Analysis of Potential Flood Magnitude and Severity for Land Surrounding the Consent Decree Area, Robert Brace Farm, Waterford, Erie County, Pennsylvania

Expert Report Prepared For

United States Department of Justice

In Regard to Case

United States v. Robert Brace and Robert Brace Farms, Inc., Civ. No. 90-229, W.D. Pa.

Prepared By

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Lexington, Kentucky

December 18, 2017

I. Introduction

1. The United States of America engaged me to conduct a flood analysis of the area immediately upstream (south) of the Lane Road Culvert (near Waterford Township in Erie County, Pennsylvania; culvert location 41° 58’ 44.17” N, 80° 2’ 35.7” W) through which the stream referred to hereafter as “Elk Creek” passes. More specifically, I was engaged to analyze flooding (peak discharges and corresponding inundated land areas), and the physical impact thereof, that might reasonably be expected in this area and to assess the circumstances and degree to which inundation due to flooding might expand outside the wetland region known as the Consent Decree Area (“CDA”) and into the adjoining uplands areas. Based on information I was provided and that I subsequently verified, I judged that flooding upstream of the Lane Road Culvert might be influenced by a downstream culvert (referred to as the Sharp Road Culvert, located roughly 2000 ft NNE of the Lane Road Culvert at 41° 58’ 59.5” N, 80° 2’ 49.2” W). As a result, the presence of the Sharp Road Culvert was incorporated into subsequent assessments of flooding upstream of the Lane Road Culvert. Both culverts and the CDA are shown in Fig. 1.

II. Qualifications

2. I hold a B.S. in Agricultural Engineering from the University of Arkansas (1984); a M.S. in Agricultural Engineering from the University of Arkansas (1986); a M.S. in Strategic Studies from the United States Army War College (2005);[1] and, a Ph.D. in Agricultural Engineering from Oklahoma State University (1988).

3. I am currently a professor in the Biosystems and Agricultural Engineering Department at the University of Kentucky, and have held a professorship and associate professorship there since 1994. From 1988 to 1994, I was an associate and assistant professor in the Biological and Agricultural Engineering Department at the University of Arkansas.

4. I hold a professional engineer license from the Arkansas State Board of Licensure for Professional Engineers and Professional Surveyors.

5. Over the course of my professional career, I have (a) conceived and conducted original research, (b) reported on my findings in peer-reviewed scientific journal and other venues, (c) served as editor of a scientific journal and thus as arbiter of scientific merit in papers submitted to that journal, and (d) provided service as a professional expert/consultant in multiple cases, with each of these activities falling within the field of knowledge referred to as “surface water resources engineering.” During each of my 23 years at the University of Kentucky, I have taught graduate-level courses in surface hydrology and statistical hydrology as well as a senior-level course on water resources engineering. The subject matter of these courses includes each of the tools, methods,

[1] In September 2014, I retired from the United States Army Reserve at the rank of Brigadier General.

models and approaches used in this report. Finally, I have served as thesis advisor and dissertation advisor to graduate students whose success depended on mastery of the techniques used in this report, as well as my own ability to guide them in this endeavor. Based on these experiences, I consider myself qualified to have performed the analysis and drawn the conclusions contained in this report.

6. My curriculum vitae, including a list of all publications I have within the last 10 years follow the main body of this report in Appendix A. The description of the information I considered in forming my opinions is contained in Appendix B. My statement of compensation and testimony history for the last four years is contained in Appendix C.

III. Standards

7. All methodologies utilized, assumptions made, and actions described herein conform to generally-accepted hydrologic and water resources engineering industry standards for flood modeling and analysis.

IV. Summary of Opinions.

8. On the basis of data and methods described in succeeding portions of the report, my opinions can be summarized as follows:

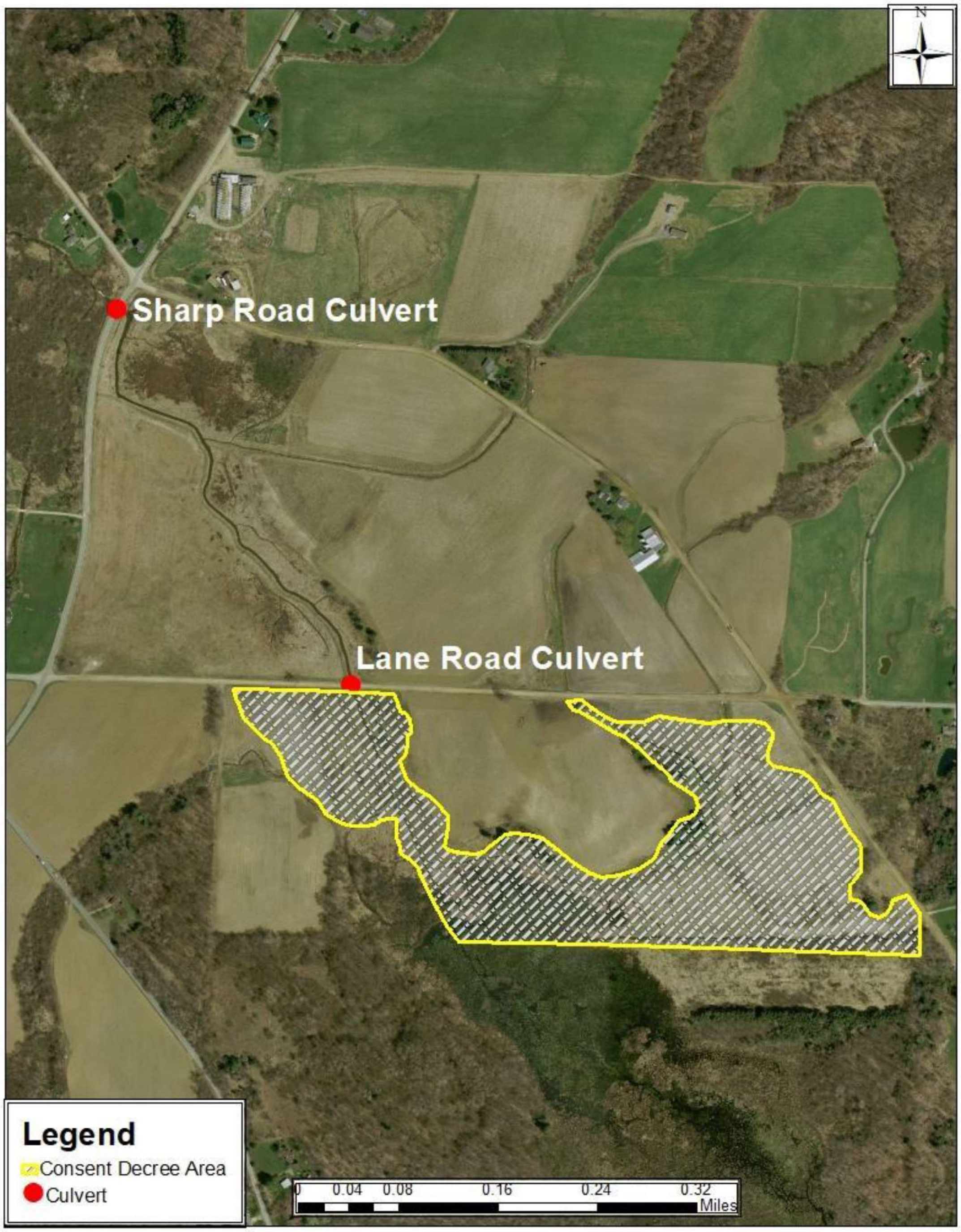
    a. Very little farmed land adjoining the CDA, if any, floods under any conditions considered. Even under severe conditions, flooding will extend outside the CDA and into adjoining uplands to an extent of 0.0636 acres or less (roughly one-quarter of one percent of the total upland acreage adjoining the CDA). This can be visualized as a roughly 50 ft x 50 ft plot of land or, alternatively, a "buffer" of 3.5 inches extending outside and along the entire (including the southern boundary) perimeter of the CDA.

    b. Depth of flooding in adjoining uplands is low (less than 2 ft at maximum) as is the duration of flooding (less than five hours for flooding anywhere, at any depth, in the adjoining uplands). Furthermore, these measures of flooding magnitude are conservative (i.e., worse than expected in reality) as a result of study area characteristics and methods used in the analysis.

    c. Based upon the extent, depth, and duration of the predicted flooding, the flooding itself would likely have no significant impact on the adjoining uplands or any activities conducted therein.

9. All conclusions and opinions described herein are offered to a reasonable degree of scientific and engineering certainty based upon industry standards, best available methods, and best available data.

Fig. 1. Immediate context of work.



Data sources: (1) 2015 orthoimagery, (2) Client-provided documents.

V. Methodology

A. Primary Datasets

10. Except as noted, physical characteristics of the study area (watershed area, slopes, soils, land use) were analyzed on a geographic information system ("GIS") using publicly-available information. The GIS software application was ArcMap for Desktop (v. 10.3.1.4959; Environmental Systems Research Institute, Redlands, California), the industry standard application that is widely, if not almost exclusively, used in hydrologic and water resources engineering. Datasets used in initial analysis were:

a. Digital Elevation Model ("DEM") Data. Data collected through Light Detection and Ranging ("LiDAR") methods to provide location and elevation (X,Y,Z) information averaged for 2.5 ft x 2.5 ft "cells." Data collection date was April 29, 2015, and the data were downloaded from http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=3204.

b. Orthoimagery. Color photography data that permit the identification of key features and attributes (roads, highways, ponds, culverts, land use, etc.), georeferencing of historical and other non-georeferenced materials, and other functions. Resolution is 2.5 ft by 2.5 ft. Data collection date was April 29, 2015, and the data were downloaded from http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=3201.

c. Soils Data. Coded data that indicate the soil associated with a location as well as the properties of that soil. These data were used primarily to determine locations' potential for runoff generation as captured by the Hydrologic Soil Group ("HSG") property. Soils classified as HSG A are considered as having the lowest runoff potential, whereas HSG D has the highest. Some soils are jointly classified to reflect that their hydrologic behavior can vary with soil moisture condition. Data are aggregated within irregular boundaries rather than grids. The data are archived in the Soil Survey Geographic ("SSURGO") database of the Natural Resources Conservation Service ("NRCS"), U.S. Department of Agriculture and were downloaded from https://datagateway.nrcs.usda.gov/GDGOrder.aspx.

d. Land Use Data. Coded data that indicate the dominant (as of 2011, the most current available) land use at a 30m x 30m resolution. The data are archived in the National Land Cover Database ("NLCD") of the U.S. Geological Survey, U.S. Department of the Interior, and were downloaded from http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=3141.

e. Historical Imagery. Images, both georeferenced and non-georeferenced, of multiple spectra (e.g., black and white, color, color infrared) that serve the same basic purposes as the orthoimagery described earlier. Images irregularly spanning the period 1939 – 2015 are available and were downloaded from http://maps.psiee.psu.edu/ImageryNavigator/ Additional imagery of the same character and irregularly spanning the period 1993 – 2016 was available through the Google Earth Pro software application v. 7.3.0.3832 (Google, Inc., Mountain View, CA). Non-georeferenced images were georeferenced using the georeferencing tools available in ArcMap and the April 2015 orthoimagery as the standard.

f. Wetlands Boundaries. Coded data, aggregated within irregular boundaries, indicating presence and nature of wetlands. These data were used in conjunction with published information to estimate flood peak flows for various return periods. The data were published by the U.S. Fish and Wildlife Service, U.S. Department of the Interior, in 2009 and were downloaded from http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1457.

g. Stream network. Irregular lines that representing the drainage network (i.e., streams and rivers). The data, known as the National Hydrograph Dataset ("NHD"), were published in 2009 by the U.S. Geological Survey, Department of the Interior, and download from http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=770.

h. Legal Boundaries. Irregular lines that indicate the areal extent of property parcels and the CDA. These data were derived by georeferencing and digitizing images provided by the Client.

i. All other data used and/or referenced in this report are derivative of one or more of these primary datasets. Projected data were used in all analyses, and the coordinate system was the North American Datum ("NAD") 1983 High Accuracy Reference Network ("HARN") State Plane Pennsylvania North Federal Information Processing System ("FIPS") 3701.

B. Hydrologic Model Parameterization

11. Flood analysis was performed using the Hydrologic Engineering Center Hydrological Modeling System ("HEC-HMS") software application, v. 4.1, developed by the Hydrologic Engineering Center, U.S. Army Corps of Engineers, and available at http://www.hec.usace.army.mil/software/hec-hms/downloads.aspx. There is a more current version (4.2) available as of March 2017; however, it does not vary from v. 4.1 in any way that is relevant to this analysis, and the older version was assessed to be more stable from the perspective of code error detection and repair. HEC-HMS has been used worldwide in hydrology and water resources research, analysis and design; it is considered an industry standard, certified for use in Federal Emergency Management Agency studies and adopted by multiple U.S. agencies.

12. ***Basic Model Elements:***

a. The process of acquiring the HEC-HMS data required to parameterize (mathematically describe) a watershed is facilitated by GIS-based tools developed by the U.S. Army Corps of Engineers for use with ArcMap. The software package of these tools, which are based on tailored sequences of ArcMap's native tools and capabilities, is referred to as HEC-GeoHMS. Version 10.2 (most current) of HEC-GeoHMS was used in this work to automate the process of generating GIS-based inputs to HEC-HMS. The major secondary datasets (layers) generated by HEC-GeoHMS and used for HEC-HMS parameterization included:

i. Reconditioned DEM Layer. A dataset resulting from alteration of the original DEM to ensure that automatically-defined streams will retain their approximately original locations. This layer is derived from the original DEM and a stream layer (in this instance, the NHD dataset, edited to include increased stream network resolution and verified by site visit on October 16-17, 2017).

ii. Filled DEM Layer. An alteration of the reconditioned DEM to remove any depressions which, in this context, are considered to be the result of small and random errors in the original LiDAR data.

iii. Stream Layer. Cells of the filled DEM identified as receiving the drainage from a specified minimum number of contributing cells. This layer should be very similar to that used in creating the reconditioned DEM layer (in this case, the modified NHD dataset).

iv. Catchment/Subwatershed Layer. Upstream areas draining to streams. Subwatersheds are defined just upstream of each junction in the stream layer and are based on the filled DEM layer.

v. Watershed Boundary Layer. Also known as area of interest ("AOI") layer. A subset of the study area that consists of the outline of all subwatersheds draining to a user-defined point of interest (in this case, the entrance to the Sharp Road Culvert).

vi. Slope Layer. A dataset based on the original DEM that indicates the "flatness" or "steepness" of the land surface.

vii. Curve Number ("CN") Layer. A dataset derived, on the basis of NRCS guidance, from NLCD and SSURGO data that quantifies potential for runoff generation. The CN is used in NRCS methods to convert rainfall depth to runoff depth and ranges from 0 (no runoff is possible) to 100 (impervious surface).

b. These secondary datasets are used with HEC-GeoHMS tools to parameterize the basic hydrologic model elements (i.e., subwatersheds, stream segments and their connectivity, but not more specialized model elements such as detention basins and diversions).

