
- Trash, debris, and sedimentation build-up (Images 3A-D)

- Failing erosion control measures (Images 4A-C)

Another impact to stormwater conveyance which is taken into account when monitoring a systems efficacy is the slope or hydraulic gradient of the system. Negatively sloped conveyance measures do not allow for stormwater to properly and efficiently flow to its designated outfall location. Instead water ponds and can lead to unwanted erosion and deposition of sediment along the conveyance system.

Following the initial site visit, M&A contracted Johnny Nobles and Associates to perform surveying tasks to collect pertinent data required to determine stormwater runoff capacity of the existing conveyance measures in the short-term and long-term corridors. Data collected included culvert sizes, materials, and locations, channel geometry, invert elevations, drop inlet and junction box locations, etc. M&A then compiled the data collected for insertion into stormwater modeling software. The modeling software utilized was AutoCAD's Civil 3D Storm and Sanitary Sewer Analysis (SSA) program. This software has the ability to route stormwater runoff from defined drainage areas into a stormwater conveyance system made up of closed conduits (i.e. concrete pipe, steel culverts, etc.) or open channels to outfalls (i.e. Bear Swamp or Lumber River). Once all pertinent data is inserted, the software can be used to identify runoff rates, peak flow, conveyance capacity limitations, conveyance size requirements, etc.

Based on a review of the topographic maps and survey data for the Town of Pembroke, Corridor 1 contains a drainage area of approximately 795 acres, Corridor 2 contains a drainage area of approximately 60 acres, and Corridor 3 contains a drainage area of approximately 84 acres. These drainage areas were broken down into sub-basins that discharge into a known structure (i.e. drop inlet, curb inlet, culvert, etc.) and into the stormwater drainage system for each corridor. Once the sub-basins were defined, a runoff coefficient was given for each drainage area based on land cover and a time of concentration calculated using the TR-55 segmental method. The rainfall intensity data for the Pembroke area provided by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service website was inserted into the SSA program and peak runoff rates were calculated within the program utilizing the Rational Method.

These sub-basins were assigned to structures and conveyance measures of the stormwater drainage systems identified in site visits, data previously collected by M&A, as well as a review of information made available by Locklear, Locklear, and Jacobs, PLLC. The structures and conveyance measures were assigned roughness coefficients and hydraulic calculations were made using Manning's Equation within the SSA program. Once all hydrologic and hydraulic information was inserted into the SSA program M&A was able to identify surcharged pipes and flood prone areas.

Based on the SSA model of runoff for Corridor 1 through Corridor 3 and the information gathered during site visits M&A has the following short-term recommendations (See Appendix A):

General

- Remove sedimentation from all channels and redefine channel centerlines to be straight without meandering.
- Clean and trim all channel banks.
- Install outlet protection and geotextile fabric in areas prone to erosion.
- Stabilize channel sides and bottom to prevent sediment transport and sedimentation.

Location Specific

1. Adjust ditch centerline to be aligned with culvert centerlines. Remove trash and vegetation blocking entrance to culverts. Repair headwall to prevent erosion observed above headwall on upstream side of culvert.
2. Trim vegetation around storm drain outfall.
3. Repair erosion, approximately 15 feet.
4. Clean out trash and debris from junction box. Reseal junction box to prevent erosion into junction box. Form invert in junction box. Repair sink holes around junction box. Clean screening of drop inlet. Remove vegetation blocking culvert outlet.
5. Remove stones and debris located inside the stormwater culverts. Remove vegetation blocking outlets.
6. Remove trash, sedimentation, vegetation, and debris from culvert inlet. Remove vegetation and debris from storm drain outfalls upstream of culverts. Remove trash and debris from inside of culvert.
7. Remove trash, sedimentation, vegetation, and debris from culvert inlet. Remove vegetation and debris from storm drain outfalls upstream of culverts. Remove trash and debris from inside of culvert.
8. Clean debris and sedimentation from culvert and culvert outlet.
9. Clean debris and sedimentation from outlet.
10. Remove trash and debris from ditch. Remove vegetation within the ditch.
11. Clean inlets and outlets of culverts. Remove sediment and debris from inside culvert.
12. Remove sediment and debris from culvert inlets and inside culverts.
13. Clean sediment, debris, vegetation, and trash from culvert inlets and outlets and inside culverts.
14. Clean sediment, debris, vegetation, and trash from culvert inlets and outlets and inside culverts.

15. Remove vegetation, sediment, and trash from junction boxes, drop inlets, and outlets. Install 12” concrete collars around drop inlets in grassy areas.
16. Remove debris from inside stormwater pipes.
17. Clean sediment, trash, and debris from culvert.
18. Reseal junction box causing sink holes around edge.
19. Remove debris from culvert entrance.
20. Remove trash and debris from culvert entrance.

5.0 METHODS OF FLOOD MITIGATION

MacConnell & Associates has identified the following methods of mitigating flooding events in the Town:

1) Increase stormwater flow capacity downstream;
2) Divert upstream flows to bypassing the Town/UNC-P;
3) Provide upstream stormwater retention to decrease flow rates entering the Town/UNC-P;
4) Add stormwater routes and outfalls to decrease amount of stormwater flowing in existing channels, and;
5) Installing berms to corral flood waters.

Feasibility of each method was considered when providing recommendations for improvements. The physical characteristics of the region provides challenges that would prohibit aspects of each method of flood mitigation. The two main characteristics of the area that control the feasibility of each method are land slope and depth to groundwater.

The topography in the vicinity of the Town is flat with only a slight relief towards either Bear Swamp, Watering Hole Swamp, or the Lumber River. A change in elevation is required for stormwater to effectively travel through a conveyance measure. While stormwater can travel effectively through an area of flat terrain, a larger cross-sectional flow area is required to provide adequate flow.

Topography is not the only physical characteristic of the area that can constrain flood mitigation design. Shallow depth to groundwater can limit conveyance sizing in flood mitigation designs. The presence of groundwater in conveyance channels and pipes/culverts decreases the effective cross-sectional flow area available for conveyance. MacConnell & Associates accessed NCDEQ’s online database of documented contaminant releases, Laserfiche, to glean depth to groundwater data from environmental investigations conducted in the area. According to environmental investigations conducted on the UNC-P campus and in the town limits of

Pembroke, depth to groundwater was identified between four and six feet below ground surface in groundwater monitoring wells.

Method 1: Increase Downstream Flow Capacity

This method would consist of removing and replacing existing culverts and junction boxes with larger structures or expanding existing stormwater channels to allow higher flow rates for stormwater to travel through corridors. The challenges associated with this method include depth of shallow groundwater, proximity of existing structures to private property, maximum slope attainable due to flat topography, and costs. Mitigating flooding via this method alone is not feasible due to these challenges. This method should be utilized in conjunction with other methods to accomplish the long-term goals.

Methods of increasing cross-sectional flow area would include enlarging existing culverts/pipes, installing additional parallel culverts/piping in the flow path, or widening/deepening existing open channels.

Method 2: Divert Upstream Flows

The stormwater runoff that flows through the Town and UNC-P originates from a large drainage area with the majority of the area being outside of the town limits and off-campus. This method would re-route runoff from upstream areas into stormwater corridors that would bypass the Town and UNC-P campus to discharge into the Bear Swamp or Lumber River at an outfall that is closer to the drainage area origin. Requirements of this method would include enlarging existing corridors or creating new corridors, if necessary. Costs associated with this method could limit the amount of runoff that can be diverted. If new corridors are required, costs for easements, clearing, and construction could be prohibitive. Additionally, costs for maintenance would be required.

Examples of diverting upstream flows include installing diversion berms or by-pass piping to re-route stormwater to outfalls to the Lumber River or Bear Swamp before it enters the UNC-P or Town of Pembroke stormwater system.

Method 3: Upstream Retention

If diverting upstream stormwater to by-pass the stormwater system is not an option, providing upstream retention could decrease peak flows in the stormwater system by storing water in ponds or basins and slowly releasing it at a rate the stormwater system can handle without causing backups. This method would require the acquisition of land by the Town or UNC-P that is solely used for stormwater storage, or used in a method that isn't greatly affected by flooding. An example of this would be to install underground storage basins beneath UNC-P's practice football field that holds water and releases it at a low rate. This method comes with the high cost of land acquisition, construction, and maintenance in perpetuity. Since depth to groundwater is shallow in the area, these water storage ponds or basins will require a large area to be effective.

Method 4: Additional Stormwater Routes and Outfalls

Since the topographic characteristics limit conveyance slopes and depth to groundwater limits conveyance sizes, additional outfalls could increase flow rates through the stormwater systems to prevent backups causing flooding upstream. Adding more routes and outfalls for stormwater to be conveyed will decrease the total volume and peak flow rates of water through stormwater systems. This method is similar to Method 2 but would include installing additional routes in the Town or on the UNC-P campus.

An example of this method would be to install a new ditch that leads to either Bear Swamp or Lumber River in town and re-routing water to the new outfall. Costs may limit the number of new routes and outfalls due to easement acquisition, construction required in the CSX right of way, and land clearing requirements. This method should also be utilized in conjunction with other methods to accomplish the long-term goals.

Method 5: Installing Berms

Levees, dams, and berms are typically utilized to keep floodwaters out of towns and off properties by installing them high enough that floodwater elevations do not exceed the top and are kept out. Installing levees, dams, or berms in Pembroke would be a possible solution to preventing floodwaters from entering the town or the UNC-P campus; however, this method comes with the highest cost to implement. Detailed planning, land acquisition, engineering, and construction would likely be more than $5,000,000 to put in place. The levees/dams/berms would be installed around the flood prone areas of Bear Swamp and Lumber River and incorporate culverts for stormwater from the town and UNC-P campus to reach these water bodies. To prevent backflow of floodwaters into town, the culverts would need to be equipped with flap gates, but installing flap gates on culverts will prevent stormwater from the town from reaching the outfall, thus causing flooding on the backside of the berm. This method would require storing stormwater prior to reaching Lumber River or Bear Swamp so that floodwater elevations can recede before stormwater can be released to the outfalls, and will require re-routing existing stormwater conveyance pathways to the storage areas and new culverts. Due to the requirements and costs of this method, installing berms is not the most economically approach to the long-term goals.

6.0 ENDANGERED SPECIES

North Carolina is home to several native species that are considered endangered by the United States Fish & Wildlife Service (USFWS). The frequent flooding experienced in Pembroke may be affecting the natural habitats of endangered species that possibly live in the area. According to the USFWS, the following species are possibly found in the Robeson County area: Red-cockaded Woodpecker, Michaux's Sumac, and the American Alligator.

<u>Red-Cockaded Woodpecker</u>

Red-cockaded Woodpeckers are about the size of cardinals and are unique to their preference for

residing in living pine trees, specifically longleaf pines (80 to 120 years old) and loblolly pine trees (70 to 100 years old). Red-cockaded Woodpeckers reside mostly in the coastal wetlands of the southeastern United States, primarily in the Carolinas and Florida, as well as parts of Georgia, Alabama, Mississippi, Louisiana, and Texas. Since these birds live high up in pine trees, flooding it not generally a concern for their habitat.

<u>Michaux's Sumac</u>

The Michaux's Sumac plant is a dense, hairy shrub with erect stems that range from one to three

feet in height. These plants typically grow in sandy or rocky open woodland areas with basic soils. These plants survive most easily in areas that have encountered some disturbance to provide an open area. In the state of North Carolina, they are typically found on the sides of roads, or other artificially maintained clearings. Flooding would likely affect this plant's natural habitat; however; MacConnell & Associates did not observe the presence of this plant during their site reconnaissance. Additionally, a reported population of the Michaux's Sumac plant has not been documented by the USFWS in Pembroke.

<u>American Alligators</u>

The American Alligator is a member of the crocodilian family that in the early to mid-20th

century was severely depleted, landing it on the list of endangered species. In 1987, the American Alligator was deemed fully recovered and removed from the list of endangered species, however, they are still protected under the Convention on International Trade in Endangered Species (CITES) and the Endangered Species Act (ESA). Regulations under CITES and ESA also protect all other members of the crocodilian species. Flooding would likely affect this plant's natural habitat; however; MacConnell & Associates did not observe the presence of this plant during their site reconnaissance. Additionally, a reported population of the American Alligator has not been documented by the USFWS in Pembroke.

7.0 RECOMMENDATIONS

MacConnell & Associates has prepared recommendations in an attempt to mitigate the flooding problems experienced in the Town and on UNC-P's campus and have been separated into stormwater improvement and non-improvement recommendations.

7.1 Non-Improvement Recommendations

Establish and Maintain a Stormwater Utility

M&A recommends setting up a Stormwater Utility within the Public Works Department of the Town of Pembroke municipality. A Stormwater Utility will establish a funding source for stormwater capital improvements and maintain existing stormwater system components through fees paid by customers. Rates can be established based on impervious area per parcel with separate rates for residential and commercial properties.

The preparation of a Stormwater Management Plan would be included in the establishment of the Stormwater Utility to specify requirements for existing and new developments. The Stormwater Management Plan can institute attenuation specifications for new development, establish water quality standards for runoff, and provide maintenance requirements for existing stormwater conveyance systems. This plan can help prevent increases in stormwater peak runoff rates and runoff volume and improve stormwater runoff quality.

The Stormwater Utility should also formulate and follow an Operations and Maintenance Plan (O&M Plan) for the Town's stormwater system. This O&M Plan can outline the course of action to take if an illicit discharge were to occur, methods of keeping the conveyance measures in optimal working condition, and establish a schedule of maintenance activities. M&A has identified the main channels that convey stormwater out of the town on in Appendix A.

Establishing a Stormwater Utility includes the pursuit of a Municipal Separate Stormwater Sewer System (MS4) permit for a Phase II community to obtain a National Pollution Discharge Elimination System.

Stormwater Awareness Campaign

Maintaining the Town's stormwater system should not solely fall upon the municipality. The citizens of the Town have equal claim as stakeholders in the effectiveness of the stormwater system as the municipality. The citizens of Pembroke are as susceptible to flooding as the municipality; therefore, the citizens should have a role in keeping the Town's stormwater system operating effectively. The biggest role the citizens can play is to help keep trash and debris out of the stormwater system. The Town's stormwater system is plagued by manmade trash that can clog up conveyance measures and prevent adequate flow rates. Informing the citizens that a very small effort to prevent littering can go a very long way.

A stormwater awareness campaign can provide information to the citizens of the Town of Pembroke and students of UNC-P on the necessity of keeping the stormwater system clean and the role they can play. Pamphlets available in the Town Hall, flyers placed in utility bill envelopes, ads in local newspapers, public meetings, etc. can inform citizens on the effects of mistreatment of the stormwater system. Simple signs or notices placed near inlets to the stormwater system can remind people to make sure their trash ends up in the place it should be rather than in stormwater pipes or channels.

The campaign should explain in basic terms what stormwater is, where it originates, and its path to its final destination. The campaign should explain what it takes to maintain the stormwater system and why the public's assistance is necessary. Informing the citizens why a Stormwater Utility should be established by the Town and the fees paid by the citizens are necessary to maintain the Stormwater Utility can help reduce resistance to the startup of the Stormwater Utility.

Stormwater Easements

Permanent stormwater easements should be recorded on private and public properties where stormwater is conveyed from more than one property into the Town of Pembroke's stormwater system. The easements should allow for maintenance equipment to enter and perform necessary work without crossing onto or damaging private property. Recording permanent stormwater easements would require surveying of property boundaries, an agreement between the Town and the land owner, and recordation on property deeds.

Beaver Management

Bear Swamp and Lumber River make ideal habitats for beavers with the available food and water sources. Beavers create dams that can block flow in creeks and streams and cause flooding in upstream locations. Beavers have historically made their homes in Bear Swamp and channels leading to the Lumber River. The dams they create can cause flooding issues within the Town of Pembroke and on UNC-P's campus. As water leaves the stormwater system and enters the Lumber River or Bear Swamp it has nowhere to go but backwards due to the dams created by beavers. M&A recommends consulting with the North Carolina Fish and Wildlife

Service – Beaver Management Assistance Program for methods of beaver removal and prevention in areas prone to beaver habitation.

<u>Installation of River Gauge at CSX Railroad Stream Crossing</u>
Downstream from Pembroke, Lumberton has a river gauge that monitors the water elevation of the Lumber River. A hydrograph displays water elevations in relation to flood stages. This river gauge has the ability to predict water elevations based on rainfall events and weather forecasts. Additionally, the National Weather Service is able to identify areas of inundation based on the current and predicted water elevations at the river gauge. This would be extremely helpful for the Town of Pembroke to identify areas that might see flooding conditions during heavy rainfall events and allow the Town and citizens to prepare for flooding.

7.2 Stormwater Improvement Recommendations

Stormwater improvement recommendations are for improving site-specific stormwater conveyance system components within the Town and on the UNC-P campus. The recommendations are designed to alleviate flooding effects experienced during a 25-year storm event; meaning the peak stormwater runoff flow produced by a storm with a greater than 4% chance of occurrence in a given year is designed to be conveyed through the stormwater system without causing flooding. These recommendations will not fully mitigate flooding for more severe events. The Town and UNC-P may still experience flood conditions for larger storm events, however the impacts will be diminished.

These stormwater improvement recommendations have been assigned a priority level based on the following criteria:

- <u>High Priority</u>
  - Increases conveyance/storage by more than 100%;
  - Mitigates flood damages to public property; or,
  - Mitigates flood damages to private properties from public stormwater conveyance issues.

- <u>Moderate Priority</u>
  - Increase conveyance/storage by more than 50% but less than 100%; or,
  - Mitigates flood damages to two or more private properties from private stormwater conveyance issues.

- <u>Low Priority</u>
  - Increases conveyance/storage by less than 50%; or,

- Mitigates flood damages to only private properties from private stormwater conveyance issues.

For planning and funding purposes, a cost estimation has been included for each stormwater improvement recommendation. The cost estimate includes approximate quantities of materials to be used for implementation of the recommendation, estimate unit costs of each material based on M&A's experience of bids in the area, and an estimated cost for engineering, surveying, and easement acquisition services. The cost for engineering and surveying services are estimated as a percentage of the total construction cost of the project. These percentages are estimated to be between 8% and 20%, depending on the complexity of the recommendation. Additionally, a contingency cost of 20% has been included to account for unforeseen conditions during the construction phase.

An aerial photograph is included with each recommendation for location purposes. Figures for each improvement recommendation can be found in Appendix C and cost estimates can be found in Appendix D.

Recommendation #1

Location: Downtown Pembroke near the ABC Store

Priority: High

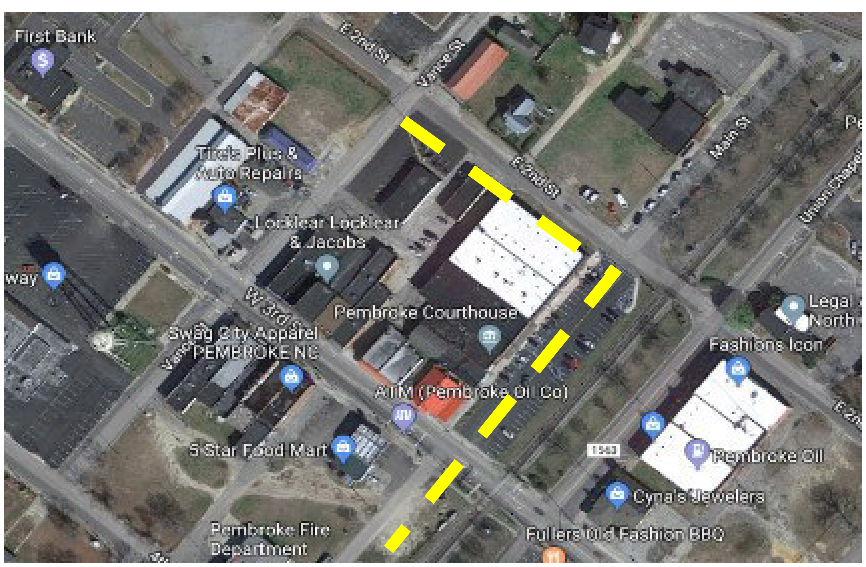
Narrative: The intersection of E. 2nd Street and Vance Street appears to be a sump and accumulates runoff from up-gradient sources not collected in the stormwater system. Drop inlets in this area appear to be filled with sediment and debris and existing 12" to 24" stormwater pipes do not appear to provide adequate flow to prevent flooding in the vicinity of the ABC Store.

Description: Clean existing drop inlets and culvert inlets. Increase size of approximately 130 feet of stormwater pipe along 2nd Street from Vance Street to Main Street, and approximately 394 feet of stormwater pipe along Main Street from 2nd Street to approximately 200 feet southeast of E. 3rd Street. Replace eight existing junction boxes to accommodate pipe size increase and maintain positive pipe slope.

Outcome: The increase in stormwater pipe will provide increased flow rates of approximately 350% while cleaning drop inlets and culverts will provide effective flow into the stormwater system.

Prerequisites: None.

Costs: $175,000.00



<u>Recommendation #2</u>

Location: Channels north of First Street between North Odum Road and Gough Street

Priority: High

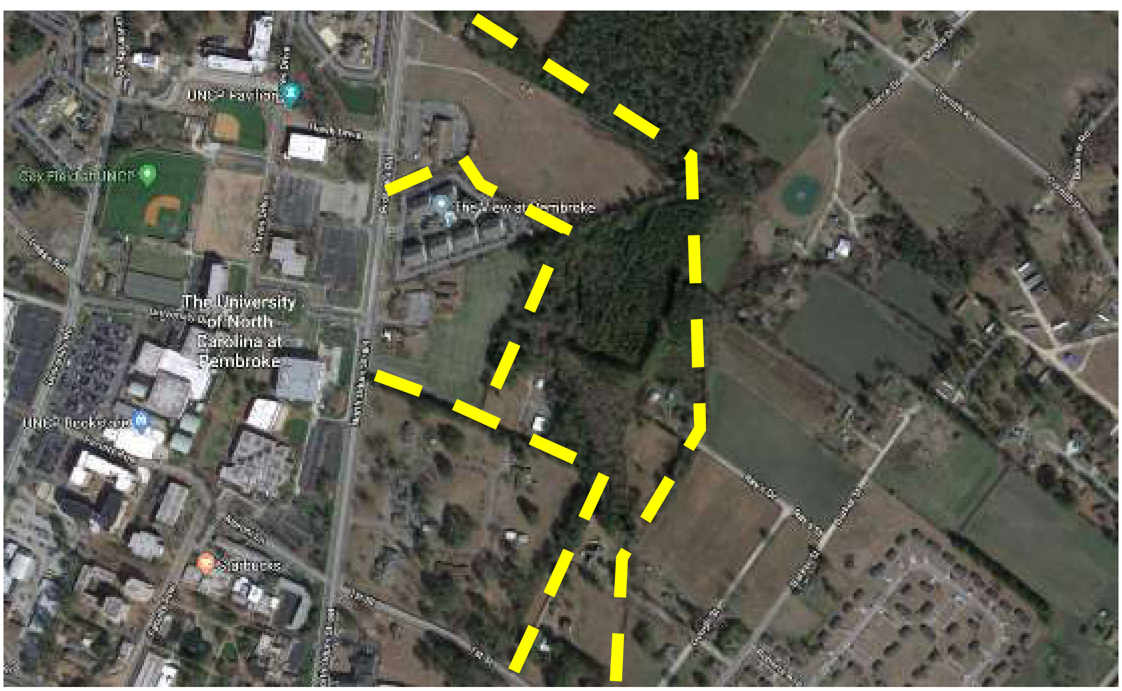
Narrative: Three outfalls from North Odum Street stormwater system discharge into open channels along North Odum Road between First Street and Cornith Road. These three channels discharge into Corridor 1 before the culverts cross beneath the First Street and Gough Street intersection. These channels contain overgrown vegetation, sediment, and debris that prevents maximum flow to be obtained and affect numerous parcels.

