Twelve Mile Creek Watershed: Assessment of Regulated Dams

Photo of Gibson's Pond Dam Breach

April 1, 2016

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REPORT VERIFICATION

PROJECT NAME: **High Level Hydrologic and Hydraulic Overview Model Report for Three Regulated Dams on 12 Mile Creek Watershed**

REVISION No.: **0**

This is to certify that I, James R Devereaux, P.E., have reviewed and prepared the attached document and have satisfied myself that the work performed was conducted in conformance with generally accepted industry practice.

Corporate Seal:

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P.E. No.: 23857

Date: April 1, 2016

Executive Summary

The Twelve Mile Creek Watershed consists of Twelve Mile Creek with three regulated dams and an unknown number of smaller, unregulated dams, impoundments, and ponds. Based upon our initial analysis of the three dams regulated by DHEC in the watershed, the rebuilding of the water management infrastructure of the Twelve Mile Creek watershed will require close coordination of the design criteria, principal and auxiliary spillway capacity, emergency action plans, and flood plain management.

HDR observed the condition of the regulated dams in early November, about 5 weeks after the October 2015 flood which approached and possibly exceeded a 500-year precipitation event within the Twelve Mile Creek watershed. HDR found that the performance of the dams, summarized in the table below, indicates significant variation in rainfall runoff characteristics within the basin and with the capability of dams to attenuate and safely pass flood events.

Performance of Regulated Dams in Response to October 2015 Flood

Hazard Class	No. of Dams	Breach
High Hazard	1	1
Significant Hazard	2	2

All three of the dams regulated by DHEC failed during the October 2015 flood event. Under current conditions these dams have not been identified as high concern due to the breached conditions. Any large rainfall event will pass flow through the breach as an uncontrolled natural stream, and there would be no potential for a sudden release of water associated with dam breach. It is difficult to establish the cause of failure based on visual observations of post-breach conditions, and there were no high water marks at remaining sections of dams and abutments that were observed by HDR or reported by FEMA for these three dams. However, HDR's review of previous engineering evaluations and results of HDR's hydrologic/hydraulic model evaluation indicates that the dams would be expected to be susceptible to overtopping for a flood of similar magnitude as the October 2015 event. HDR's observations also indicate maintenance practices that are not consistent with prudent dam safety practices including trees and woody underbrush on embankment dams and steep embankment slopes.

Failure of the three dams during the October 2015 storm supports the consideration of a watershed-wide evaluation of the design and health of the Twelve Mile Creek Watershed dam/reservoir system and its ability to provide the appropriate capability to safety pass significant storm events prior to repair or reconstruction of the dams. Evaluation of the following dam safety aspects of the Twelve Mile Creek Watershed should be considered:

- Hazard Classification with consideration of potential cascading failure of dams in series
- Spillway Adequacy
- Detailed Condition and Design Assessment
- Maintenance Practices
- Emergency Action Plans

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1 Introduction

HDR performed engineering services for the South Carolina Department of Health and Environmental Control (DHEC) subsequent to an October 2015 storm event that caused flooding within the Twelve Mile Creek Watershed in Lexington County, South Carolina. These services included initial condition assessments and hydrologic evaluations of three dams regulated by the DHEC. The storm event resulted in a total accumulation of over 10 inches of precipitation between October 2 and 5 within the Twelve Mile Creek Watershed. Flooding resulted in the failure of the three regulated dams.

The purpose of this report is to provide an overview of the current conditions of the breached regulated dams and to provide a "high-level" hydrologic model including all three dams in series for use in evaluation of proposed plans for reconstructing the dams and spillways. This report summarizes the extent of breach and overall condition of the dams based on observations from site visits conducted on November 4, 2015. A hydrologic model of the Twelve Mile Creek Watershed was developed to estimate potential peak flood conditions for a range of rainfall events for the pre- and post-flood condition of the dams considering the hydraulic response of the three dams in series for the same assumed rainfall events.

HDR reviewed a 1979 US Army Corps of Engineers (USACE), Charleston, SC District report entitled "Phase I Inspection Report." The report notes that as of the time of the Phase I review, the Lexington Old Mill Pond Dam spillway was designed to pass approximately 10 percent of the spillway design flood, or 5 percent of the probable maximum flood, without overtopping of the dam. Subsequent inspection reports for this dam reiterated concern for inadequate spillway capacity. The June 9, 2015, Inspection Report identified seepage and developing sinkholes at Lexington Old Mill Pond Dam and categorized the dam as unsafe and in need of repairs. DHEC approved a plan to perform repairs at the dam in September 2015. HDR understands that the pond was lowered approximately 15 feet for this repair and construction had just begun at the time of the October storm event.

In addition, the South Carolina Department of Health and Environmental Control performed a simulated dam breach analysis in November of 2000. The report noted that a 100-year flood event would likely cause the most upstream dam (Barr Lake Dam) to fail which would then likely cause both the Gibson's Pond and Lexington Old Mill Pond Dams to fail as well. From the data provided in the November 17, 2015, FEMA white paper on the October 2015 flood event, it appears the precipitation in the Twelve Mile Creek basin approached the 500-year recurrence interval.

The failure of the three regulated dams indicates a need for a comprehensive review of the future design of the dams. Future designs should be developed in the context of a more comprehensive dam safety regulation program and the need for an updated dam design database considering changes in the watershed system including hydrology, resources, land use, and public safety.

2 Site Visits

Site visits to regulated dams within the Twelve Mile Creek Watershed were conducted to assess the overall condition of the dams subsequent to the flood event of October 2–5, 2015.

The site visit objectives included:

- Documentation of the general current condition of dams, spillways, and adjacent areas including current headpond and tailwater levels.
- Identification/observations of damage, indications of distress of dams and spillways, and impairment of site discharge capacity.
- Documentation of the type of each dam and spillway, and estimates/measurements of existing facilities and features of damaged areas.

Detailed site visit reports for the three regulated dams are provided in Appendix D.

This information is intended to provide the DHEC with initial information to allow them to make informed decisions regarding implementation of actions under their authority.

2.1 Hydrologic Evaluations

A HEC-HMS model of the Twelve Mile Creek watershed and system of regulated reservoirs was developed to estimate peak flood conditions that would result from a range of rainfall events for pre- and post-flood conditions. The model simulates runoff response to rainfall based on hydrologic characteristics of the watershed and estimates peak pond levels at each dam based on active reservoir storage and spillway capacity. Four 24-hour rainfall events were simulated: 1-inch, 2-inch, 10-year (5.27 inches), and 100-year (8.27inches). The total rainfall over the duration of the October 2 to 5, 2015[1], event ranged from 10.2 to 12.5 inches. According to NOAA Atlas 14, 2006, the 500-year 24-hour rainfall for the basin is approximately 11.2 inches.

The development of the model and results of flood scenarios is summarized in a memorandum in Appendix C.

2.2 Twelve Mile Creek Watershed

The Twelve Mile Creek Watershed consists of Twelve Mile Creek and its three significant water bodies—Barr Lake, Gibson's Pond, and Lexington Old Mill Pond—that are impounded by dams regulated by DHEC. The Twelve Mile Creek Watershed covers approximately 33 square miles including parts of the towns of Gilbert and Lexington in Lexington County, South Carolina, and eventually drains into the Saluda River. The Lexington Old Mill Pond is the largest reservoir, which has a surface area of 28.5 acres and 325 acre feet of active storage. The Barr Lake and Gibson's Pond reservoirs are somewhat smaller with 243 and 128 acre-feet of storage, respectively. All reservoirs were impounded by non-overflow embankment dams ranging in height from 14 to

[1] National Climatic Data Center for stations Gilbert 1.2 SSW and Lexington 1.6 WNW

20 feet, with lengths between approximately 190 and 625 feet. Flow was discharged at each dam through a spillway.

2.3 FEMA Guidelines

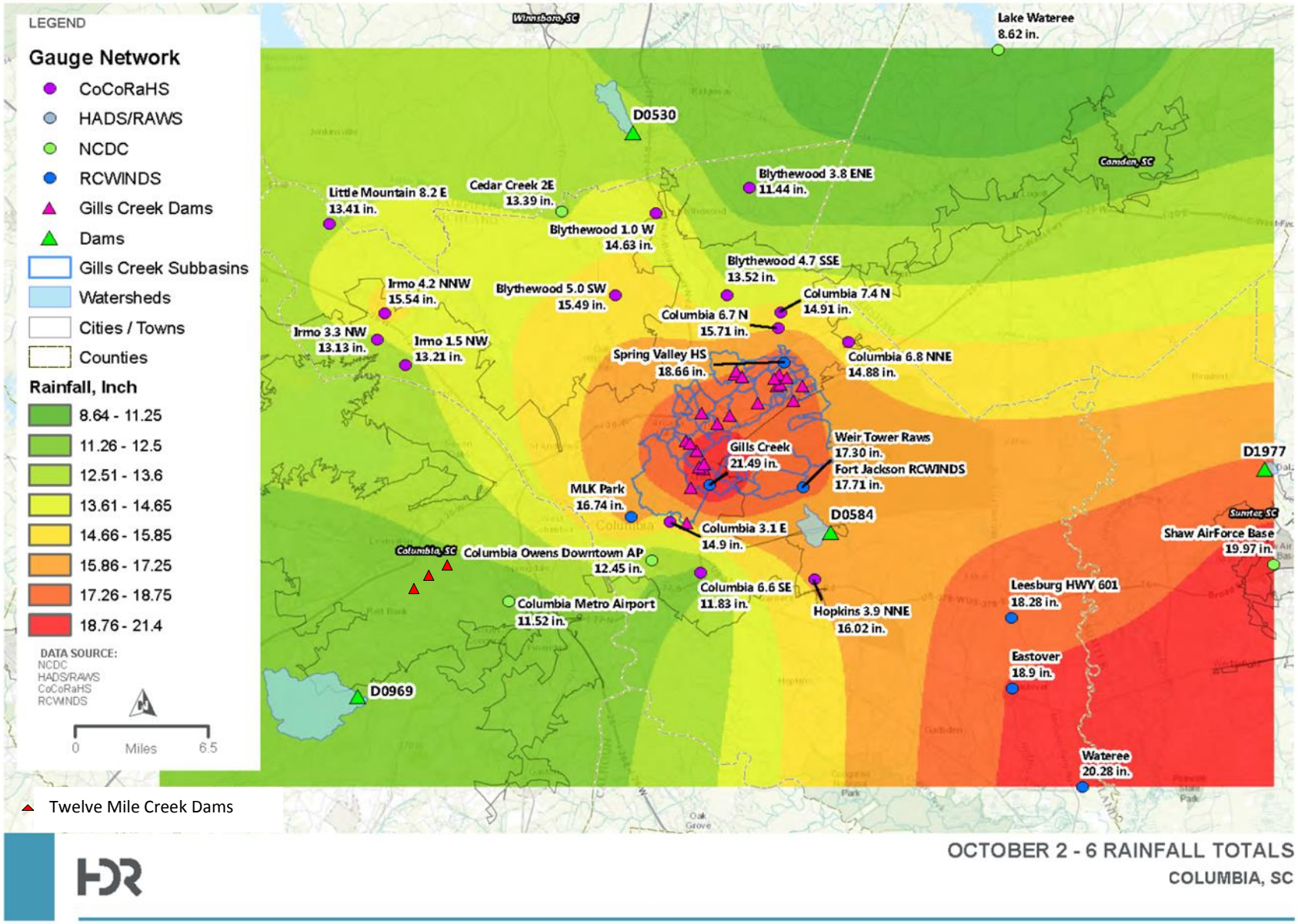
For the purposes of this assessment, HDR has adopted the following guidelines from FEMA P-94 *Selecting and Accommodating IDF for Dams* (August 2013):

> "Dams and their appurtenant structures should be designed to give satisfactory performance. In addition to distinguishing between controlled and uncontrolled spillways, these guidelines identify three specific types of spillways: (1) service or principal spillways, (2) auxiliary spillways, and (3) emergency spillways. Outlet works can also be used to lower reservoir levels in anticipation of a flood event or to pass floodwaters.
>
> *Service spillways* should be designed for frequent use and should safely convey releases from a reservoir to the natural watercourse downstream of the dam. A service spillway should exhibit excellent performance characteristics for frequent and sustained flows, such as up to the 100-year flood event. In general, service spillways should pass design flows without sustaining any damage.
>
> *Auxiliary spillways* are usually designed for infrequent use. It is acceptable for an auxiliary spillway to sustain limited damage during passage of the IDF [Inflow Design Flood] provided it does not jeopardize the structural integrity of the dam or the function of the spillway. Reference to these spillways as "emergency spillways" should be discontinued. Media references to flow through "emergency spillways" often leads to a misconception by the public that an emergency condition exists at a dam when the dam is safely functioning as designed.
>
> *Emergency Spillways* are not intended to be used for the routing of the IDF. They are provided where there is a desire to protect against a malfunction of another feature required to safely pass the IDF."