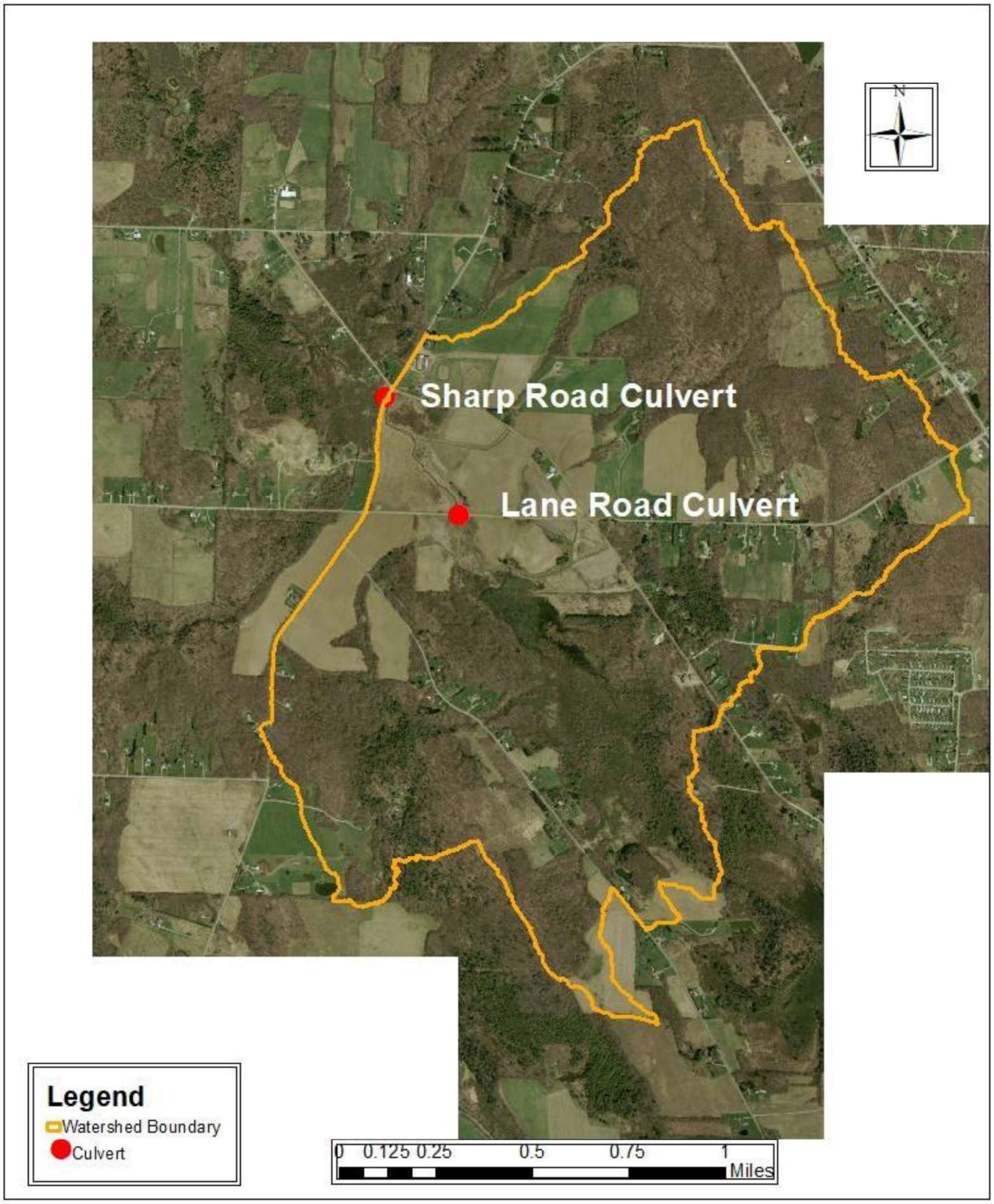
c. The AOI (watershed relative to the Sharp Road Culvert inlet) is given in Fig. 2. The watershed covers an extent of roughly 10,000 ft (southwest to northeast axis) by 6,000 ft (northeast to southwest axis) with a total area of 2.13 mi^2. Elevations within the watershed range from 1216.4 ft to 1516.9 ft (generally highest along the northeast boundary) with an average of 1319.8 ft. Slopes range from 0.0 to 210.5% with an average slope of 10.1%. The lowest slopes generally correspond to the valley of the Elk Creek, whereas the highest slopes are of a localized extent and primarily associated with steep stream bank slopes in the northeastern portion of the watershed.

d. Land use in the AOI as determined by the NLCD data consisted primarily of deciduous forest (37.2%), cultivated crops (24.9%), pasture/hay (15.1%) and woody wetlands (12.5%). All other identified land uses (developed – open space, developed – low intensity, developed – medium intensity, evergreen forest, mixed forest, shrub/scrub and emergent herbaceous wetlands) accounted for the balance (10.3%) of land uses within the AOI (Fig. 3).

e. Based on SSURGO data, 42.1% of the AOI is classified as having a soil belong to HSG D (highest runoff potential), while HSG A (lowest runoff potential) accounted for 11.5% of the AOI. Roughly 0.2% of the watershed consisted of HSG B soils, whereas no pure HSG C soils were identified. Jointly-classified HSG A/D soils accounted for 15.4% of the AOI, B/D soils made up 12.4% of the AOI, and the balance (18.4%) consisted of HSG C/D soils (Fig. 4).

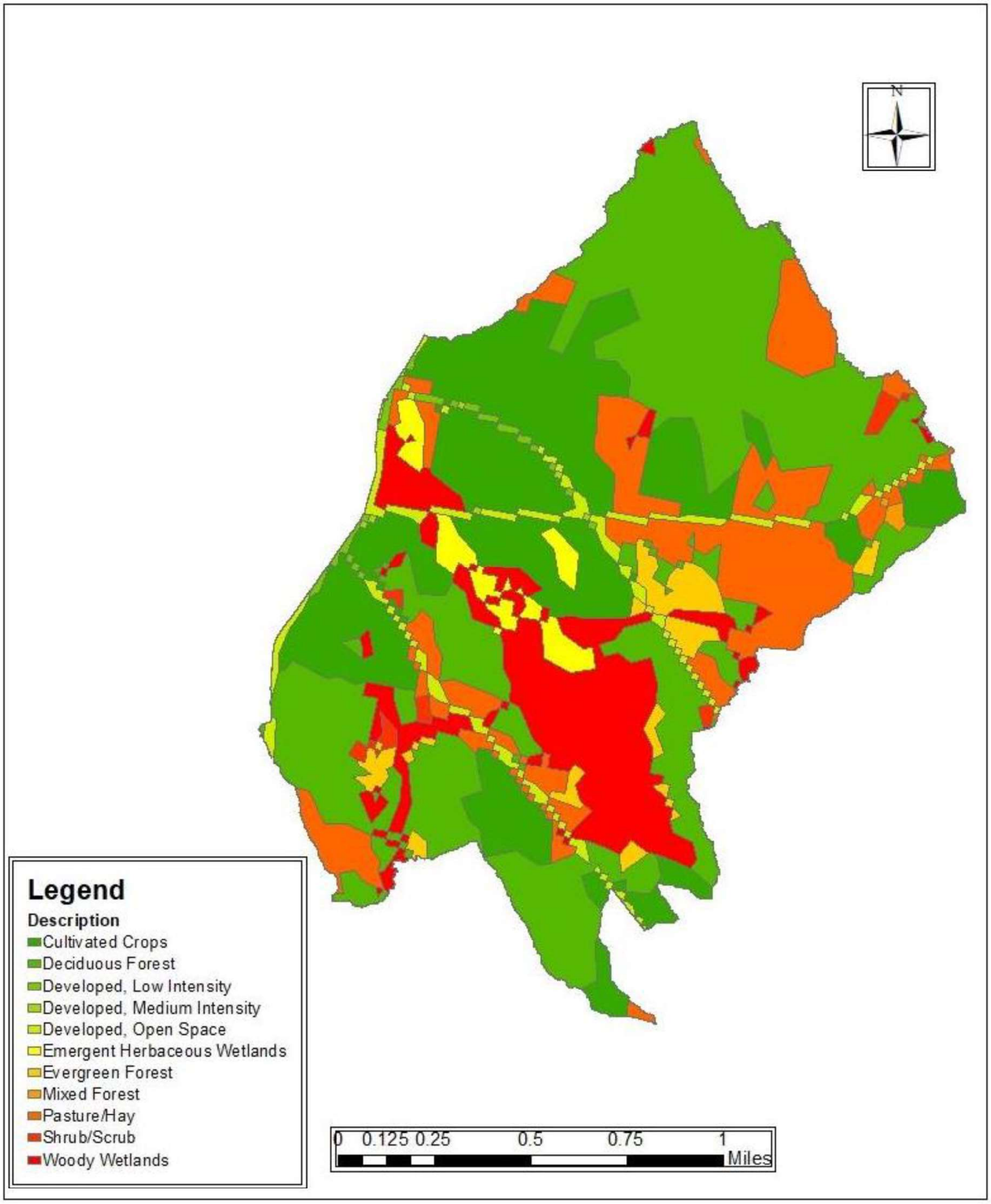
f. The CN layer is given in Fig. 5. The average over the AOI is 77.8, ranging from a low of 36 to a high of 98 along the Elk Creek valley. These CN values reflect average soil moisture conditions as defined by NRCS.

Fig. 2. Area of interest, defined as the watershed relative to the Sharp Road Culvert.



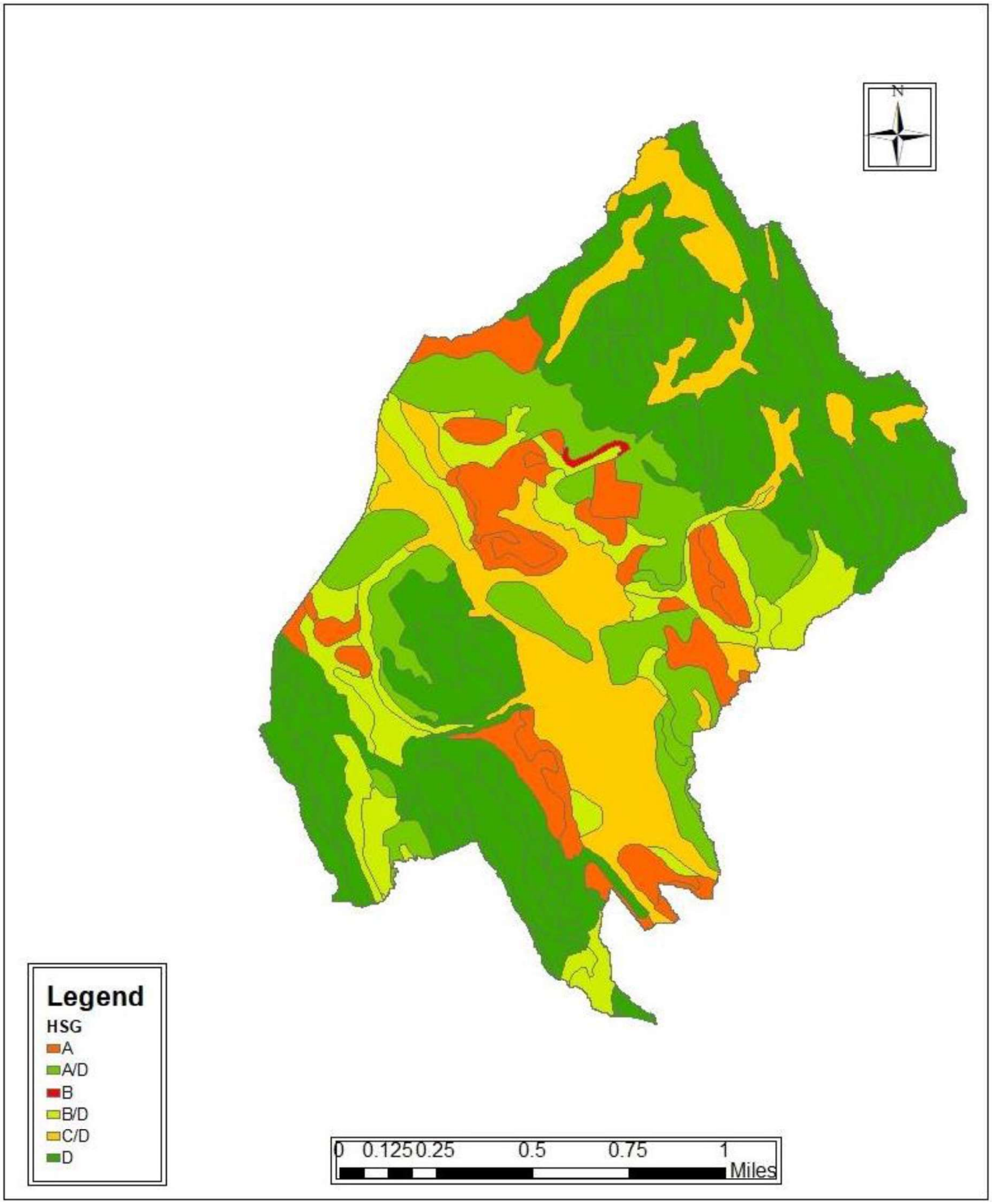
Data sources: (1) 2015 orthoimagery, (2) 2015 DEM.

Fig. 3. Land uses within area of interest.



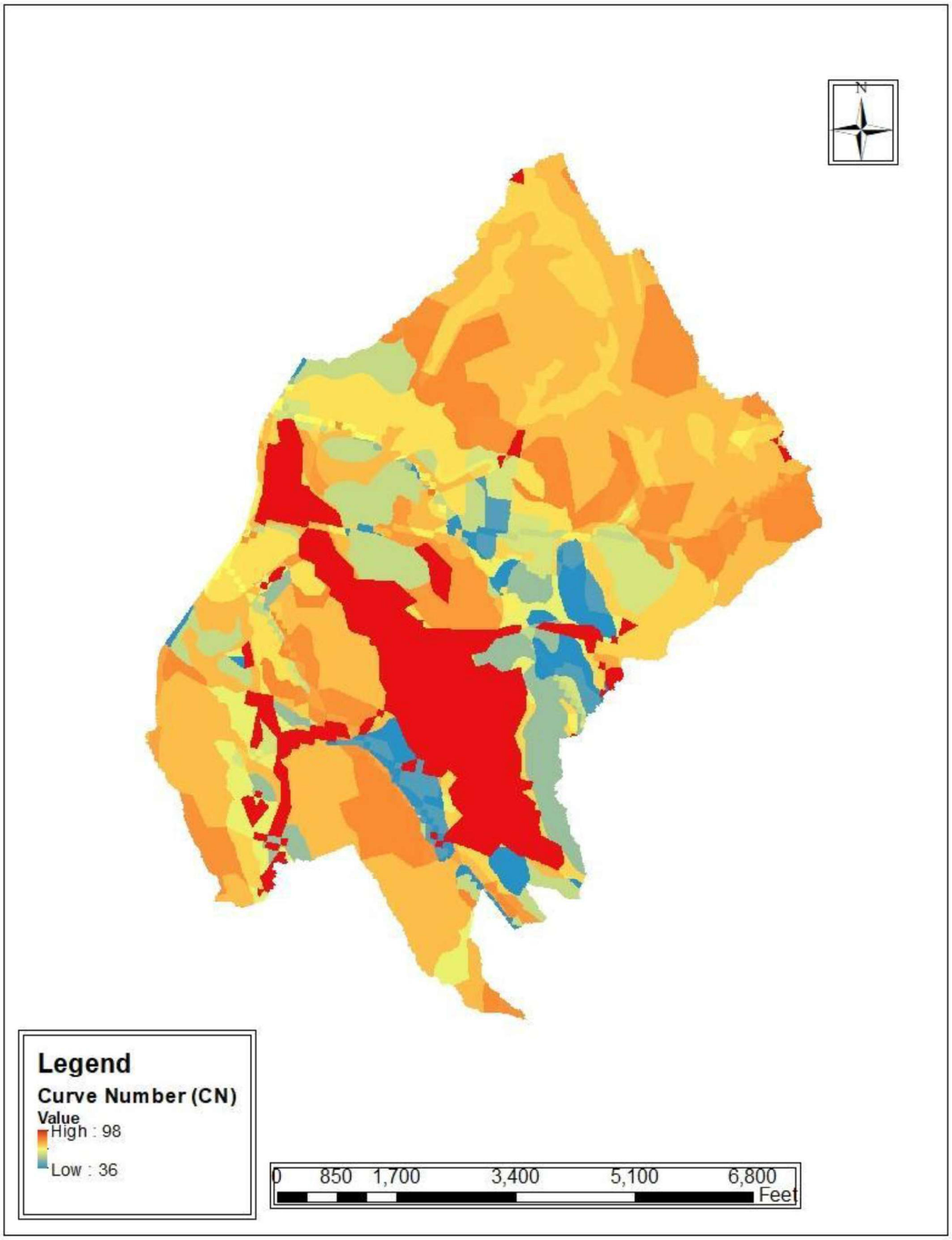
Data sources: (1) 2015 orthoimagery, (2) 2015 DEM, (3) 2011 NLCD.

Fig. 4. Hydrologic soil groups (HSG) within area of interest.



Data sources: (1) 2015 orthoimagery, (2) 2015 DEM, (3) USDA NRCS SSURGO database.

Fig. 5. Curve Number (CN) values within area of interest.

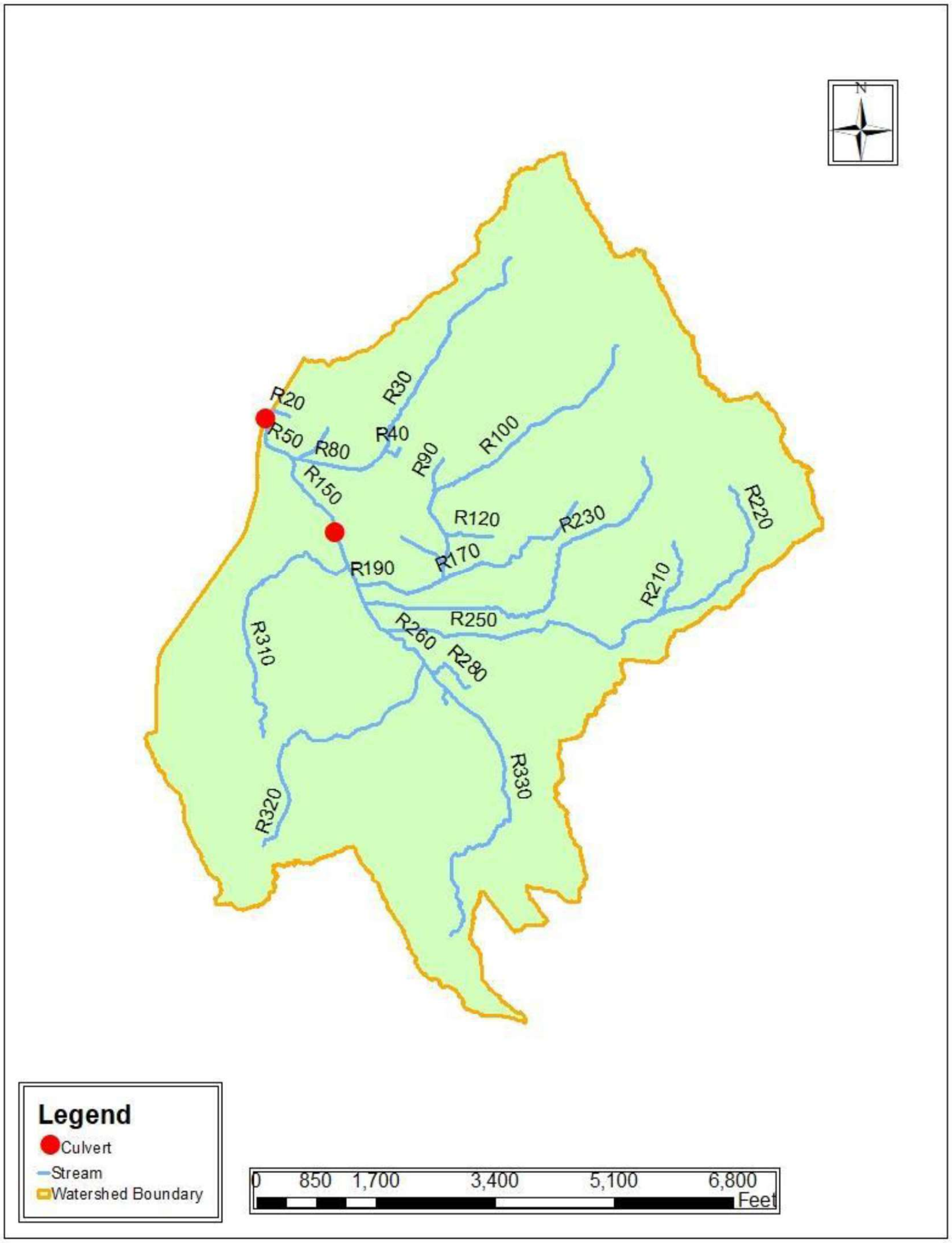


Data sources: (1) 2015 orthoimagery, (2) 2015 DEM, (3) USDA NRCS SSURGO database, (4) 2011 NLCD.