Description: Clean and remove vegetation, sediment, and debris from approximately 8,000 linear feet of stormwater channels.

Outcome: Cleaning these open channels will allow for at least a 50% increase in effective flow area for maximum flow through existing channel geometry.

Prerequisites: None.

Costs: $110,000



<u>Recommendation #3</u>

Location: Corridor 3 – East Railroad Street to Bear Swamp outfall

Priority: High

Narrative: Corridor 3 collects stormwater from the commercial areas along the northern portion of Union Chapel Road and the residential areas between North Jones Street and the solar farm. Currently, the corridor begins at East Railroad Street and discharges to Bear Swamp north of the new railroad connector track. The corridor is in need of cleaning to remove debris, sediment, and vegetation as well as repairs to culverts and headwalls. Instead implementing repairs needed to return the channel's function to the original design, this recommendation proposes to connect Corridor 3 with Corridor 2 and redefine the corridor completely. Connecting Corridor 3 with Corridor 2 and redefining the channel to allow additional flow will provide relief to upstream stormwater conveyances in the Town. Additionally, connecting Corridor 3 with Corridor 2 will provide a partial by-pass of the CSX railroad crossing at Bear Swamp. This recommendation would include a permanent stormwater easement between East Railroad Street and the CSX railroad so the Town can enter the corridor to conduct regular maintenance practices.

The proposed connection to Corridor 2 would begin between East Railroad Street and the CSX railroad and slope east towards the existing head of Corridor 3. Culverts will be installed under East Railroad Street to connect the new channel to the existing corridor channel. The existing corridor channel will be enlarged to handling the increased stormwater flow coming from Corridor 2. Enlarging the channel will remedy the existing issues with debris, sediment, and vegetation built up. The existing culvert at the east end of Florence Street will be removed and replaced with the open channel to allow additional flow and prevent the need to maintain an underground culvert. New culverts will be installed beneath the access road to the Town of Pembroke's sewer lift station at the east end of Chavis Street to allow for the additional flow in the channel. Enlarging the channel will continue northeast to the East Wardell Street culvert. Here, the existing culvert will be replaced with a much larger aluminum box culvert with headwall and wingwalls. Continuing beyond East Wardell Street, the existing channel will be enlarged and cleaned of vegetation to the CSX railroad connector culverts.

The proposed channel connecting Corridor 3 to Corridor 2 will be located within the CSX right-of-way and will require coordination with CSX to approve plans. Additionally, the installation of culverts under East Railroad Street and East Wardell Street may require coordination with the NCDOT. Costs for the project include coordination with CSX and NCDOT as well as recordation of permanent stormwater easements.

Description: Install an approximately 625-linear foot channel beginning at culverts under East Railroad Street and the CSX railroad and slope channel to the east. The proposed channel geometry will be trapezoidal, four feet deep, two feet wide at the bottom, and have 1:1 side slopes. Install approximately 60 linear feet of double barrel projecting 36-inch RCP culverts under East Railroad Street to connect to the beginning of the existing Corridor 3. Redefine approximately 660 linear feet of existing channel along edge of residential area and solar farm to follow the proposed channel geometry. Remove existing headwall and culvert at the east end of Florence Street and continue open channel for approximately 400 linear feet. Install approximately 35 feet of double-barrel, projecting 36-inch corrugated metal pipe culverts at the east end of Chavis Street for crossing for Town of Pembroke lift station access. Enlarge channel to proposed channel geometry from Chavis Street to East Wardell Street for approximately 1,200 linear feet. At East Wardell Street, remove existing culvert and replace with 65-linear foot 4’10” by 10’ aluminum box culvert with wingwalls and headwalls. Redefine existing channel from East Wardell Street for approximately 765 linear feet to the CSX railroad and Bear Swamp outfall.

This recommendation includes cleaning approximately 925 linear feet of the existing channel in the residential area that discharges into Corridor 3.

Outcome: Provides partial by-pass of CSX railroad crossing culverts north of the Town at Bear Swamp. Increases flow in corridor by more than 400%.

Prerequisites: None

Costs: $885,000

Recommendation #4

Location: Old Main Road and CSX Railroad

Priority: High

Narrative: Stormwater from a large area immediately west of town limits is conveyed into the town's stormwater system along the western edge of the town. This area enters the Town at a culvert under Old Main Road, north of the Highway 711 and Pembroke Pointe Lane intersection. Currently, the stormwater enters a 48-inch corrugated metal pipe culvert under Old Main Road and then conveyed through the CSX right-of-way via a 48-inch RCP. M&A has proposed recommendations that will increase flow to these culverts; therefore, increasing culvert sizes will be necessary.

This recommendation may require coordination with CSX which is included in the cost estimate.

Description: Remove an approximately 50-linear foot 48-inch corrugated metal pipe culvert under Old Main Road and replace with a projecting 50-linear foot, double barrel 36-inch corrugated aluminum pipe culvert. Install a second 48-inch RCP culvert next to the existing 48-inch RCP culvert beneath the CSX railroad. Adjust ditch between railroad and CSX to accommodate increased culvert sizes.

Outcome: Provides increased flow through Old Main Road and CSX right-of-way by more than 100%.

Prerequisites: 20, 26

Costs: $310,000

Recommendation #5

Location: Mabe Street

Priority: High

Narrative: Corridor 2 discharges into Watering Hole Swamp located on the east side of town. The first culvert located in Watering Hole Swamp that stormwater reaches after leaving Corridor 2 is located at Mabe Street. The existing culvert is negatively sloped and is not large enough to convey the required flow to prevent upstream flooding. This recommendation proposes to adjust the existing 36-inch RCP culvert to be positively sloped and add a second 36-inch RCP culvert next to it.

Description: Adjust existing 36-inch RCP culvert to be positively sloped. Install approximately 25 linear feet of projecting 36-inch RCP next to existing culvert.

Outcome: Increased flow capacity by more than 100%.

Prerequisites: 6, 12

Costs: $60,000

Recommendation #6

Location: Joseph H Street

Priority: High

Narrative: The second stream crossing in Watering Hole Swamp is located at Joseph H Drive. This crossing is not a standard RCP or CMP culvert, but a crossing of timbers across stacked stones measuring approximately three feet wide by three feet deep. Replacing this crossing with two 42-inch projecting RCP will provide additional flow capacity by increasing flow area and decreasing friction values.

Description: Remove existing crossing and install 15 feet of two 42-inch RCP projecting culverts.

Outcome: Increased flow capacity by more than 300%.

Prerequisites: 12

Costs: $70,000

Recommendation #7

Location: CSX railroad crossing at Bear Swamp

Priority: High

Narrative: The CSX railroad crossing at Bear Swamp is constricting the stream flow due to undersized culverts. This recommendation proposes installing additional culverts to increase flow rates through the stream crossing and decrease water elevations during flooding conditions.

To determine the number and size of culverts to be installed, stream modeling will need to be conducted using the Army Corp of Engineer's HEC-RAS program. The modeling data will need to be submitted to the North Carolina Floodplain Mapping Program and FEMA as part of the Conditional Letter of Map Revision (CLOMR) process. MacConnell & Associates has performed initial stream modeling utilizing HNTB's modeling data prepared as part of the recently constructed CSX railroad bridge over Bear Swamp north of Pembroke. This modeling was conducted to formulate estimations for project recommendations and should not be considered as a full hydraulic analysis of the stream crossing. A full stream modeling analysis should be conducted.

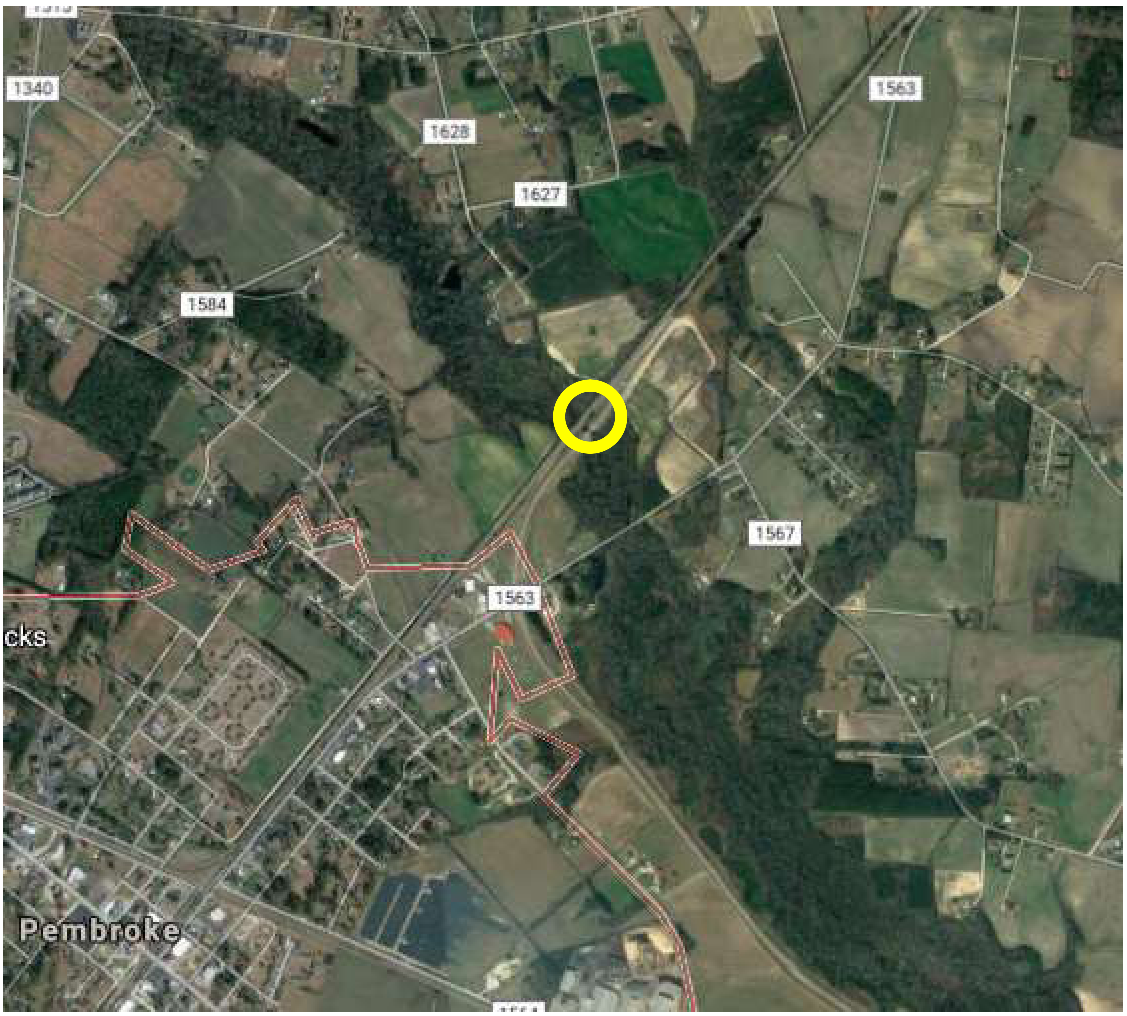
MacConnell & Associates performed initial modeling with the goal of decreasing flood elevations so that the Town's and UNC-P's stormwater system does not become inundated during heavy rainfall events. Initial modeling indicates that this goal can be achieved by installing two 36-inch culvert next to the existing 36-inch culvert. This will decrease the 100-year flood elevation and allow for additional stormwater volume to be conveyed through the stormwater system.

Description: Perform hydraulic stream modeling of Bear Swamp to verify the number and sizes of culverts to install. Complete the CLOMR process through FEMA and the North Carolina Floodplain Mapping Program. Install new culvert in the effective flow area of Bear Swamp. Complete the Letter of Map Revision with FEMA and the North Carolina Floodplain Mapping Program.

Outcome: Based on MacConnell & Associates initial modeling, it is estimated that installing two 36-inch ductile iron pipe via jack and bore method at the same invert elevation as the existing 36-inch would decrease the 100-year flood plain elevation by more than three feet. This will decrease the water elevations experienced during flooding within the Town and on the UNC-P campus.

Prerequisites: None

Costs: $158,000



Recommendation #8

Location: Harry West Lane Extension

Priority: Low

Narrative: Homes on the west side of Harry West Lane Ext. experience flooding conditions due to an undersized ditch located between 606 Harry West Lane and 807 James Lynn Lane. At the constricting point, the ditch is compressed down to being one foot wide by two feet deep from being approximately five feet wide and two feet deep. After exiting the constricting point, the ditch opens up to being approximately 14 feet wide and 5 foot deep. This recommendation proposes to increase ditch geometry.

Description: Redefine existing ditch to be trapezoidal with two-foot wide bottom, two-foot deep, and have side slopes of 2:1.

Outcome: Flow area will be increased by 400%.

Prerequisites: None

Costs: $110,000

Recommendation #9

Location: Cornith Road

Priority: High

Narrative: The northern portion of the UNC-P campus discharges into open channels on the north side of Cornith Road that eventually discharge to Corridor 1 near the Cornith Road and Bonnie Road intersection. NCDOT calculations for the North Odum Road improvements project estimates the 10-year peak runoff rate to be 31.7 cubic feet per second (cfs). Survey data collected at North Odum Road and the Cornith Road ditch outfall at Corridor 1 indicates that the ditch has a general slope of approximately 0.2%. Numerous 24-inch RCP driveway culverts have been installed along Cornith Road that are undersized to carry the 10-year peak storm runoff from the UNC-P campus. This recommendation proposes to increase driveway culvert sizes all along the north site of Cornith Road. Additionally, the Cornith Road ditch is overgrown with vegetation that should be trimmed to allow maximum flow.

Description: Increase 11 culverts to be 42-inch RCP for a total length of approximately 612 linear feet, increase 5 culverts to be 48-inch RCP for a total length of approximately 176 linear feet, trim existing ditch to remove overgrown vegetation and remove trash and debris in approximately 4,000 linear feet of ditch line.

Outcome: Cleaning ditches and installing larger culverts will allow for at least 600% increase in flow capacity.

Prerequisites: 7, 24

Costs: $360,000

Recommendation #10

Location: Old Main Road

Priority: High

Narrative: A drainage channel is located between Old Main Road and the CSX railroad between University Road and Pembroke Pointe Lane. This drainage ditch does not have a positive slope from University Road to where the ditch crosses under the railroad tracks north of Pembroke Pointe Lane. Following Hurricane Florence, this ditch was observed to contain at least one foot of standing water that could not reach the culverts with approximately one more foot of water needed to continue flowing downstream. This means the stormwater system at this location requires approximately two feet of water in this area before water in the ditch can continue to flow downstream. This recommendation proposes to adjust the existing ditch to be positively sloped to the culverts under the railroad north of Pembroke Pointe Lane.

Description: Excavate approximately 1,650 linear feet of ditch to be positively sloped from University Road to Pembroke Pointe Lane.

Outcome: Can remove approximately two feet of water from the stormwater system in this area.

Prerequisites: 4, 20, 26

Costs: $75,000

Recommendation #11

Location: Howard Road and Harry West Lane

Priority: High

Narrative: The northeast corner of the Howard Road and Harry West Lane Road contains a sump area that collects water and does not have an outlet to discharge. Currently, stormwater ponds in this area have to be pumped across the street to prevent floodwaters encroaching upon residential structures during large storm events. This recommendation proposes to add a ditch and culvert under Howard Road to connect to a nearby drainage channel to prevent flooding during major rainfall events.

Description: Excavate an approximately 100-linear foot drainage ditch from edge of wooded area. Ditch geometry should be trapezoidal with two-foot bottom, two feet deep, and have 2:1 side slopes. Invert of ditch should be the topographically lowest point of the wooded area. Slope towards Howard Road. Install 18-inch RCP culvert under Howard Road at minimum 0.5% slope. Excavate an additional 140 feet at the same channel geometry to connect to the existing channel to the west.

Outcome: Flooding at Howard Road and Harry West Lane intersection will be mitigated.

Prerequisites: None

Costs: $90,000

<u>Recommendation #12</u>

Location: Jones Street

Priority: High

Narrative: The Jones Street road at Watering Hole Swamp has been over topped during Hurricane Matthew and Hurricane Florence. Severe erosion occurred on the downstream side of the stream crossing and deposited immediately downstream of the culvert. This indicates that the Jones Street culvert is not large enough to provide adequate flow during large storm events. This culvert should be increased to an aluminum box culvert with headwalls and wingwalls to increase flow capacity and stabilize soil on the downstream side of the crossing. Additionally, sediment deposited during Hurricane Matthew and Hurricane Florence should be removed to return channel geometry to existing conditions.

Description: Remove existing 60-inch corrugated metal pipe culvert and install an approximately 60-foot 5-foot by 10-foot aluminum box culvert with headwalls and wingwalls. Remove sedimentation on the downstream side of the crossing.

Outcome: Increased flow by more than 200% and removes deposited sediment.

Prerequisites: None.

Costs: $280,000

<u>Recommendation #13</u>

Location: UNC-P Parking Lot #1 and Lot #2

Priority: Medium

Narrative: Parking Lots #1 and #2 on the UNC-P campus are notorious for flooding during large storm events. This appears to occur due to poor conveyance through culverts leaving the parking lots and sediment built up in the ditch due to erosion at curb outfalls. This recommendation proposes to clean culverts located in these parking lots along the railroad tracks at University Road and North Odum Street crossings as well as install new culverts at the pedestrian railroad crossing. Additionally, this recommendation proposes to install geotextile fabric and riprap at curb outlets to prevent further erosion and remove sedimentation within the ditch.

Description: Clean out three 24-inch RCP culverts under roads at railroad crossings. Install approximately 20 linear feet of 18-inch RCP culvert at the pedestrian crossing. Remove sedimentation from ditch south of railroad tracks between University Road and North Odum Street. Install geotextile fabric with riprap at curb outlets in parking lot.

Outcome: Provides clear conveyance in blocked culverts, removes sedimentation within ditch, and prevents further sedimentation from curb outlets.

Prerequisites: None.

Costs: $100,000

Recommendation #14

Location: Prospect Road and Vogue Road

Priority: High

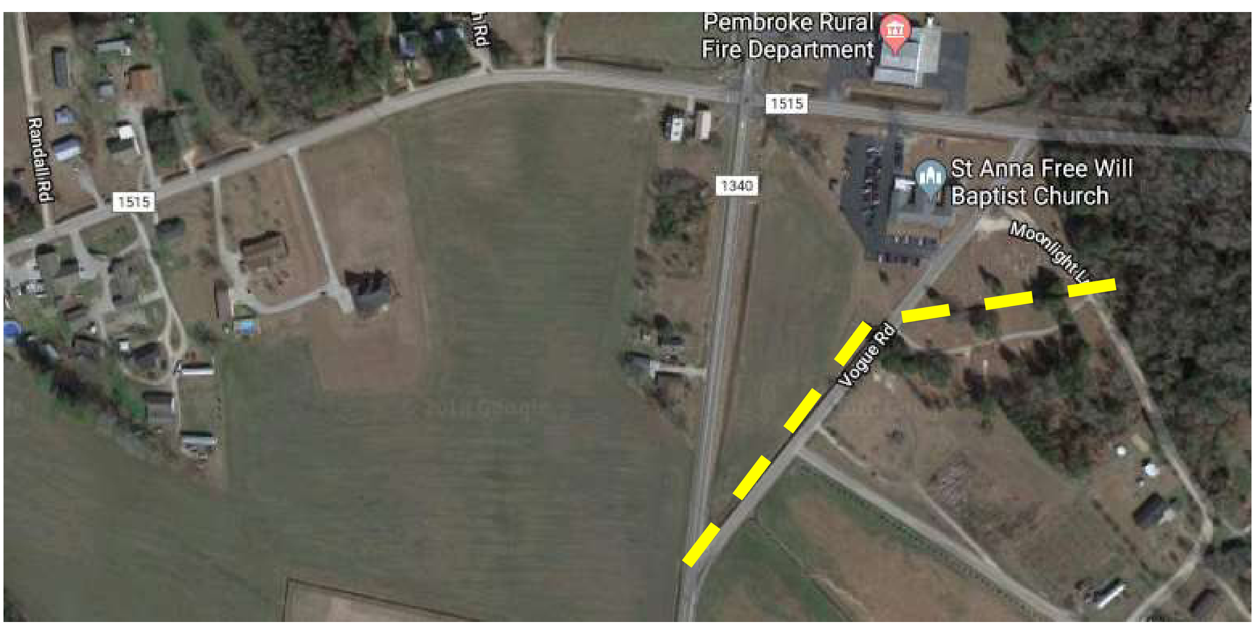
Narrative: The northern portion of the UNC-P campus flows north down Prospect Road just beyond the town limits and turns down Vogue Road, through a cemetery and into Bear Swamp near St. Anna Free Will Baptist Church. This ditch is overgrown with vegetation and has culverts that are not large enough. This recommendation proposes to increase culverts at the Prospect Road and Vogue Road intersection, Vogue Road near the St. Anna FWB Church, and Moonlight Lane in the cemetery with projecting 54-inch corrugated aluminum pipe culverts. Additionally, the ditch will be cleaned of overgrown vegetation, trash, and debris.

Description: Clean and remove vegetation, sediment, and debris from approximately 1,000 linear feet of ditch. Remove existing culverts and replace with 54-inch corrugated aluminum pipe culverts.