2.4 2015 October Storm Event

The October 2015 storm event resulted in a total accumulation of approximately 11.6 inches of precipitation between October 2 and 5 as estimated by the NOAA radar (FEMA White Paper). These precipitation amounts exceed the 24-hr 500-year event of 11.2 inches (NOAA Atlas 14, 2006). It is important to note that the distribution of precipitation frequency at the time of establishment of design criteria changes with additional hydrologic record (e.g., the statistical 100-year precipitation event determined in 1970, based on available precipitation records, would be expected to be different compared to the current 100-year precipitation event based on frequency analysis of the additional 45 years of record through 2015).

Figure 1. October 2-6 Rainfall Totals



3 Significant Observations

Within the Twelve Mile Creek Watershed, the October storm event resulted in the breach of the three dams regulated by DHEC. Natural river flow currently passes through the breach area resulting in unregulated flow conditions to downstream areas. Site observations were made in order to understand the current condition of the dam sites, and rainfall scenarios were modeled to understand response to various rainfall events. This information is used to identify concerns for potential impacts from future rainfall events until the dams can be reconstructed. The results of these evaluations are summarized in Table 1.

Significant observations of current conditions made during the site visits are provided in the HDR Site Observations Summary – DHEC Regulated Dams table presented in Appendix A. Detailed observations, including photographs of conditions during the site visits, are provided in the Site Assessment Reports included in Appendix D.

3.1 Current Site Conditions

Site observations provided an understanding of the extent of dam breach and current general conditions at each the dam sites. This understanding of current conditions allows for identification of possible concerns for further potential impacts that may result from future rainfall events.

Embankments – The crest and slopes of remaining sections of embankments were observed to have a wide range of vegetative cover and overall maintenance. All three of the embankment dams have significant trees and woody vegetative growth and steep and irregular embankment slopes. Woody growth on embankment dams does not reflect prudent dam safety practices and does not comply with DHEC dam safety requirements due to potential for internal erosion (piping) along voids created by root systems.

Service Spillways – The service spillways for Lexington Old Mill Pond and Gibson's Pond dams appeared to be intact and operational. The left gated concrete outlet structure at Barr Lake Dam had failed, and the right gated concrete outlet structure could not be observed due to access limitations.

Auxiliary Spillways – A rock-riprap-lined channel that appears to serve as an auxiliary spillway at Barr Lake Dam appeared to be intact.

3.2 Breached Dams

All three regulated dams within the Twelve Mile Creek Watershed were breached during the October storm event resulting in uncontrolled releases of water. Breached conditions provide natural river channel-like conveyance of significant runoff events with some constriction due to debris and no attenuation due to the loss of lake storage capacity. A brief summary of observed conditions of each breach is provided below.

Barr Lake (D 1717): The dam embankment is completely breached at the location of the left gated structure. The breach was estimated to be 30 feet. The embankment was completely eroded away, so the dam is not susceptible to further erosion from a

significant runoff event. For these reasons, the overall concern for this site is considered to be low.

Gibson's Pond (D 0959): The left embankment section of the dam was completely washed away during the event. The concrete ogee-crest dam and bridge remain in place. No trace of the embankment remained. The embankment was completely eroded away so the dam is not susceptible to further erosion from significant runoff events. For these reasons, the overall concern for this site is considered to be low.

Lexington Old Mill Pond (D 0958): The embankment was completely breached, with an opening approximately 150 feet wide exposing the Old Mill Building foundation. Significant base flow discharge is flowing through the breach. At the time of the site visit, there continued to be some active erosion at the toe of the remaining embankment as the stream flow caused eddies. The erosion at the toe appears to result in additional sloughs in the upstream face of the remaining embankment. This dam is considered to be of moderate concern due to the continued active erosion and the undermining of the old mill building foundation.

3.3 Response to Significant Rain Events

Four rainfall scenarios were evaluated to estimate peak storage response to the pre- and post-flood reservoir system using the HEC-HMS model developed for the watershed (Appendix C). The 50th percentile, first quartile Atlas 14 rainfall distribution was used for all scenarios. These scenarios include:

- A 1-inch rainfall, uniform over the watershed over 24 hours;
- A 2-inch rainfall, uniform over the watershed over 24 hours;
- The 10-year Atlas 14 rainfall of 5.27 inches over 24 hours and uniform over the watershed; and
- The 100-year Atlas 14 rainfall of 8.27 inches over 24 hours and uniform over the watershed.

Pre-Flood Conditions

Initial reservoir elevations were set to the primary outlet elevations (normal pool), and current spillway capacities were assumed for the model simulation of pre-flood conditions. Model results are summarized for rain events that would bring the pond level up to within 1.0 foot of the crest of the embankment dam. Considering accuracy of the HEC-HMS model, this would conservatively indicate potential for overtopping of the embankment under pre-flood conditions.

<u>2-inch/24-hour rainfall event</u>

The model results indicate that rainfall events equal to or greater than the 2-inch/24-hour rainfall may bring the pond level up to within 1.0 foot of the embankment crest for Lexington Old Mill Pond Dam and Barr Lake Dam, indicating potential for overtopping. This flood would likely activate the auxiliary spillway for Barr Lake Dam.

10-year/24-hour rainfall event

The model results indicate that rainfall events equal to or greater than the 10-year/ 24-hour rainfall may bring the pond level up to within 1.0 foot of the embankment crest for Gibson's Dam, indicating potential for overtopping.

100-year/24-hour rainfall event

The model results indicate that rainfall events equal to or greater than the 100-year/ 24-hour rainfall may overtop the embankment crest for all three regulated dams.

Post-Flood (Current) Conditions

Starting pools for post-flood, breached conditions were set at the bottom of the reservoirs. The impoundments have limited ability to attenuate flood flows under current conditions; however, some storage may still occur due to constriction of outflows through the embankment breaches. Model results are summarized below by maximum reservoir storage retention characterized by elevation increase and peak reservoir storage volume. Model results do not include any further increase in breach conditions.

1-inch/24-hour rainfall event

The results of the HEC-HMS model indicate that the 1-inch/24-hour rainfall scenario may cause reservoir retention of 0.6 to 1.4 feet, representing the following peak storage volumes:

- Lexington Old Mill Pond Dam - 11.6 acre-feet
- Gibson's Pond Dam - 28.9 acre-feet
- Barr Lake Dam - 28.3 acre-feet

2-inch/24-hour rainfall event

The results of the HEC-HMS model indicate that the 2-inch/24-hour rainfall scenario may cause reservoir retention of 1.0 to 2.3 feet, representing the following peak storage volumes:

- Lexington Old Mill Pond Dam - 19.9 acre-feet
- Gibson's Pond Dam - 49.0 acre-feet
- Barr Lake Dam - 47.2 acre-feet

10 year/24-hour rainfall event

The results of the HEC-HMS model indicate that the 10-year/24-hour rainfall scenario may cause reservoir retention of 2.2 to 4.7 feet, representing the following peak storage volumes:

- Lexington Old Mill Pond Dam - 41.6 acre-feet
- Gibson's Pond Dam - 100.5 acre-feet
- Barr Lake Dam - 94.9 acre-feet

100-year/24-hour rainfall event

The results of the HEC-HMS model indicate that the 100-year/24-hour rainfall scenario may cause reservoir retention of reservoir retention of 3.1 to 6.4 feet, representing the following peak storage volumes:

- Lexington Old Mill Pond Dam - 59.4 acre-feet
- Gibson's Pond Dam - 132.8 acre-feet
- Barr Lake Dam - 130.3 acre-feet

Table 1. Observed Post-Flood Conditions

	Hazard Classification	Breach	Estimate of Breach Length used in HMS Model[1]	Estimate of Breach bottom Elev. used in HMS Model[1]	Spillway Impairment	Level of Concern	Concern
1 - Barr Lake Dam	Significant	Left embankment breached at gated structure	30 ft	313.01 ft	Failure of Left Gated Concrete Overflow Structure	Low	Minor impoundment storage retention; downstream areas subject to natural river hydrology.
2 – Gibson's Pond Dam	Significant	Left embankment completely eroded	70 ft	298.21 ft	None	Low	Minor impoundment storage retention; downstream areas subject to natural river hydrology.
3 - Lexington Old Mill Pond Dam	High	150 ft wide	150 ft	274.5 ft	None	Moderate	Continued erosion of remaining embankment section; and undermining of the old mill foundation

Note: 1. No field surveys were included in the scope of work performed by HDR to support the HEC-HMS modeling work. Approximations for bottom of breach elevation used in modeling are from available SC DHEC file data or LiDAR data for downstream streambed/base of dam.

4 Conclusions

The October 2015 flood resulted in dam failure of all three of the DHEC-regulated dams within the Twelve Mile Creek watershed. Although the failure mode could not be ascertained from observations of post-flood conditions, it is likely the dams failed from overtopping. HDR's HEC-HMS model for pre-flood conditions for the three regulated dams indicate peak impoundment levels may reach within 1 foot of the embankment crest under 24-hour rainfall events ranging from 2 inches to 5.3 inches (10-year event), indicating potential for overtopping. HDR's pre-flood conditions model estimated overtopping (zero freeboard) of Lexington Old Mill Pond Dam and Barr Lake dams for the 10-year rainfall event and overtopping of Gibson's Pond Dam under the 100-year rainfall event. These 24-hour rainfall events are significantly lower than the October 2015 storm event that resulted in a total accumulation of approximately 11.6 inches of precipitation between October 2 and 5.

Debris accumulation may have reduced spillway capacity and increased peak flood levels at some dams; however, review of previous engineering evaluations and hydrologic information indicates that all three of the dams appear to have had inadequate spillway capacity. Information regarding design spillway capacity was available only for Lexington Old Mill Pond Dam, a high-hazard dam, which indicated that the design spillway capacity was 5 percent of the Probable Maximum Flood (PMF). However, the DHEC Dam and Reservoirs Safety Act (72-1 through 72-9) requires that the high-hazard dam within Twelve Mile Creek Watershed be capable of safely passing an inflow design flood (IDF), established from engineering evaluations, between 50 percent of the PMF and the full PMF.

DHEC's November 7, 2000, Breach Analysis Study indicates total rainfall accumulation of 21.33 inches for the 50 percent PMF and that all three dams would be overtopped from the 50 percent PMF event. This indicates that the Lexington Old Mill Pond Dam, with adequate spillway, would have been capable of safely passing the October 2015 event not considering failure of upstream dams.