g. The stream layer and subwatersheds identified by HEC-GeoHMS, both labeled according to HEC-GeoHMS convention, are given in Figs. 6 and 7, respectively. Streams were defined as cells draining 1% or more (the HEC-GeoHMS default threshold; can be adjusted to provide the desired level of subwatershed resolution) of the total watershed area. Characteristics of stream reaches (which can include both streams and segments of streams as needed to describe the connectivity of the subwatersheds) identified by HEC-GeoHMS are given in Table 1. Lengths, elevations and bed slopes are based on original DEM data, with the exception that bed slopes calculated as negative (for stream segments R10, R240, R270, R280 and R300, which were calculated as slightly negative) were corrected to zero.[2] Stream segments used to connect subwatersheds required estimates of travel time within the stream segment. For those segments, travel time was calculated as segment distance divided by the sum of celerity and segment velocity. Segment velocities were based on Manning's Equation (the classical industry standard) with channel properties estimated from orthoimagery and Manning's roughness coefficient taken as 0.025 (from best judgment based on October 16-17, 2017 site visit) to reflect a natural streambed composed primarily of silt. Subwatershed characteristics appear in Table 2. Lag values, which are a measure of how quickly subwatershed runoff flows respond to rainfall, are estimated internally within HEC-GeoHMS using industry-standard methods that are based on NRCS guidance; all other parameters (e.g., lengths, areas, slopes, CN values) are derived from previously-discussed data, but disaggregated and averaged over individual subwatersheds.

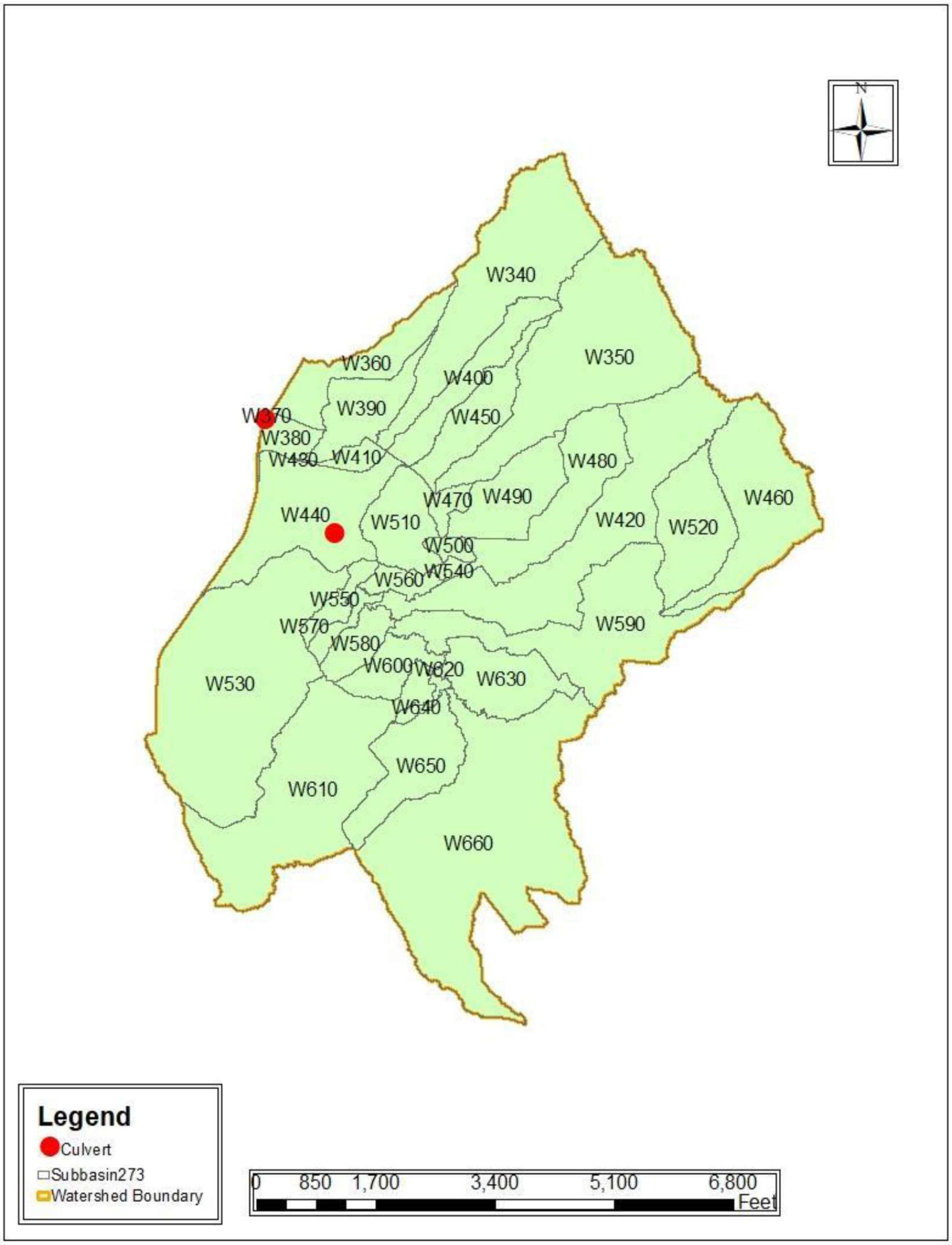
[2] Bed slopes can be identified as negative due to small and random errors in the DEM, relatively flat terrain, short segment lengths, or a combination of these factors. A negative bed slope would indicate that, under steady conditions, the water in the segment is flowing in the opposite direction than indicated on the map. Given that the true overall direction of flow is well-established by other data (e.g., hydrography, orthoimagery), corrections under these circumstances are appropriate.

Fig. 6. Stream layer for area of interest.



Data sources: (1) 2015 orthoimagery, (2) 2015 DEM, (3) 2009 NHD.

Fig. 7. Subwatersheds within area of interest.



Data sources: (1) 2015 orthoimagery, (2) 2015 DEM, (3) 2009 NHD.

Table 1. Characteristics of stream reaches in the area of interest.

Label	Length (ft)	Upstream Elevation (ft)	Downstream Elevation (ft)	Slope	Travel Time[3] (minutes)
R10[4]	5	1217.40	1217.52	0.0000	0.0
R20	441	1221.61	1217.40	0.0095	
R30	3785	1422.30	1249.25	0.0457	
R40	338	1254.33	1249.25	0.0151	
R50[4]	814	1217.61	1217.40	0.0003	1.4
R60	126	1218.58	1217.61	0.0077	0.2
R70	674	1232.46	1218.58	0.0206	
R80	1459	1249.25	1218.58	0.0210	1.0
R90	570	1262.62	1241.20	0.0375	
R100	3782	1433.76	1241.20	0.0509	
R110	736	1241.20	1230.46	0.0146	0.6
R120	752	1255.80	1230.46	0.0337	
R130	769	1229.56	1223.43	0.0080	
R140	449	1230.46	1223.43	0.0157	0.4
R150[4]	1950	1217.61	1217.61	0.0000	3.3
R160	265	1223.43	1221.96	0.0055	0.5
R170	2678	1305.72	1221.96	0.0313	
R180[4]	326	1218.93	1217.61	0.0040	0.6
R190	1388	1221.96	1218.93	0.0022	2.0
R200[4]	302	1224.15	1218.93	0.0173	0.5
R210	1440	1341.28	1291.75	0.0344	
R220	2937	1446.83	1291.75	0.0528	
R230	6227	1386.41	1224.15	0.0261	
R240[4]	557	1224.01	1224.15	0.0000	0.9
R250	4625	1291.75	1224.01	0.0146	6.8
R260[4]	797	1224.58	1224.01	0.0007	1.7
R270[4]	208	1224.23	1224.58	0.0000	0.5
R280	861	1224.08	1224.23	0.0000	
R290[4]	314	1224.59	1224.23	0.0011	0.9
R300	305	1224.12	1224.59	0.0000	
R310	4481	1280.30	1217.61	0.0140	
R320	4679	1308.86	1224.58	0.0180	
R330	5191	1290.02	1224.59	0.0126	

[3] Reaches without travel times are first-order reaches; travel time computations were unnecessary and are incorporated into subwatershed lag values.

[4] Elk Creek main stem.

Table 2. Characteristics of subwatersheds in the area of interest.

Name	Area (mi^2)	Average Slope	Averag e CN	Lag (minutes)
W340	0.14	12.2	78.7	24.7
W350	0.18	12.0	79.2	23.8
W360	0.05	8.0	71.9	27.5
W370	0.00	18.8	79.0	0.2
W380	0.01	6.7	85.0	7.9
W390	0.04	6.9	73.4	23.4
W400	0.04	10.3	79.1	19.6
W410	0.01	7.5	69.6	13.0
W420	0.16	10.1	74.1	38.9
W430	0.00	15.5	98.0	0.5
W440	0.10	4.8	81.8	24.9
W450	0.04	10.0	79.6	17.8
W460	0.10	11.3	80.6	20.3
W470	0.01	6.8	73.2	13.5
W480	0.07	10.9	74.5	23.9
W490	0.05	7.5	69.6	23.7
W500	0.01	6.4	78.5	6.2
W510	0.04	7.0	71.8	17.0
W520	0.06	12.6	80.1	14.8
W530	0.23	10.6	77.4	30.8
W540	0.00	11.3	97.7	1.5
W550	0.01	11.7	81.5	8.3
W560	0.01	11.1	76.0	9.5
W570	0.01	12.0	87.4	6.3
W580	0.02	12.2	86.7	7.3
W590	0.13	6.9	71.3	42.6
W600	0.03	9.8	91.7	7.9
W610	0.17	12.1	81.2	23.6
W620	0.00	3.4	98.0	1.5
W630	0.05	7.1	82.6	20.7
W640	0.01	6.4	97.4	5.2
W650	0.06	9.3	78.9	19.9
W660	0.28	10.9	77.6	31.3

13. ***Special Model Elements:***

a. Beaver Dams. Orthoimagery indicated the presence of beaver dams along Elk Creek south of Lane Road. The dams and their impacts on upstream water surface elevations ("WSE") are indicated in Fig. 8, in which the orthoimagery was created roughly 12 years ago. Historical orthoimagery indicates that the dams have not been continuously present, but rather that one or more have been removed on occasion. Present orthoimagery and my site visit on October 16-17, 2017, however, indicate the presence of two major dams (dams that raise the upstream WSE by approximately 3 ft each) as indicated in Fig. 8, as well as at least two minor dams (that increase upstream WSE by approximately 1 ft; not shown).

i. The effects of the major dams on downstream flooding were accounted for by adding reservoir elements to HEC-HMS to reflect the dams' connectivity to other elements, their WSE vs. discharge characteristics, and their WSE vs. storage characteristics. This is the method by which HEC-HMS represents confined (by dams, embankments, topography or other methods) regions that attenuate inflows by physically restricting outflows.

ii. The smaller of the two dams impounds water at an elevation of approximately 1221.5 ft (as determined from DEM). At greater WSE, water exits the impounded area across the dam and the connected terrain at the same elevation, at which point the dam and connected terrain function as a weir crest having measured crest length of approximately 320 ft. Required elevation-storage-discharge information were derived using these data along with the broad-crested weir equation and ArcMap's Surface Volume tool (the classical, industry-standard method). The process of deriving required information was the same for the larger of the two dams, which was found to impound water at an elevation of approximately 1224.5 ft, above which the dam and connected terrain function as a weir crest having total length of approximately 400 ft. Elevation vs. discharge and elevation vs. storage curves for the two dams are given in Figs. 9 and 10, respectively and were used in HEC-HMS to parameterize these two elements.

Fig. 8. Major beaver dam locations.

Dams are situated to the immediate right of corresponding text labels, inside the circles.

Data sources: (1) 2005 orthoimagery.

Fig. 9. Elevation vs. discharge curves for major beaver dams.

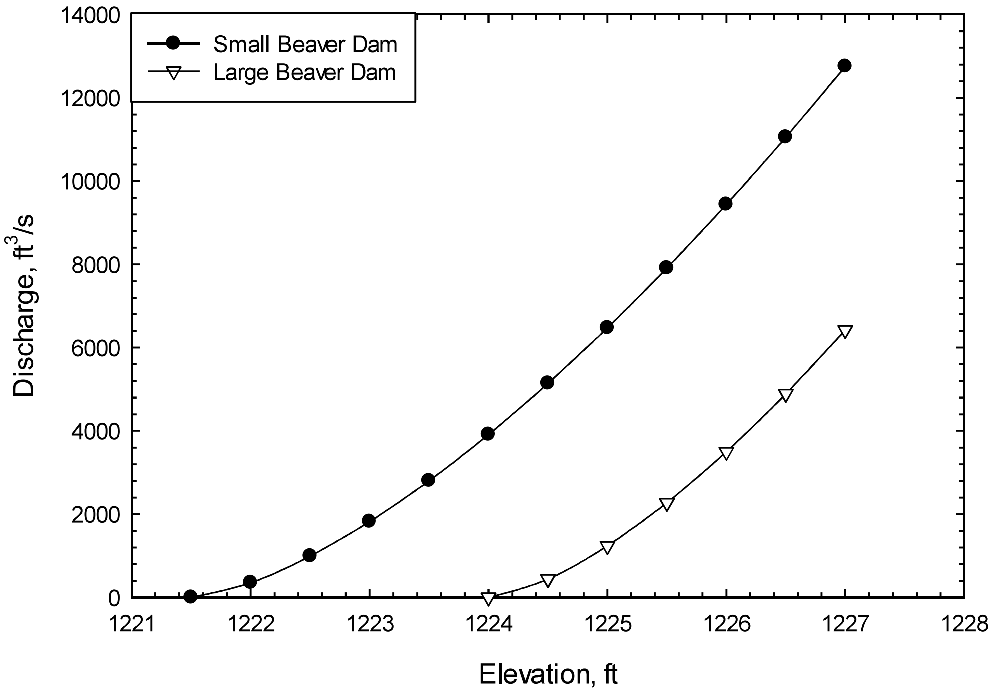
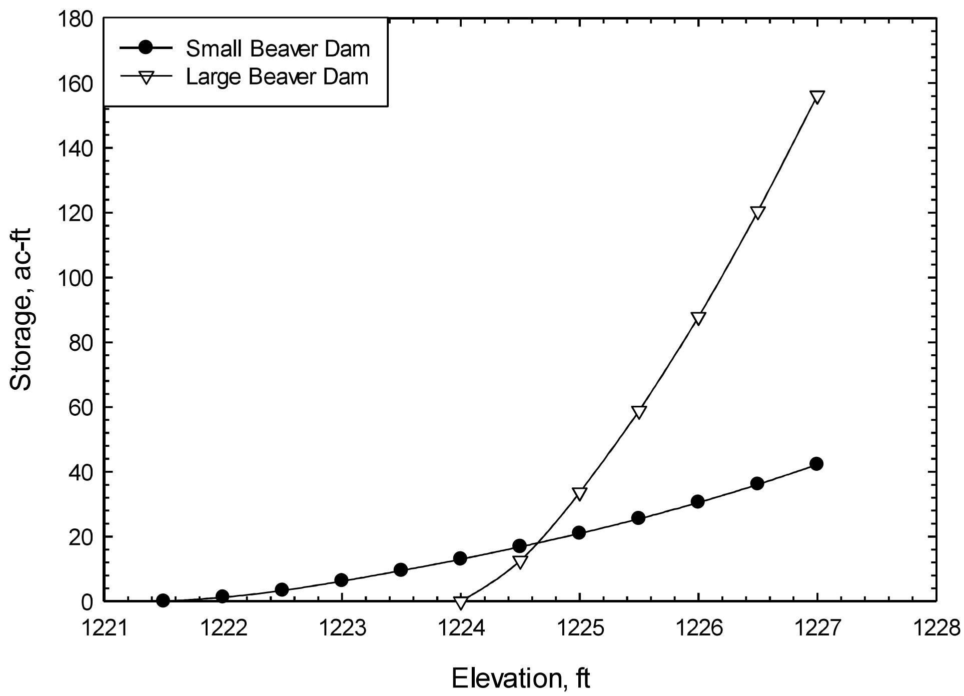


Fig. 10. Elevation vs. storage curves for major beaver dams.



b. Culverts. Reservoir elements representing the Lane Road and Sharp Road Culverts were added to HEC-HMS to assess impacts on flooding because, similar to the beaver dams, they act to restrict flow and impound water upstream. As with the beaver dam elements, HEC-HMS requires elevation vs. discharge and elevation vs. storage information at each culvert inlet location. Elevation vs. storage data were derived as described earlier (using the ArcMap Surface Volume tool in connection with the DEM). Elevation vs. discharge data were generated using the industry standard HY-8, v. 7.5 (most current as of time of report preparation) software application. This application was developed by the Federal Highway Administration, US Department of Transportation, and is available at https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/

i. Culvert data required by HY-8 were collected during the 16-17 October 2017 site visit and are as indicated below in Table 3. The span and rise used for the Sharp Road Culvert were the nearest standard match to on-site measurements (115 and 69 inches, respectively), which were affected by the presence of concrete paving at the bottom of the culvert. Manning's n values represent best professional judgment given the culvert materials (aged metal for Lane Road, corrugated metal for Sharp Road). Inlet configurations as given are best matches, in professional judgment, to non-standard on-site conditions.