Outcome: Increased peak flow by approximately 300%.

Prerequisites: None.

Costs: $125,000



Recommendation #15

Location: UNC-P Campus – Behind Jones Health and Physical Education Center

Priority: High

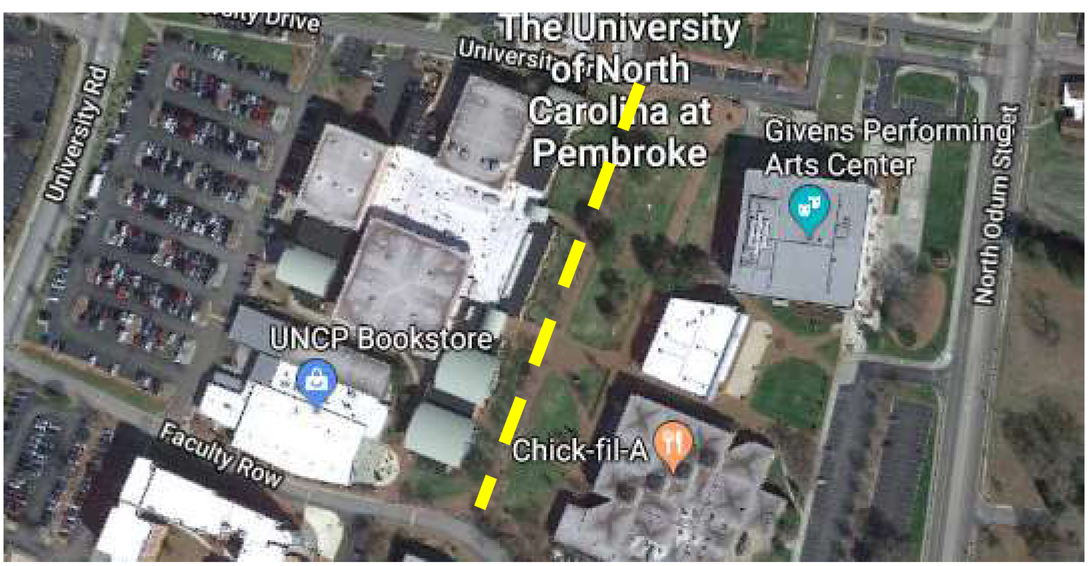
Narrative: The UNC-P campus experiences frequent flooding at the University Drive and Braves Road intersection near the center of campus. This flooding appears to occur due to undersized stormwater piping located to the east of the Jones Health and Physical Education Center. This recommendation proposes to increase flow capacity down this conveyance link by replacing the existing 12-inch to 18-inch RCP piping with 30-inch RCP piping.

Description: Replace approximately 134 linear feet of 12-inch RCP, 126 linear feet of 15-inch RCP, and 338 linear feet of 18-inch RCP with 30-inch RCP beginning at the University Drive and Braves Road intersection and ending at Faculty Drive. Replace seven drop inlets to accommodate new pipe size. Adjust one drop inlet near Faculty Drive to accommodate new pipe size.

Outcome: Increasing stormwater pipe size can achieve up to 300% increase in peak flow capacity.

Prerequisites: None.

Costs: $425,000



Recommendation #16

Location: University Road

Priority: High

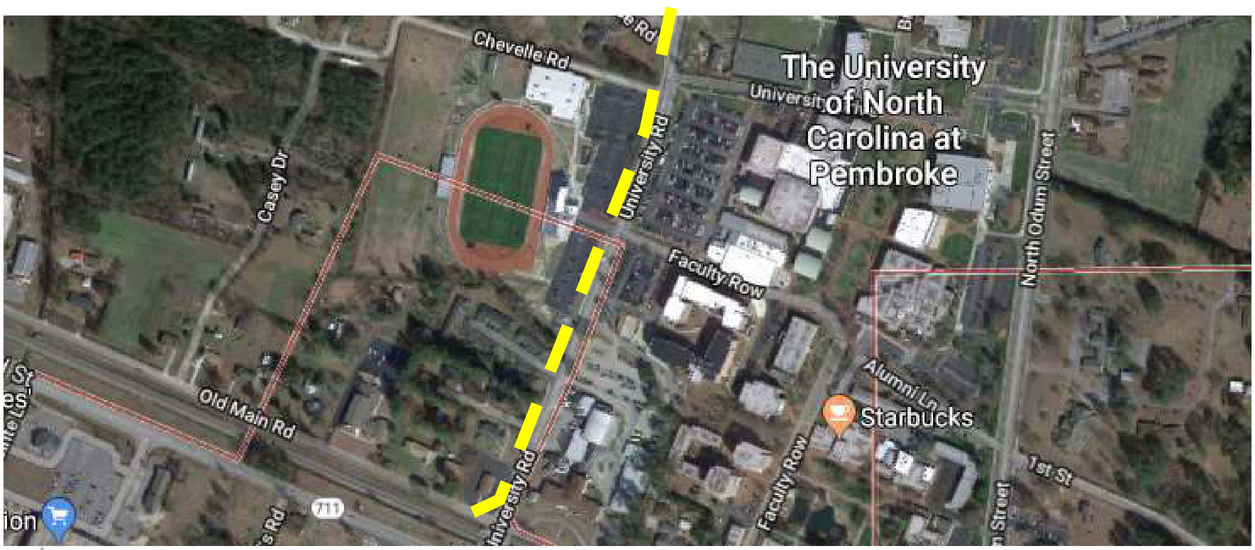
Narrative: This recommendation aims to decrease the amount of stormwater that enters the UNC-P stormwater system to aid in flood mitigation on campus. Once implemented, this recommendation will allow a portion of the runoff from up-gradient areas along Deese Road and University Road to by-pass the UNC-P and Town's stormwater systems. Additionally, this recommendation will redirect stormwater from the southwest portion of the campus towards the west and away from campus. This recommendation will require entry into the NCDOT and CSX right-of-ways.

Description: Install approximately 1,700 linear feet of single-barrel 36-inch RCP and approximately 150 linear feet of double-barrel 36-inch RCP with replacement of 12 drop inlets to accommodate increased pipe size. This recommendation will require removal and replacement of curb and gutter, asphalt, and concrete sidewalk.

Outcome: This will decrease the total amount of volume that passes through the UNC-P stormwater system and through Corridor 1.

Prerequisites: 4, 10, 20, 26

Costs: $900,000



<u>Recommendation #17</u>

Location: University Drive

Priority: Low

Narrative: Runoff from the western portion of campus near the tennis courts and Parking Lot #14 collects in several drop inlets and is conveyed along the western side of the Jones Health and Physical Education Building. The stormwater piping appears to be undersized in this area. This recommendation proposes to connect the upstream portion of this conveyance link with the proposed increased stormwater conveyance link located on the east side of the Jones Health and Physical Education Building (see Recommendation #15).

Description: Install approximately 70 linear feet of 24-inch RCP to connect junction box on University Drive with junction box at Braves Drive and University Drive. Adjust the two junction boxes that are proposed to be connected.

Outcome: Provides secondary route for stormwater to by-pass undersized piping on the west side of the Jones Health and Physical Education Building.

Prerequisites: 15

Costs: $45,000

Recommendation #18

Location: Corridor 2 – Between Union Chapel Road and North Jones Street

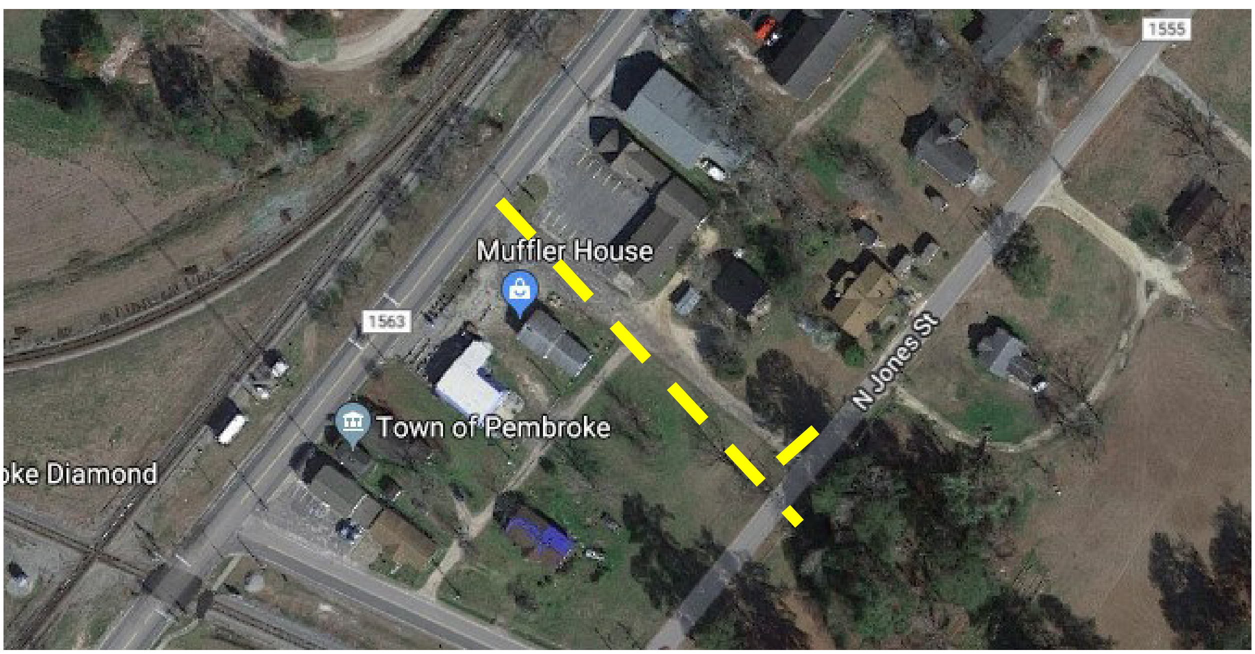
Priority: High

Narrative: Increasing flow capacity of downstream stormwater structures will allow more stormwater to flow through the system and decrease the volume of flooding experienced upstream. Increasing flow into Corridor 2 will help decrease flood levels experienced in Corridor 1 and on the UNC-P campus. This recommendation proposes to install a second culvert next to the existing culvert to increase flow capacity.

Description: Install approximately 400 linear feet of 36-inch RCP culvert beginning at Union Chapel Road flowing southeast towards N. Jones Street. Install four drop inlets next to existing drop inlets of existing 36-inch culvert. Install new drop inlet next to North Jones Street on the north side of dirt road and connect to new 36-inch RCP culvert with 30-inch RCP pipe. Install new double barrel headwall for 36-inch RCP culverts.

Outcome: Increased flow capacity by 200%.

Costs: $369,000



Recommendation #19

Location: Corridor 2 – CSX railroad crossing

Priority: High

Narrative: Recommendation #18 proposes to increase flow into Corridor 2. Increasing flow will require increasing culvert sizes throughout the corridor, including at East Railroad Street and at the CSX railroad. This recommendation proposes to remove the existing culverts and replace with larger culverts. This will require entry into the CSX right-of-way

Description: Remove three 24-inch RCP culverts under East Railroad Street and replace with two 65-linear foot 36-inch RCP culverts. Jack and bore additional 40 linear feet of 36-inch RCP culvert next to existing 36-inch RCP culvert beneath CSX railroad tracks. Adjust open channel between East Railroad Street and CSX railroad tracks.

Outcome: Increased flow capacity by more than 200%.

Prerequisites: 6, 12, 18

Costs: $455,000.00

<u>Recommendation #20</u>

Location: Harry West Lane and Pembroke Pointe Lane

Priority: High

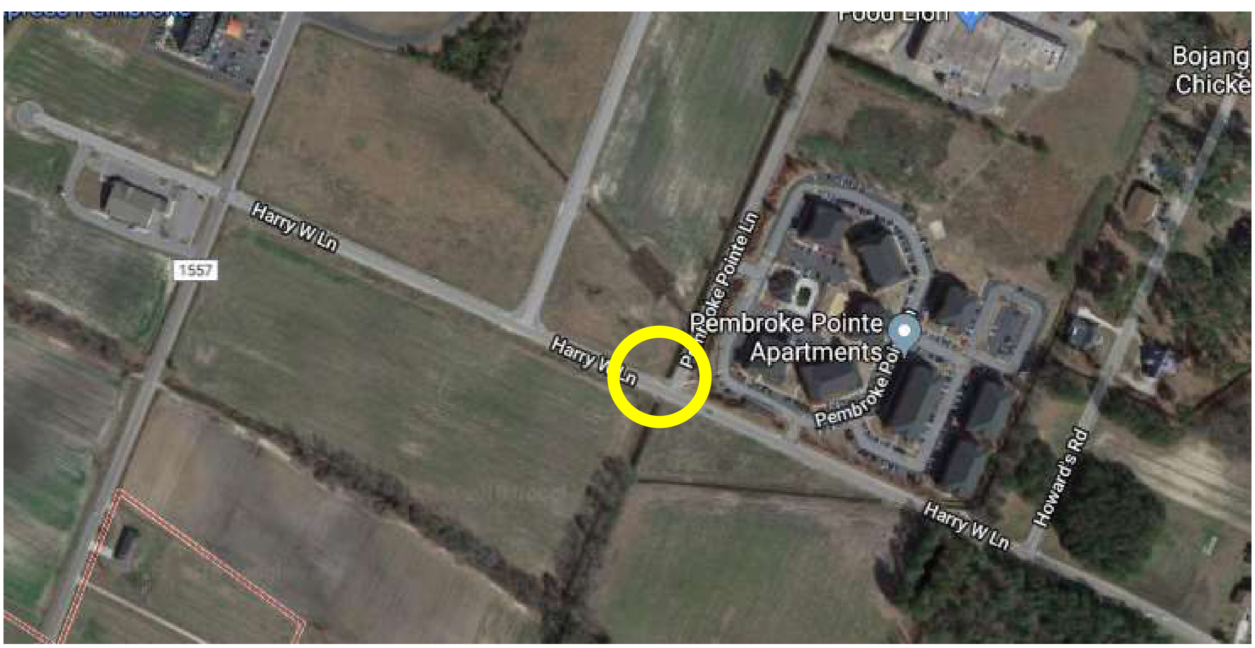
Narrative: The culvert underneath Harry West Lane at the Pembroke Pointe Lane intersection appears to contribute to the flooding experienced in the western and northwestern portion of the town. Increasing the size of the culvert will help mitigate flooding in the western portion of the town as well as allow for additional flow from upstream modifications increasing stormwater volume through the culvert.

Description: Remove existing 48-inch corrugated metal pipe and replace with 103-inch by 71-inch corrugated aluminum pipe arch with headwalls.

Outcome: Increased flow capacity by more than 375%.

Prerequisites: 26

Costs: $175,000



<u>Recommendation #21</u>

Location: UNC-P Campus – ROTC Building

Priority: High

Narrative: The northern portion of the UNC-P campus discharges stormwater to the north and eventually down Prospect Road to Vogue Road and into Bear Swamp. Conveyance ditches identified around the ROTC building are overgrown with vegetation and culverts are undersized. This recommendation proposes to clean ditches and upsize culverts to allow maximum flow capacity of stormwater off the campus.

Description: Clean and remove vegetation, sediment, and debris from approximately 1,300 linear feet of stormwater ditches and replace existing 24-inch RCP culverts with 36-inch RCP culverts at the ROTC building driveways.

Outcome: Cleaning ditches and installing larger culverts will increase peak flow by approximately 300%.

Prerequisites: 14

Costs: $90,000

Recommendation #22

Location: UNC-P Campus – Faculty Road

Priority: High

Narrative: The south-center portion of the UNC-P campus commonly experiences flooding on Faculty Drive near the Chavis University Center. This area contains stormwater piping that is undersized and does not provide the most efficient route for conveyance to off-site outfalls. This recommendation proposes to increase stormwater pipe sizes and adjust the flow path to provide the most efficient route.

Description: Replace eight drop inlets and replace existing pipe with larger pipe. Install approximately 125 total linear feet of 18-inch RCP, 70 total linear feet of 24-inch RCP, and 275 total linear feet of 30-inch RCP. Modify existing junction box in Lot #10 to accommodate new pipe size.

Outcome: Peak flow capacity will increase by more than 300%.

Prerequisites: None.

Costs: $385,000

Recommendation #23

Location: Corridor 1

Priority: High

Narrative: The short-term portion of this project included the installation of larger stormwater culverts in Corridor 1 along 1st Street, Gough Street, Baker Street, Vance Street, and Clifton Street. It did not include increasing the culvert size that is located near the 1st Street and Bonnie Road intersection. Currently, this culvert is large enough to provide the conveyance capacity needed during the 25-year design storm; however, as development continues and upstream stormwater systems are improved as part of the long-term portion of the project, this culvert will no longer be capable of providing adequate flow. This recommendation proposes to increase the culvert size and replace with RCP to ensure proper flow capacity and longevity.

Description: Remove existing 66-inch corrugated metal pipe and replace with two projecting 48-inch RCP pipes. Install 5-foot diameter junction box when pipes turn north. Install 18-inch RCP pipe connected to one junction box for runoff entering from railroad ditch southwest of new stormwater piping.

Outcome: Increased peak flow capacity by more than 200%.

Prerequisites: None.

Costs: $210,000

<u>Recommendation #24</u>

Location: Corridor 1 - North of Town

Priority: High

Narrative: The short-term portion of this project included the installation of larger stormwater culverts in Corridor 1 along 1st Street, Gough Street, Baker Street, Vance Street, and Clifton Street. It did not include increasing the culvert size that is located near the 1st Street and Bonnie Road intersection. Currently, this culvert is large enough to provide the conveyance capacity needed during the 25-year design storm; however, as development continues and upstream stormwater systems are improved as part of the long-term portion of the project, this culvert will no longer be capable of providing adequate flow. This recommendation proposes to increase the culvert size to ensure proper flow capacity and longevity.

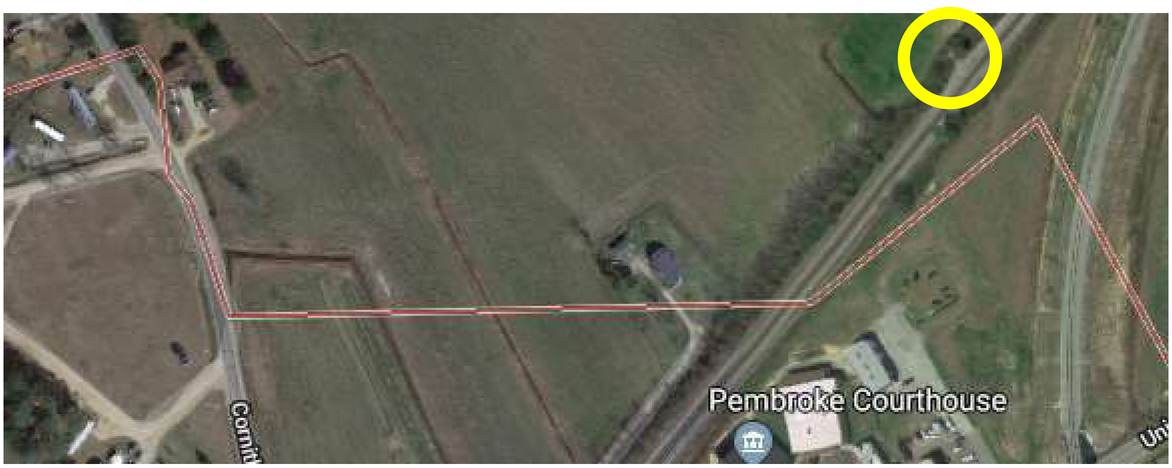
This recommendation may require coordination with CSX which is included in the cost estimate

Description: Remove existing corrugated metal pipe culvert and replace with a 103" x 71" corrugated aluminum pipe arch with headwalls.

Outcome: Increased peak flow capacity by more than 200%.

Prerequisites: 7.

Costs: $190,000



Recommendation #25

Location: West of UNC-P Campus

Priority: Low

Narrative: The UNC-P Campus stormwater drainage system is overloaded with stormwater from the UNC-P campus runoff as well as upstream runoff that is diverted through the campus. This recommendation would capture a portion of the runoff from upstream sources and divert them to a different route to decrease the volume of water entering the UNC-P stormwater drainage system.

The recommendation would install a drainage ditch from Deese Road at 881 Deese Road to connect to the existing drainage ditch located approximately 250 feet south of Deese Road. The head of the proposed ditch would be located near a topographic divide in Deese Road that has ditches sloping to the northwest towards the St. Anna Road intersection and to the southeast towards the UNC-P campus. The portions of Deese Road that slope towards St. Anna Road connect to a drainage channel via a culvert under St. Anna Road and continue downstream along the northwest side of St. Anna Road, turn south along Sally's Road, then turn southeast towards the existing channel that the proposed ditch would connect to. Since the Pembroke area is topographically flat, drainage channels depend on hydraulic head to push water through since ideal slopes are not achievable. During large storm events, the St. Anna Road and Sally's Road channel fills, building hydraulic head and increasing depth of water upstream. Once the depth of water reaches a certain elevation, the topographic divide on Deese Road allows water to flow from St. Anna Road southeast towards the UNC-P campus.

This recommendation will intercept the runoff flowing towards the UNC-P campus from the north and south side of Deese Road and divert it south. This recommendation has been given a low priority due to the benefits seen only during large storm events.

This recommendation may require coordination with NCDOT which is included in the cost estimate.

Description: Install a 40-foot, 24-inch RCP culvert under Deese Road at the 881 Deese Road driveway. Begin excavation of proposed ditch along the east side of driveway with trapezoidal geometry, two feet deep, one wide at the bottom, with 2:1 side slopes. Connect to existing drainage ditch located approximately 250 feet to the south of Deese Road.

Outcome: Provides upstream by-pass of UNC-P stormwater system for runoff from Deese Road during large storm events.

Prerequisites: None

Costs: $65,000

Recommendation #26

Location: West of Town

Priority: High

Narrative: Stormwater from a large area immediately west of town limits is conveyed down St. Anna Road, turns south down Sally's Road, then turns east into a wooded area and then turns south towards Old Main Road. This conveyance path is overgrown with vegetation and should be cleaned to allow peak flow.

Description: Clean and remove vegetation, sediment, and debris from approximately 5,000 linear feet of stormwater channels.

Outcome: Cleaning these open channels will allow for at least a 50% increase in effective flow area for maximum flow through existing channel geometry.

Prerequisites: None.