Barr Lake and Gibson's Pond dams are a significant hazard which meets a "small" dam classification. DHEC Dam and Reservoirs Safety Act require these dams to be capable of safely passing a design flood between the 100-year flood and the 50 percent PMF. As stated above, HDR's HEC-HMS pre-flood conditions model indicates these dams would be overtopped for rainfall events with return intervals less than 100 years (total accumulated 24-hour rainfall of 8.3 inches).

The three breached dams currently allow for uncontrolled release of water with minimal storage capacity in the reservoirs. Downstream areas will be subject to natural river hydrology. The observed general condition of the dams and appurtenances indicate maintenance practices that are not consistent with prudent dam safety practices. These observations include trees and woody underbrush on embankment dams and steep embankment slopes.

The failure of the dams during the October 2015 storm supports the consideration of a watershed-wide evaluation of the design and health of the Twelve Mile Creek Watershed dam/reservoir system and its ability to provide the appropriate capability to safely pass

significant storm events prior to remediation or replacement of the dams. Evaluation of the following dam safety aspects of the Twelve Mile Creek Watershed should be considered.

1. Hazard Classification - This should include a re-evaluation of the current downstream developments and potential consequences of dam failure for the purposes of hazard classification. This may require performing dam failure and hazard analysis including cascading failure of downstream dams.
2. Spillway Adequacy - Perform site-specific hydrologic evaluations as required to establish the appropriate Inflow Design Flood (IDF) based on potential downstream hazard. Specific guidelines should be established for determining the IDF. A review of current spillway capacity and active storage capacity should be conducted to ensure spillway adequacy.
3. Detailed Condition and Design Assessment - Detailed condition assessments should be conducted by an independent professional engineer including detailed dam inspections, review of construction and maintenance records, and review of the design of the dam and appurtenant facilities to assess overall integrity of the remaining structures and facilities. This would require engineering analysis including stability analysis of principal water-retaining structures. A technical review of spillway design and condition, including gate operability, should be conducted to ensure spillway capability.
4. Maintenance Practices - Repair/design should include specific requirements for low-level outlets at all dams to draw down the pond for maintenance activities and in anticipation of significant flood events. Specific guidelines should be developed for proper maintenance of earth embankment dams, concrete structures, and appurtenances including spillways, gates, trash screens, and outlet pipes.
5. Emergency Action Plans - Detailed Emergency Action Plans that include inundation mapping to identify structures and people at risk, notification procedures, preventive measures, and roles and responsibilities should be developed for at least the high-hazard dams. Effective preventative measures would include timely draw down of ponds in anticipation of forecasted flood events.

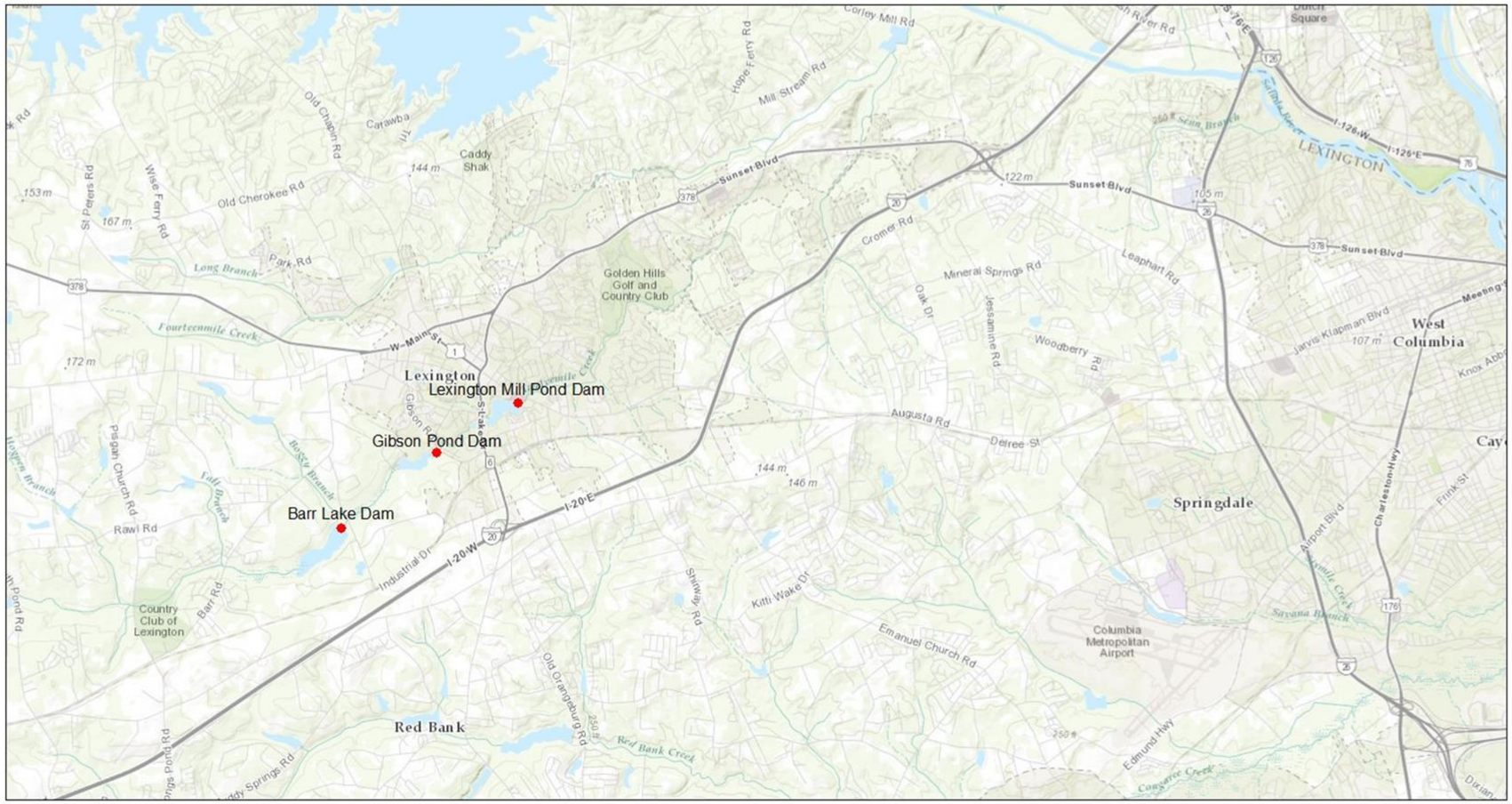
Appendix A. HDR Site Observations Summary: SCDHEC Regulated Dams

HDR Site Observations Summary: SCDHEC Regulated Dams

Regulated Dam ID (HDR No.)	Current Water Levels and Discharge	Spillway Impairment	General Condition	Significant Observations	Conclusions
(1) Barr Lake Dam D 1717, HDR 01 Earthen auxiliary spillway Left and right embankment dams Two gated concrete outlet structures	Date of Observations: 11/4/2015 River discharge is through the breach.	Remnants of left gated concrete outlet, asphalt roadway, and overflow spillway in river channel causing some constriction of the natural river channel.	Embankment dam completely breached. Dam breached, left gated concrete outlet structure completely washed away. Rock-lined earthen auxiliary spillway had no significant erosion. Right gated concrete outlet structure appears to be in working condition.	Gate operation during flood event unknown.	Breached conditions provide natural river channel conveyance of significant rain events with some constriction due to debris.
(2) Gibson's Pond Dam D 0959, HDR 02 Embankment dam section with walking trail on crest Service spillway is an overflow structure with concrete ogee crest and steel through-girder bridge	Date of Observations: 11/4/2015 Embankment completely washed away. River discharge is through the breach. Undermining of large trees could cause them to fall into and obstruct channel.	No apparent spillway impairment	Embankment completely eroded. Some debris from walkway, large pieces of concrete and wooden decks in channel. Service spillway appears to be undamaged.	River flow is through the breach.	Breached conditions provide natural river channel conveyance of significant rain events Spillway capacity is not impaired.
(3) Lexington Old Mill Pond Dam D 0958, HDR 03 Embankment Dam The penstock to the mill is non-operational. The service spillway has a concrete uncontrolled overflow section and a gated section at the right abutment, which discharges to the mill race bypass.	Date of Observations: 11/4/2015 Breach about 150 feet wide Mill race bypass fenced off and not accessible for observations.	There was a sinkhole that had formed just downstream of the penstock intake near the area of the breach. Engineered drawings of the repair of the sinkhole were dated 8/18/2015.	Remaining section of the embankment is in generally poor condition due to significant erosion that continues to occur at the toe. The penstock to the mill is not operational.	It is probable that the sink hole contributed to the failure. The old mill building foundation is exposed and subject to undercutting by stream flow.	Breached conditions provide natural river channel conveyance of significant rain events Spillway capacity does not appear to be impaired. Integrity of embankment dam is compromised due to continued erosion along the toe by stream flow. Building foundation susceptible to additional undercutting with a high flow event.

Appendix B. Twelve Mile Creek Regulated Dams

Twelve Mile Creek Regulated Dams



March 29, 2016

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Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Bureau of Water, SC DHEC

Appendix C. Twelve Mile Creek HECHMS Memo

Memo

Date:	Thursday, March 17, 2016
Project:	SC DHEC/RM/Emerg. Response (268356)
To:	Chris Ey
From:	Ted Shannon
Subject:	Twelve Mile Creek HEC-HMS Model Development and Rainfall Scenarios

1. Purpose and Scope

A rainfall event in the Twelve Mile Creek watershed in Lexington, South Carolina, ranging from 10.3 to 12.5 inches, from October 2nd to 5th, 2015[1] breached three dams. Timing of the flow through the watershed is not well documented, and no known streamflow gauges are known in the watershed records. Reconstruction of the historic event is beyond the scope of this work.

Based on discussions with the South Carolina Department of Health and Environmental Control (SC DHEC) while preparing the scope of work for the Twelve Mile Creek Watershed Emergency Response, a high-level HEC-HMS model was proposed to be developed to identify connectivity between the three breached dams and downstream affected area to Corely Mill Pond. The model could then be used moving forward to evaluate potential reconstruction plans that will be submitted by the dam owners to DHEC for review prior to significant reconstruction in the watershed. This memorandum documents the development of the HEC-HMS model and simulates several 24-hour NOAA Atlas 14 rainfall scenarios within the watershed.

2. Model Development

The HEC-HMS model ("model") was developed with selected methods summarized in Table 1. Summary of HEC-HMS Model Methods. Details of these methods, assumptions, and data used are described in further detail in subsequent sections.

There were no interception methods used in the model; this is primarily due to lack of information, but also conservative for the recovery application of the model. A simple surface abstraction was used to simulate effects of multiple small impoundments. The Green and Ampt method was selected to estimate soil infiltration losses. This method is scientifically robust and used soils data from the detailed soil survey of the area along with remotely sensed land use and impervious area estimates. The SCS Unit Hydrograph, with standard peaking factor of 484, was the selected unit hydrograph method. Supporting data for this method served to estimate the lag time in each area of the watershed.

The outflow structures method was used to simulate the spillways. The spillway and dam crest lengths and elevations were directly input to the model.

[1] National Climatic Data Center for stations Gilbert 1.2 SSW and Lexington 1.6 WNW

Losses from the reservoirs, such as seepage or evaporation, were neglected. This was appropriate for the rainfall scenarios that were considered and also conservative. Baseflow was also neglected which, while not conservative, is appropriate for the rainfall scenarios that were considered. Reach routing currently is not considered. This is conservative with regards to peak flows reaching each reservoir and neglecting of floodplain storage. Further refinement of the model may be performed that adds routing, additional upper watershed reservoirs, or other details.