Table 3. Evaluated culvert properties.

	Lane Road	Sharp Road
Shape	Circular	Pipe Arch
Diameter (ft)	6	---
Span (in)	N/A	117
Rise (in)	N/A	79
Manning's n	0.016	0.028
Inlet Configuration	Square Edge With Headwall	Mitered
Inlet elevation	1215.94	1217.3
Outlet Elevation	1215.60	1217.3

ii. HY-8 requires roadway data (distance vs. elevation profile, roadway top width, weir coefficient) to calculate overtopping discharges during high flow conditions. Roadway profile data were taken from the DEM using ArcMap's Interpolate Line tool. The weir coefficient was based on a paved crest for the Sharp Road Culvert and a gravel crest for the Lane

Road Culvert. Roadway top widths were estimated from orthoimagery using ArcMap's linear measurement tool (25 ft for Lane Road and 22 ft for Sharp Road).

iii. HY-8 additionally requires information on the downstream channel to account for any outlet limitations on culvert discharge. Channel cross-sections for both downstream channels were determined using ArcMap's Interpolate Line tool with the DEM. For the Lane Road Culvert, the downstream channel slope was estimated as 0.001. The in-channel Manning's n was estimated as 0.025, and the out-of-bank Manning's n was estimated as 0.045 (based on best judgment following October 16-17, 2017 site visit). For the Sharp Road Culvert, the downstream channel slope was estimated as 0.0024. Manning's n was estimated as 0.03 in the channel, and the out-of-bank Manning's n was estimated as 0.045 based on best judgment following the October 16-17, 2017 site visit. Elevation vs. discharge curves for both downstream channels were developed using the sum of segments approach in HY-8 and are given in Fig. 11. The curves are of a very similar nature, having an apparent horizontal offset due to the Sharp Road Culvert downstream channel being situated at a lower elevation than the Lane Road Culvert downstream channel.

iv. It should be noted that the inlet to the Sharp Road Culvert is higher (approximately 1.7 ft) than the outlet of the Lane Road Culvert. This can create a backwater condition that extends upstream for 2500 ft or more and decreases the discharge capacity of the Lane Road Culvert. This potential backwater condition was incorporated into the analysis by correcting the elevation of the channel bed downstream of Lane Road Culvert to 1217.3 ft in HY-8, the same elevation as the Sharp Road Culvert inlet invert.

v. The resulting elevation vs. discharge and elevation vs. storage curves for the two culverts are indicated in Figs. 12 and 13, respectively, and were used in HEC-HMS to parameterize the reservoir elements. The rating curves for the culverts are again very similar in nature; the horizontal offset is due to flow overtopping Sharp Road (minimum crest elevation is 1222.09 ft) before Lane Road (minimum crest elevation is 1222.75 ft).

c. <u>Split Subwatershed</u>. It was noted that, as a result of the automatic subwatershed delineation procedures in HEC-GeoHMS, the entirety of one of the subwatersheds (W440) was routed downstream of the Lane Road Culvert when, in reality, an approximately 20-ac portion of this subwatershed (as measured within ArcGIS) drains through the Lane Road Culvert. This situation was corrected by manually subdividing W440 to create a new subwatershed element

(W440A), having the same slope and CN value as W440 but one-third the area and lag, and directing it to drain through the Lane Road Culvert in HEC-HMS. The area and lag of the original subwatershed W440 were adjusted downward to two-thirds of the respective original values.

Fig. 11. Elevation vs. discharge curves for the Lane Road Culvert and Sharp Road Culvert downstream channels.

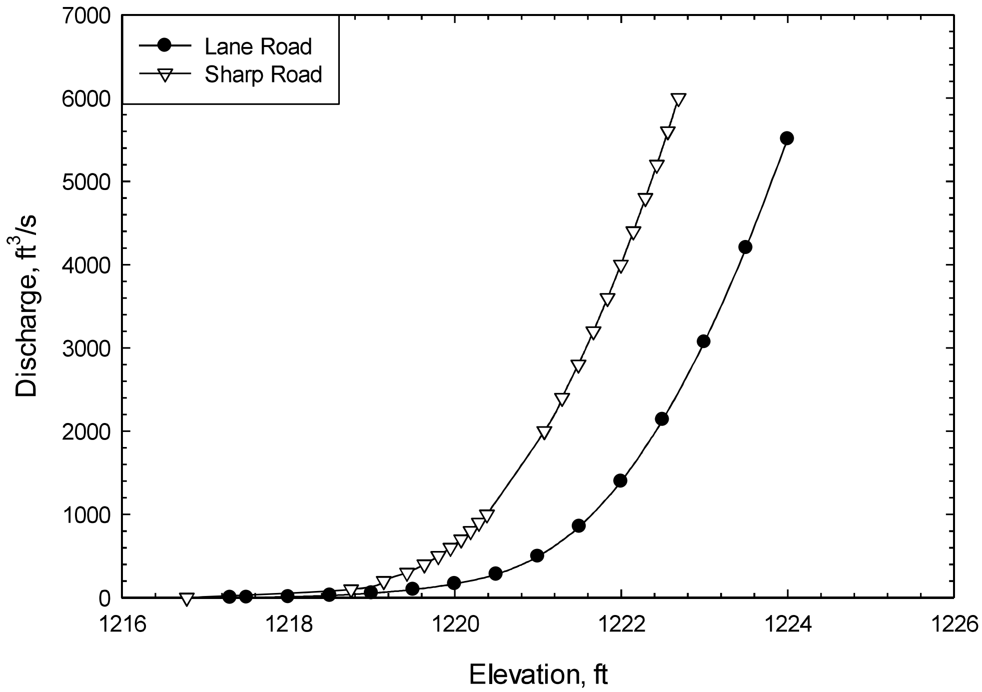


Fig. 12. Elevation vs. discharge curves for the Lane Road Culvert and Sharp Road Culvert.

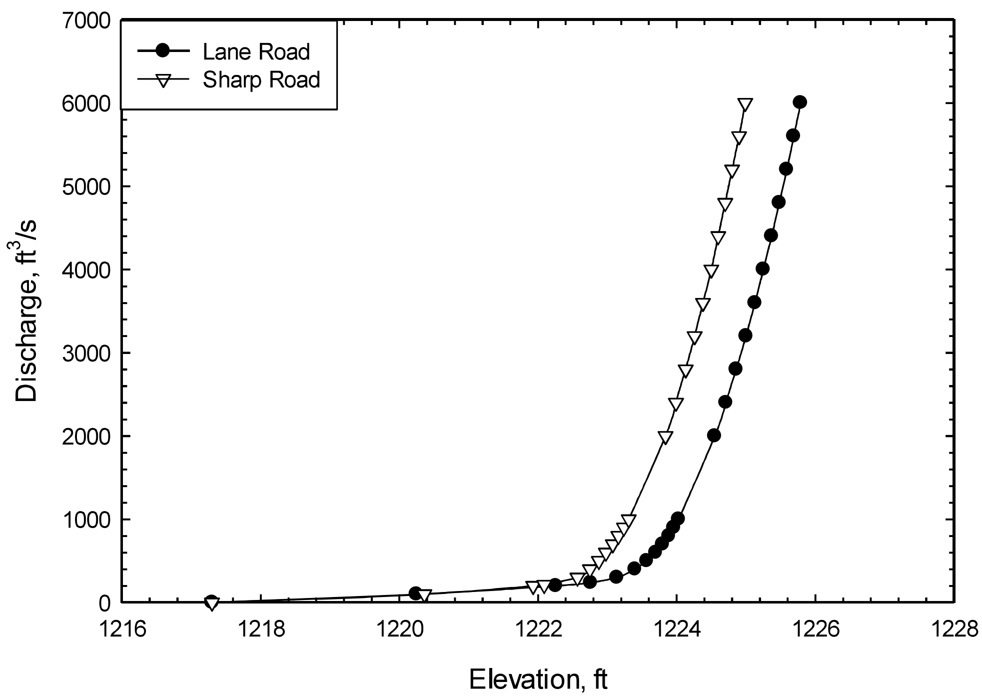
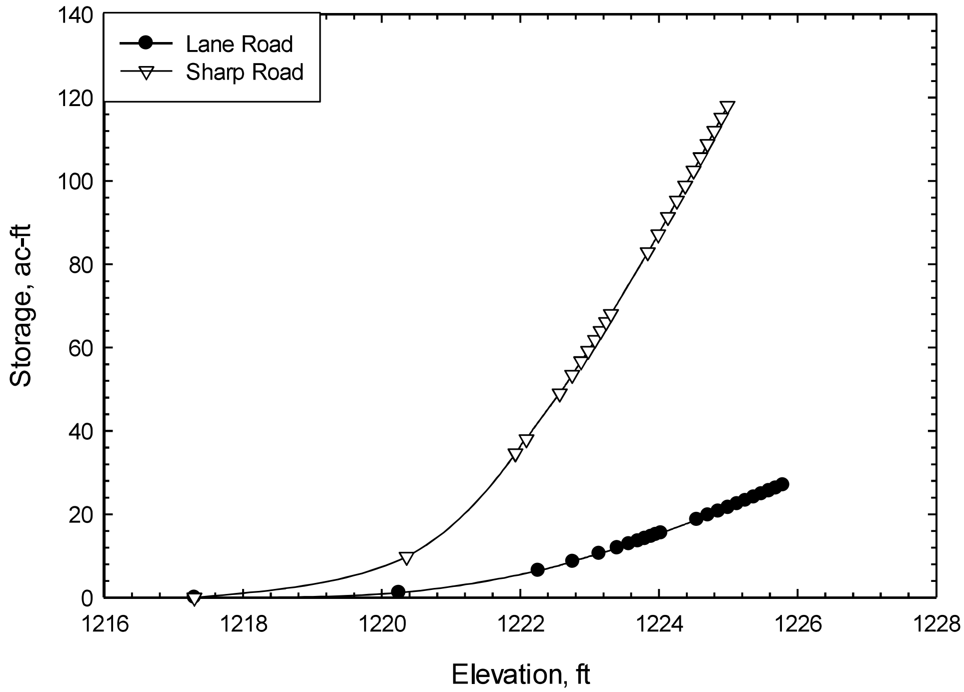


Fig. 13. Elevation vs. storage curves for the Lane Road Culvert and Sharp Road Culvert.



C. Consent Decree Area

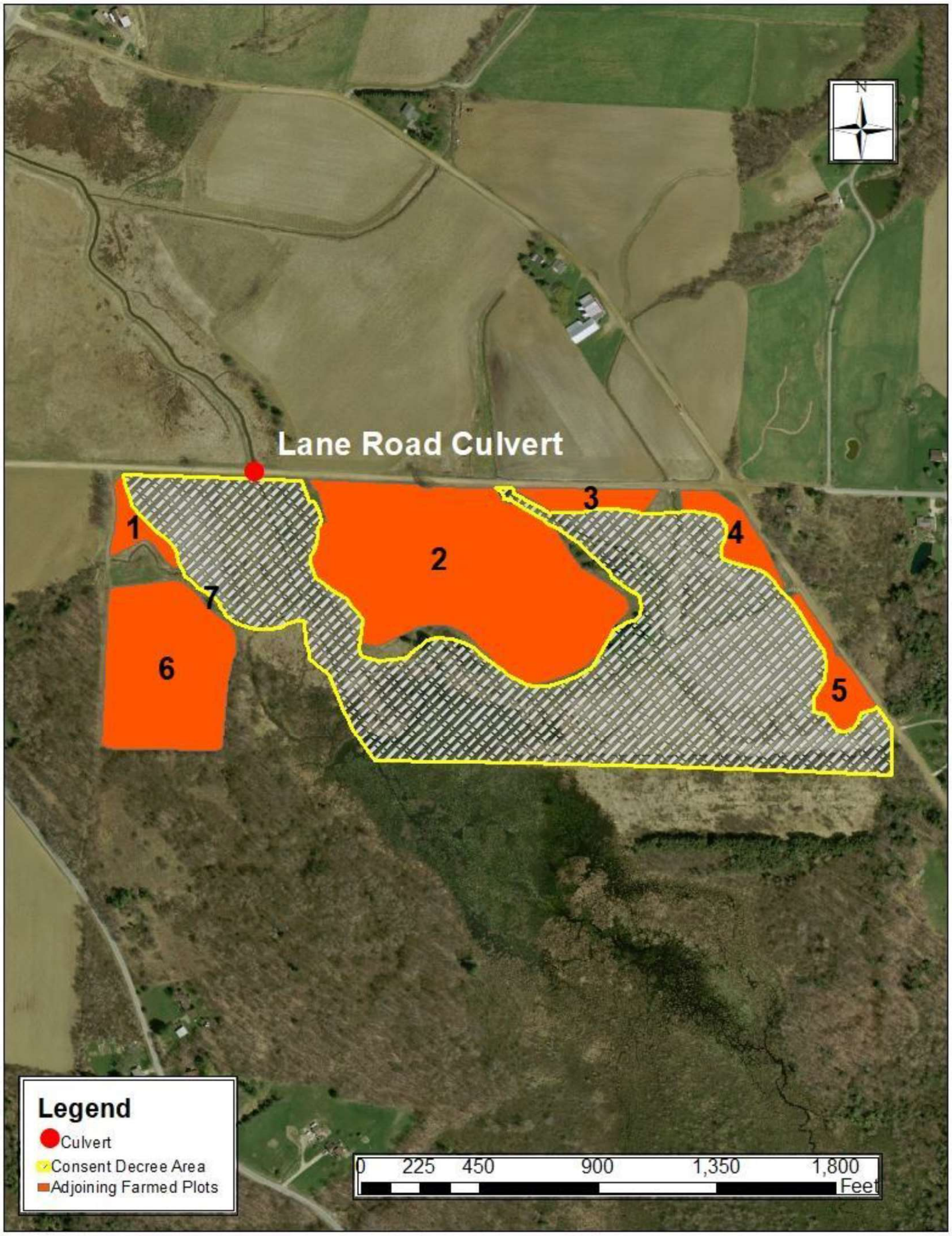
14. Characteristics of the CDA and immediately surrounding land were not used as direct inputs to HEC-HMS. However, given that this region is the context of the study, some of its relevant attributes are described.

15. As was apparent from Fig. 1, the CDA is an irregular “U-shaped” area enclosing approximately 33.9 acres as measured within ArcGIS. Elevations within the CDA range from 1216.77 ft to 1238.77 ft, averaging 1225.71 ft, with the lowest elevations near the Lane Road Culvert inlet and the highest along the eastern edge of the CDA. The CDA is surrounded by seven adjoining plots (each continuous but separated from the others by streams) that, based on interpretation of 2015 orthoimagery, have been used for farming at some point in the past. These adjoining plots lie to the west, north and east of the CDA. Characteristics of the adjoining plots are given in Table 4. As indicated, flood waters begin to encroach on the adjoining plots at a WSE of 1223.08 ft (i.e., when water is overtopping Lane Road by approximately 1.3 ft at its lowest point).

Table 4. Characteristics of plots adjoining the Consent Decree Area

Plot	Area (ac)	Minimum Elevation (ft)	Maximum Elevation (ft)	Average Elevation (ft)
1	0.74	1223.62	1235.38	1229.61
2	13.67	1224.68	1253.43	1239.14
3	0.89	1226.35	1235.22	1231.45
4	1.08	1229.02	1236.97	1233.06
5	1.18	1228.65	1242.49	1236.26
6	6.49	1223.08	1276.53	1243.93
7	0.01	1223.50	1224.06	1223.79
Total	24.1			

Fig. 14. Upland plots adjoining the Consent Decree Area.



Data sources: (1) 2015 orthoimagery, (2) Client-provided documents.

D. Rainfall Data

16. Rainfall data to be input to HEC-HMS were selected to represent a range of average frequencies, ranging from a 2-year return period (equaled or exceeded every other year, on average) to a 1000-year return period (equaled or exceeded once in a thousand years, on average). These data were obtained from the Precipitation Frequency Data Server (https://hdsc.nws.noaa.gov/hdsc/pfds/), hosted by the Hydrometeorological Design Studies Center, National Weather Service, National Oceanic and Atmospheric Administration. The location was set to the Lane Road Culvert, and the rainfall duration was taken as 24 hours in each case, consistent with common engineering design practice. The method of analysis option within the Precipitation Frequency Data Server (time series type) was selected as annual maximum. The annual maximum series analysis is common for locations having substantial record lengths, as is the case for the nearby Erie weather station (75 years of rainfall data). Analyses based on annual maximum series and the alternative partial duration series are generally very similar for return periods of greater than 20 years. The rainfall depths are as given in Table 5 below.