Costs: $75,000

Recommendation #27

Location: Deep Branch Road - Southwest of town

Priority: High

Narrative: Stormwater channels located along the southwest edge of the town convey a large amount of stormwater from the town and up-gradient sources. These channels have become overgrown with trees, shrubs, and other plants and do not allow for peak flow. This appears to be backing up stormwater for more than a mile along the length of the channel and causes flooding problems upstream. Additionally, the culvert under Deep Branch Road is undersized and should be replaced with a larger culvert. This recommendation will require entry into NCDOT right-of-way.

Description: Clean vegetation from approximately 3,700 linear feet of stormwater channel discharging to the Lumber River. Remove and replace existing 54-inch RCP culvert at Deep Branch Road with 60-linear foot, 112-inch by 75-inch corrugated aluminum pipe arch culvert with minimum 1% slope.

Outcome: Provides increase in peak flow capacity by 450% and helps with mitigating flooding upstream.

Prerequisites: None.

Costs: $515,000

<u>Recommendation #28</u>

Location: Pine Street – South of Town

Priority: High

Narrative: An open channel located between Normal Street and Pine Street conveys runoff from approximately 75 acres within the town limits. The channel flows towards the south and eventually beneath Pine Street near the baseball field of Locklear Court via a 42-inch RCP culvert. MacConnell & Associates observed the culvert to be in good condition with the exception of erosion and sedimentation on the downstream side of the culvert. This culvert appears to be too small and does not allow the required peak flow necessary to prevent ponding on the upstream side of the culvert during heavy rainfall events.

Description: Install approximately 55 linear feet of 42-inch RCP next to existing 42-inch RCP with precast concrete headwalls. Clean vegetation and sediment from approximately 200 linear feet of stormwater channel immediately downstream of culvert.

Outcome: Provides increase in peak flow capacity by 200% and prevents erosion from immediately downstream of culvert.

Prerequisites: None.

Costs: $57,000

Recommendation #29

Location: Old Main Road – South of Town

Priority: High

Narrative: A portion of the western part of town conveys stormwater through a culvert under Old Main Road and under the CSX railroad near the Sallys Road and Old Main Road intersection. These culverts have become overgrown with vegetation and has accumulated a substantial amount of trash and debris. Additionally, the sediment and debris appears to have built up within the culverts. The culverts should be cleaned and the vegetation and debris should be removed from the entrances to the culverts to allow for effective flow. This recommendation will require entry into the NCDOT and CSX right-of-ways.

Description: Remove vegetation and debris from around culverts at Sallys Road and Old Main Road intersection and beneath CSX railroad. Clean out sediment and debris inside culverts.

Outcome: Increases effective flow into and through existing culverts.

Prerequisites: None.

Costs: $7,000

8.0 COMMUNITY INPUT

A draft of this report was provided to the Town of Pembroke citizens as well as UNC-P personnel on November 5, 2018. This section has been added to address the topics that citizens expressed concerns about following review of the draft report.

8.1 Pine Street

Ponding reportedly occurs in the vicinity of the Locklear Court neighborhood located on Lumbee Street off of Pine Street within the town limits. This ponding appears to be created by an undersized culvert beneath Pine Street approximately 400 feet south of the Lumbee Street and Pine Street intersection. This issue is further discussed in Section 7.2 – Recommendation #28.

8.2 North of Ernest Lowery Drive – North of UNC-P Campus

Areas north of Ernest Lowery Road in the northern part of the UNC-P campus experience frequent flooding with water remaining for days after large rainfall events. This area appears to drain towards the south through the northern part of campus. This area will benefit greatly from the implementation of Recommendations 9, 14, and 21. These recommendations will allow for increased flow out of the northern part of the UNC-P campus allowing for the area north of the Ernest Lowery Road to drain more effectively.

8.3 Brookfield Neighborhood – South of Town

The Brookfield neighborhood is located in the southern portion of the Town of Pembroke limits, immediately north of Deep Branch Road and west of Pembroke Middle School. A citizen has expressed concerns that the neighborhood experiences ponding of stormwater during heavy rainfall events. This ponding is likely caused by an undersized culvert beneath Deep Branch Road that conveys stormwater from an open channel that is located adjacent to the west of the neighborhood. The culvert is not capable of allowing the necessary flow rates, therefore, stormwater is impeded and begins to pond at the headwall of the culvert. This ponded water appears to back up to an open channel that is located along the northern boundary of the neighborhood and eventually into the low lying areas of the neighborhood. A larger culvert beneath Deep Branch Road in this location would allow higher stormwater flow rates and decrease the amount of stormwater ponded in the area. This issue would likely be resolved with the implementation of Recommendation #27.

8.4 CSX Railroad

CSX Transportation owns a railroad track that runs in the north-south direction and in the east-west direction that passes through the Pembroke town limits. These railroads separate the town into quadrants between the Lumber River and Bear Swamp. The railroad tracks are typically higher in elevation than the surrounding area and creates a berm that prevents stormwater runoff from freely crossing the tracks to reach the Lumber River or Bear Swamp. To allow for stormwater to convey downstream, CSX has installed culverts in numerous locations along the railroad tracks and open channels have been excavated to divert stormwater to these culverts.

While these culverts provide conveyance across CSX's property, they were installed decades ago and are poorly maintained or no longer large enough to convey peak flows experienced during frequent heavy rainfall events. MacConnell & Associates observed several culverts under CSX railroad property to be overgrown with vegetation and filled with sediment and debris. CSX should implement better culvert maintenance practices so that existing culverts provide the maximum flow that can be obtained.

At the time of the installation of the existing culverts, the Town of Pembroke, surrounding areas, and upstream municipalities were less developed and had lower percentages of build-upon areas. Historically, Robeson County and the Town of Pembroke did not have stormwater attenuation regulations; therefore, as the area became more developed and impervious areas increased, stormwater runoff volume and peak flow rates also increased. With the increase in stormwater runoff, the existing culverts are no longer capable of conveying stormwater effectively without ponding upstream. M&A has provided recommendations to increase culverts beneath the CSX railroad that would greatly improve stormwater conveyance and decrease flooding and ponding caused by insufficient capacities (See Recommendations 4, 7, 19, and 29)

8.5 Jones Street at CSX Railroad

A citizen has expressed concern with flooding near the Jones Street and Railroad Street intersection caused by an undersized culvert beneath the CSX railroad. This area of flooding appears to be caused by the same reasons mentioned in Section 8.4. The flooding in this area would be mitigated with the implementation of Recommendations 3 and 19.

Appendix A

Figures

Soils are classified into hydrologic soil groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The HSG's, which are A, B, C, and D, are one element used in determining runoff curve numbers (see chapter 2). For the convenience of TR-55 users, exhibit A-1 lists the HSG classification of United States soils.

The infiltration rate is the rate at which water enters the soil at the soil surface. It is controlled by surface conditions. HSG also indicates the transmission rate—the rate at which the water moves within the soil. This rate is controlled by the soil profile. Approximate numerical ranges for transmission rates shown in the HSG definitions were first published by Musgrave (USDA 1955). The four groups are defined by SCS soil scientists as follows:

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

In exhibit A-1, some of the listed soils have an added modifier; for example, "Abrazo, gravelly." This refers to a gravelly phase of the Abrazo series that is found in SCS soil map legends.

Disturbed soil profiles

As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply. In these circumstances, use the following to determine HSG according to the texture of the new surface soil, provided that significant compaction has not occurred (Brakensiek and Rawls 1983).

HSG	*Soil textures*
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Drainage and group D soils

Some soils in the list are in group D because of a high water table that creates a drainage problem. Once these soils are effectively drained, they are placed in a different group. For example, Ackerman soil is classified as A/D. This indicates that the drained Ackerman soil is in group A and the undrained soil is in group D.

Hydrologic Soil Groups (USDA 1986, 103)

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Typical Curve Number Values for Urban Areas (SCS 1986)

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.435** (0.398-0.477)	**0.513** (0.470-0.563)	**0.600** (0.549-0.658)	**0.667** (0.608-0.729)	**0.748** (0.679-0.816)	**0.808** (0.732-0.881)	**0.867** (0.781-0.944)	**0.923** (0.827-1.00)	**0.994** (0.882-1.08)	**1.05** (0.926-1.14)
10-min	**0.695** (0.636-0.761)	**0.820** (0.751-0.900)	**0.961** (0.878-1.05)	**1.07** (0.972-1.17)	**1.19** (1.08-1.30)	**1.29** (1.17-1.40)	**1.38** (1.24-1.50)	**1.46** (1.31-1.59)	**1.57** (1.40-1.71)	**1.65** (1.46-1.80)
15-min	**0.868** (0.795-0.952)	**1.03** (0.945-1.13)	**1.22** (1.11-1.33)	**1.35** (1.23-1.48)	**1.51** (1.37-1.65)	**1.63** (1.48-1.78)	**1.74** (1.57-1.90)	**1.85** (1.65-2.01)	**1.98** (1.76-2.15)	**2.08** (1.83-2.26)
30-min	**1.19** (1.09-1.31)	**1.42** (1.31-1.56)	**1.73** (1.58-1.90)	**1.95** (1.78-2.14)	**2.24** (2.03-2.44)	**2.46** (2.22-2.68)	**2.67** (2.40-2.90)	**2.87** (2.57-3.13)	**3.15** (2.80-3.43)	**3.36** (2.96-3.66)
60-min	**1.48** (1.36-1.63)	**1.79** (1.64-1.96)	**2.22** (2.02-2.43)	**2.54** (2.32-2.78)	**2.98** (2.71-3.25)	**3.33** (3.01-3.62)	**3.68** (3.31-4.00)	**4.03** (3.61-4.39)	**4.52** (4.01-4.92)	**4.91** (4.33-5.35)
2-hr	**1.72** (1.57-1.90)	**2.08** (1.89-2.30)	**2.63** (2.39-2.91)	**3.06** (2.78-3.38)	**3.65** (3.29-4.02)	**4.13** (3.71-4.55)	**4.62** (4.13-5.09)	**5.14** (4.55-5.64)	**5.85** (5.13-6.42)	**6.42** (5.59-7.06)
3-hr	**1.82** (1.65-2.03)	**2.20** (2.00-2.45)	**2.79** (2.53-3.10)	**3.28** (2.97-3.63)	**3.96** (3.56-4.38)	**4.52** (4.04-5.00)	**5.11** (4.53-5.65)	**5.75** (5.06-6.34)	**6.66** (5.79-7.34)	**7.40** (6.37-8.16)
6-hr	**2.16** (1.97-2.41)	**2.62** (2.38-2.91)	**3.33** (3.02-3.69)	**3.91** (3.53-4.33)	**4.73** (4.25-5.23)	**5.42** (4.83-5.97)	**6.16** (5.45-6.77)	**6.95** (6.09-7.63)	**8.08** (6.99-8.86)	**9.02** (7.72-9.89)
12-hr	**2.54** (2.30-2.84)	**3.08** (2.78-3.44)	**3.93** (3.54-4.38)	**4.64** (4.17-5.17)	**5.66** (5.05-6.28)	**6.52** (5.78-7.22)	**7.45** (6.53-8.23)	**8.45** (7.34-9.33)	**9.93** (8.49-11.0)	**11.2** (9.42-12.3)
24-hr	**3.02** (2.81-3.27)	**3.67** (3.41-3.97)	**4.69** (4.35-5.07)	**5.52** (5.10-5.96)	**6.69** (6.15-7.22)	**7.64** (6.99-8.25)	**8.65** (7.88-9.35)	**9.72** (8.81-10.5)	**11.2** (10.1-12.2)	**12.5** (11.1-13.5)
2-day	**3.52** (3.28-3.79)	**4.26** (3.96-4.59)	**5.40** (5.01-5.82)	**6.32** (5.86-6.81)	**7.62** (7.03-8.21)	**8.68** (7.97-9.35)	**9.80** (8.95-10.6)	**11.0** (9.97-11.9)	**12.6** (11.4-13.7)	**14.0** (12.5-15.2)
3-day	**3.74** (3.50-4.02)	**4.52** (4.22-4.85)	**5.70** (5.31-6.11)	**6.65** (6.18-7.13)	**7.98** (7.38-8.55)	**9.05** (8.34-9.72)	**10.2** (9.34-10.9)	**11.4** (10.4-12.2)	**13.1** (11.8-14.1)	**14.4** (12.9-15.6)
4-day	**3.97** (3.72-4.25)	**4.78** (4.48-5.11)	**6.00** (5.60-6.41)	**6.97** (6.50-7.45)	**8.33** (7.73-8.90)	**9.43** (8.72-10.1)	**10.6** (9.73-11.3)	**11.8** (10.8-12.6)	**13.5** (12.2-14.5)	**14.8** (13.4-16.0)
7-day	**4.62** (4.32-4.93)	**5.54** (5.19-5.92)	**6.87** (6.42-7.35)	**7.93** (7.39-8.47)	**9.39** (8.72-10.0)	**10.6** (9.77-11.3)	**11.8** (10.9-12.6)	**13.0** (12.0-14.0)	**14.8** (13.5-15.9)	**16.2** (14.7-17.4)
10-day	**5.31** (5.00-5.65)	**6.35** (5.97-6.75)	**7.75** (7.28-8.24)	**8.84** (8.30-9.39)	**10.3** (9.65-11.0)	**11.5** (10.7-12.2)	**12.7** (11.8-13.5)	**13.9** (12.9-14.9)	**15.6** (14.4-16.7)	**17.0** (15.5-18.2)
20-day	**7.15** (6.76-7.56)	**8.49** (8.03-8.99)	**10.2** (9.63-10.8)	**11.5** (10.9-12.2)	**13.3** (12.5-14.1)	**14.8** (13.8-15.6)	**16.2** (15.1-17.2)	**17.7** (16.4-18.8)	**19.7** (18.2-20.9)	**21.3** (19.6-22.7)
30-day	**8.86** (8.42-9.34)	**10.5** (9.95-11.1)	**12.4** (11.7-13.0)	**13.8** (13.1-14.6)	**15.7** (14.9-16.6)	**17.2** (16.2-18.2)	**18.7** (17.6-19.7)	**20.2** (18.9-21.3)	**22.2** (20.7-23.5)	**23.7** (22.0-25.2)
45-day	**11.2** (10.6-11.7)	**13.1** (12.5-13.8)	**15.3** (14.5-16.0)	**16.9** (16.0-17.7)	**19.0** (18.0-20.0)	**20.6** (19.5-21.7)	**22.2** (20.9-23.4)	**23.7** (22.3-25.1)	**25.8** (24.2-27.3)	**27.4** (25.6-29.0)
60-day	**13.3** (12.7-14.0)	**15.7** (14.9-16.5)	**18.0** (17.2-18.9)	**19.8** (18.8-20.8)	**22.1** (21.0-23.2)	**23.9** (22.6-25.1)	**25.6** (24.2-26.9)	**27.2** (25.7-28.7)	**29.4** (27.6-31.0)	**31.0** (29.0-32.8)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Rainfall depth in inches per average recurrence interval and duration for Pembroke, NC (NOAA)

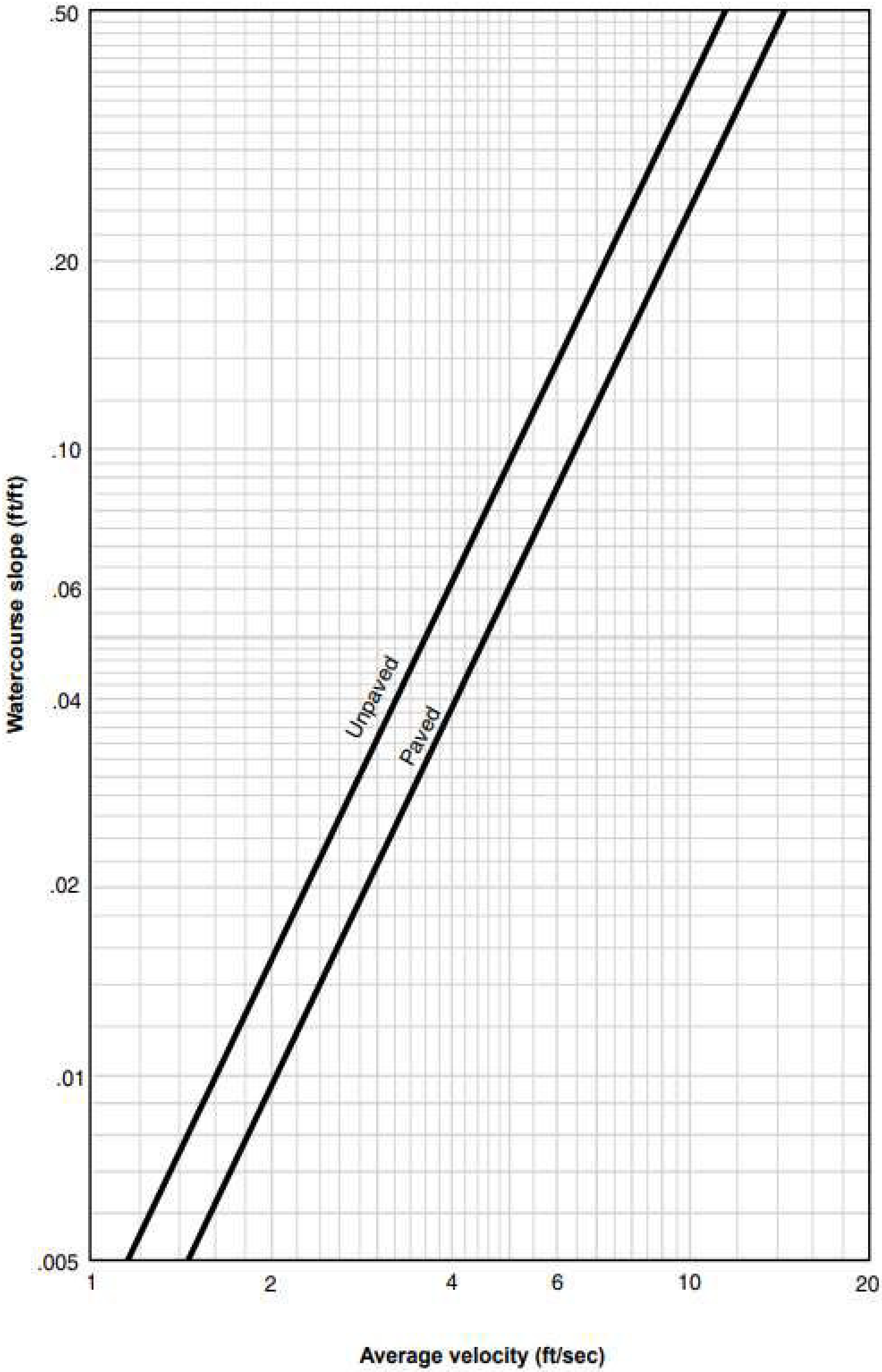
PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**5.22** (4.78-5.72)	**6.16** (5.64-6.76)	**7.20** (6.59-7.90)	**8.00** (7.30-8.75)	**8.98** (8.15-9.79)	**9.70** (8.78-10.6)	**10.4** (9.37-11.3)	**11.1** (9.92-12.0)	**11.9** (10.6-13.0)	**12.6** (11.1-13.7)
10-min	**4.17** (3.82-4.57)	**4.92** (4.51-5.40)	**5.77** (5.27-6.32)	**6.40** (5.83-7.00)	**7.15** (6.49-7.80)	**7.73** (7.00-8.41)	**8.27** (7.45-9.00)	**8.78** (7.86-9.55)	**9.44** (8.38-10.3)	**9.92** (8.75-10.8)
15-min	**3.47** (3.18-3.81)	**4.12** (3.78-4.52)	**4.86** (4.44-5.34)	**5.39** (4.92-5.90)	**6.04** (5.49-6.59)	**6.52** (5.90-7.10)	**6.97** (6.27-7.58)	**7.38** (6.61-8.04)	**7.92** (7.03-8.62)	**8.30** (7.32-9.05)
30-min	**2.38** (2.18-2.61)	**2.85** (2.61-3.13)	**3.46** (3.16-3.79)	**3.91** (3.56-4.27)	**4.48** (4.06-4.88)	**4.91** (4.45-5.35)	**5.34** (4.80-5.81)	**5.75** (5.15-6.25)	**6.30** (5.59-6.86)	**6.72** (5.93-7.33)
60-min	**1.48** (1.36-1.63)	**1.79** (1.64-1.96)	**2.22** (2.02-2.43)	**2.54** (2.32-2.78)	**2.98** (2.71-3.25)	**3.33** (3.01-3.62)	**3.68** (3.31-4.00)	**4.03** (3.61-4.39)	**4.52** (4.01-4.92)	**4.91** (4.33-5.35)
2-hr	**0.858** (0.782-0.952)	**1.04** (0.946-1.15)	**1.32** (1.20-1.45)	**1.53** (1.39-1.69)	**1.82** (1.65-2.01)	**2.06** (1.85-2.27)	**2.31** (2.06-2.54)	**2.57** (2.28-2.82)	**2.92** (2.57-3.21)	**3.21** (2.79-3.53)
3-hr	**0.605** (0.551-0.675)	**0.733** (0.666-0.816)	**0.930** (0.844-1.03)	**1.09** (0.987-1.21)	**1.32** (1.18-1.46)	**1.50** (1.35-1.66)	**1.70** (1.51-1.88)	**1.91** (1.68-2.11)	**2.22** (1.93-2.44)	**2.47** (2.12-2.72)
6-hr	**0.361** (0.328-0.402)	**0.437** (0.398-0.486)	**0.555** (0.504-0.616)	**0.653** (0.590-0.722)	**0.791** (0.710-0.873)	**0.905** (0.807-0.997)	**1.03** (0.910-1.13)	**1.16** (1.02-1.27)	**1.35** (1.17-1.48)	**1.51** (1.29-1.65)
12-hr	**0.211** (0.191-0.236)	**0.255** (0.231-0.285)	**0.326** (0.294-0.364)	**0.385** (0.346-0.429)	**0.470** (0.419-0.521)	**0.541** (0.479-0.599)	**0.618** (0.542-0.683)	**0.702** (0.609-0.775)	**0.824** (0.705-0.910)	**0.926** (0.782-1.02)
24-hr	**0.126** (0.117-0.136)	**0.153** (0.142-0.165)	**0.195** (0.181-0.211)	**0.230** (0.213-0.248)	**0.279** (0.256-0.301)	**0.318** (0.291-0.344)	**0.361** (0.328-0.390)	**0.405** (0.367-0.438)	**0.468** (0.421-0.507)	**0.519** (0.464-0.563)
2-day	**0.073** (0.068-0.079)	**0.089** (0.083-0.096)	**0.112** (0.104-0.121)	**0.132** (0.122-0.142)	**0.159** (0.146-0.171)	**0.181** (0.166-0.195)	**0.204** (0.186-0.220)	**0.229** (0.208-0.247)	**0.263** (0.237-0.285)	**0.291** (0.260-0.316)
3-day	**0.052** (0.049-0.056)	**0.063** (0.059-0.067)	**0.079** (0.074-0.085)	**0.092** (0.086-0.099)	**0.111** (0.102-0.119)	**0.126** (0.116-0.135)	**0.142** (0.130-0.152)	**0.158** (0.144-0.170)	**0.181** (0.164-0.195)	**0.200** (0.180-0.216)
4-day	**0.041** (0.039-0.044)	**0.050** (0.047-0.053)	**0.062** (0.058-0.067)	**0.073** (0.068-0.078)	**0.087** (0.081-0.093)	**0.098** (0.091-0.105)	**0.110** (0.101-0.118)	**0.123** (0.112-0.131)	**0.140** (0.127-0.151)	**0.154** (0.139-0.166)
7-day	**0.027** (0.026-0.029)	**0.033** (0.031-0.035)	**0.041** (0.038-0.044)	**0.047** (0.044-0.050)	**0.056** (0.052-0.060)	**0.063** (0.058-0.067)	**0.070** (0.065-0.075)	**0.078** (0.071-0.083)	**0.088** (0.080-0.095)	**0.096** (0.087-0.104)
10-day	**0.022** (0.021-0.024)	**0.026** (0.025-0.028)	**0.032** (0.030-0.034)	**0.037** (0.035-0.039)	**0.043** (0.040-0.046)	**0.048** (0.045-0.051)	**0.053** (0.049-0.056)	**0.058** (0.054-0.062)	**0.065** (0.060-0.070)	**0.071** (0.065-0.076)
20-day	**0.015** (0.014-0.016)	**0.018** (0.017-0.019)	**0.021** (0.020-0.022)	**0.024** (0.023-0.025)	**0.028** (0.026-0.029)	**0.031** (0.029-0.033)	**0.034** (0.032-0.036)	**0.037** (0.034-0.039)	**0.041** (0.038-0.044)	**0.044** (0.041-0.047)
30-day	**0.012** (0.012-0.013)	**0.015** (0.014-0.015)	**0.017** (0.016-0.018)	**0.019** (0.018-0.020)	**0.022** (0.021-0.023)	**0.024** (0.023-0.025)	**0.026** (0.024-0.027)	**0.028** (0.026-0.030)	**0.031** (0.029-0.033)	**0.033** (0.031-0.035)
45-day	**0.010** (0.010-0.011)	**0.012** (0.012-0.013)	**0.014** (0.013-0.015)	**0.016** (0.015-0.016)	**0.018** (0.017-0.018)	**0.019** (0.018-0.020)	**0.021** (0.019-0.022)	**0.022** (0.021-0.023)	**0.024** (0.022-0.025)	**0.025** (0.024-0.027)
60-day	**0.009** (0.009-0.010)	**0.011** (0.010-0.011)	**0.013** (0.012-0.013)	**0.014** (0.013-0.014)	**0.015** (0.015-0.016)	**0.017** (0.016-0.017)	**0.018** (0.017-0.019)	**0.019** (0.018-0.020)	**0.020** (0.019-0.022)	**0.022** (0.020-0.023)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