Table 1. Summary of HEC-HMS Model Methods

Method Type	Selected Method	Data Sources
Interception Method	None	n/a
Surface Method	Simple Surface	LiDAR derived drainage areas and Impoundment storage
Loss Method	Green and Ampt	USDA Soil Survey NLCD Land Use and Imperviousness
Transform Method	SCS Unit Hydrograph (Peak Rating Factor 484)	NLCD Land Use and Imperviousness LiDAR derived drainage area and flowpaths
Reservoir Outflow Method	Outflow Structures-Dam Crests, Spillway Structures	SCDHEC Dam Information USACE Surveys
Elevation-Storage Function	Elevation and Storage data	SCDHEC Dam Information
Main Tailwater	None Assumed	n/a
Dam Seepage	None Assumed	n/a
Dam Evaporation	None Assumed	n/a
Baseflow Method	None	n/a
Reach Routing Method	None	n/a

2.1. Drainage Area Delineation

The direct drainage area to each dam was developed using the available LiDAR digital elevation model data ("LiDAR DEM") and the ESRI ArcGIS Spatial Analyst Hydrology toolset ("hydrology toolset"). The hydrology toolset traces the flow path through the watershed from any point to the outlet. Tracing flow paths to a common "pour point" located at each dam site generated direct drainage areas captured by that reservoir.

The LiDAR DEM contains roadways and other features that can modify the drainage area. The LiDAR DEM will not include subsurface culverts that conduct flow across roadway, spoil piles, or other embankments. Additionally, high water surface in water features at the time of the LiDAR survey, features obscured by vegetation, or features lost when resampling to a 10-foot grid size may affect flow paths. Hydrologic conditioning is the process of creating a revised LiDAR-based digital elevation model (modified DEM) that incorporates known or assumed flow paths.

Hydrologic conditioning was achieved by developing a set of terrain modification linework. The elevations under these lines were leveled to a constant elevation, which resulted in removing

portions of embankments, deepening existing flow paths, or in some cases emphasizing embankments. Terrain modification lines are classified into two types:

- Breach Lines: Breach lines are typically short segments which connect two flow paths through an embankment (for example a roadway embankment). The minimum elevation at either end point is used to flatten elevation grid cells under the line.
- Wall Lines: Wall lines generate an embankment in order to select a preferred flow path when there are two or more competing flow paths. The elevation for a wall line is set from the maximum elevation along the line.

Professional opinion was used based on the DEM and aerial photography as to the possible location of culverts and other features. The delineated drainage areas were not independently reviewed or verified.

Multiple small impoundments were noted in the upper portion of the watershed. Review of LiDAR and aerial photography noted at least 194 small impoundments that each have a contributing drainage area of at least 3 acres. Modeling these small impoundments was not within the scope of this study. However, neglecting these impoundments may overestimate contributing areas to the breached reservoirs. A simplified approach was used which modeled these small impoundments as an initial abstraction. Storage was calculated between the water surface present in the LiDAR dataset and the top of each small impoundment crest. This volume was divided by the contributing drainage area to each small impoundment. The resulting depth was used as an initial abstraction of the regulated drainage area. Storm depths less than the initial abstractions result in the drainage area as non-contributing.

Table 2. Drainage Areas, lists the delineated direct (incremental) drainage areas to each reservoir. The cumulative drainage area of the entire system above Corely Mill Pond is 59.53 square miles. Some larger drainage areas were subdivided into smaller units on the basis of land use, soil types, and larger upper watershed impoundments within the HEC-HMS model. For the purposes of this study, only Lexington Old Mill Pond, Gibson's Pond, Barr Lake, and Smith Pond were modeled.

Table 2. Drainage Areas

Lake Name	Direct Drainage Area [square miles]	Total Drainage Area [square miles]
Corely Mill Pond	26.32	59.53
Lexington Old Mill Pond	2.12	33.21
Gibson's Pond	3.71	31.09
Oswald Pond	0.44	27.38
Barr Lake	8.75	26.94
Smith Pond	9.48	18.19
Hayes Pond	1.10	8.71
Crout Pond	2.99	7.61
Taylor Millpond	4.62	4.62

Note: Only Lexington Old Mill Pond, Gibson's Pond, Barr Lake, and Smith Pond were modeled.

2.2. Soils and Infiltration

The Green and Ampt soil infiltration method uses soil characteristics of saturated hydraulic conductivity, suction pressure, and porosity. The U.S. Department of Agriculture, Natural Resources Conservation Service Soil Survey Geographic (SSURGO) database for Lexington County, South Carolina (2013) spatial and tabular data was used to estimate these infiltration parameters. The saturated hydraulic conductivity was calculated using a harmonic mean of the median conductivity to a depth of 40-inches. The suction pressure and porosity was estimated from the USDA soil textures and the generalized values in the HEC-HMS Technical Reference Manual. The Green and Ampt parameters for each soil type were then spatially averaged over the model subbasins. Table 3. Representative Soil Textures, provides predominate soil types in each of model subbasins (the direct drainage area to each reservoir). Soil types were generally sands or loams.

Table 3. Representative Soil Textures

Lake Name	Representative Soil Texture of the Direct Drainage Area
Corely Mill Pond	Sandy loam, Clay loam
Lexington Old Mill Pond	Sandy loam
Gibson's Pond	Sand, Sandy loam
Oswald Pond	Sand
Barr Lake	Sand
Smith Pond	Sand
Hayes Pond	Loamy sand
Crout Pond	Sand
Taylor Millpond	Sandy loam

2.3. Impervious Area

The remotely sensed National Land Cover Dataset (NLCD) was used to estimate impervious areas within each reservoir direct drainage area. The year 2011 condition imperviousness and land use were used (USGS, October 2014). The impervious dataset contained an estimate of the impervious area within each drainage area. The water surfaces from the land use dataset was added as a fully impervious area to simulate lossless rain on water. The proportion of impervious areas are provided in Table 4. Model Impervious Areas. The upper watershed is mostly undeveloped. The developed areas are located downstream of Smith Pond. It is assumed that the impervious areas are directly connected to each lake. It is also assumed that any urban best management practices (BMP) will not significantly store runoff. Smaller impoundments are considered in Section 2.5.3, Small Impoundments.

Table 4. Model Impervious Areas

Lake Name	Impervious Area of the Direct Drainage Area [%]
Corely Mill Pond	18
Lexington Old Mill Pond	33
Gibson's Pond	18
Oswald Pond	27
Barr Lake	17
Smith Pond	4
Hayes Pond	8
Crout Pond	3
Taylor Millpond	4

2.4. Time of Concentration

The time of concentration for each subbasin was calculated using the NRCS TR-55 "Urban Hydrology for Small Watersheds". A longest flow path was determined for the direct drainage area to each reservoir using the ESRI ArcGIS Spatial Analyst Flow Length tool. This longest flow path was divided into sheet, shallow, and channel flow. The first 100 feet of the flow path was assigned to sheet flow. The location of shallow to channel flow was determined from inspection of the LiDAR data based on the presence of a cross sectional channel. Slopes and cross-sectional channel data was obtained from LiDAR. Land use information was based on year 2013 aerial photography. Table 5. Times of Concentration, provides the time of concentrations within the direct drainage area to each reservoir. The SCS unit hydrograph lag time was estimated at 60 percent of the time of concentration.

Table 5. Times of Concentration

Lake Name	Time of Concentration of the Direct Drainage Area [hr]
Corely Mill Pond	18.9
Lexington Old Mill Pond	1.8
Gibson's Pond	3.9
Oswald Pond	2.4
Barr Lake	10.7
Smith Pond	7.9
Hayes Pond	0.9
Crout Pond	2.1
Taylor Millpond	3.2

2.5. Reservoirs and Dams

Model inputs for the reservoir and dam characteristics are the elevation-storage data and outlet structures.

2.5.1. Elevation and Storage Data

The elevation-storage data for each reservoir for this effort was represented as three values: the elevation at the stream thalweg where the reservoir has no storage, the storage and elevation of the normal pool, and the storage and elevation of the top of dam. The normal pool storages were obtained from SCDHEC files. The top of dam elevations were provided by either SCDHEC, the USACE, or estimated from LiDAR. Normal pool elevation and dam height was obtained from available files generated by the SCDHEC or the USACE. Table 6. Key Reservoir Elevation and Storage Values, summarizes the reservoir storage information used in the modeling.

Table 6. Key Reservoir Elevation and Storage Values

Lake Name	Top of Dam		Normal Pool		Stream Thalweg	Dam Height
	Elevation [ft]	Storage [ac ft]	Elevation [ft]	Storage [ac ft]	Elevation [ft]	[ft]
Corey Mill Pond	185.4	---[a]	175.5	---[a]	---[a]	---[a]
Lexington Old Mill Pond	294.5	440	291.3	325	274.5	20
Gibson's Pond	313.2	240	309.2	128	298.2	15
Barr Lake	327.0	359	325.0	243	313.0	14
Smith Pond	377.5	414[b]	361.4	Unknown[b]	Unknown[b]	Unknown

Notes:

Elevations are in vertical datum NGVD 29.

The Gibson's Pond elevations are from FEMA, 2015, FEMA Mitigation Dam Task Force Strategic White Paper on Dam Risk, DR-SC-4241, November 17, 2015.

[a] Storage data not available for Corey Mill Pond. Elevations estimated from LiDAR.

[b] Storage data not available for Smith Pond. Elevations and storage estimated from LiDAR and does not include storage below the normal pool.

2.5.2. Outlet Capacities

Outlet capacities were estimated from data provided by the SCDHEC or the USACE. Table 7. Reservoir Outlet Structures, summarizes the characteristics of the outlet structures. A coefficient of discharge of 3.2 was used for spillways and 2.6 used for dam crests in the weir flow equation. Hydropower generation facilities are assumed to be non-functioning or not significant in flood situations.

The outlet structures summarized in Table 7 are pre-flood conditions. In the post-flood condition, Lexington Old Mill Pond, Gibson's Pond, and Barr Lake were fully breached. These dams, in the post flood condition, were modeled as having the spillways located at the thalweg elevation. HDR field surveys were referenced to determine the extent of the breach at each location.

Table 7. Reservoir Outlet Structures

Lake Name	Primary Outlet	Auxiliary Spillway	Top of Dam
Lexington Old Mill Pond	20 feet service spillway @ elevation 291.3 feet	n/a	475 feet long @ 294.5 feet elevation
Gibson's Pond	50 feet service spillway @ elevation 309.2 feet	n/a	190 feet long @ 313.2 feet elevation
Barr Lake	Two service spillways with combined length of 42 feet @ elevation 325.0 feet	85 feet long @ elevation 326.0 feet	625 feet long @ 327.0 feet elevation
Smith Pond	85 feet service spillway @ elevation 361.4 feet	n/a	430 feet long @ 377.5 feet elevation

Notes: Elevations are in vertical datum NGVD 29.
Barr Lake top of dam elevation and Gibson's Pond elevations from FEMA. 2015. FEMA Mitigation Dam Task Force Strategic White Paper on Dam Risk. DR-SC-4241. November 17, 2015.

2.5.3. Small Impoundments

Small impoundments were noted throughout the upper watershed area. A total of 194 impoundments that have drainage areas of at least 3 acres were noted. The average drainage area of the smaller impoundments was 76 acres. The influence of the small impoundments was assessed by dividing the impoundment storage volume by the contributing drainage area. The impoundment storage was estimated using the LiDAR surface between the normal pool and top of each impoundment. The resulting storage depth was input as an initial abstraction.