Table 5. Rainfall depths at selected return periods for the area of interest.

Return Period (years)	Rainfall Depth (inches)
2	2.36
5	3.10
10	3.63
25	4.37
50	4.97
100	5.62
500	7.32
1000	8.16

E. HEC-HMS Model Calibration

17. No observed data for Elk Creek were available to calibrate HEC-HMS model parameters, which is ideally done to produce an acceptable match between model predictions and observations. Therefore, as is common when no site-specific observations are available, independent estimates of peak flow rates were derived using the methods and data of Roland and Stuckey (2008) and the characteristics of the AOI as previously reported and compared to HEC-HMS predictions of peak flows entering the Sharp Road Culvert. For the calibration process, the HEC-HMS model of the AOI did not include the two culverts or beaver dams since (a) stream gaging stations as used in the Roland and Stuckey (2008) study are normally not situated upstream of culverts due to their mitigating influence on peak flows, and (b) as discussed earlier, the beaver dams have not been continuously present in the AOI. Neglecting the beaver dams for this portion of the work has the additional effect of producing conservative (higher than would be expected in reality) calibrated HEC-HMS peak flow estimates, since the presence of beaver dams generally reduces downstream peak flows.

18. The CN model parameter in the HEC-HMS model was calibrated by varying each subwatershed's CN by a fixed proportion relative to the original CN until peak flow at the Sharp Road Culvert matched as closely as possible to the Roland and Stuckey (2008) estimates of peak flow at the same location. This occured when original CN values were adjusted downward to 0.79 (identified by trial-and-error) of their respective original values.

19. As may be inferred from Table 6, there was no single CN adjustment that produced a perfect fit to the Roland and Stuckey (2008) estimates for the investigated return periods (Roland and Stuckey (2008) estimates were not available for the 1000-year return period). The CN calibration factor of 0.79 was evaluated as acceptable in this context because it (a) produced HEC-HMS peak flow estimates that varied from Roland and Stuckey (2008) estimates by 17% or less for return periods of 5-10 years and (b) HEC-HMS peak flow estimates for the larger, rarer storms will be even more conservative. HEC-HMS underestimation of peak flows at the 2-year return period is proportionately substantial but will prove to have little, if any, bearing on the major findings of this report. Table 7 indicates calibrated CN values and updated lag values for each of the subwatersheds.

Table 6. Peak flows at the Sharp Road Culvert inlet estimated from Roland and Stuckey (2008) methods (Target), HEC-HMS in uncalibrated mode (Uncalibrated) and HEC-HMS after setting CN values to 0.79 of original (Calibrated).

Return Period (years)	Target (ft^3/s)	Uncalibrated (ft^3/s)	Calibrated (ft^3/s)
2	124	531	48
5	213	961	176
10	284	1305	311
50	465	2242	770
100	552	2718	1035
500	789	3997	1813

Table 7. Corrected Curve Number (CN) and lag values from HEC-HMS model calibration.

Name	Area (mi^2)	Average Slope	Average CN	Lag (minutes)
W340	0.14	12.2	62.2	38.9
W350	0.18	12.0	62.6	37.6
W360	0.05	8.0	56.8	40.8
W370	0.00	18.8	62.4	0.3
W380	0.01	6.7	67.2	13.3
W390	0.04	6.9	58.0	35.1
W400	0.04	10.3	62.5	30.9
W410	0.01	7.5	55.0	18.9
W420	0.16	10.1	58.5	58.7
W430	0.00	15.5	77.4	1.1
W440	0.06	4.8	64.7	27.0
W440A	0.03	4.8	64.7	13.5
W450	0.04	10.0	62.9	28.3
W460	0.10	11.3	63.6	32.7
W470	0.01	6.8	57.8	20.2
W480	0.07	10.9	58.8	36.1
W490	0.05	7.5	55.0	34.5
W500	0.01	6.4	62.0	9.7
W510	0.04	7.0	56.7	25.1
W520	0.06	12.6	63.3	23.7
W530	0.23	10.6	61.1	47.8
W540	0.00	11.3	77.2	3.5
W550	0.01	11.7	64.3	13.5
W560	0.01	11.1	60.0	14.5
W570	0.01	12.0	69.1	11.1
W580	0.02	12.2	68.5	12.7
W590	0.13	6.9	56.4	62.8
W600	0.03	9.8	72.4	15.1
W610	0.17	12.1	64.1	38.1
W620	0.00	3.4	77.4	3.4
W630	0.05	7.1	65.3	34.0
W640	0.01	6.4	77.0	11.7
W650	0.06	9.3	62.3	31.4
W660	0.28	10.9	61.3	48.8

F. Modeling Scenarios

20. To obtain results that would enable conclusions for a variety of conditions, the following scenarios were modeled using HEC-HMS and the data described previously. The order of the scenarios increases in anticipated inundated area due to floodwater detention upstream of the Lane Road Culvert.

21. Scenario 1 ("EcoStrategies" Model).[5]

a. Beaver dams omitted from the model (reflecting their destruction/nonpresence);

b. Initial water surface elevation at the Lane Road Culvert set to 1215.94 ft (inlet invert);

c. Initial water surface elevation at the Sharp Road Culverts set to 1215.60 ft (same as the outlet invert of the Lane Road Culvert, representing a lowering of the Sharp Road culvert by 1.70 ft; in reality, this would require substantial downstream channel modification given existing topography); and,

d. Average soil moisture conditions at the time of rainfall.

22. Scenario 2.

a. Beaver dams omitted from the model (reflecting their destruction/nonpresence);

b. Initial water surface elevations at the Lane Road and Sharp Road Culverts set to 1217.30 ft (representing conditions observed during the site visit of October 16-17, 2017); and,

c. Average soil moisture conditions at the time of rainfall.

23. Scenario 3 ("Current" Circumstances - conditions during October 16-17, 2017 site visit).

a. Beaver dams are present in the model;

b. Initial water surface elevations at the Lane Road and Sharp Road Culverts set to 1217.30 ft; and,

c. Average soil moisture conditions at the time of rainfall.

[5] Defendants Robert Brace and Robert Brace & Sons, Inc., provided the United States with a "Wetland Evaluation Report," dated August 5, 2015, drafted by EcoStrategies Civil Engineering ("EcoStrategies' Report"). *See* EPA0001238-1242. The EcoStrategies Report suggests that Defendants' alleged hydrologic issues would be alleviated if beaver dams were removed and the Sharp Road Culvert lowered. *See* EPA0001239-1240.

24. Scenario 4.

a. Beaver dams are present in the model;

b. Initial water surface elevations at Lane Road and Sharp Road Culverts set to 1218.5 ft with a corresponding flow rate of 40 ft^3/s to model Elk Creek at bankfull condition as determined from DEM; and,

c. Average soil moisture conditions at the time of rainfall

25. Scenario 5.

a. Beaver dams are present in the model;

b. Initial water surface elevations at the Lane Road and Sharp Road Culverts set to 1217.30 ft (representing current conditions);

c. Wetter-than-average soil moisture conditions at the time of rainfall (requiring adjustments to CN and lag values). Based on standard methods of classifying soil moisture condition using (a) the location of the AOI, (b) daily rainfall data for the Erie FAA weather station (KERI) for Jan 1, 1926 to December 21, 2016, (c) an assumed crop of corn, with (d) a growing season of May 1 to October 31, these conditions are estimated to exist approximately 12.9% of the time.

26. Scenario 6 ("Severe" Circumstances).

a. Beaver dams are not present in the model;

b. Initial water surface elevations at Lane Road and Sharp Road Culverts set to 1218.5 ft with a corresponding flow rate of 40 ft^3/s to model Elk Creek at bankfull condition; and,

c. Wetter-than-average soil moisture conditions at the time of rainfall (requiring adjustments to CN and lag values). Based on the location of the AOI and assuming a crop of corn, with a growing season of May 1 to October 31, these conditions are estimated to exist approximately 12.9% of the time.

Differences among the scenarios are represented in Table 8.

Table 8. HEC-HMS modeling scenarios.

Variable	**Scenario**					
	1 "Ecostrategies"	**2**	**3 "Current"**	**4**	**5**	**6 "Severe"**
Beaver Dams	Absent	Absent	Present	Present	Present	Absent
Lane Road Downstream Channel Elevation	1215.6	1217.3	1217.3	1217.3	1217.3	1217.3
Lane Road Upstream Water Surface Elevation	1215.94	1217.3	1217.3	1218.5	1217.3	1218.5
Sharp Road Inlet Invert Elevation	1215.6	1217.3	1217.3	1217.3	1217.3	1217.3
Soil Moisture	Average	Average	Average	Average	Wetter than Average	Wetter than Average

VI. Modeling Results

A. Scenario 1 - "EcoStrategies" Model

27. Results for Scenario 1 are given in Table 9. Based on WSE upstream of the Lane Road Culvert, floodwaters do not begin to exceed the boundaries of the CDA until return periods of 25 years or more. At greater return periods, only very small portions of plots 1, 6 and 7 experience any flooding.

28. Flooded surfaces are demonstrated in Figs. 15-17 for return periods of 10, 100 and 1000 years, respectively. As indicated in Table 10, however, flooded areas within the adjoining plots are very small (a maximum of only 0.03 ac at the 1000-year return period) with maximum depths of 1.41 ft. Table 10 also indicates flooded durations, or the time during which any portion of any of the adjoining plots experiences any flooding. Flooded durations range from zero to a maximum of 3.25 hours

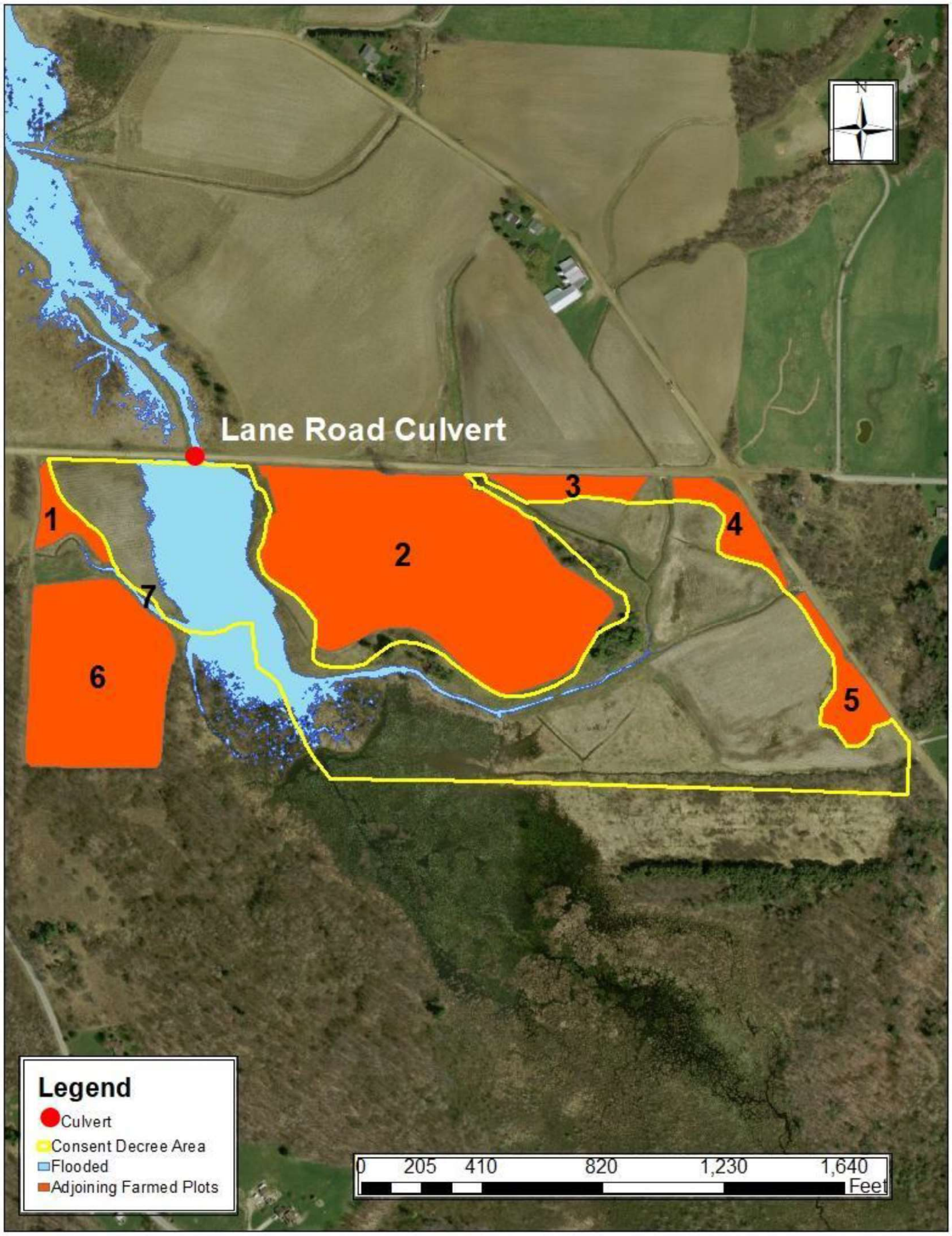
Table 9. Simulation results for Scenario 1 (beaver dams absent, Sharp Road Culvert inlet invert lowered to 1215.90 ft). Data are peak culvert discharges and maximum upstream water surface elevation (WSE).

Return	Lane Road Culvert		Sharp Road Culvert	
Period (years)	Peak Discharge (ft3/s)	WSE (ft)	Peak Discharge (ft3/s)	WSE (ft)
2	39	1217.4	46	1217.1
5	125	1220.3	128	1219.2
10	201	1222.0	191	1220.1
25	373	1223.3 [1,2]	257	1221.0
50	593	1223.7 [1,2]	322	1221.9
100	835	1223.9 [1,2]	462	1222.6 [2]
500	1475	1224.3 [1,2]	1323	1223.4 [2]
1000	1814	1224.5 [1,2]	1786	1223.6 [2]

[1] Extends outside Consent Decree Area into at least one adjoining plot.

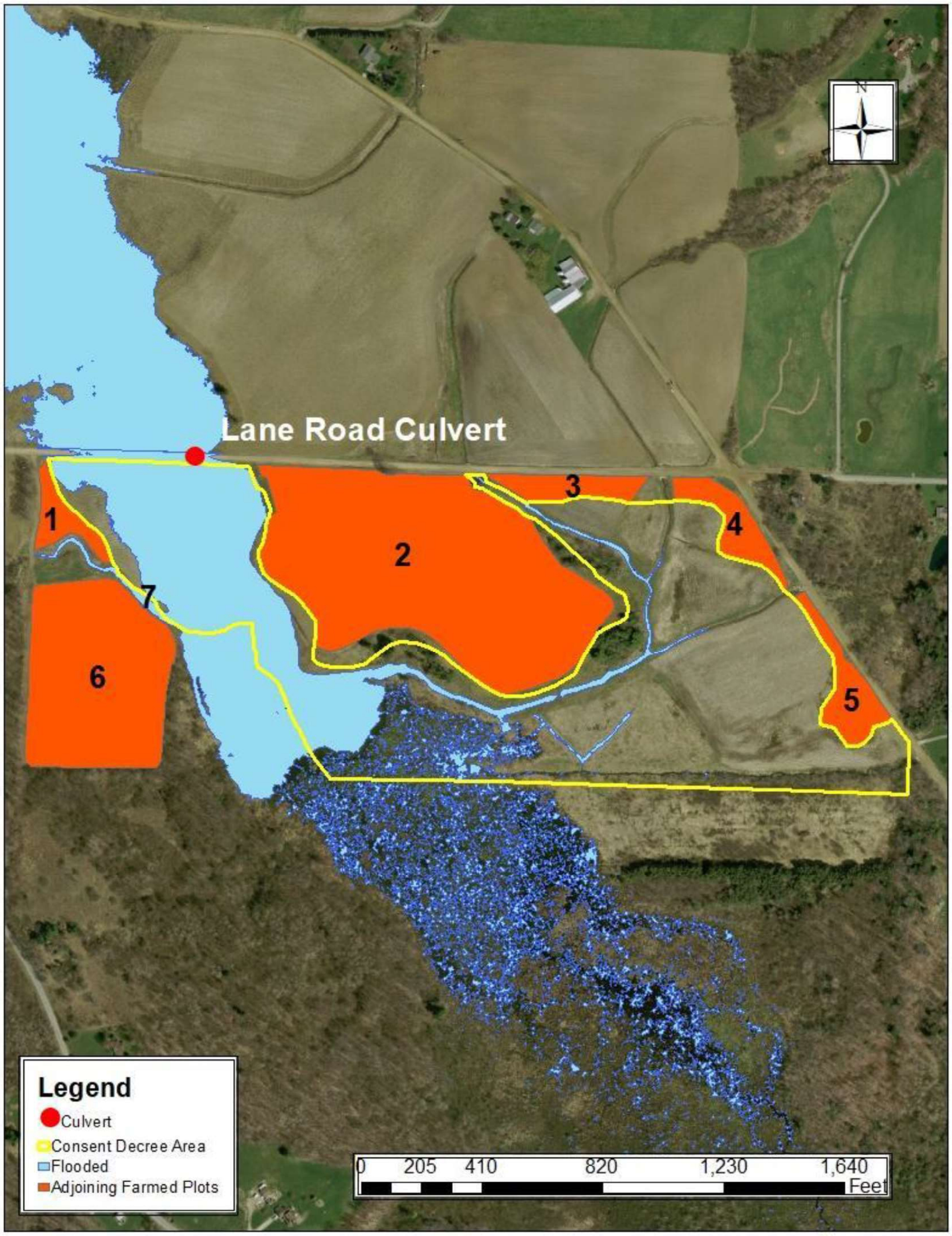
[2] Overtopping roadway

Fig. 15. Scenario 1- Flooded surface for 10-year return period.[6]