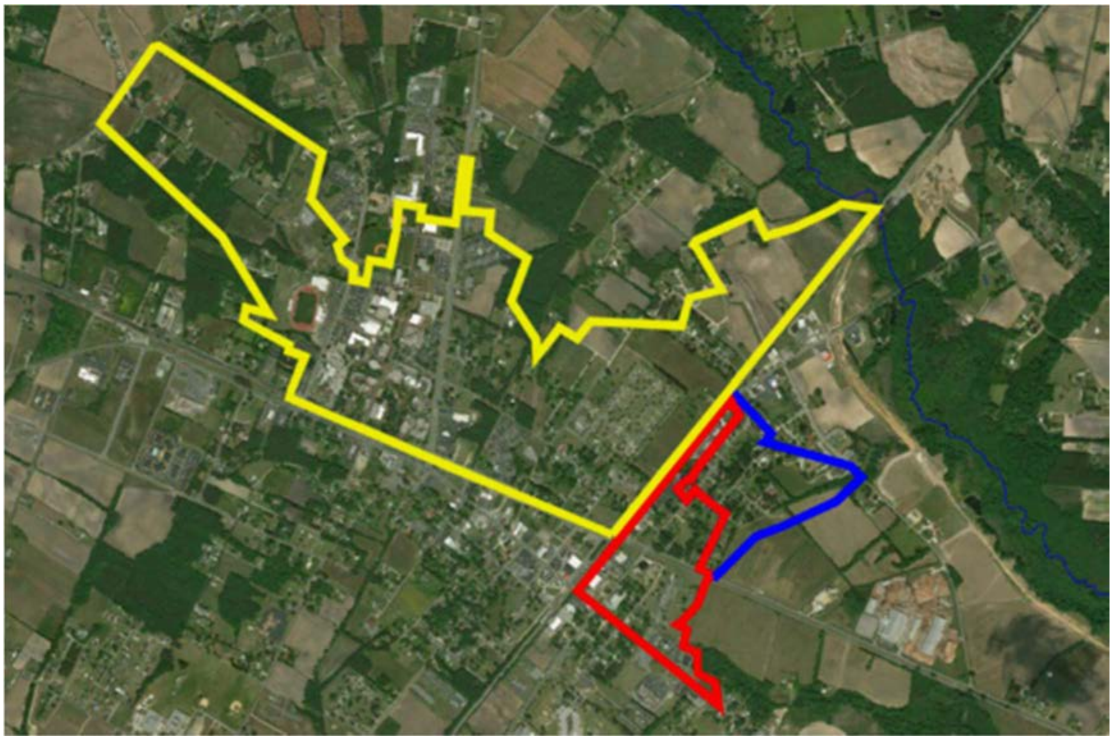
Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

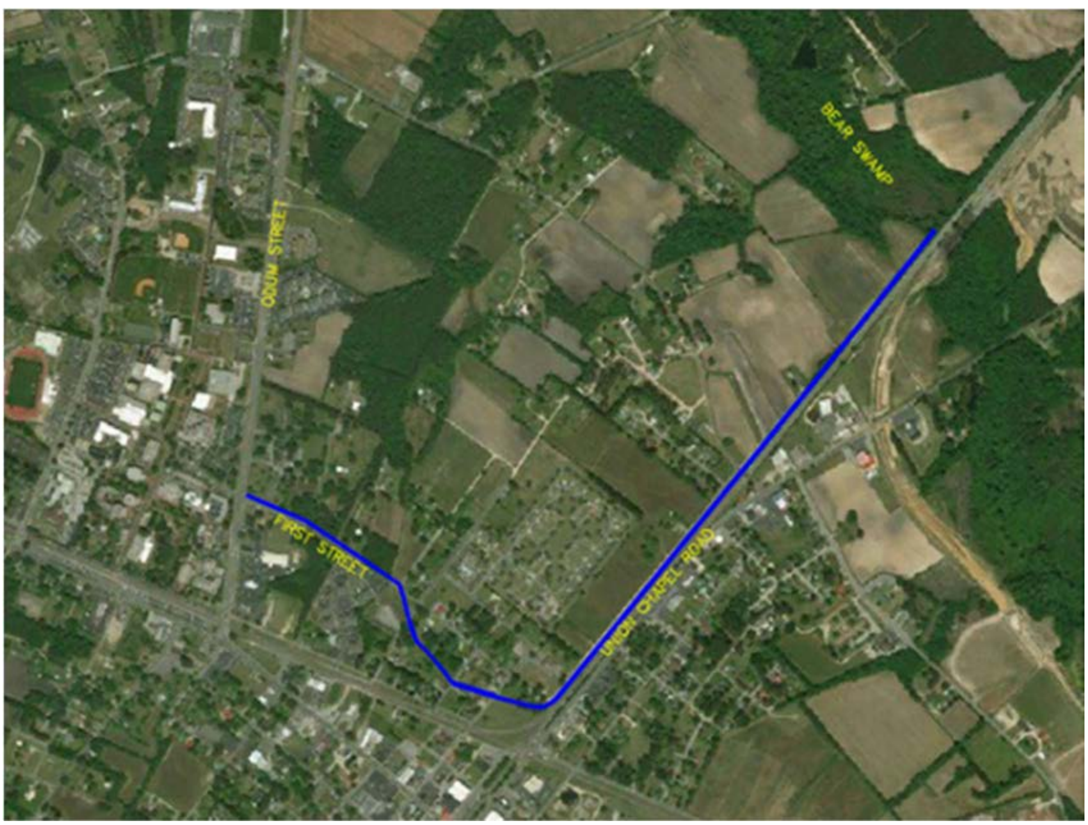
Rainfall intensity in inches per hour per average recurrence interval and duration for Pembroke, NC (NOAA)



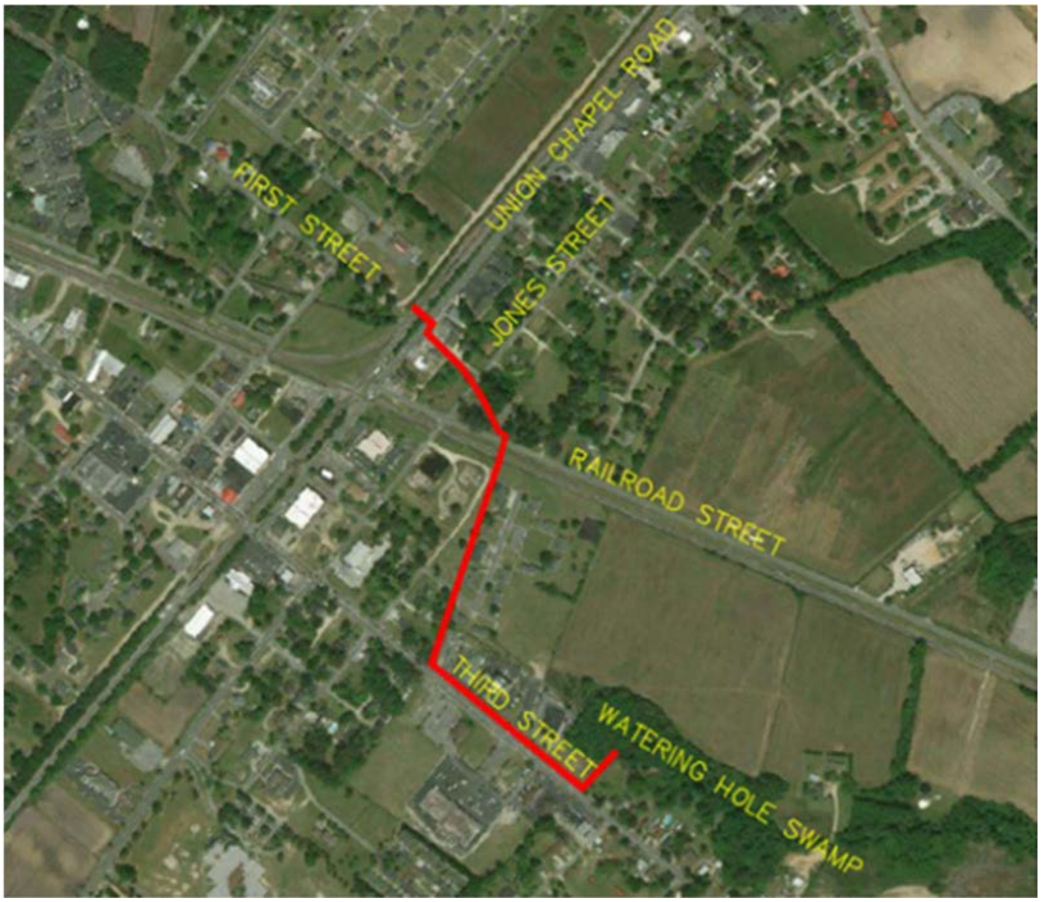
Average velocities for estimating travel time for shallow concentrated flow (TR-55)



Drainage Areas of Corridor 1(Yellow), Corridor 2(Red), Corridor 3(Blue)



Corridor 1 – FIRST ST from N ODUM ST to RR and NE.



Corridor 2 – From UNION CHAPEL RD, SE to RAILROAD ST, then S to THIRD ST, and E to Watering Hole Swamp

Corridor 3 – From RAILROAD ST to E WARDELL ST to Bear Swamp

Short-Term Recommendations

FIGURE

MAIN DITCHES IN PEMBROKE

PROJECT:
TOWN OF PEMBROKE
HYDROLOGICAL STUDY
LONG-TERM RECOMMENDATIONS
ROBESON COUNTY, NC

BY: TAP

JOB #: A61301.00

DATE: 1/4/2019

MacCONNELL & Associates, P. C.

1101 NOWELL ROAD, SUITE 118
RALEIGH, NORTH CAROLINA 27607
P. O. BOX 129
MORRISVILLE, NORTH CAROLINA 27560
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Appendix B

Images

Images 1A-D. Observations of structural damage and possible improper installation along conveyance measures in short-term corridors.

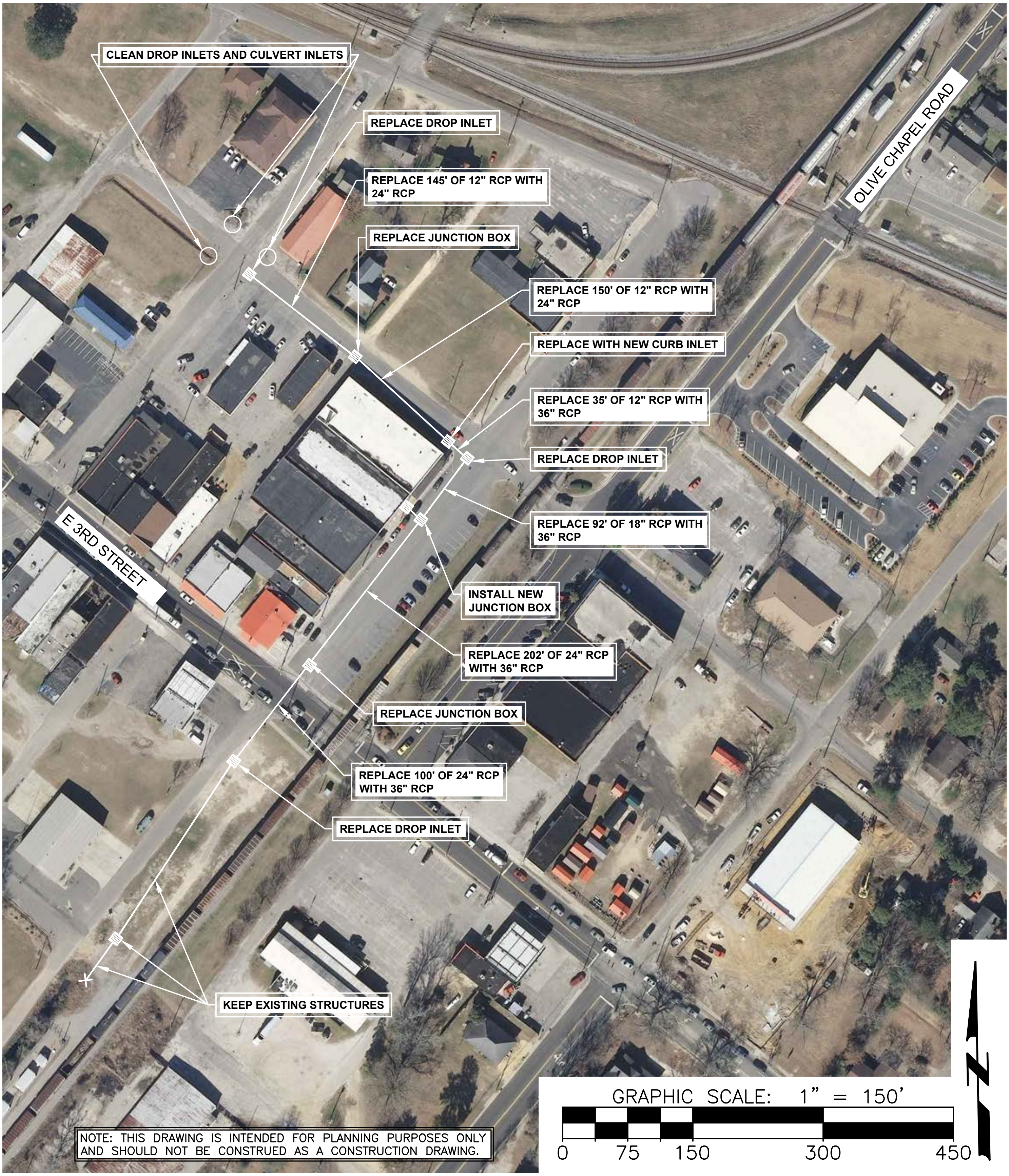
Images 2A-D. Observations of excess vegetation hindering the effectiveness of conveyance along the short-term corridors.

Images 3A-D. Trash, debris, and sedimentation build-up observed along short-term corridors.

Images 4A-C. Trash, debris, and sedimentation build-up observed along short-term corridors.

Appendix C

Recommendation Figures



NOTE: THIS DRAWING IS INTENDED FOR PLANNING PURPOSES ONLY AND SHOULD NOT BE CONSTRUED AS A CONSTRUCTION DRAWING.

MacCONNELL & Associates, P. C.	1101 NOWELL RD., SUITE 118 RALEIGH, NORTH CAROLINA 27607 P. O. BOX 129 MORRISVILLE, NORTH CAROLINA 27560 TEL: (919) 467-1239 FAX: (919) 319-6510	BY: TAP JOB #: A61301.00 DATE: 1/4/2019	TOWN OF PEMBROKE HYDROLOGICAL STUDY LONG-TERM RECOMMENDATIONS ROBESON COUNTY, NC	FIGURE R-1

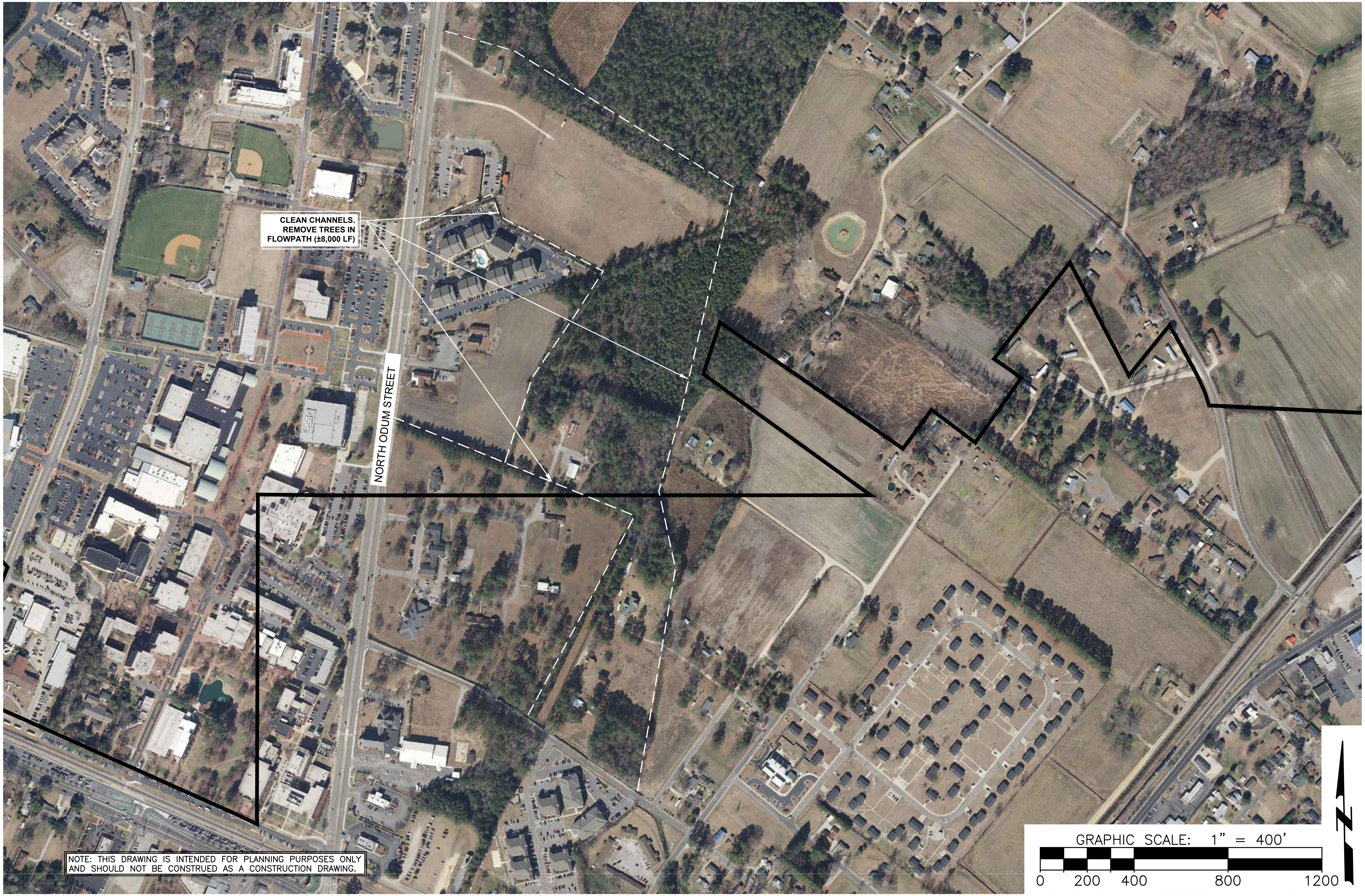


FIGURE R-2

PROJECT:
TOWN OF PEMBROKE
HYDROLOGICAL STUDY
LONG-TERM RECOMMENDATIONS
ROBESON COUNTY, NC

BY: TAP
JOB #: A61301.00
DATE: 1/4/2019

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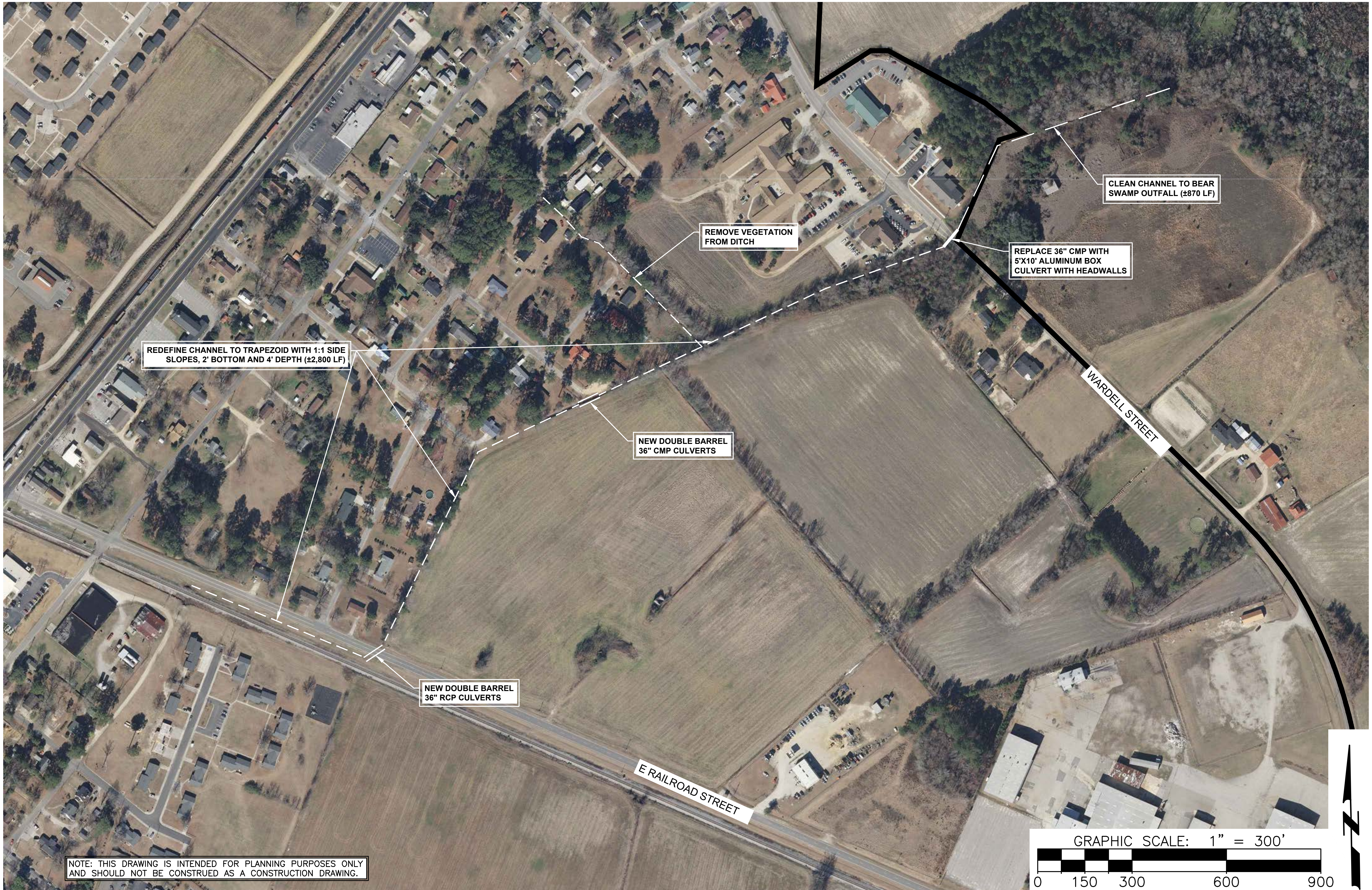