Table 8. Abstraction from Small Impoundments

Lake Name	Number of Small Impoundments	Total Impoundment Storage [acre-feet]	Direct Drainage Area [square miles]	Abstraction [in]
Corely Mill Pond	n/a	n/a	26.32	n/a
Lexington Old Mill Pond	5	176.8	2.12	1.6
Gibson's Pond	23	226.7	3.71	1.1
Oswald Pond	1	47.7	0.44	2.0
Barr Lake	59	803.1	8.75	1.7
Smith Pond	59	519.9	9.48	1.0
Hayes Pond	9	103.7	1.10	1.8
Crout Pond	14	86.4	2.99	0.5
Taylor Millpond	24	566.4	4.62	2.3

Notes: Small impoundments in Corely Mill Pond direct drainage area not evaluated.

3. Analysis of Reservoir System

Four rainfall scenarios were evaluated to estimate impacts to the post-flood reservoir system. The 50th percentile, first quartile Atlas 14 rainfall distribution was used for all scenarios. These scenarios were:

- A 1-inch rainfall, uniform over the watershed over 24 hours
- A 2-inch rainfall, uniform over the watershed over 24 hours
- The 10-year Atlas 14 rainfall of 5.27 inches over 24 hours and uniform over the watershed
- The 100-year Atlas 14 rainfall of 8.27 inches over 24 hours and uniform over the watershed.

The starting reservoir elevations were set to the primary outlet elevations (normal pool) for the pre-flood conditions. Post-flood conditions contained breached spillways and starting pools were set at the bottom of the breached reservoirs. The peak runoff and releases from each dam for these rainfall scenarios are provided in subsequent Tables (Table 9 to Table 16).

In the pre-flood condition, a 2-inch storm over 24-hours could reduce freeboard at Lexington Old Mill Pond and Barr Lake to less than 1.0 foot. The auxiliary spillway at Barr Lake could be activated. The 10-year 24-hour storm could overtop Lexington Old Mill Pond and Barr Lake. The 100-year 24-hour event could overtop all three reservoirs: Lexington Old Mill Pond, Gibson's Pond, and Barr Lake.

Some storage in the breach reservoirs may still occur based on differences between inflows to the reservoir and outflows through the breached embankments. The 1-inch storm could have retention of 0.6 to 1.4 feet in the reservoirs. The 2-inch storm could have retention of 1.0 to 2.3 feet; the 10-year storm could have 2.2 to 4.7 feet. The 100-year storm could have retention of 3.1 to 6.4 feet. Most of the retained storage occurs in Gibson's Pond, with lesser amounts in Barr Lake and Lexington Old Mill Pond.

Table 9. Model Results for One Inch/24-Hour Rainfall Scenario (Pre Flood Conditions)

	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
Lake Name	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	450.7	---	273	---	---	---	---	---	---
Lexington Old Mill Pond	291.3	291.3	n/a	294.5	201.6	201.2	163	118	378.9	292.8	1.7	n/a	n/a
Gibson's Pond	309.2	309.2	n/a	313.2	164.8	164.8	129	128	208.0	310.1	3.1	n/a	n/a
Barr Lake	325.0	325.0	326.0	327.0	122.8	122.7	162	91	287.8	325.8	1.2	0.0	0.0
Smith Pond	361.4	361.4	n/a	377.5	41.7	41.7	48	48	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29

Table 10. Model Results for One Inch/24-Hour Rainfall Scenario (Post Flood Conditions)

	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
Lake Name	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	451.2	---	278	---	---	---	---	---	---
Lexington Old Mill Pond	274.5	291.3	n/a	294.5	201.7	201.7	185	182	11.6	275.1	n/a	n/a	n/a
Gibson's Pond	298.2	309.2	n/a	313.2	164.9	164.9	176	153	28.9	299.1	n/a	n/a	n/a
Barr Lake	313.0	325.0	326.0	327.0	122.8	122.8	162	127	28.3	314.4	n/a	n/a	n/a
Smith Pond	361.4	361.4	n/a	377.5	41.7	41.7	48	48	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29.

Table 11. Model Results for Two Inch/24-Hour Rainfall Scenario (Pre Flood Conditions)

Lake Name	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	901.9	---	558	---	---	---	---	---	---
Lexington Old Mill Pond	291.3	291.3	n/a	294.5	403.3	402.9	385	290	423.4	294.0	0.5	n/a	n/a
Gibson's Pond	309.2	309.2	n/a	313.2	329.7	329.7	315	313	215.2	310.8	2.4	n/a	n/a
Barr Lake	325.0	325.0	326.0	327.0	245.6	245.6	323	229	316.5	326.3	0.7	0.3	44.7
Smith Pond	361.4	361.4	n/a	377.5	83.5	83.5	96	96	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29.

Table 12. Model Results for Two Inch/24-Hour Rainfall Scenario (Post Flood Conditions)

Lake Name	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	902.4	---	546	---	---	---	---	---	---
Lexington Old Mill Pond	274.5	291.3	n/a	294.5	403.4	403.4	410	408	19.9	275.5	n/a	n/a	n/a
Gibson's Pond	298.2	309.2	n/a	313.2	329.8	329.9	381	341	49.0	299.7	n/a	n/a	n/a
Barr Lake	313.0	325.0	326.0	327.0	245.6	245.4	323	276	47.2	315.3	n/a	n/a	n/a
Smith Pond	361.4	361.4	n/a	377.5	83.5	83.5	96	96	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29.

Table 13. Model Results for 10-Year/24-Hour Rainfall Scenario (Pre Flood Conditions)

Lake Name	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	2,377.3	---	1,482	---	---	---	---	---	---
Lexington Old Mill Pond	291.3	291.3	n/a	294.5	1,062.9	1,062.5	1,329	1,307	467.0	295.3	0.0	n/a	n/a
Gibson's Pond	309.2	309.2	n/a	313.2	869.0	868.9	1,090	1,072	235.4	312.8	0.4	n/a	n/a
Barr Lake	325.0	325.0	326.0	327.0	647.2	647.1	852	797	365.7	327.1	0.0	1.1	313.8
Smith Pond	361.4	361.4	n/a	377.5	220.0	219.9	254	254	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29.

Table 14. Model Results for 10-Year/24-Hour Rainfall Scenario (Post Flood Conditions)

Lake Name	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	2,377.9	---	1,453	---	---	---	---	---	---
Lexington Old Mill Pond	274.5	291.3	n/a	294.5	1,063.0	1,063.0	1,240	1,230	41.6	276.7	n/a	n/a	n/a
Gibson's Pond	298.2	309.2	n/a	313.2	869.1	869.1	1,083	1,008	100.5	301.3	n/a	n/a	n/a
Barr Lake	313.0	325.0	326.0	327.0	647.2	647.0	852	789	94.9	317.7	n/a	n/a	n/a
Smith Pond	361.4	361.4	n/a	377.5	220.0	219.9	254	254	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29.

Table 15. Model Results for 100-Year/24-Hour Rainfall Scenario (Pre Flood Conditions)

	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
Lake Name	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	3,731.0	---	2,435	---	---	---	---	---	---
Lexington Old Mill Pond	291.3	291.3	n/a	294.5	1,668.0	1,667.6	2,218	2,212	483.1	295.7	0.0	n/a	n/a
Gibson's Pond	309.2	309.2	n/a	313.2	1,363.7	1,363.7	1,796	1,796	246.0	313.8	0.0	n/a	n/a
Barr Lake	325.0	325.0	326.0	327.0	1,015.7	1,015.5	1,337	1,319	381.1	327.4	0.0	1.4	450.6
Smith Pond	361.4	361.4	n/a	377.5	345.2	345.1	398	398	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29.

Table 16. Model Results for 100-Year/24-Hour Rainfall Scenario (Post Flood Conditions)

	Reference Reservoir Elevations [ft]				Total Inflow	Total Outflow	Peak Inflow	Peak Outflow	Peak Storage		Impact Analysis		
Lake Name	Starting Elevation	Primary Outlet Elevation	Auxiliary Spillway Elevation	Top of Dam Elevation	[ac ft]	[ac ft]	[cfs]	[cfs]	Volume [ac ft]	Elevation [ft]	Freeboard (re: Top of Dam) [ft]	Auxiliary Spillway Depth [ft]	Auxiliary Spillway Flow [cfs]
Above Corely Mill Pond	---	---	---	---	3,731.5	---	2,362	---	---	---	---	---	---
Lexington Old Mill Pond	274.5	291.3	n/a	294.5	1,668.1	1,668.1	2,125	2,100	59.4	277.6	n/a	n/a	n/a
Gibson's Pond	298.2	309.2	n/a	313.2	1,363.8	1,363.8	1,737	1,716	132.8	302.7	n/a	n/a	n/a
Barr Lake	313.0	325.0	326.0	327.0	1,015.7	1,015.4	1,337	1,270	130.3	319.4	n/a	n/a	n/a
Smith Pond	361.4	361.4	n/a	377.5	345.2	345.1	398	398	no data	no data	n/a	n/a	n/a

Notes: Elevations are in vertical datum NGVD 29.