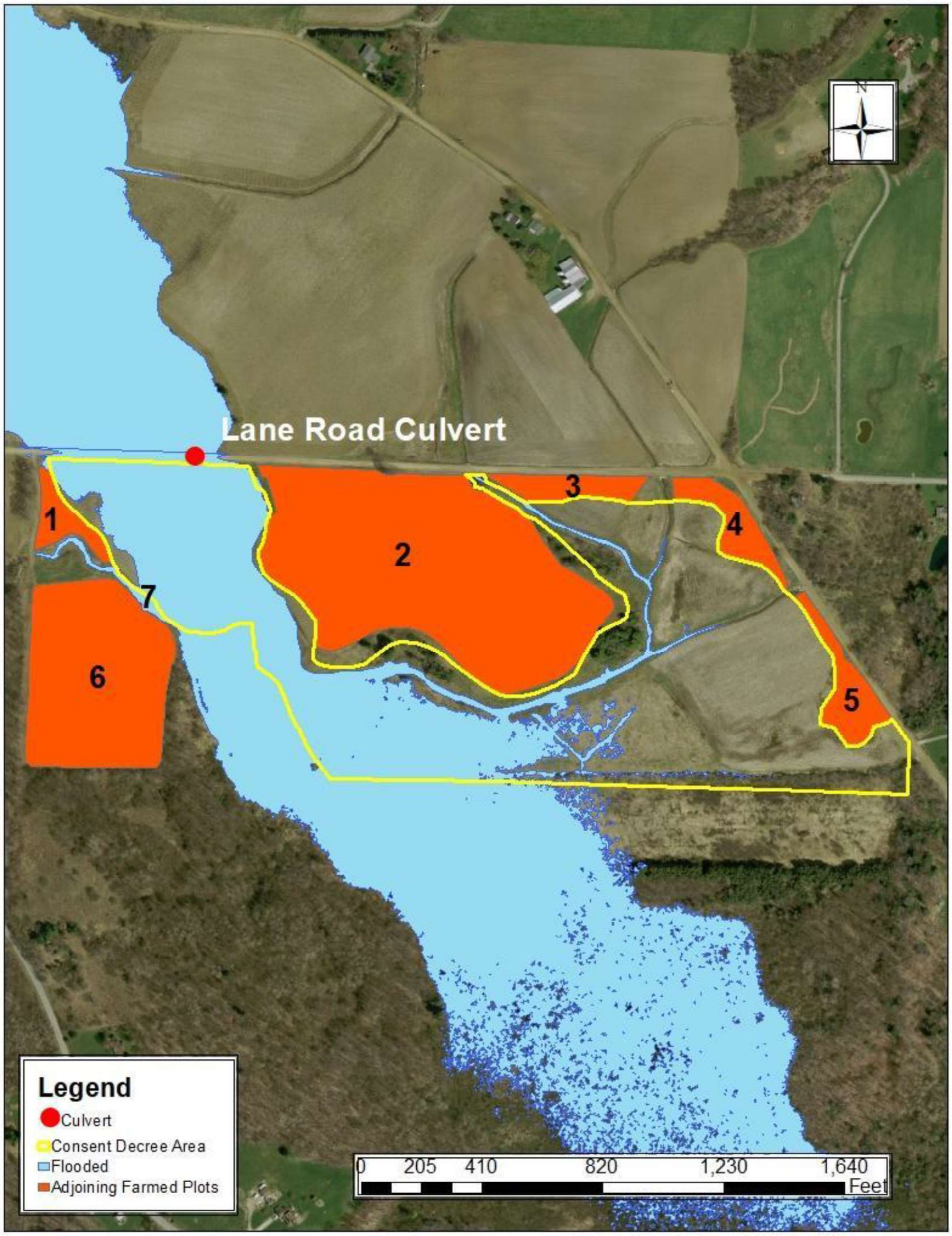
[6] There is no flooding of adjoining plots at this return period.

Fig. 16. Scenario 1 - Flooded surface for 100-year return period.[7]



[7] Small portions of plots 1, 6, and 7, totaling 0.0148 ac (0.0615% of the total adjoining area), experience flooding at this return period.

Fig. 17. Scenario 1 - Flooded surface for 1,000-year return period.[8]



[8] Small portions of plots 1, 6, and 7, totaling 0.0336 ac (0.1394% of the total adjoining area), experience flooding at this return period.

Table 10. Adjoining plot flooding for Scenario 1.

Return Period (years)	Flooded Area (ac)	Fraction of Plot Area %	Average Depth (ft)	Maximum Depth (ft)	Maximum Duration (hours)
10	None	N/A	N/A	N/A	N/A
25	0.0001	0.0006	0.08	0.16	0.75
50	0.0034	0.0141	0.50	0.61	1.42
100	0.0148	0.0615	0.66	0.89	1.92
500	0.0294	0.1220	0.82	1.21	2.75
1000	0.0336	0.1394	0.89	1.41	3.25

B. Scenario 2

29. Results for Scenario 2 are given in Table 11. Identical to Scenario 1, floodwaters are not predicted to extend into the adjoining plots until return periods of 25 years or more (Plots 1, 6 and 7).

30. Flooding for this scenario is illustrated in Figs. 18-20. As indicated in Table 12, flooded areas and depths in the adjoining plots are again small and, for practical purposes, identical to results from Scenario 1. Comparison of results from Scenarios 1 and 2 suggests that lowering the Sharp Road Culvert (again, putting aside feasibility) would have no significant effect on flooding upstream of the Lane Road Culvert.

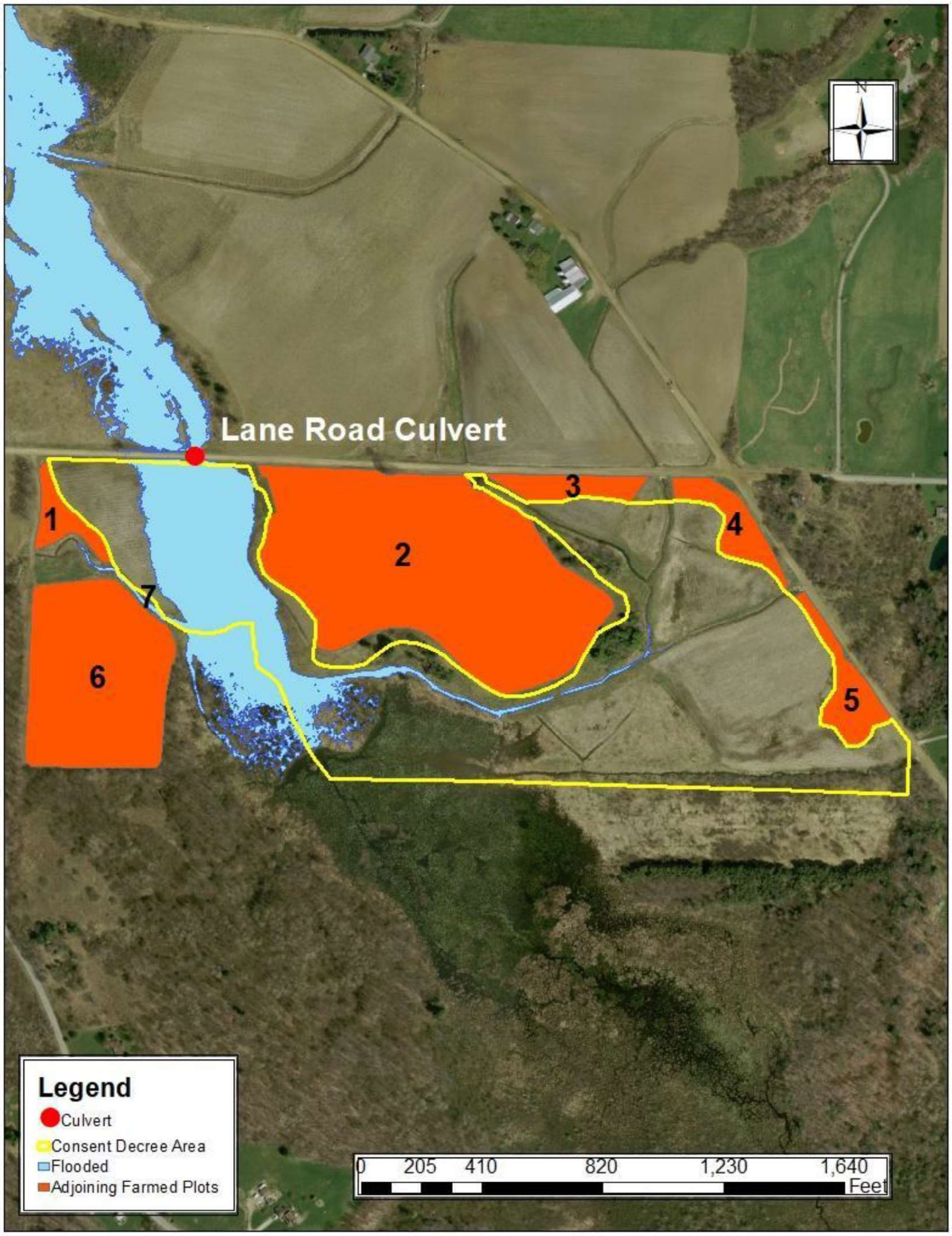
Table 11. Simulation results for Scenario 2 (beaver dams absent, Sharp Road Culvert inlet invert as current). Data are peak culvert discharges and maximum upstream water surface elevation (WSE).

Return	Lane Road Culvert		Sharp Road Culvert	
Period (years)	Peak Discharge (ft^3/s)	WSE (ft)	Peak Discharge (ft^3/s)	WSE (ft)
2	38	1218.4	31	1218.2
5	122	1220.7	100	1220.4
10	195	1222.2	134	1220.9
25	381	1223.3 [1,2]	197	1221.9
50	597	1223.7 [1,2]	283	1222.5 [2]
100	835	1223.9 [1,2]	513	1222.9 [2]
500	1475	1224.3 [1,2]	1380	1223.5 [2]
1000	1814	1224.5 [1,2]	1839	1223.8 [2]

[1] Flooding in at least one adjoining plot.

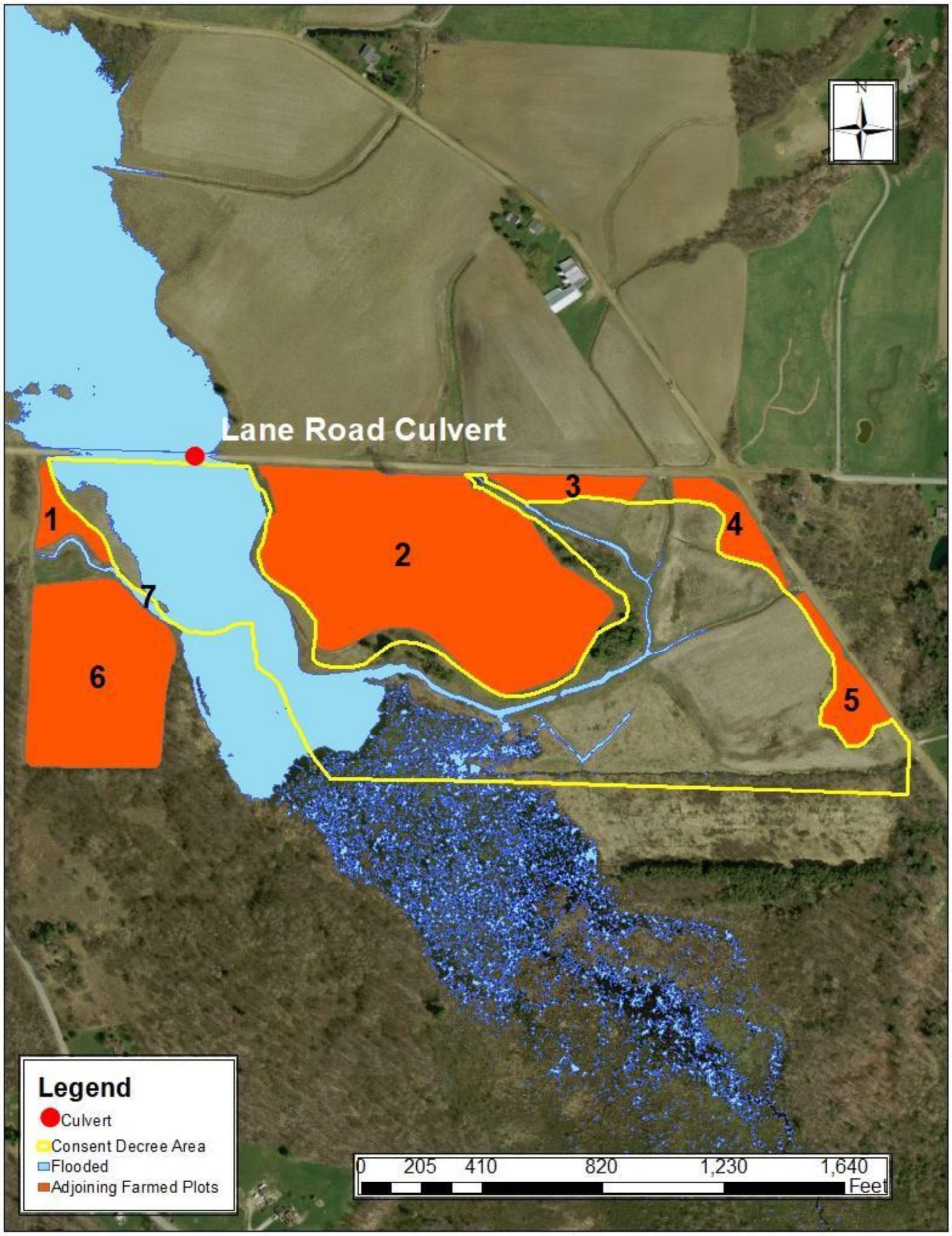
[2] Overtopping roadway

Fig. 18. Scenario 2 - Flooded surface for 10-year return period.[9]



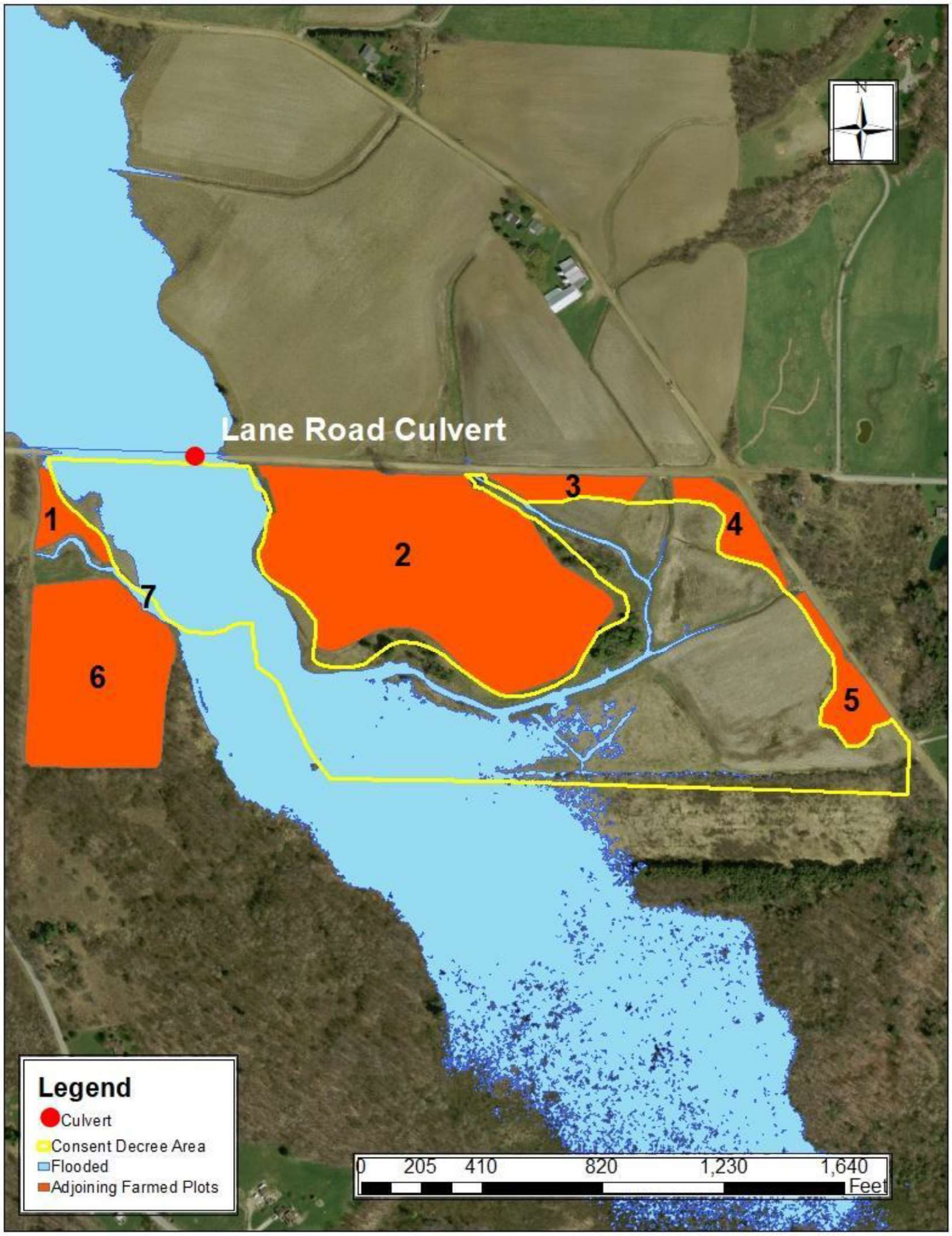
[9] There is no flooding of adjoining plots at this return period.