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MORRISVILLE, NORTH CAROLINA 27560
TEL: (919) 467-1239 FAX: (919) 319-6510

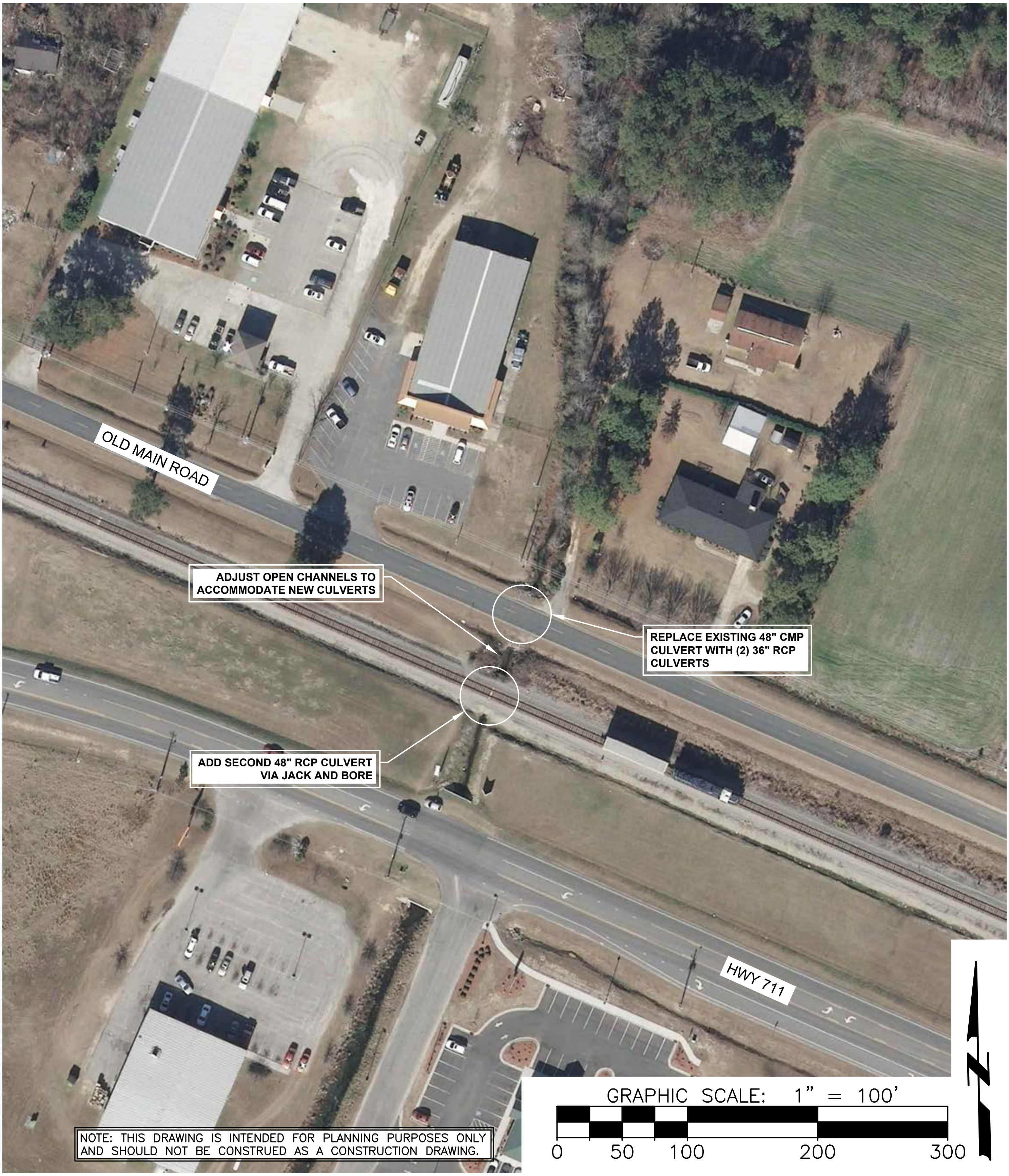
BY: TAP

JOB #: A61301.00

DATE: 1/4/2019

PROJECT:
TOWN OF PEMBROKE
HYDROLOGICAL STUDY
LONG-TERM RECOMMENDATIONS
ROBESON COUNTY, NC

FIGURE R-3



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BY: TAP	TOWN OF PEMBROKE	FIGURE
JOB #: A61301.00	HYDROLOGICAL STUDY LONG-TERM RECOMMENDATIONS	R-4
DATE: 1/4/2019	ROBESON COUNTY, NC	

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BY: TAP JOB #: A61301.00 DATE: 1/4/2019	TOWN OF PEMBROKE HYDROLOGICAL STUDY LONG-TERM RECOMMENDATIONS ROBESON COUNTY, NC	FIGURE R-5

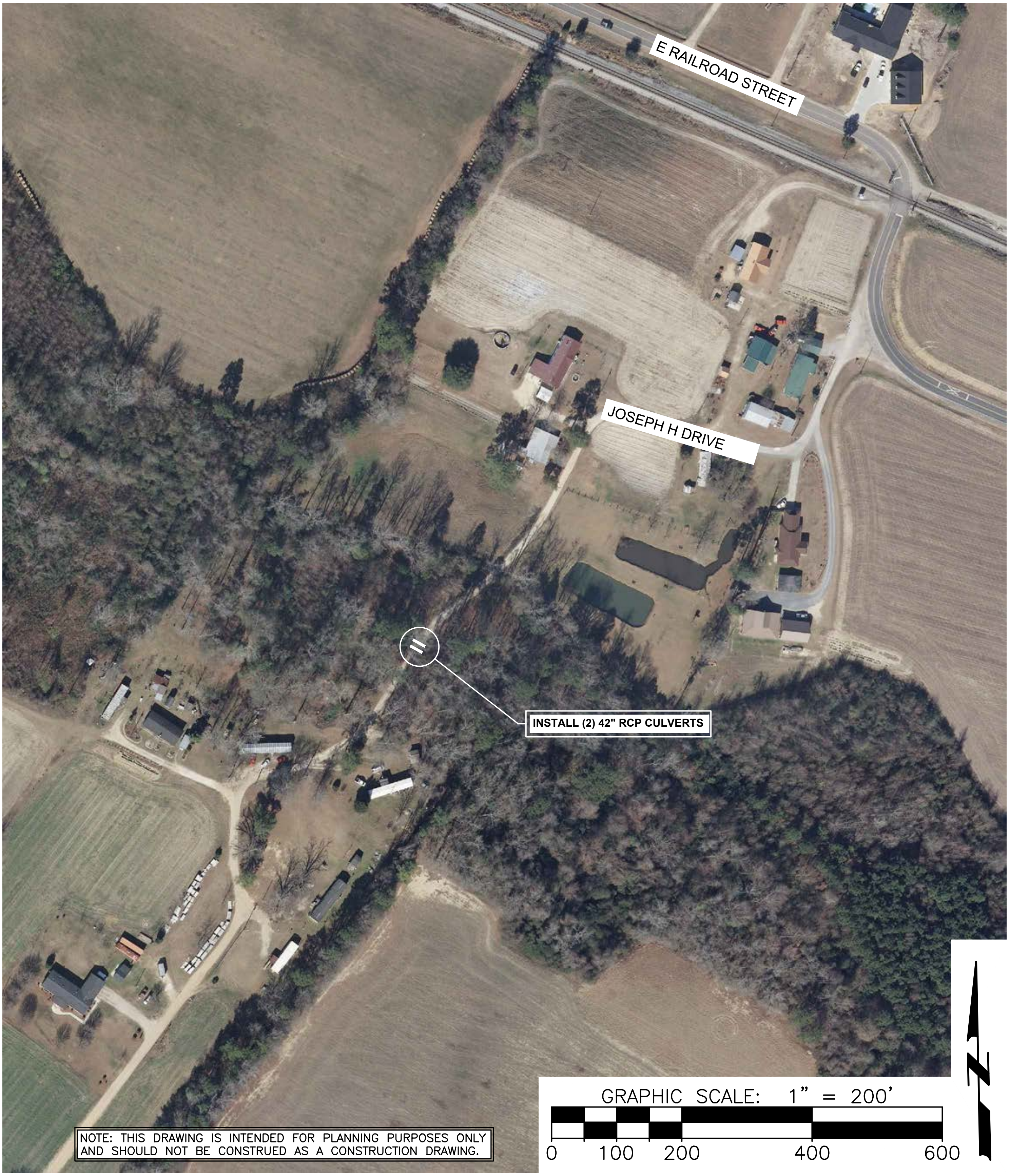

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FIGURE R-9

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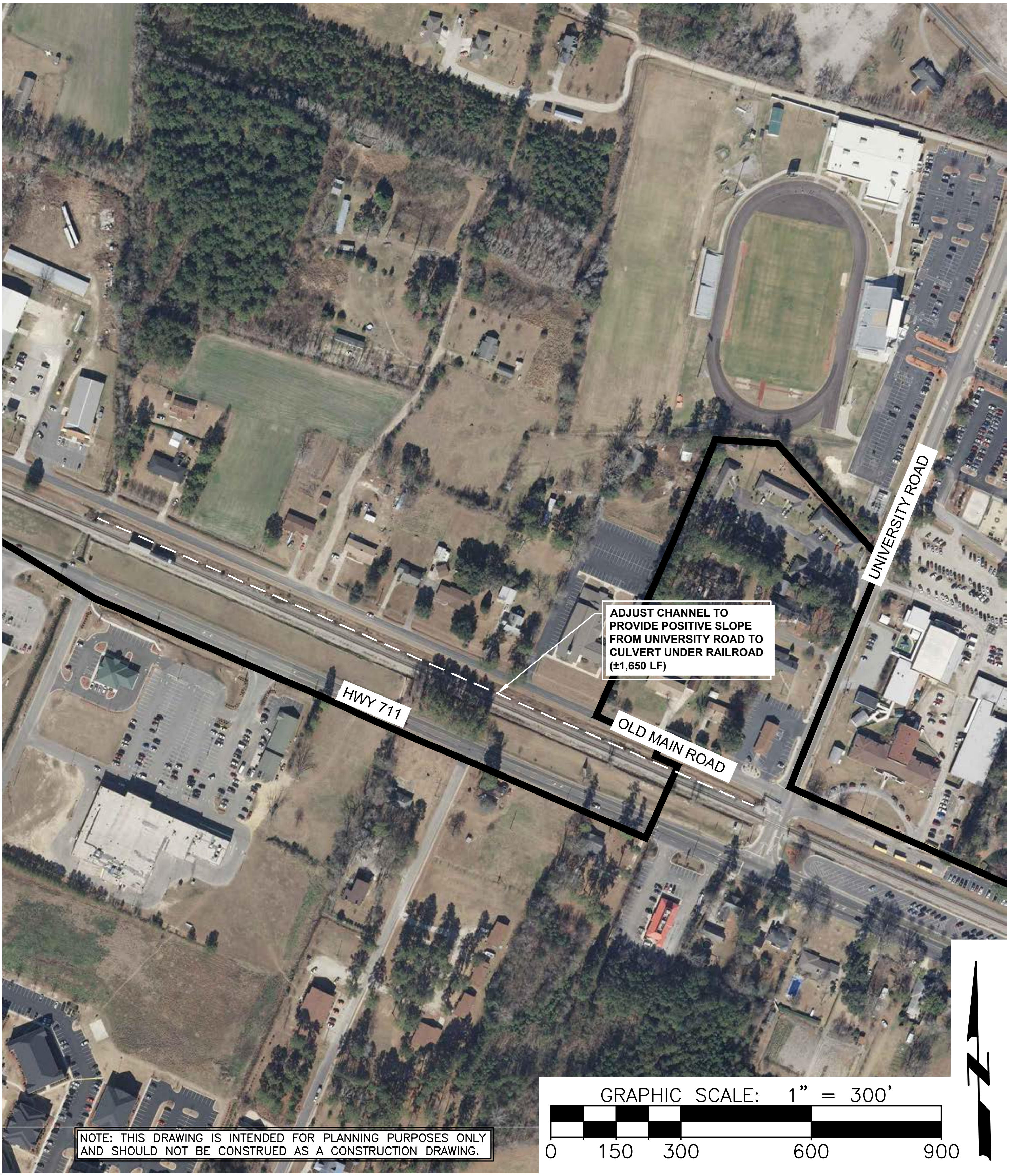

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TOWN OF PEMBROKE

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LONG-TERM RECOMMENDATIONS

ROBESON COUNTY, NC

FIGURE R-11

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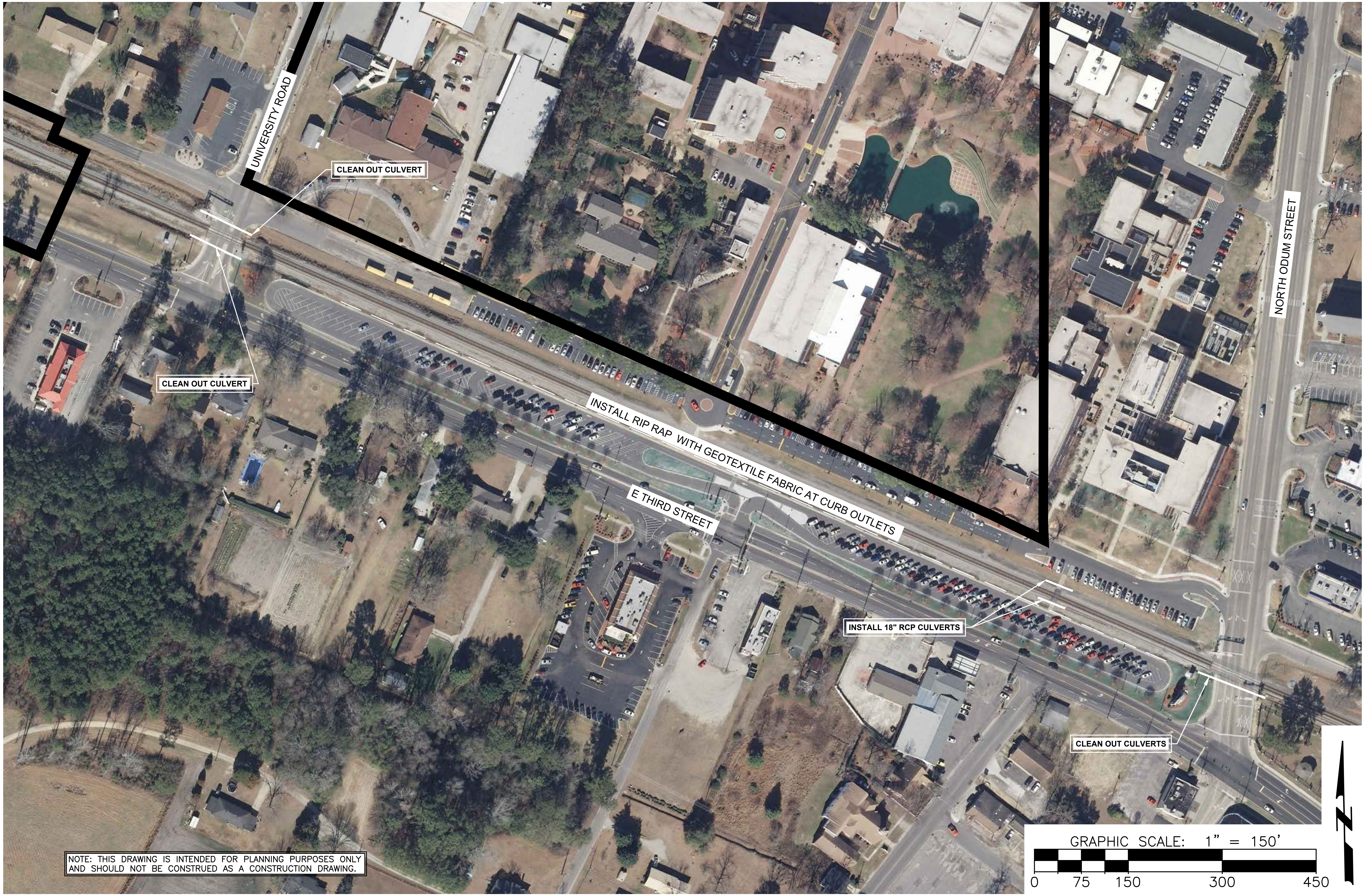

FIGURE

R-13

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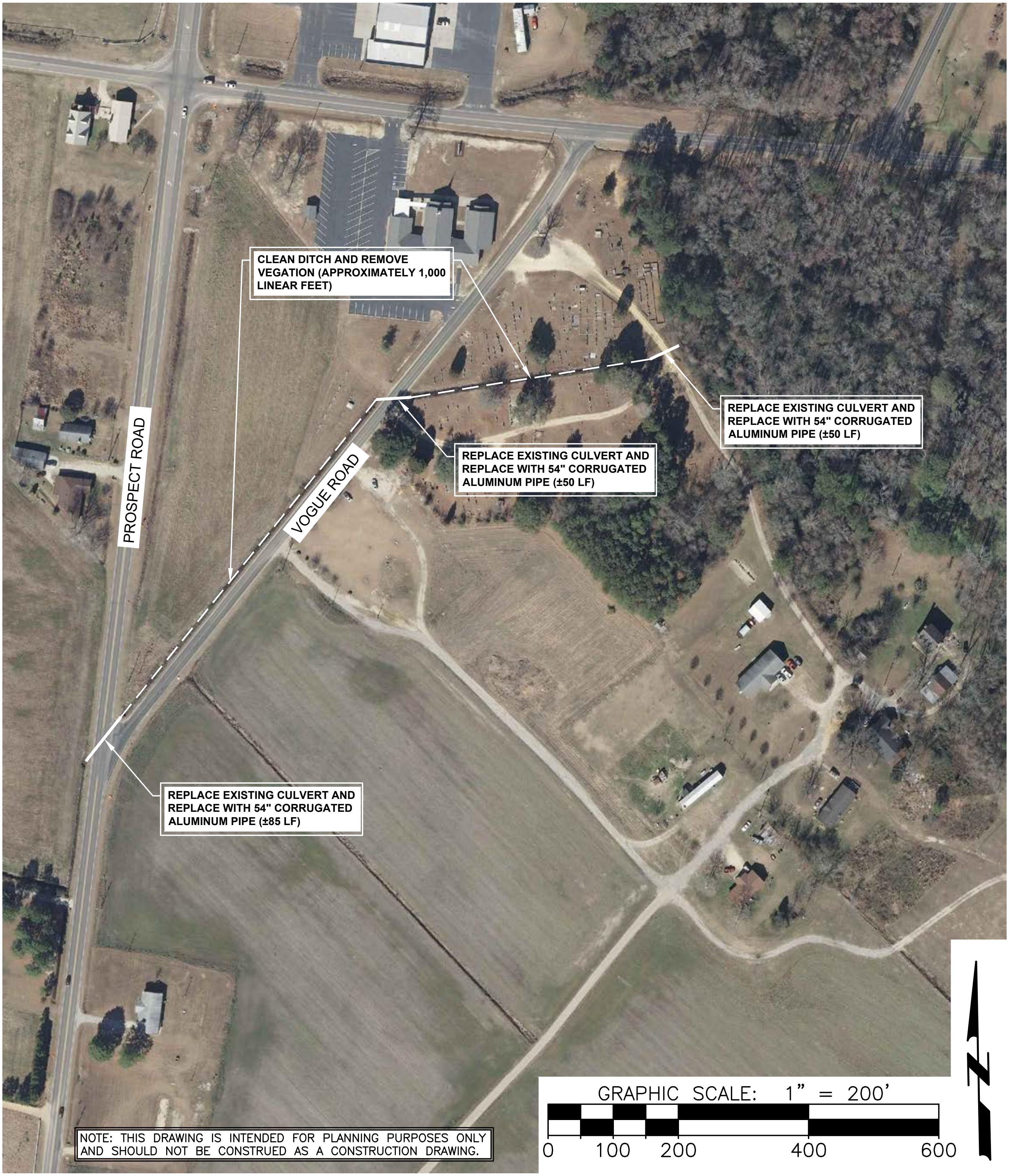