Appendix

Figure 1. Subbasin Delineations

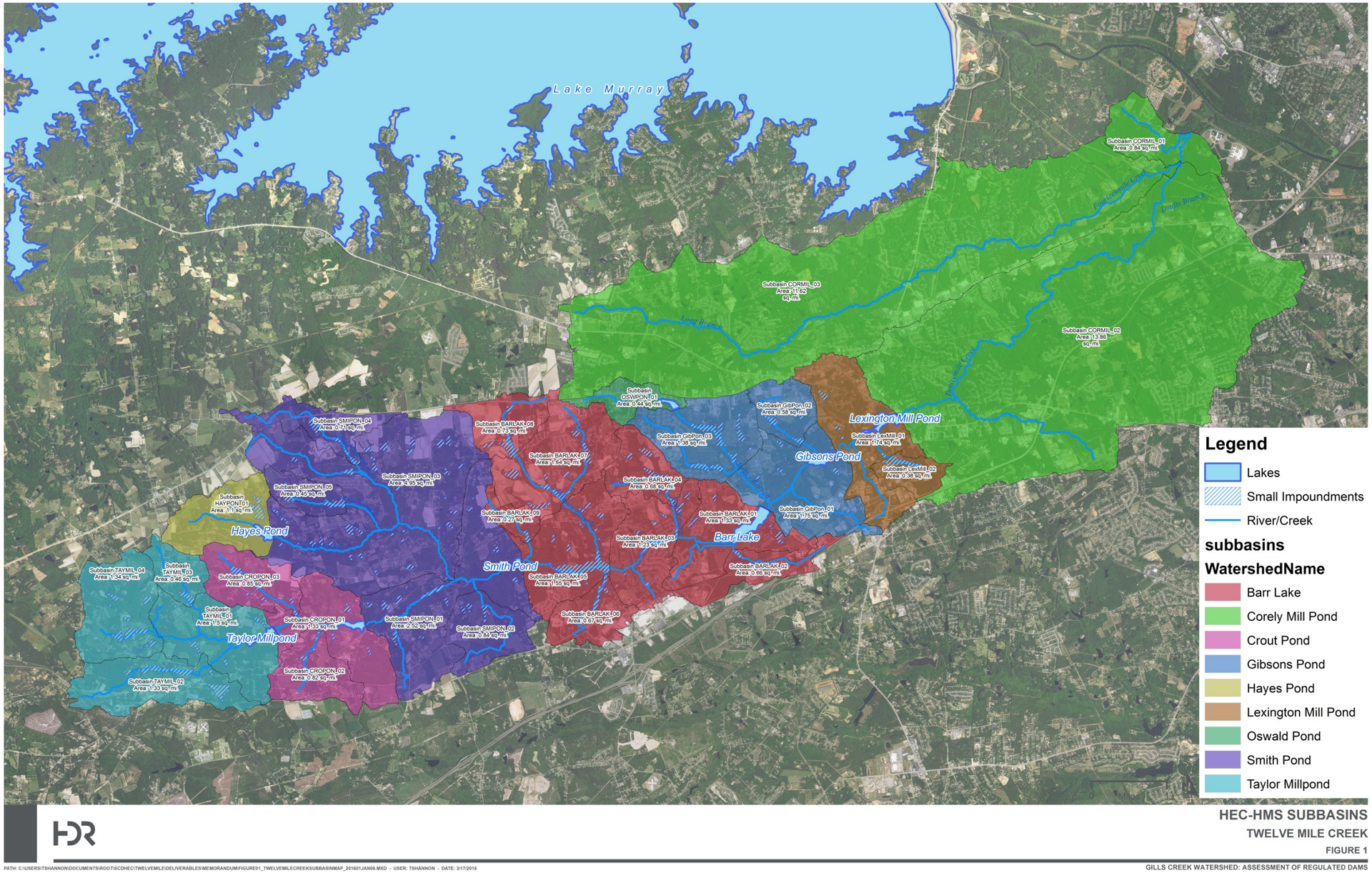


Figure 2. Soils Texture Mapping

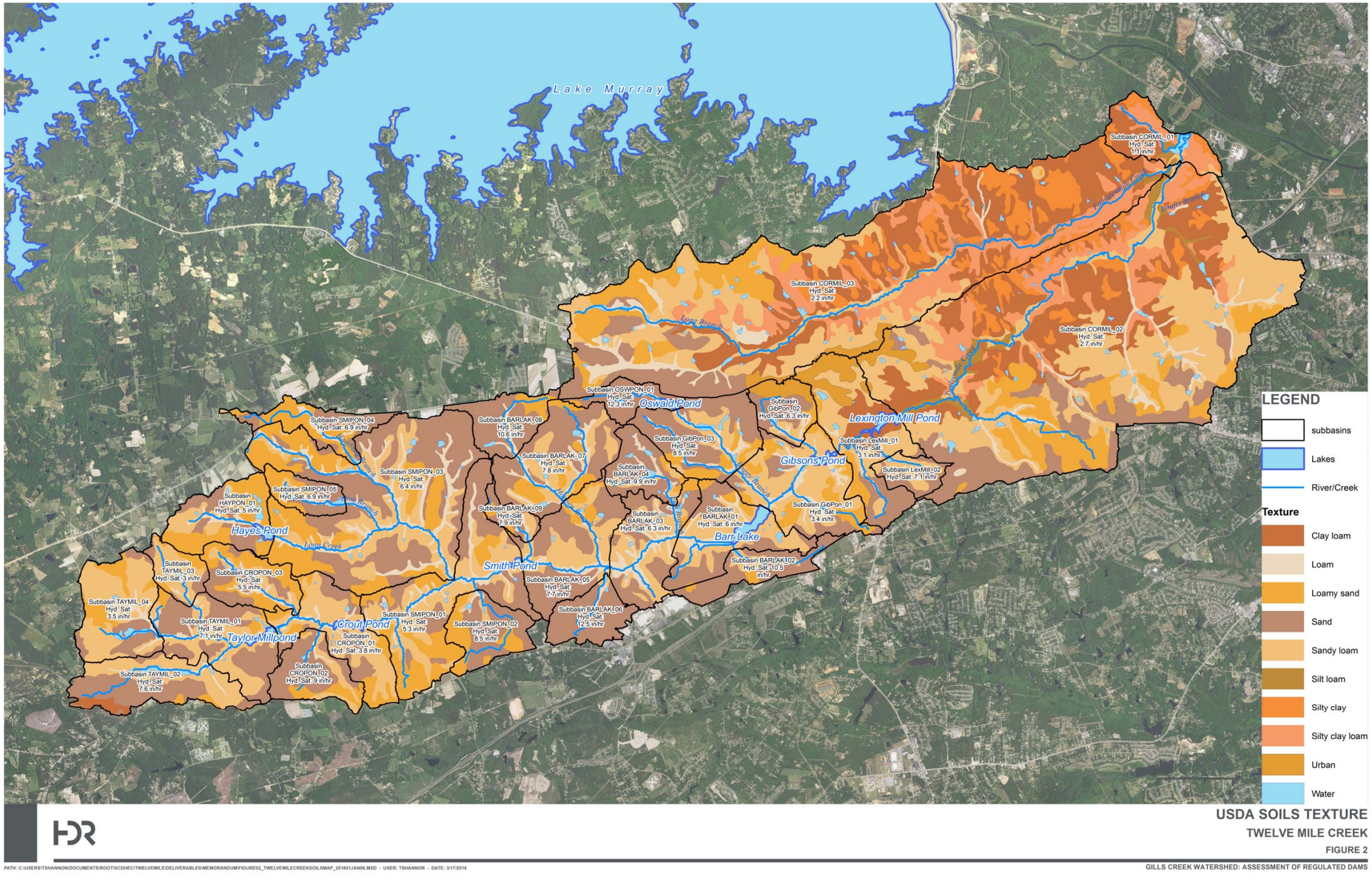


Figure 3. Land Use Classifications

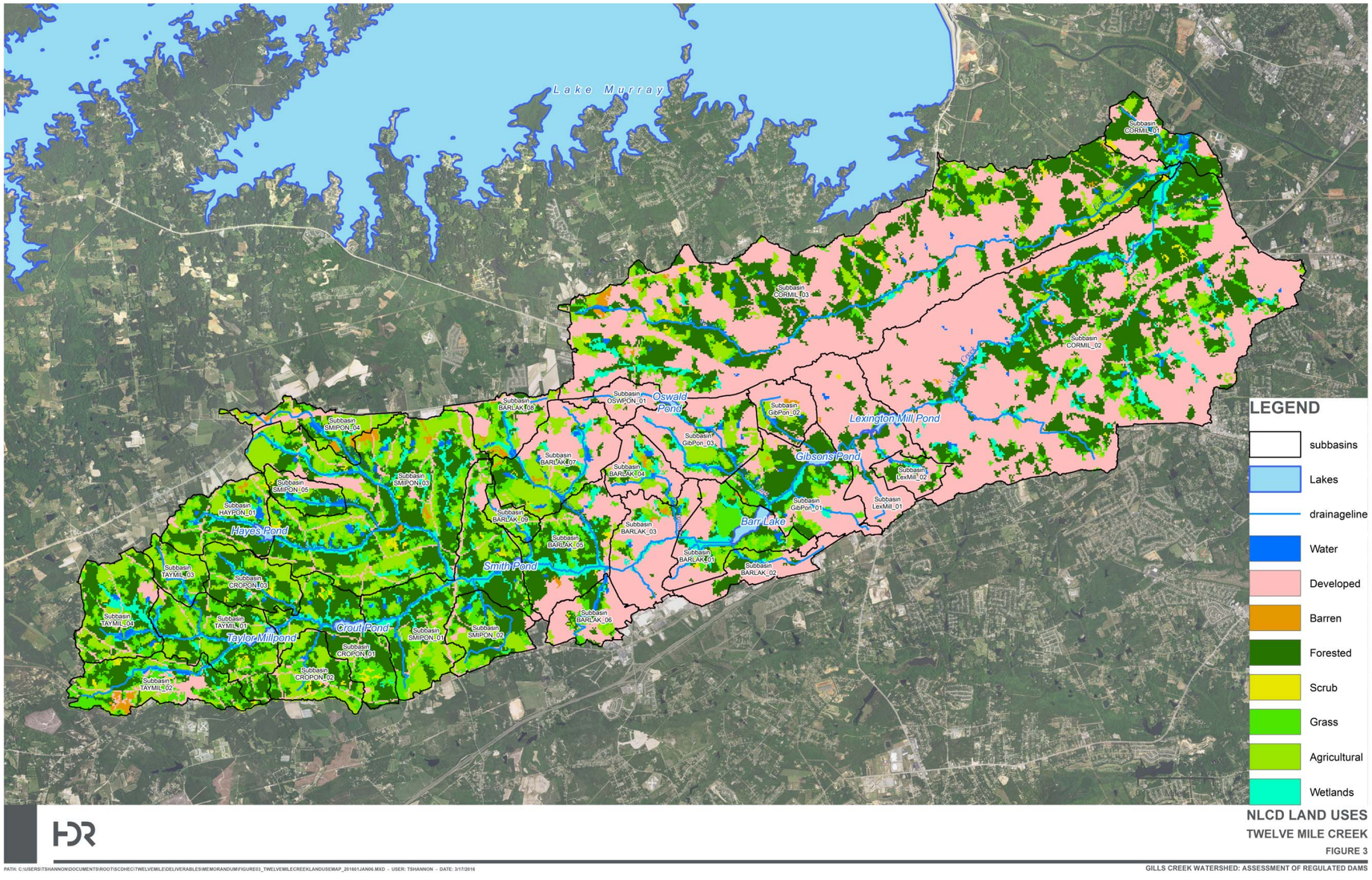
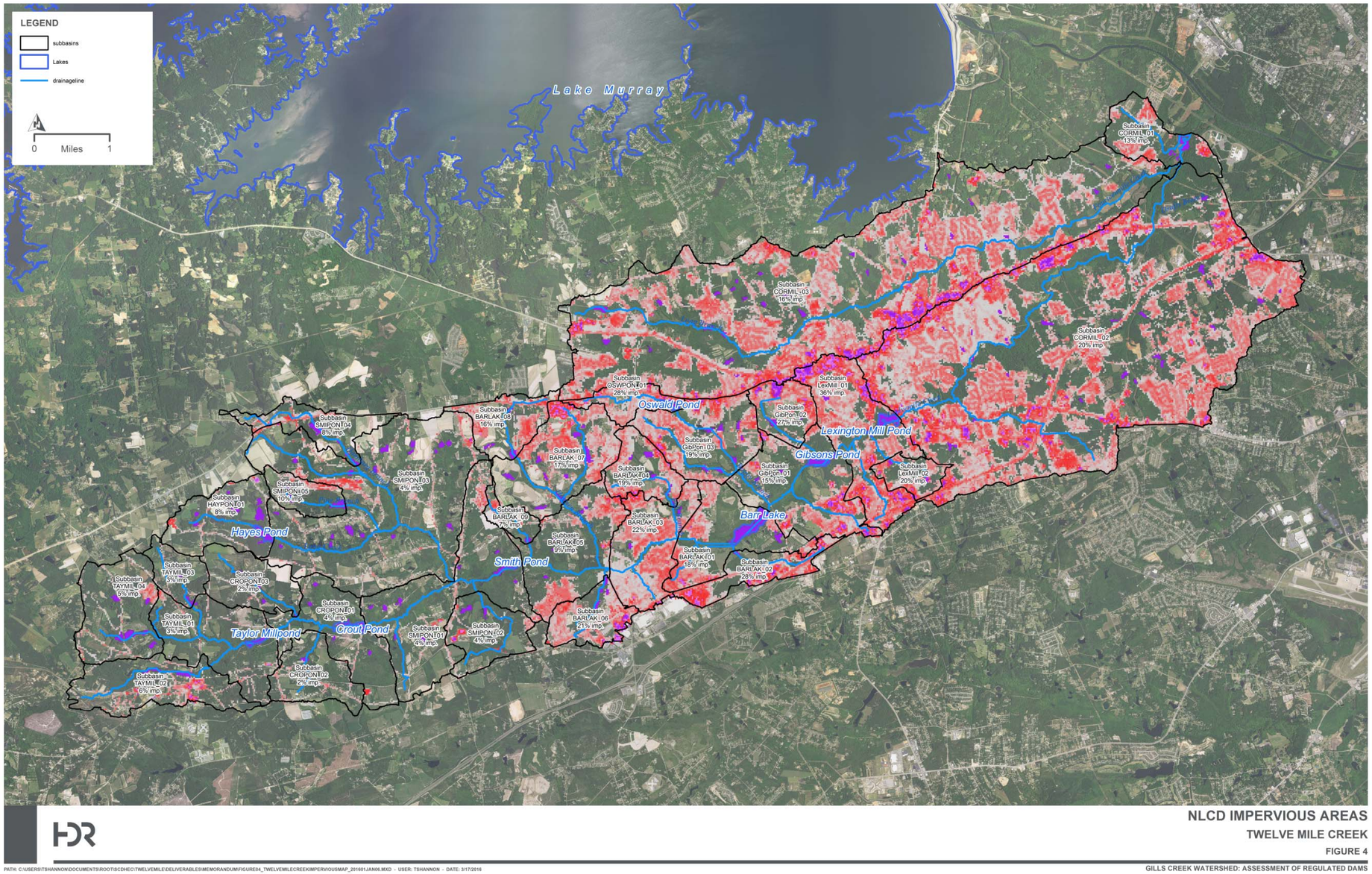