Fig. 19. Scenario 2 - Flooded surface for 100-year return period.[10]



[10] Small portions of plots 1, 6, and 7, totaling 0.0148 ac (0.0615% of the total adjoining acreage), experience flooding at this return period.

Fig. 20. Scenario 2 - Flooded surface for 1,000-year return period.[11]



[11] Small portions of plots 1, 6, and 7, totaling 0.0336 ac (0.1394% of the total adjoining acreage), experience flooding at this return period.

Table 12. Adjoining plot flooding for Scenario 2.

Return Period (years)	Flooded Area (ac)	Fraction of Plot Area %	Average Depth (ft)	Maximum Depth (ft)	Maximum Duration (hours)
10	None	N/A	N/A	N/A	N/A
25	0.0001	0.0006	0.08	0. 16	0.92
50	0.0034	0.0141	0.50	0.61	1.42
100	0.0148	0.0615	0.66	0.89	1.92
500	0.0294	0.1220	0.82	1.21	2.75
1000	0.0336	0.1394	0.89	1.41	3.25

C. Scenario 3 - "Current" Circumstances

31. Results for Scenario 3, which represent the circumstances that existed during the site visit on October 16-17, 2017, are given in Table 13 with flooded surfaces shown in Figs. 21-23. Measures of flooding in adjoining plots are given in Table 14. This scenario differs from the preceding two in that generally less flooding occurs upstream of the Lane Road Culvert (as evidenced by lower peak discharges and WSE values). This finding is attributed to the presence of the upstream beaver dams, which function to store a portion of incoming flows and release the stored floodwaters more slowly. As with the previous scenarios, small portions of adjoining plots 1, 6 and 7 are predicted to be flooded (but only at return periods of 25 years – at which the flooded area amounts to approximately eight square inches - and more), and there are no large differences in this regard from previous scenarios. Maximum flooded duration is slightly longer (3.42 hours) than for the previous scenarios due to the beaver dam storages.

32. Neither lowering the Sharp Road Culvert nor removing the two major beaver dams reduces flooding upstream of the Lane Road Culvert; in fact, removing the beaver dams is predicted to increase the flooding, as can be seen by comparing flood depths in Table 14 to those in Tables 10 and 12.

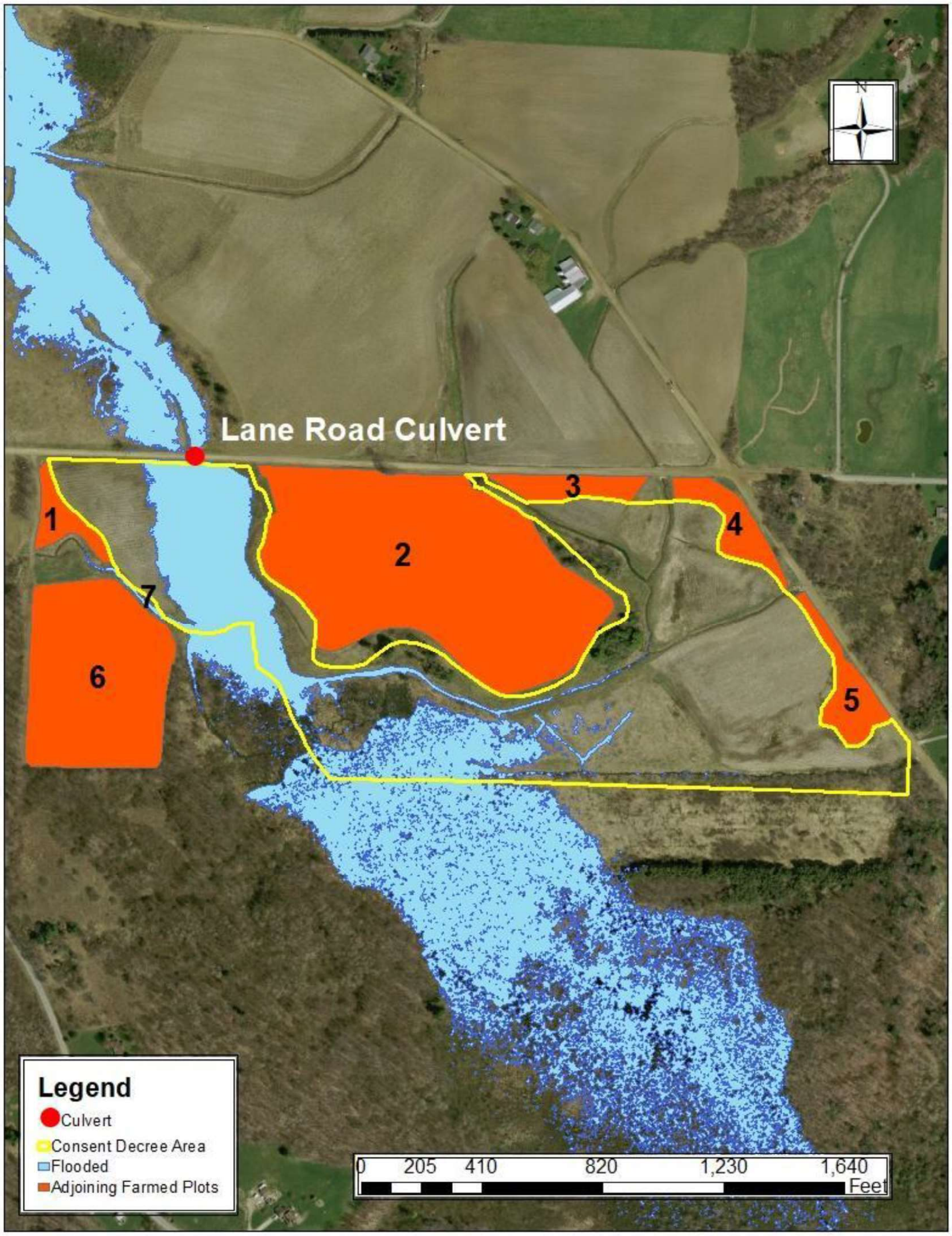
Table 13. Simulation results for Scenario 3 (current conditions; beaver dams present, Sharp Road Culvert inlet invert as current). Data are peak culvert discharges and maximum upstream water surface elevation (WSE).

Return	Lane Road Culvert		Sharp Road Culvert	
Period (years)	Peak Discharge (ft^3/s)	WSE (ft)	Peak Discharge (ft^3/s)	WSE (ft)
2	35	1218.3	30	1218.2
5	113	1220.5	96	1220.2
10	179	1221.8	131	1220.8
25	326	1223.2 [1,2]	192	1221.8
50	509	1223.6 [1,2]	272	1222.4 [2]
100	709	1223.8 [1,2]	471	1222.8 [2]
500	1265	1224.2 [1,2]	1226	1223.4 [2]
1000	1556	1224.3 [1,2]	1624	1223.6 [2]

[1] Flooding in at least one adjoining plot.

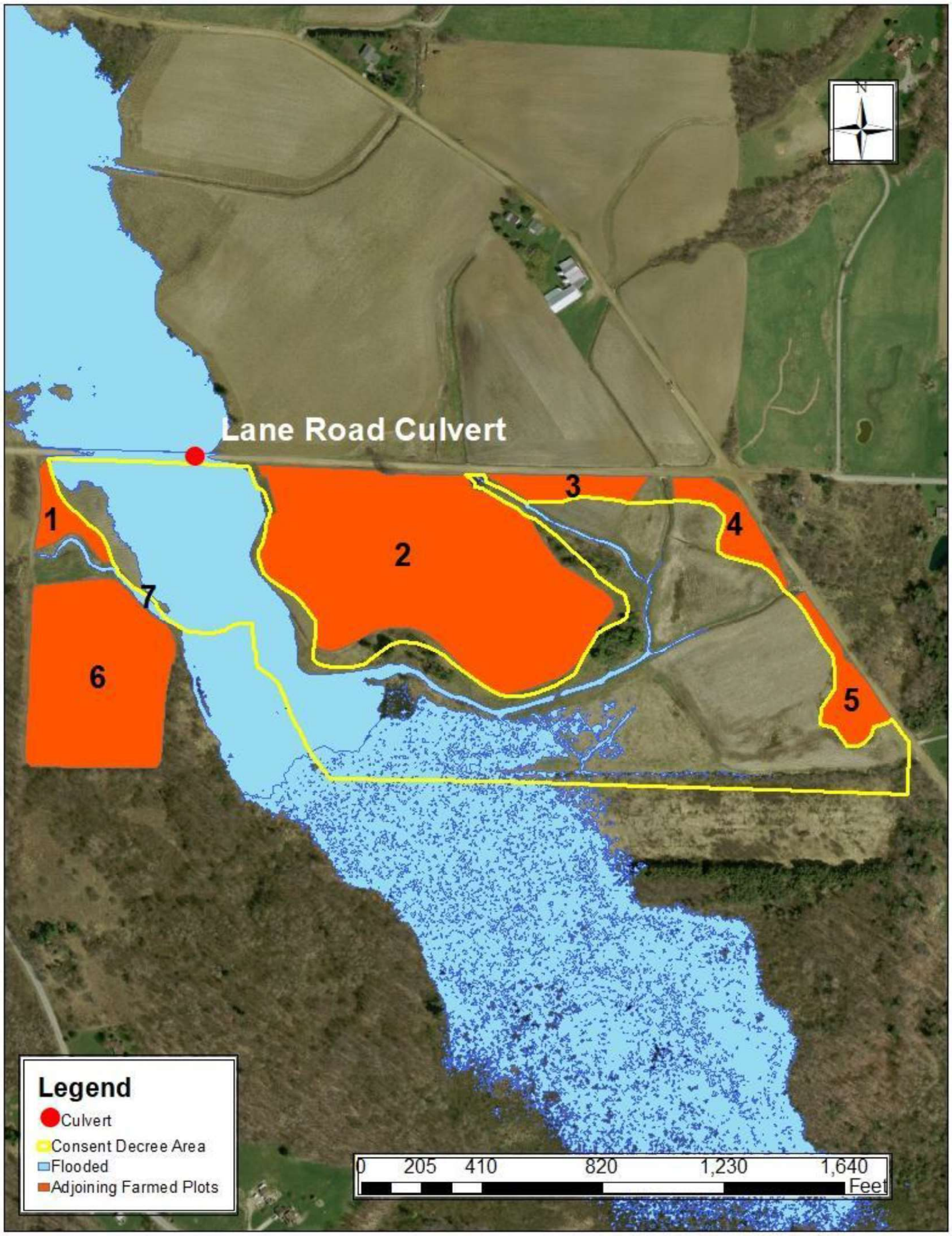
[2] Overtopping roadway

Fig. 21. Scenario 3 - Flooded surface for 10-year return period.[12]



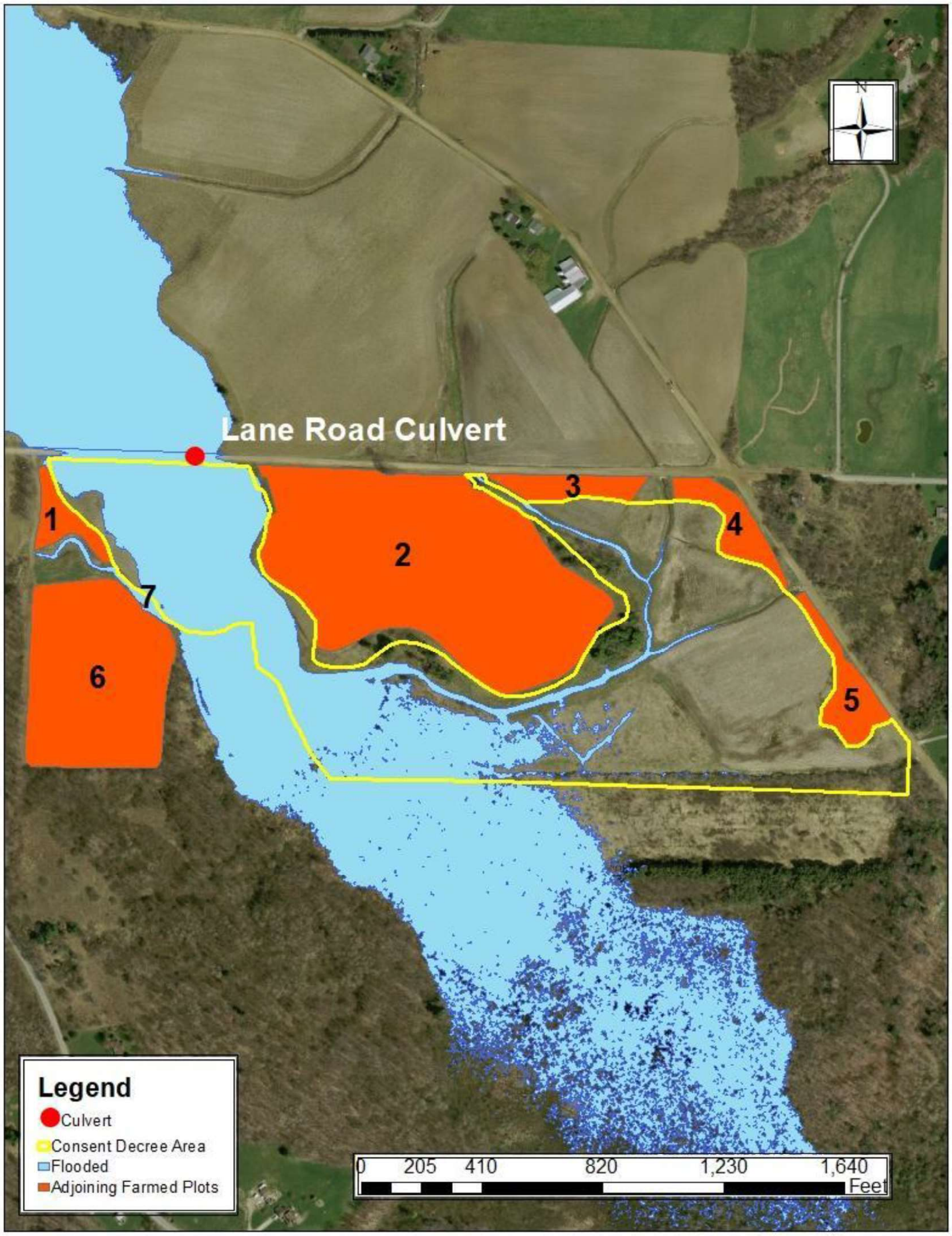
[12] There is no flooding of adjoining plots at this return period.

Fig. 22. Scenario 3 - Flooded surface for 100-year return period.[13]



[13] Small portions of plots 1, 6, and 7, totaling 0.0094 ac (0.0392% of the total adjoining acreage), experience flooding at this return period.

Fig. 23. Scenario 3 - Flooded surface for 1,000-year return period.[14]



[14] Small portions of plots 1, 6, and 7, totaling 0.0294 ac (0.122% of the total adjoining acreage), experience flooding at this return period.

Table 14. Adjoining plot flooding for Scenario 3.

Return Period (years)	Flooded Area (ac)	Fraction of Plot Area %	Average Depth (ft)	Maximum Depth (ft)	Maximum Duration (hours)
10	None	N/A	N/A	N/A	N/A
25	0.0000	0.0000	0.00	0.00	0.75
50	0.0010	0.0041	0.42	0.57	1.58
100	0.0094	0.0392	0.61	0.77	2.08
500	0.0256	0.1077	0.78	1.11	3.00
1000	0.0294	0.1220	0.82	1.21	3.42

D. Scenario 4

33. Results for Scenario 4 are given in Table 15. Relative to Scenario 3, peak discharges upstream of Lane Road Culvert are increased as a result of Elk Creek being modeled as bankfull from the onset. However, these differences are of decreasing significance at the higher return periods. Flooded surfaces are given in Figs. 24-26. Flooding in adjoining plots is described in Table 16, which is highly consistent with the results for Scenario 3.