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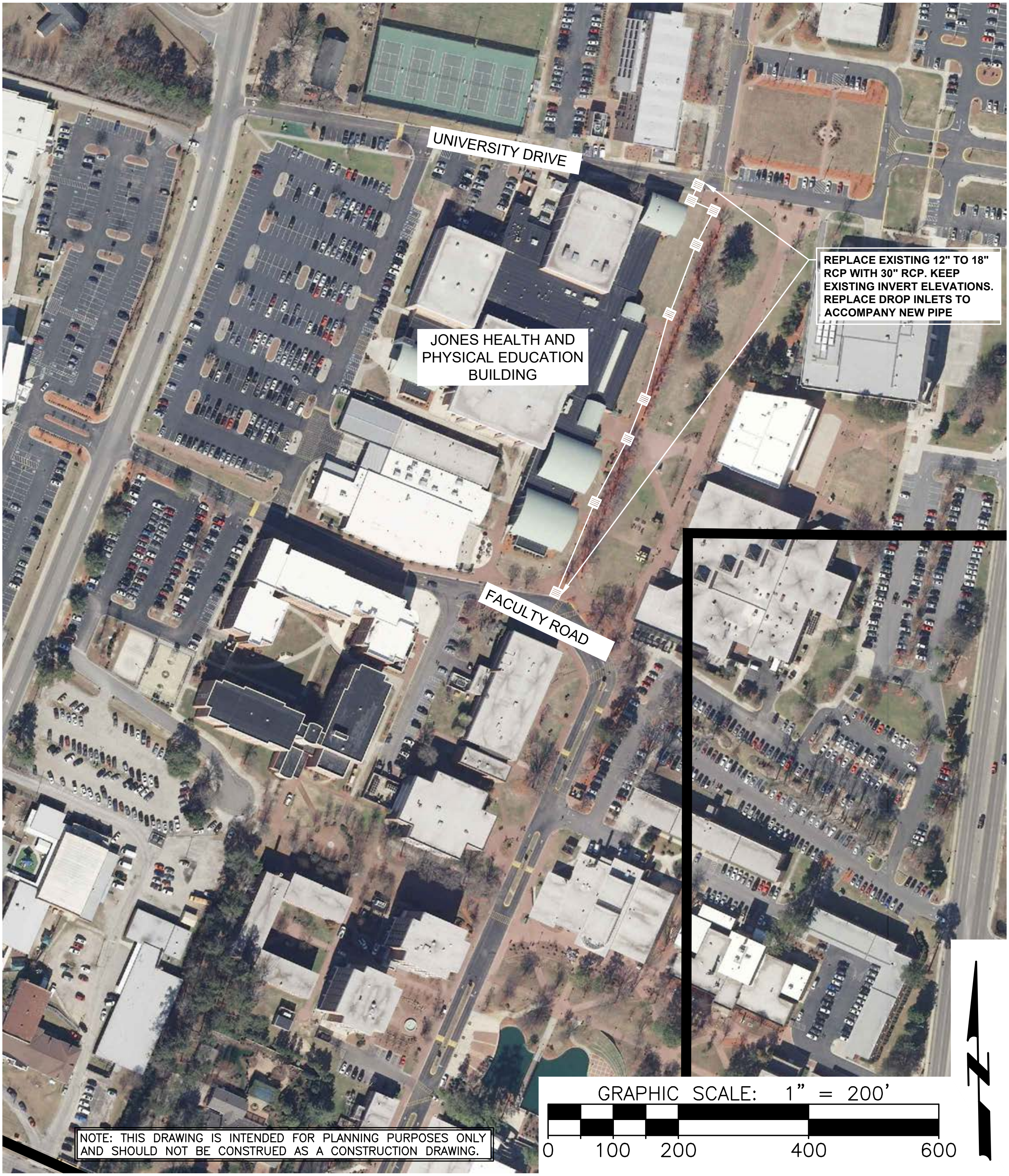

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TOWN OF PEMBROKE
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LONG-TERM RECOMMENDATIONS
ROBESON COUNTY, NC

FIGURE R-15

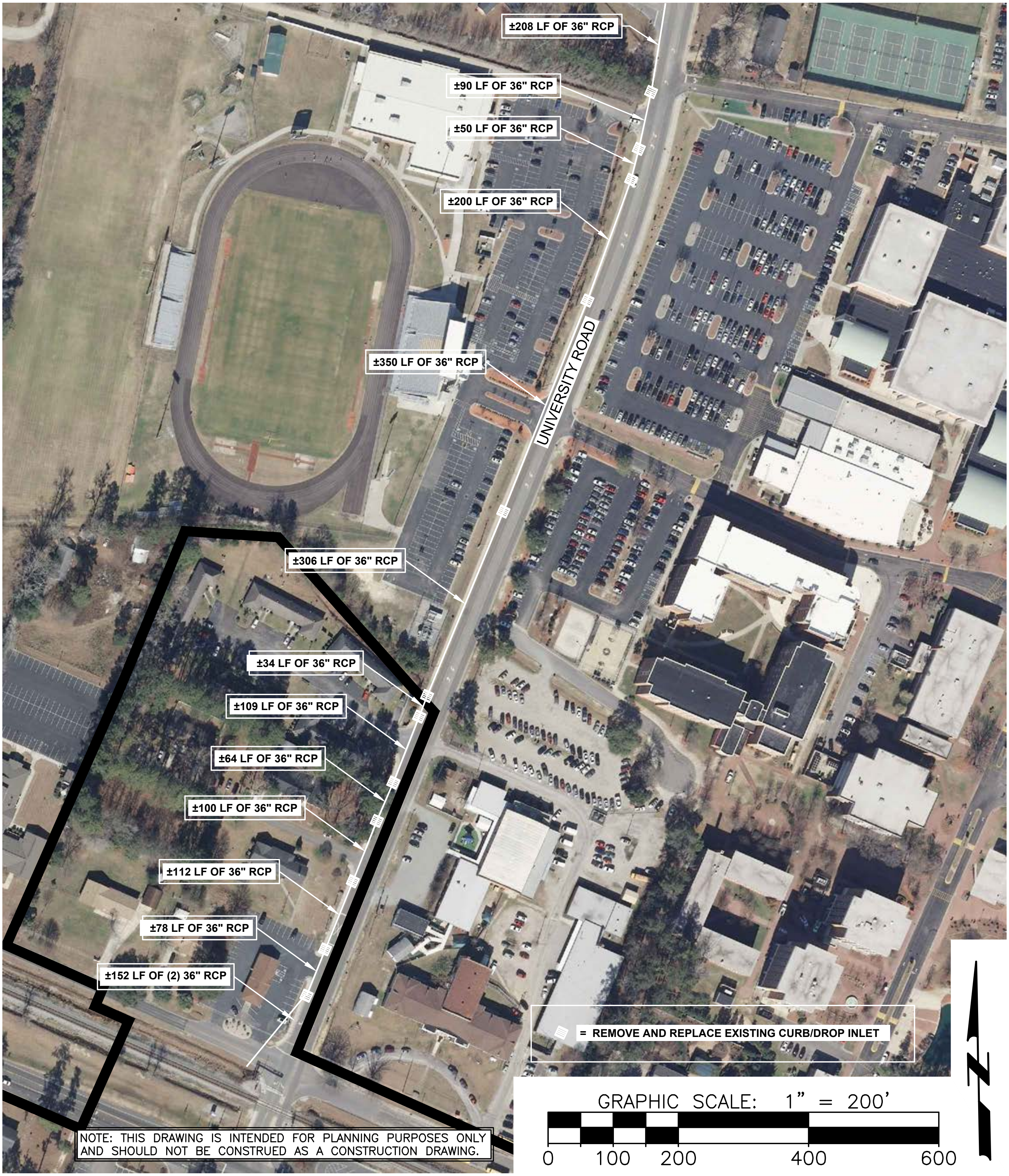

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FIGURE R-16

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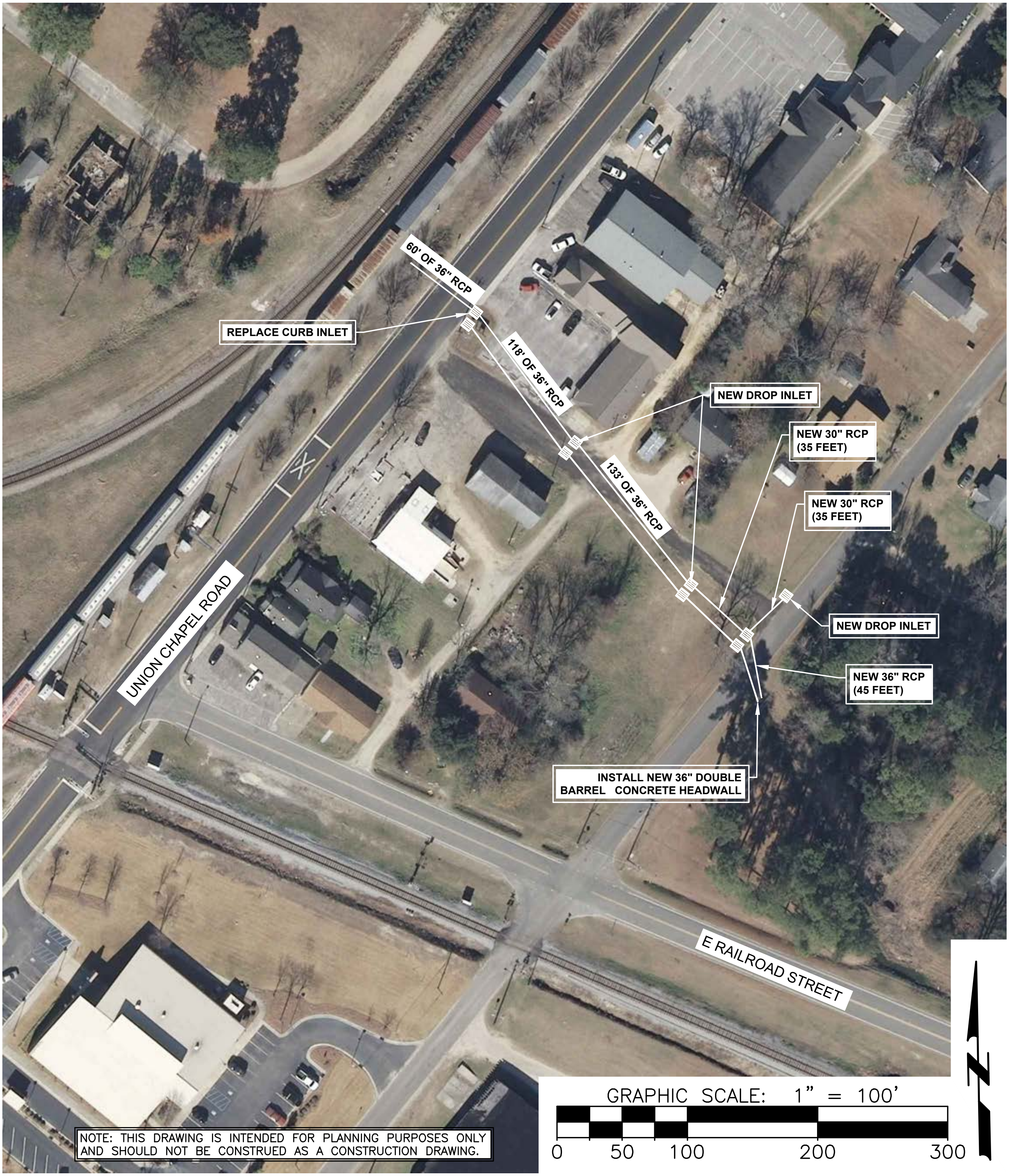

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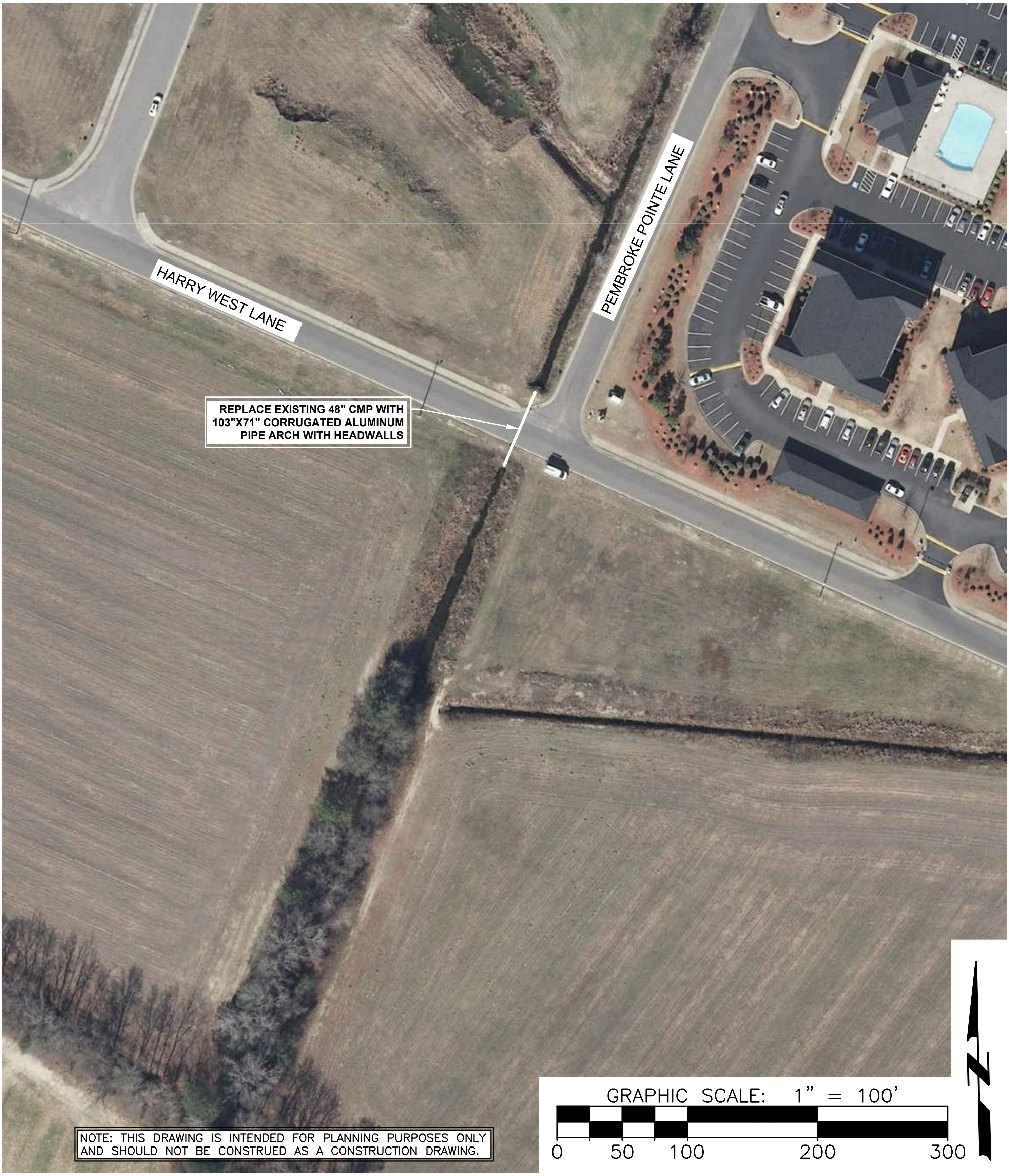

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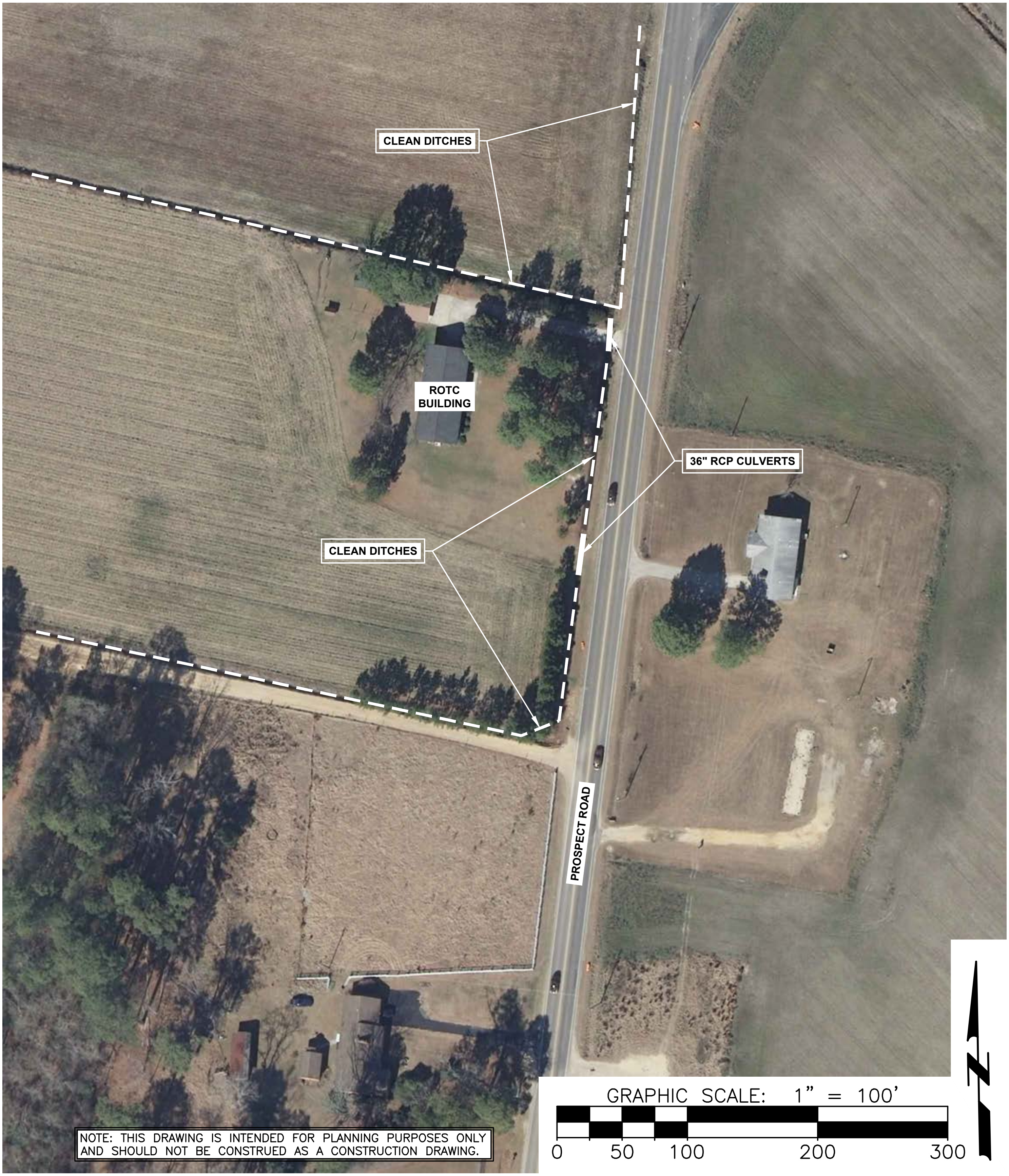
JOB #: A61301.00	HYDROLOGICAL STUDY LONG-TERM RECOMMENDATIONS	R-20
DATE: 1/4/2019	ROBESON COUNTY, NC	



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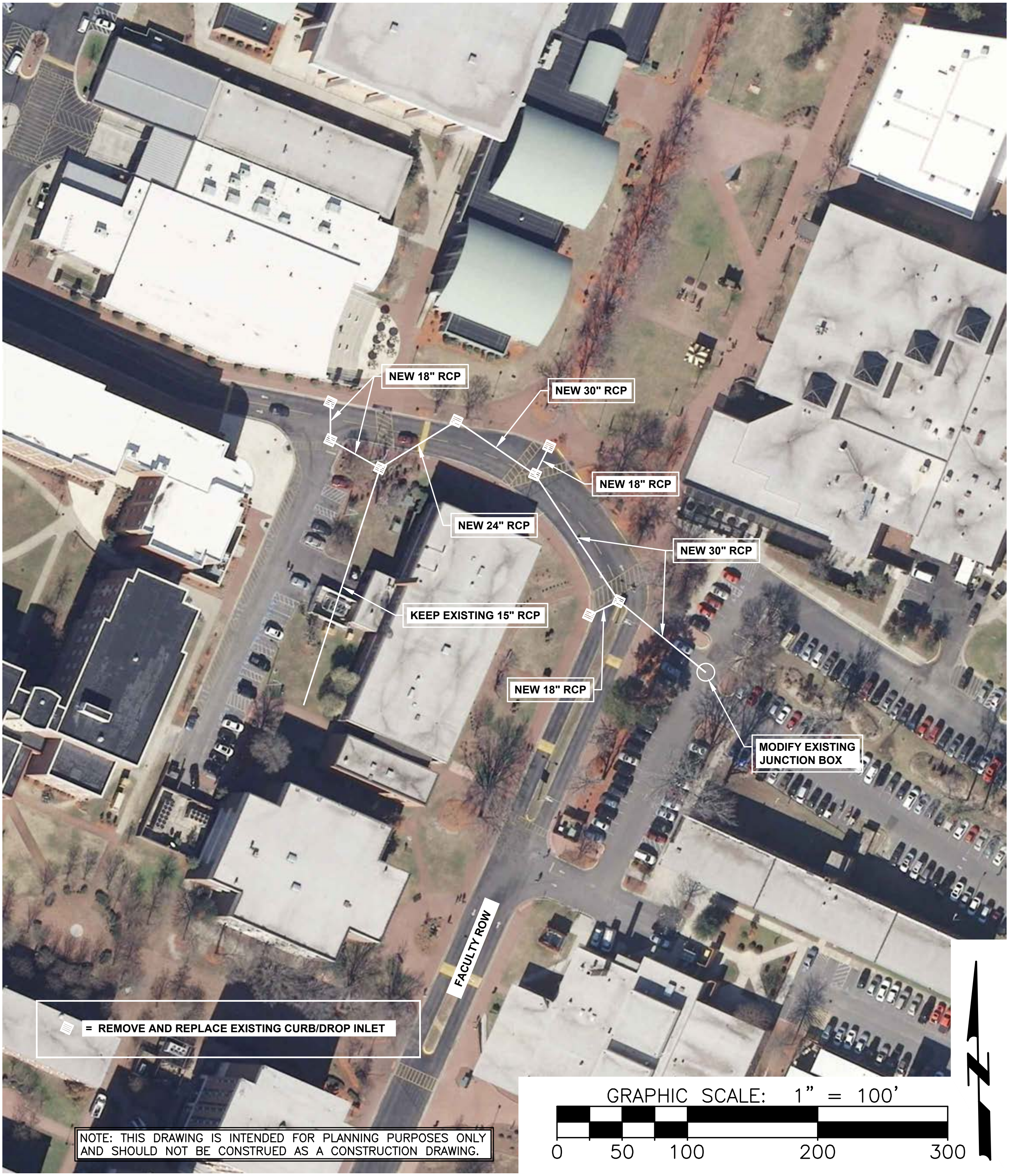