Figure 4. Imperviousness



Appendix D. Site Assessment Reports

01 Barr Lake Dam

02 Gibson's Pond Dam

03 Lexington Old Mill Pond Dam

01 Barr Lake Dam

Twelve Mile Creek Watershed
Site Visit Assessment Report
Barr Lake Dam

1.0 Introduction

1.1 Purpose

The purpose of the site visit was to assess the overall condition of Barr Lake Dam subsequent to the recent flood event of October 2–5, 2015. The site visit objectives included:

- Documentation of the general current condition of principal water retaining structures, spillways, and adjacent areas, including current pond headwater and tailwater levels.
- Identification/observations of damage and indications of distress of principal water retaining structures, and impairment of site discharge capacity.
- Estimates/measurements of existing facilities for comparison to data on file, and of damaged areas/indications of distress.
- Understanding of extent of overtopping that occurred, and measures that have been taken to repair damage and reduce risk for overtopping/failure in the event of a future significant rain event.

This information is intended to provide the DHEC with initial information that will allow them to make informed decisions regarding implementation of orders/actions under their authority.

1.2 Dam ID

Dam name: Barr Lake Dam
Class: C2
DHEC Dam No: D 1717
HDR No: 01
Hazard: Significant
Long_DD: -81.25967849560
Lat_DD: 33.95866556240

The dam consists of, from left abutment to right abutment (looking downstream):

- Earthen Auxiliary Spillway
- Left Embankment Dam
- Gated Concrete Outlet Structure, approximately 14 feet wide
- Center Embankment Dam
- Gated Concrete Outlet Structure, approximately 28 feet wide
- Right Embankment Dam

See Attachment A – Aerial Photo

2.0 Site Visit

2.1 Site Visit Details

Date: November 4, 2015

Team: John Cambridge (HDR), Don Kozak (HDR)

Site Conditions:

- Weather: Clouds and Mist
- HWEL: Dam completely breached, observed approximately 1.0 foot of fall through opening.
- TWEL: See above
- Discharge: No estimate

Overall Status: Embankment completely breached

3.0 Observations

Visual observations made during the site visit are summarized below by each dam structure and spillway. Photos of existing conditions are provided in Attachment B.

The dam embankment is completely breached at the location of the left gated structure (Attachment A: Aerial Photo). The breach is estimated to be 30 feet wide. The upstream water surface measured 13.6 feet below the top of wing wall elevation, and the water adjacent to the wing wall was about 3 feet deep. Road crews were preforming repairs to the Wildlife Road Bridge downstream of the dam on the day of the site visit.

3.1 Embankment Dam

The left embankment section of the dam did not appear to be overtopped as no significant erosion, sloughs, or slope failures were observed. The crest is approximately 14 feet wide and vegetated with grass (Photo 1); no areas of significant depressions were observed. The upstream and downstream slopes of the left embankment are vegetated with grass, heavy underbrush, and with mature trees along the toe of the upstream and downstream slope (Photo 1). The downstream slopes of the center and right embankment are heavily vegetated with trees and underbrush (Attachment A: Aerial Photo). The upstream and downstream slopes are generally at 2H:1V, but vary.

3.2 Left Abutment

The left abutment was a wooded area as recently as 27 February 2015, but had been cleared in conjunction with development of a residential subdivision on the left shoreline of Barr Lake when the 04 October 2015 aerial photograph was flown. It is assumed the auxiliary spillway channel observed during the site visit was also constructed at that time. The riprap-lined auxiliary spillway experienced flow during the flood. Minor erosion and some debris accumulation were observed in the wooded area downstream with the maintenance road fill around a culvert at the gate washed away; minor to moderate erosion was observed in the rock-riprap-lined earthen spillway channel.

3.3 Left Gated Concrete Structure

The breach was at this location, and all that remains of the 14-foot-wide structure are the upstream left wingwall and the downstream left footing. The structure width was estimated from aerial photographs. It is unknown if the gates were operational and if they were open or closed during the event.

3.4 Right Gated Concrete Structure

This structure is approximately 28 feet wide (estimated from aerial photographs). It is unknown if the gates were operational and if they were open or closed during the event. It was not possible to access this structure during the site visit due to high water and washed out access routes.

3.5 Right Abutment

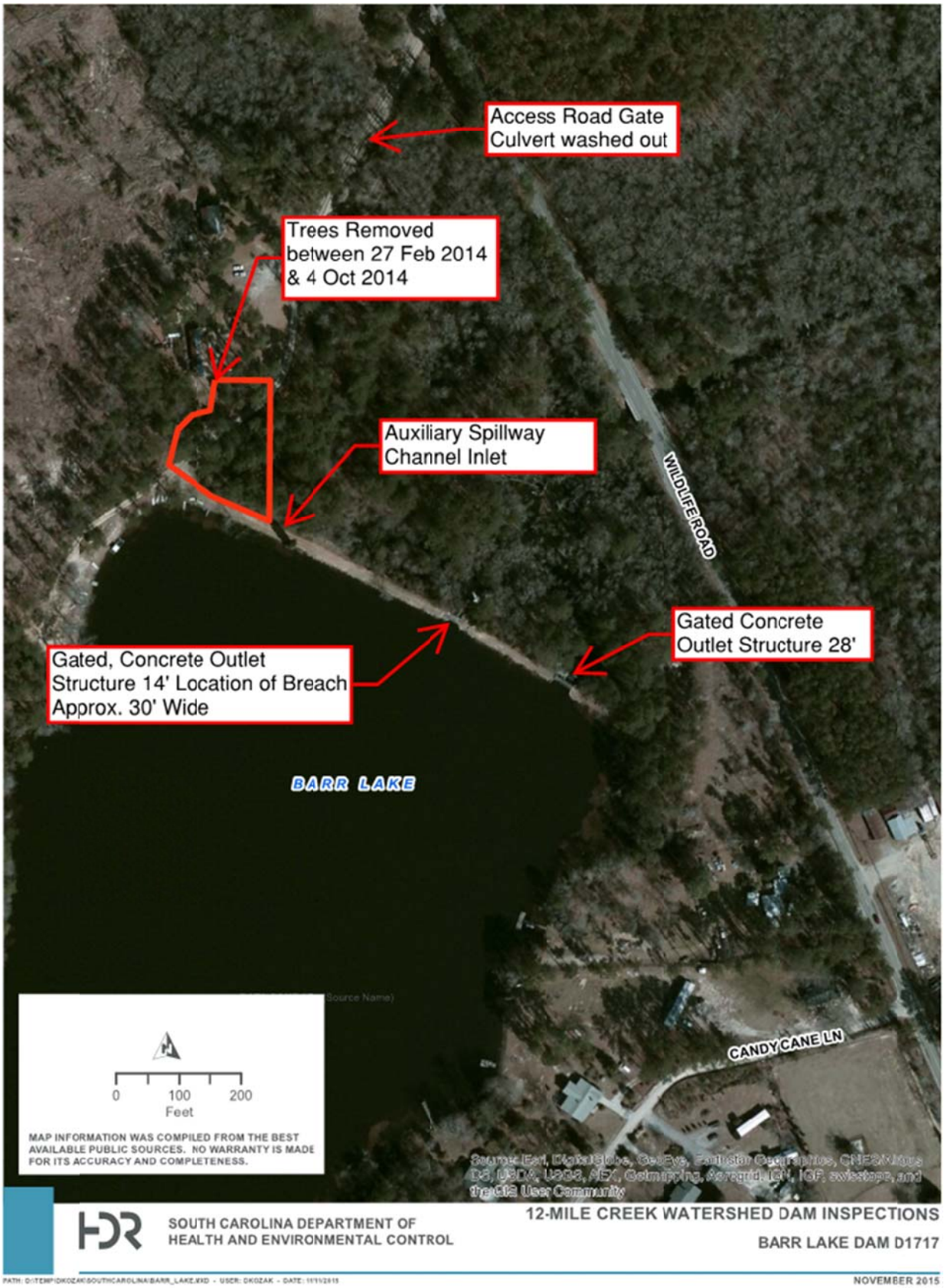
The access route to the right abutment was washed out on the day of the site visit. The right abutment was not observed since it appeared the only alternative access was via private property not associated with the residential development under construction.

3.6 Auxiliary Spillways/Outlets

Based on comparison of dated aerial photography, timber was cleared from the left overbank, left of the auxiliary spillway, between 27 February 2014 and 04 October 2014. The ground surface was observed to be 2 to 3 feet below top of dam elevation and may have been intended to serve as an auxiliary spillway. This rock-riprap-lined channel may have been intended to serve as the maintenance access road, but it disappears into running water below the breach and it is unknown if it extended to the access road connecting off Wildlife Road.

- The rock-riprap-lined channel is approximately 15 feet wide with depth varying from 1.0 to 2.0 feet.
- No significant debris accumulation in the auxiliary spillway channel was observed.
- There is a 15- to 18-inch-diameter HDPE culvert under the channel perpendicular to the direction of flow. It does not connect to the lake, and its purpose is unknown.

Attachment A: Aerial Photo



Attachment B: Inspection Photos

Photo 1: Left abutment on top of dam.

Photo 2: View is of center embankment at breach.

Photo 3: Looking upstream from top of dam.

Photo 4: Looking downstream from top of dam.

Photo 5: Looking at breach at right abutment.

Photo 6: 28-foot concrete gate structure.

02 Gibson’s Pond Dam

Twelve Mile Creek Watershed
Site Visit Assessment Report
Gibson's Pond Dam

1.0 Introduction

1.1 Purpose

The purpose of the site visit was to assess the overall condition of Gibson's Pond Dam subsequent to the recent flood event of October 2–5, 2015. The site visit objectives included:

- Documentation of the general current condition of principal water retaining structures, spillways, and adjacent areas, including current headpond and tailwater levels.
- Identification/observations of damage and indications of distress of principal water retaining structures, and impairment of site discharge capacity.
- Estimates/measurements of existing facilities for comparison to data on file, and of damaged areas/indications of distress.
- Understanding of extent of overtopping that occurred, and measures that have been taken to repair damage and reduce risk for overtopping/failure in the event of a future significant rain event.

This information is intended to provide the DHEC with initial information that will allow them to make informed decisions regarding implementation of orders/actions under their authority.

1.2 Dam ID

Dam name: Gibson's Pond Dam
Class: C2
DHEC Dam No: D 0959
HDR No: 02
Hazard: Significant
Long_DD: -81.24359769440
Lat_DD: 33.9646491800

The dam consists of, from left abutment to right abutment (looking downstream):

- Concrete Ogee Crest Spillway with steel through-girder bridge
- Left Embankment Dam

See Attachment A – Aerial Photo

2.0 Site Visit

2.1 Site Visit Details

Date: November 4, 2015

Team: John Cambridge and Don Kozak (HDR)

Site Conditions:

- Weather: Clouds and Mist
- HWEL: Dam completely breached down to bedrock at left abutment.
- TWEL: See above
- Discharge: No estimate

Overall Status: Embankment completely breached.

3.0 Observations

Visual observations made during the site visit are summarized below by each dam structure and spillway. Photos of existing conditions are provided in Attachment B.

3.1 Embankment Dam

The left embankment section of the dam was completely washed away during the event. The concrete ogee-crest dam and bridge remain in place. No trace of the embankment remained.

3.2 Left Abutment

The left abutment is a parking lot for a picnic shelter and an asphalt sidewalk to access an observation deck for viewing the channel downstream of the dam. Root balls of two trees are partially undercut and are likely to completely erode if another event occurs. Debris consists of wood deck and walkway remnants and large concrete slabs. One hundred percent of base flow is going through the breach.

3.3 Right Abutment

The right abutment consists of the concrete ogee-crest dam and bridge. It is founded on bedrock. The abutment tie-in was inaccessible and not observed.

3.4 Principal Spillway

The uncontrolled ogee-crest dam serves as the principal spillway, and there were no mechanisms for discharge through the dam.

3.5 Auxiliary Spillways/Outlets

There is no auxiliary spillway.

Attachment A: Aerial Photo

Attachment B: Inspection Photos

Photo 1: Left abutment looking downstream.

Photo 2: View from approximate dam centerline looking downstream.

Photo 3: Remnants of wood walkway on left abutment.

Photo 4: View from left abutment looking upstream.

Photo 5: View from left abutment along centerline of dam.

Photo 6: Looking from Gibson Road Bridge at left abutment.

Photo 7: View from Gibson Road Bridge looking downstream.

Photo 8: Wooden observation deck piers and walkway on left abutment.

03 Lexington Old Mill Pond Dam

Twelve Mile Creek Watershed
Site Visit Assessment Report
Lexington Old Mill Pond Dam

1.0 Introduction

1.1 Purpose

The purpose of the site visit was to assess the overall condition of Lexington Old Mill Pond Dam subsequent to the recent flood event of October 2–5, 2015. The site visit objectives included:

- Documentation of the general current condition of principal water retaining structures, spillways, and adjacent areas, including current headpond and tailwater levels.
- Identification/observations of damage and indications of distress of principal water retaining structures, and impairment of site discharge capacity.
- Estimates/measurements of existing facilities for comparison to data on file, and of damaged areas/indications of distress.
- Understanding of extent of overtopping that occurred, and measures that have been taken to repair damage and reduce risk for overtopping/failure in the event of a future significant rain event.

This information is intended to provide the DHEC with initial information that will allow them to make informed decisions regarding implementation of orders/actions under their authority.

1.2 Dam ID

Dam name: Lexington Old Mill Pond Dam
Class: C1
DHEC Dam No: D 0958
HDR No: 03
Hazard: High
Long_DD: -81.22930476760
Lat_DD: 33.97669360670

The dam consists of, from left abutment to right abutment (looking downstream):

- Lexington Old Mill Building
- Gated Penstock Intake
- Embankment Dam
- Concrete/Bedrock Overflow with Gated Concrete Intake Structure

See Attachment A – Aerial Photo

2.0 Site Visit

2.1 Site Visit Details

Date: November 4, 2015

Team: John Cambridge (HDR), Don Kozak (HDR)

Site Conditions:

- Weather: Clouds and Mist
- HWEL: Dam completely breached, approximately 2.0 feet of fall through breach opening
- TWEL: See above
- Discharge: No estimate

Overall Status: Embankment has completely breached with an opening approximately 150 feet wide exposing the Old Mill Building foundation (Photos 11 and 15). Significant base flow discharge is flowing through the breach. Flow rate may be still influenced by previous events, but given that the next two dams upstream (Gibson Pond and Barr Lake) are also breached, the rate is likely near base flow values.

3.0 Observations

Visual observations made during the site visit are summarized below by each dam structure and spillway. Photos of existing conditions are provided in Attachments B.

3.1 Embankment Dam

An eddy on the upstream face is actively eroding the toe of the remaining embankment, and a 150-foot-long, near-vertically-faced slough has developed to within 10 to15 feet of the dam crest (Photos 9, 10, and 18). No significant storage volume remains behind the dam (Photo 8). Based on the observed riprap line and aerial photos showing the dam prior to breach, it appears the slough on the upstream slope is currently at the original shoreline.

There were no indications of overtopping flow with only minor surface erosion apparent; no significant erosion, sloughs, or slope failures observed on the remaining portion of the downstream slope. There were remnants of pier footings from a previously removed building, last visible on GoogleEarth in a 2012 aerial photo. A brick building remains at that location on the downstream slope near the embankment crest (Photos 3 and 4). The crest is approximately 11 feet wide and partially vegetated with grass and two trees on the crest near the building(Photos 4 and 5); no areas of significant depressions were observed. The portion of the upstream slope that has not yet sloughed is about 2.8H:1V. The downstream slope is generally at 1.7H:1V and brush appears to have been recently mowed.

3.2 Left Abutment

The left abutment is the old mill building currently being utilized as a commercial mall. The building footings have been exposed by the breach. The stone masonry wall of the penstock inlet is partially damaged and is being supported by a screw-jack set on the remaining footing/cut bedrock.

3.3 Right Abutment

The right abutment is a wooded residential area adjacent to the mill race bypass. The mill race gate is open and experienced flow during the flood. The outlet channel is natural bedrock. Debris has been removed from the culvert under E Main Street. The mill race bypass has an open gate, with mature trees along the toe of the downstream slope (Photo 5). The mill race bypass appears to be founded in bedrock and piers (Photo 12).

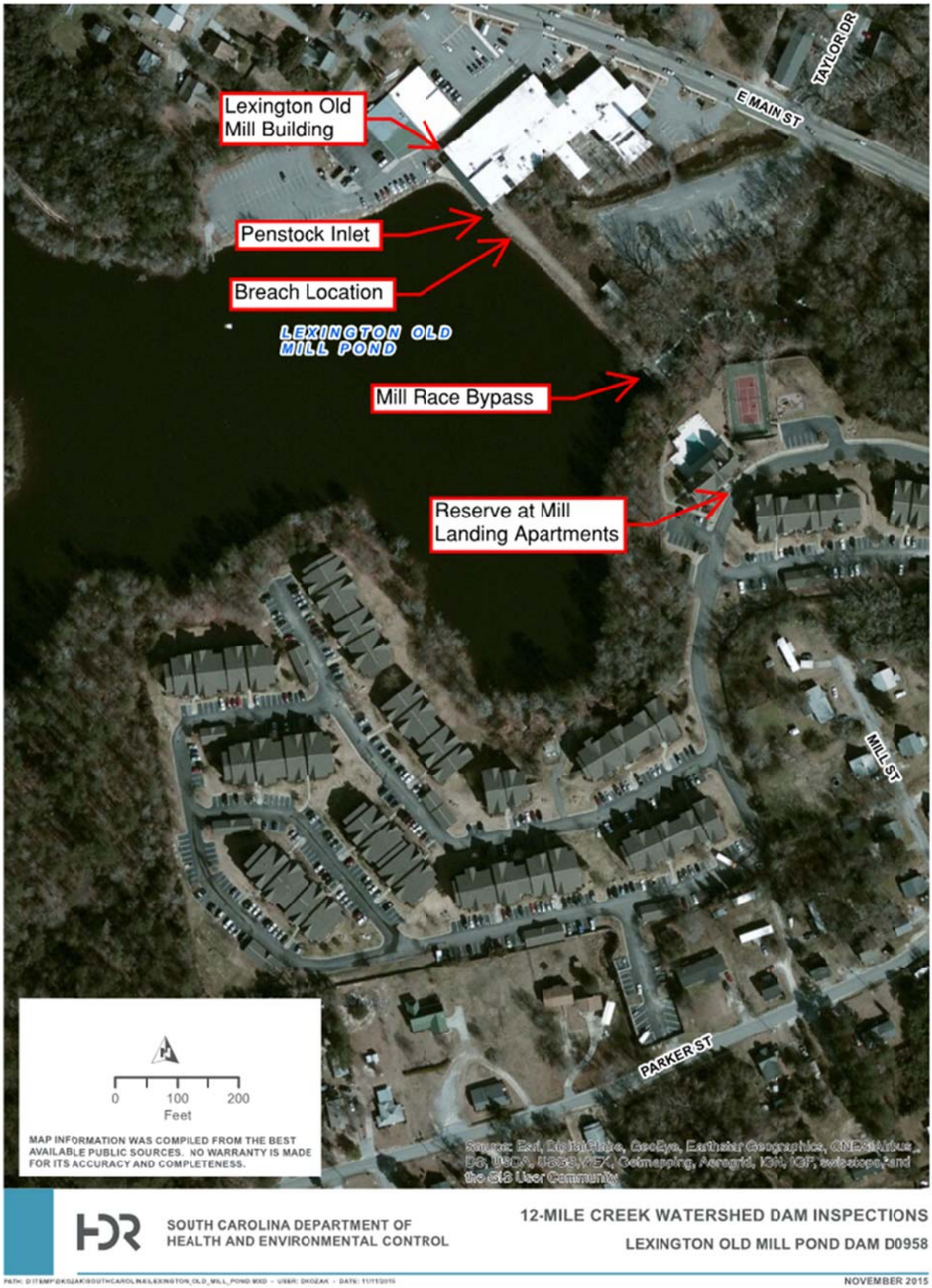
3.4 Penstock

The existing penstock pipe inlet is closed and assumed to be non-operational.

3.5 Spillway

The spillway consists of an uncontrolled concrete overflow section and a gated section that discharges into the mill race bypass. The gate at the mill race bypass structure was open during the site visit and appears to be operational. The catwalk was fenced to prohibit unauthorized access to the mill race catwalk, and the inlet and outlet channels were temporarily inaccessible during the site visit due to flowing water and unstable lake bed. Dimensions of the gate and opening were not obtained.

Attachment A: Aerial Photo



Attachment B: Inspection Photos

Photo 1: View shows left downstream abutment debris.

Photo 2: View is looking at downstream face of dam left abutment.

Photo 3: View shows downstream face of right abutment

Photo 4: View is from top of dam looking at left abutment.

Photo 5: View is from top of dam looking at right abutment.

Photo 6: View is looking at upstream face of dam.

Photo 7: View showing newly placed earthfill and old timber cribbing upstream of the dam breach as viewed from the right abutment.

Photo 8: View is looking upstream.

Photo 9: View is looking at upstream face of dam.

Photo 10: View is looking at upstream face of dam.

Photo 11: View is looking at penstock pipe.

Photo 12: View shows the mill race bypass channel.

Photo 13: View is from standing on right abutment looking downstream.

Photo 14: View is looking at downstream face of mill race bypass channel.

Photo 15: View is at left abutment sluice gate looking downstream.

Photo 16: View is looking upstream from left abutment.

Photo 17: View is at upstream face of dam breach viewed from left abutment.

Photo 18: View is looking at dam breach from left abutment.

Photo 19: View is looking downstream at dam breach.

Photo 20: View is looking downstream at dam breach.