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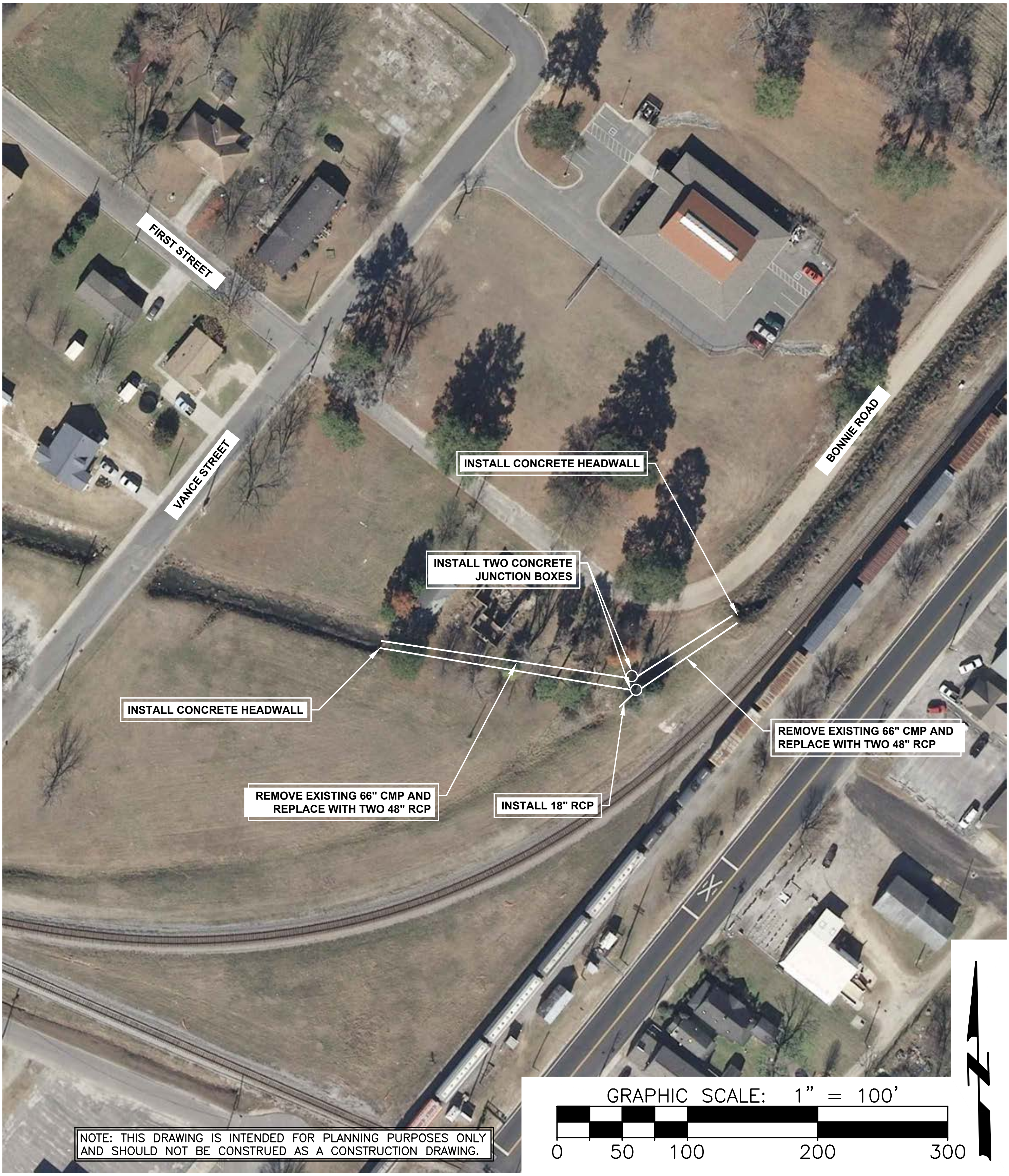
JOB #: A61301.00	HYDROLOGICAL STUDY LONG-TERM RECOMMENDATIONS	R-22
DATE: 1/4/2019	ROBESON COUNTY, NC	



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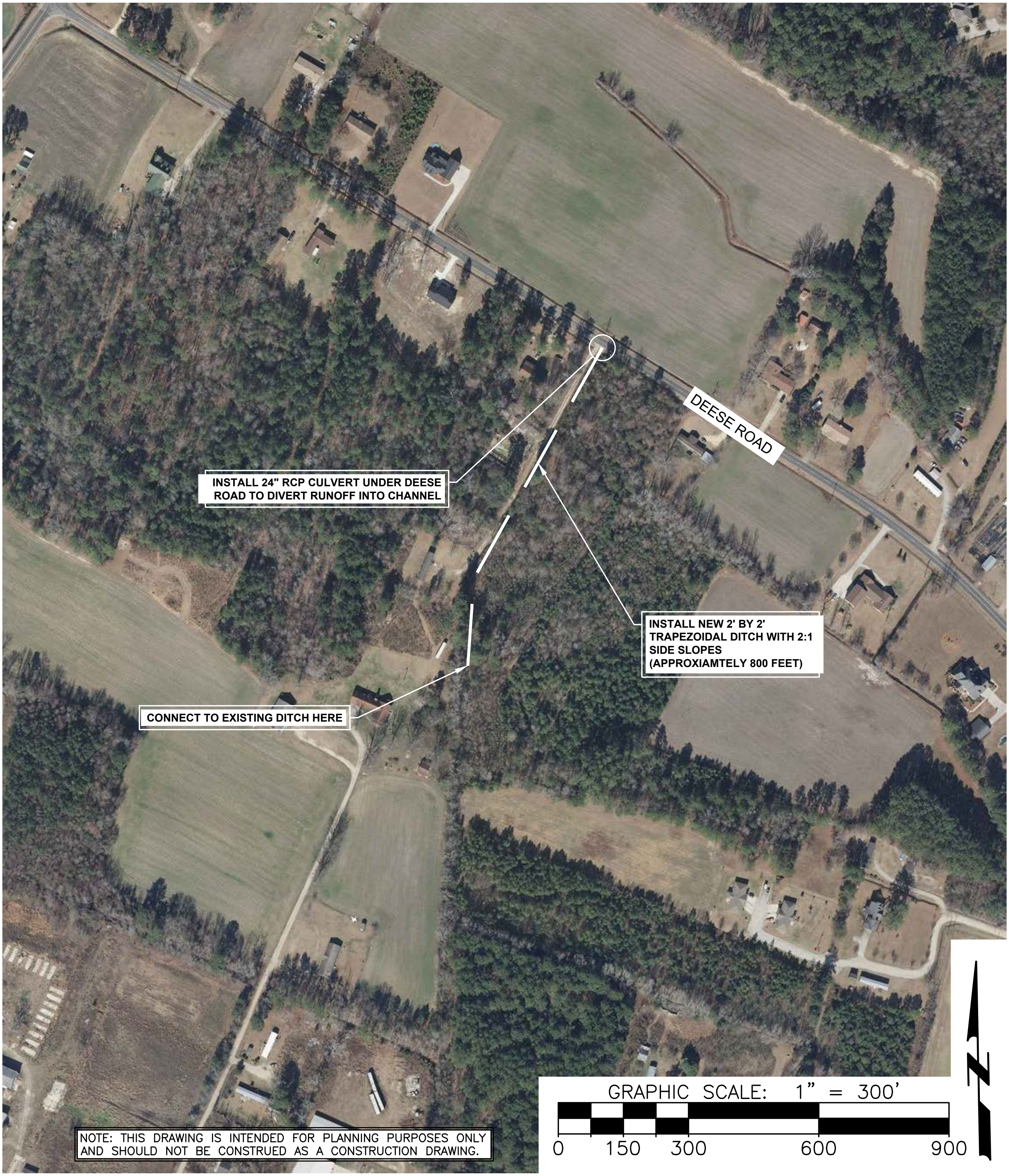

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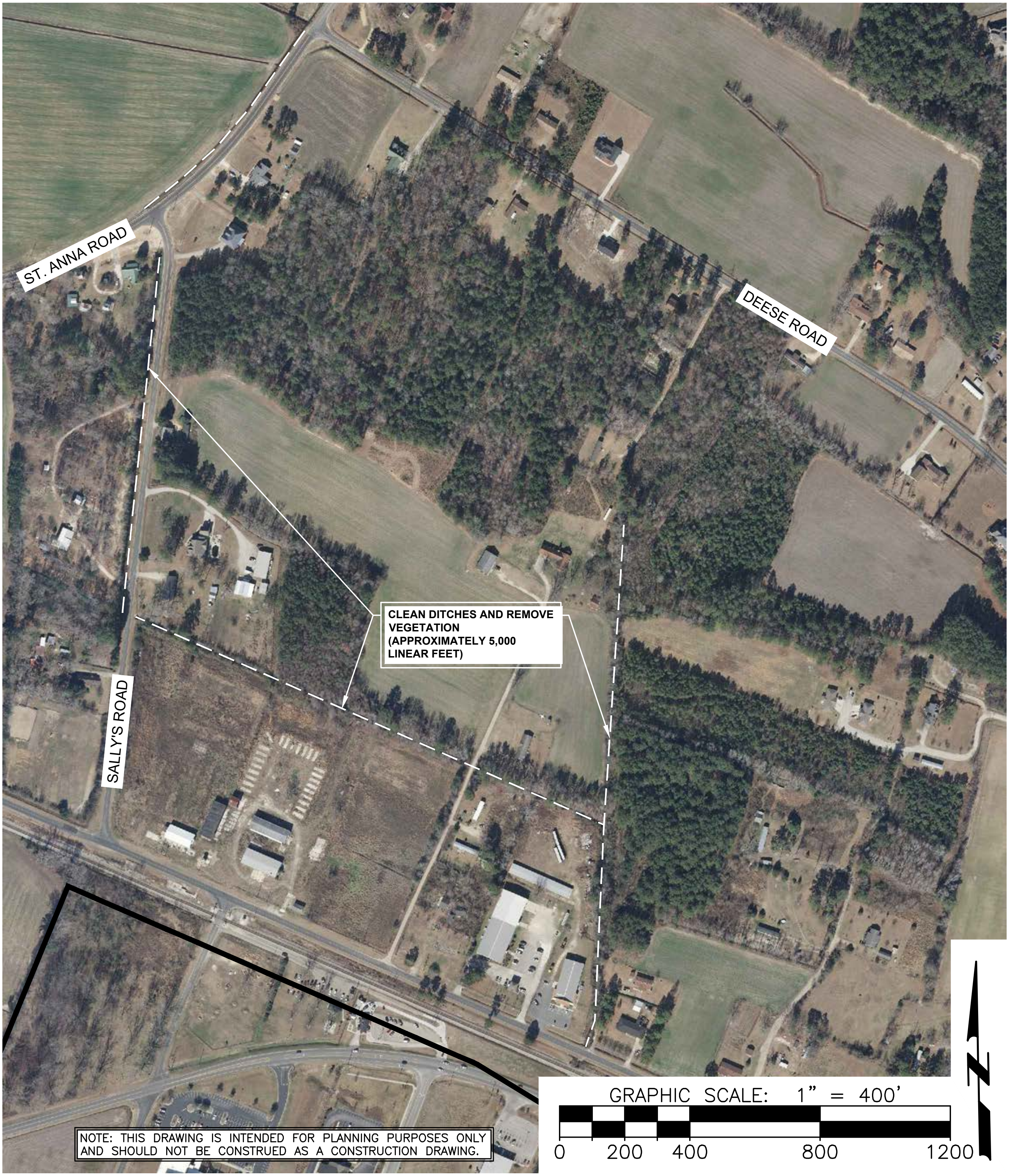
LONG-TERM RECOMMENDATIONS
ROBESON COUNTY, NC

FIGURE
R-25



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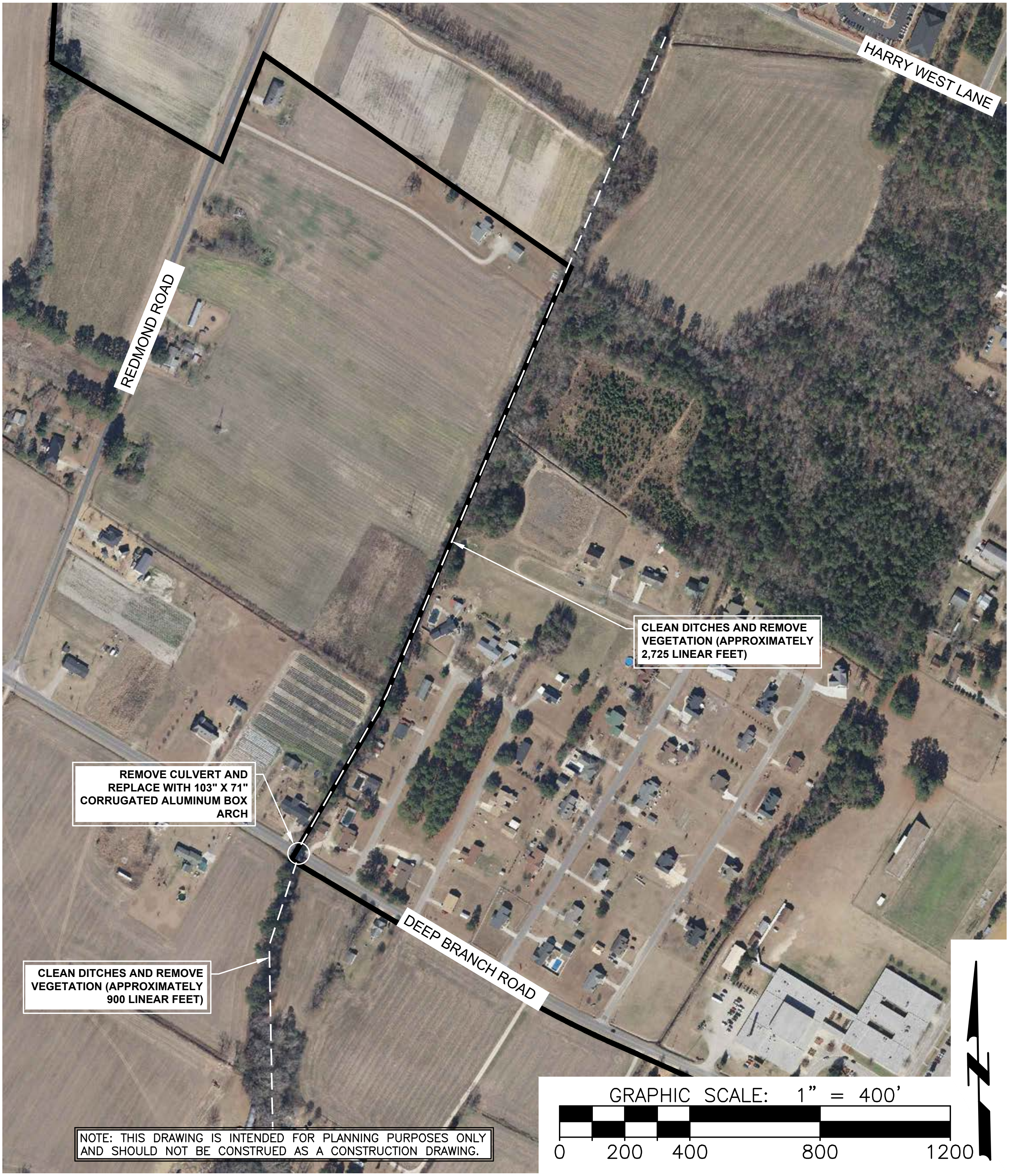
HYDROLOGICAL STUDY
LONG-TERM RECOMMENDATIONS
ROBESON COUNTY, NC

FIGURE
R-26



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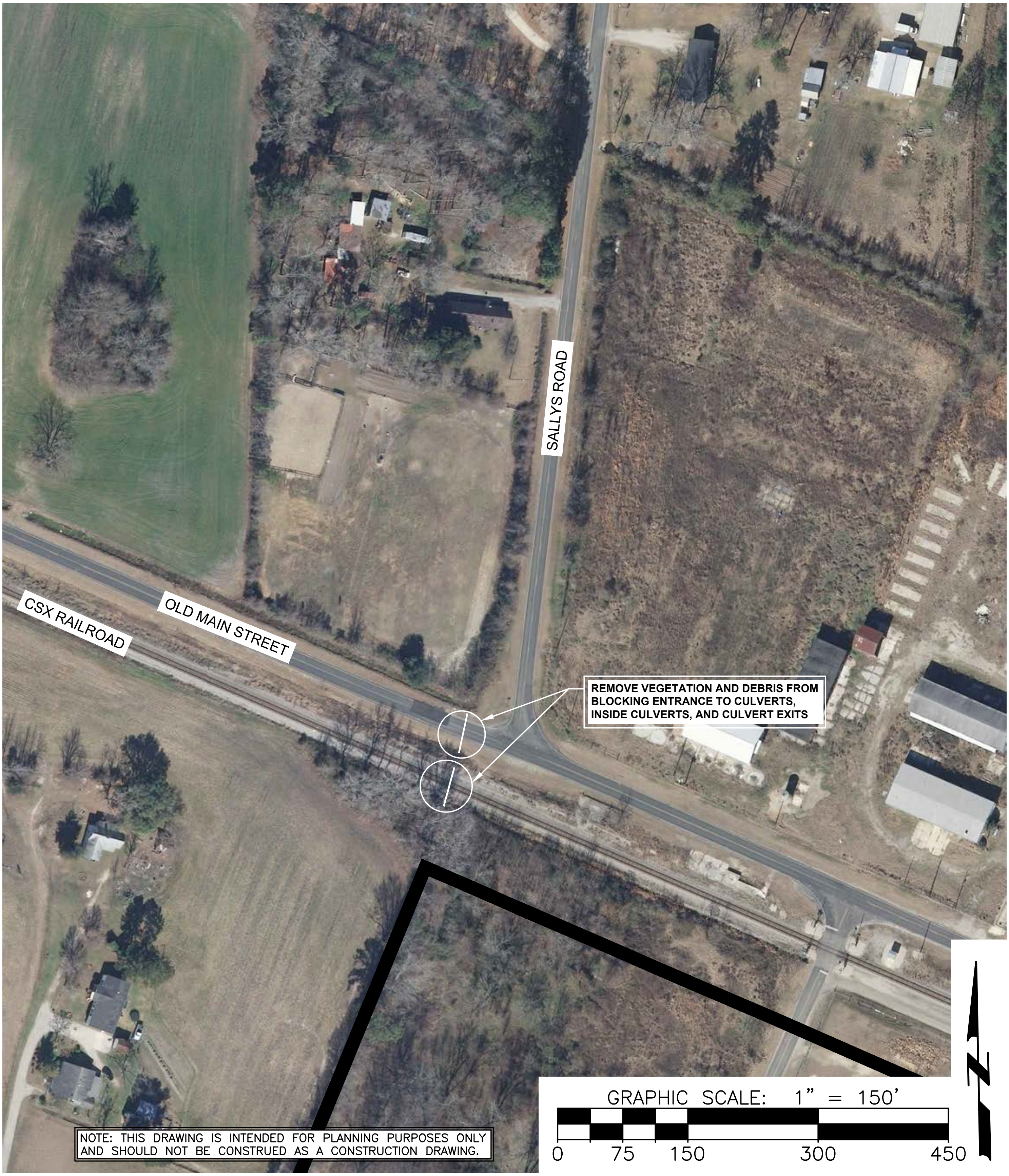
BY: TAP	TOWN OF PEMBROKE	FIGURE
JOB #: A61301.00	HYDROLOGICAL STUDY LONG-TERM RECOMMENDATIONS	R-28
DATE: 1/4/2019	ROBESON COUNTY, NC	



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Appendix D

Definitions

DEFINITIONS

Action Stage – the stage which, when reached by a rising stream, represents the level where some type of mitigation action needs to be taken in preparation for possible significant hydrologic activity. The type of action taken varies by gauge location/data.

Culvert – a man-made tunnel or open drain carrying stormwater underground.

Erosion – the action of surface processes (wind and/or water flow) that removes soil, rock, or dissolved material from one location to another.

Flood Crest – the maximum height of a flood wave as it passes a location.

Floodplain – an area of low-lying ground adjacent to a stream or river which stretches from the banks of its channel to the base of its enclosing valley walls. This area is prone to flooding and typically consists of levees, silts, and sands deposited during flooding.

Flood Stage – an established gage height for a given location above which a rise in water surface level begins to create a hazard. The issuance of flood advisories or warnings is linked to flood stage.

Minor Flooding – having minimal or no property damage, but possibly some public threat. A "flood advisory" is issued to advise the public of flood events that are expected not to exceed the minor flood category.

Moderate Flooding – having some inundation of structures and roads near a stream. Some evacuations of people and/or transfer of property to higher elevations may be necessary. A "flood warning" should be issued if expected during an event.

Major Flooding – having extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations are necessary. A "flood warning" should be issued if expected during an event.

Stage – the level of the water surface of a river or stream above an established point at a given location. The established point, or "gage datum" level usually is located slightly below the lowest point of the stream bottom such that the stage is greater than the maximum depth of water.

Sediment – a naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported most often by water. This matter then settles out of slow-moving or standing water in lakes, oceans, or streams.

Static Groundwater Elevation – The depth to groundwater below ground under normal conditions.

Topographic Relief - topographic relief describes the amount of topographic change within a particular area