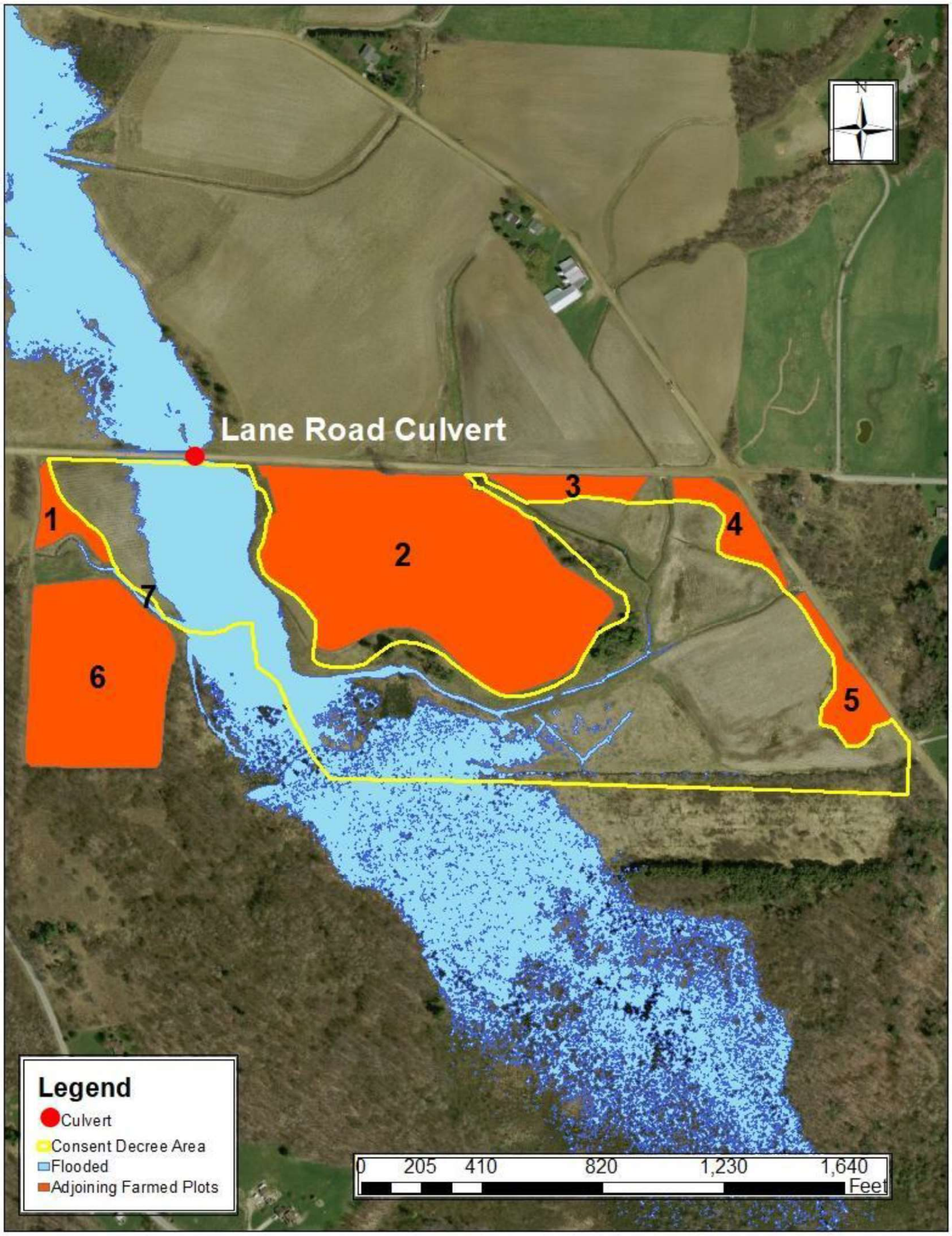
Table 15. Simulation results for Scenario 4 (current conditions; except that Elk Creek is flowing under bankfull conditions). Data are peak culvert discharges and maximum upstream water surface elevation (WSE).

Return	Lane Road Culvert		Sharp Road Culvert	
Period (years)	Peak Discharge (ft^3/s)	WSE (ft)	Peak Discharge (ft^3/s)	WSE (ft)
2	75	1219.5	70	1219.4
5	144	1221.1	118	1220.6
10	212	1222.4	155	1221.2
25	381	1223.4 [1,2]	218	1222.1 [2]
50	557	1223.6 [1,2]	326	1222.6 [2]
100	750	1223.8 [1,2]	554	1222.9 [2]
500	1305	1224.2 [1,2]	1300	1223.5 [2]
1000	1596	1224.3 [1,2]	1689	1223.7 [2]

[1] Flooding in at least one adjoining plot.

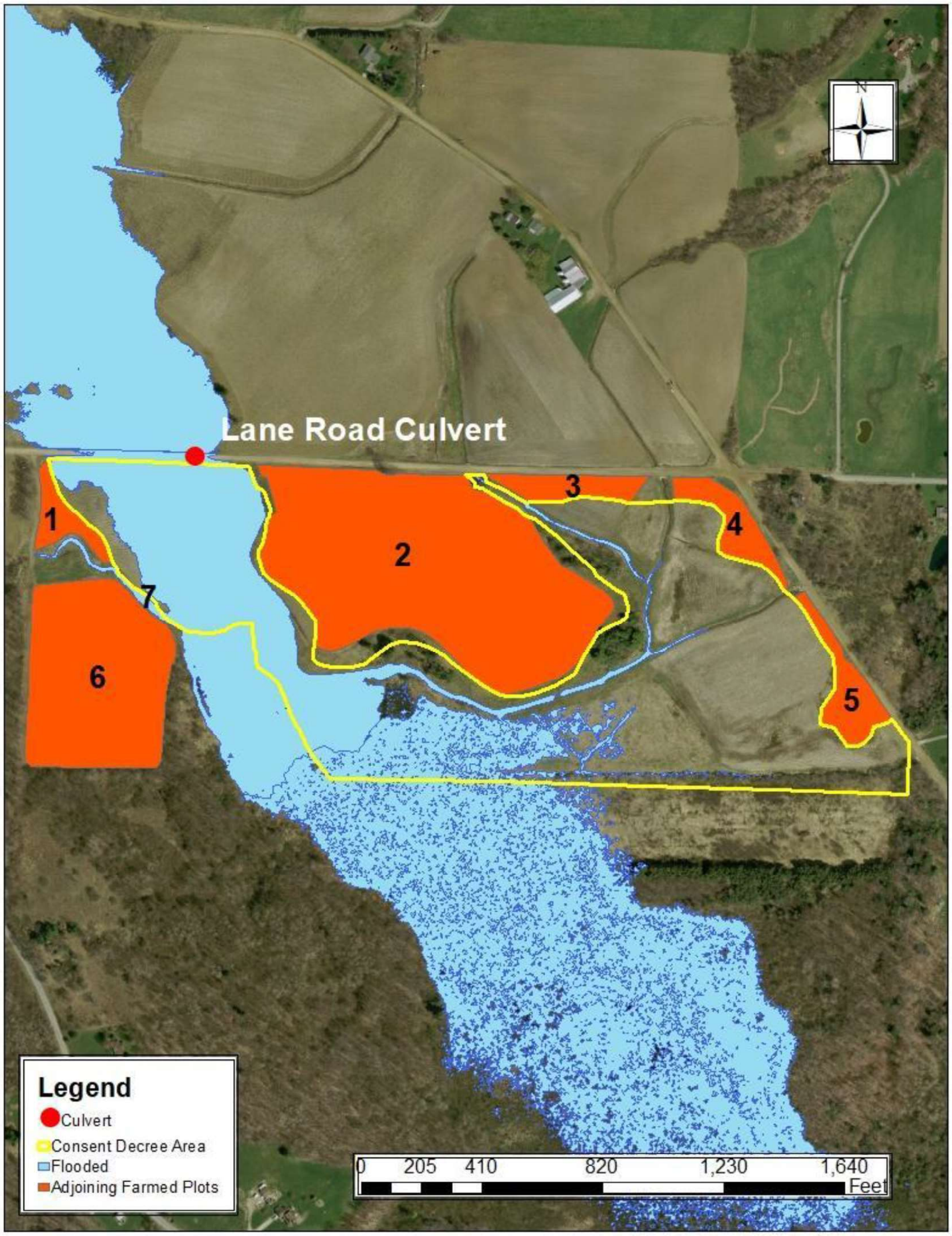
[2] Overtopping roadway

Fig. 24. Scenario 4 – Flooded surface for 10-year return period.[15]



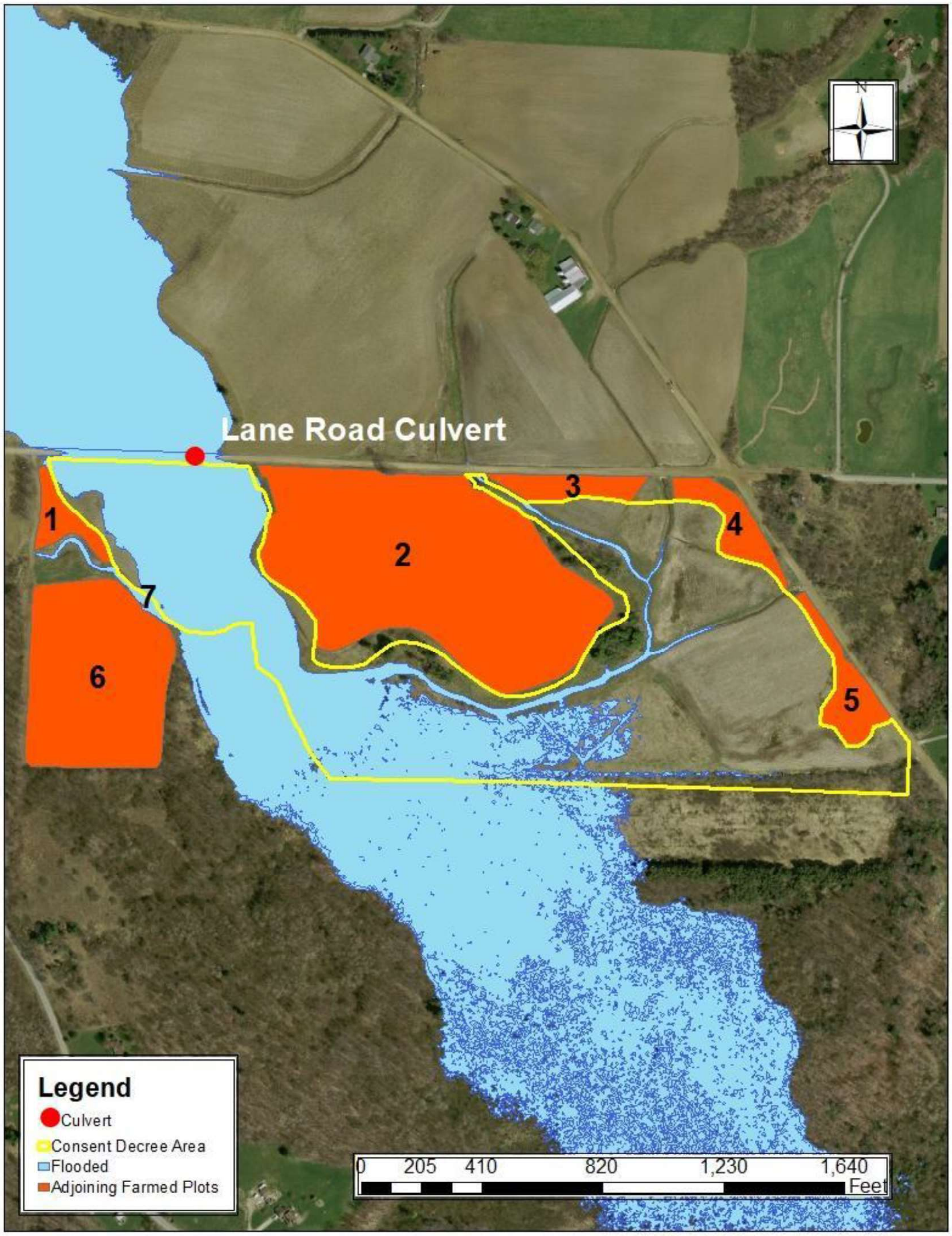
[15] There is no flooding of adjoining plots at this return period.

Fig. 24. Scenario 4 – Flooded surface for 100-year return period.[16]



[16] Small portions of plots 1, 6, and 7, totaling 0.0094 ac (0.0392% of the total adjoining acreage), experience flooding at this return period.

Fig. 26. Scenario 4 – Flooded surface for 1,000-year return period.[17]



[17] Small portions of plots 1, 6, and 7, totaling 0.0294 ac (0.122% of the total adjoining acreage), experience flooding at this return period.

Table 16. Adjoining plot flooding for Scenario 4.

Return Period (years)	Flooded Area (ac)	Fraction of Plot Area %	Average Depth (ft)	Maximum Depth (ft)	Maximum Duration (hours)
10	None	N/A	N/A	N/A	N/A
25	0.0001	0.0005	0.08	0.16	1.08
50	0.0010	0.0041	0.42	0.57	1.75
100	0.0094	0.0392	0.61	0.77	2.33
500	0.0256	0.1077	0.78	1.11	3.42
1000	0.0294	0.1220	0.82	1.21	3.92

E. Scenario 5

34. Results for Scenario 5 are given in Table 17. As suggested by magnitudes of peak discharges relative to Scenarios 1-4, this scenario is quite severe in terms of flooding (peak discharges and WSE values) predictions. Lane Road is predicted to overtop at all return periods investigated, and Sharp Road for return periods > 2 years. The flooded surfaces are demonstrated in Figs. 27-29. As indicated in Table 18, flooding in the adjoining plots occurs at return periods of 5 years and greater and covers roughly double the area (including a portion of Plot 2 at return periods of 500 years and greater) as the preceding four scenarios. Even so, the flooded surfaces remain small (0.06 ac and less), and average depth of flooding is below 1.3 ft for the return periods investigated. Flooded duration is seen to increase slightly over previous scenarios (a maximum of 4.17 hours) due to higher flood magnitudes.

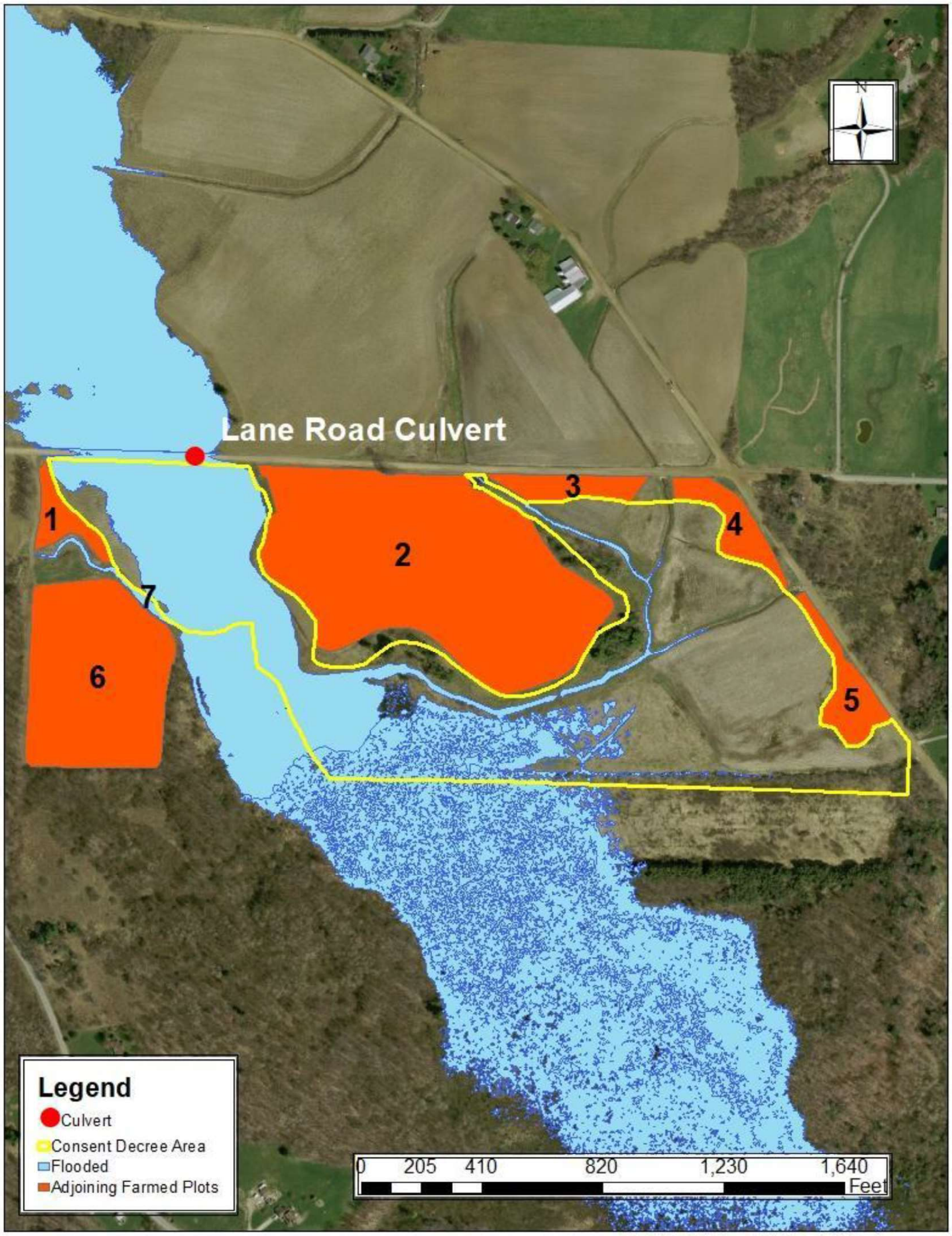
Table 17. Simulation results for Scenario 5 (current conditions with higher-than-average soil moisture). Data are peak culvert discharges and maximum upstream water surface elevation (WSE).

Return	Lane Road Culvert		Sharp Road Culvert	
Period (years)	Peak Discharge (ft^3/s)	WSE (ft)	Peak Discharge (ft^3/s)	WSE (ft)
2	266	1222.9 [2]	158	1221.3
5	613	1223.7 [1,2]	272	1222.4 [2]
10	873	1223.9 [1,2]	499	1222.9 [2]
25	1230	1224.1 [1,2]	941	1223.3 [2]
50	1522	1224.3 [1,2]	1362	1223.5 [2]
100	1845	1224.5 [1,2]	1792	1223.7 [2]
500	2725	1224.8 [1,2]	2991	1224.2 [2]
1000	3169	1225.0 [1,2]	3553	1224.4 [2]

[1] Flooding in at least one adjoining plot.

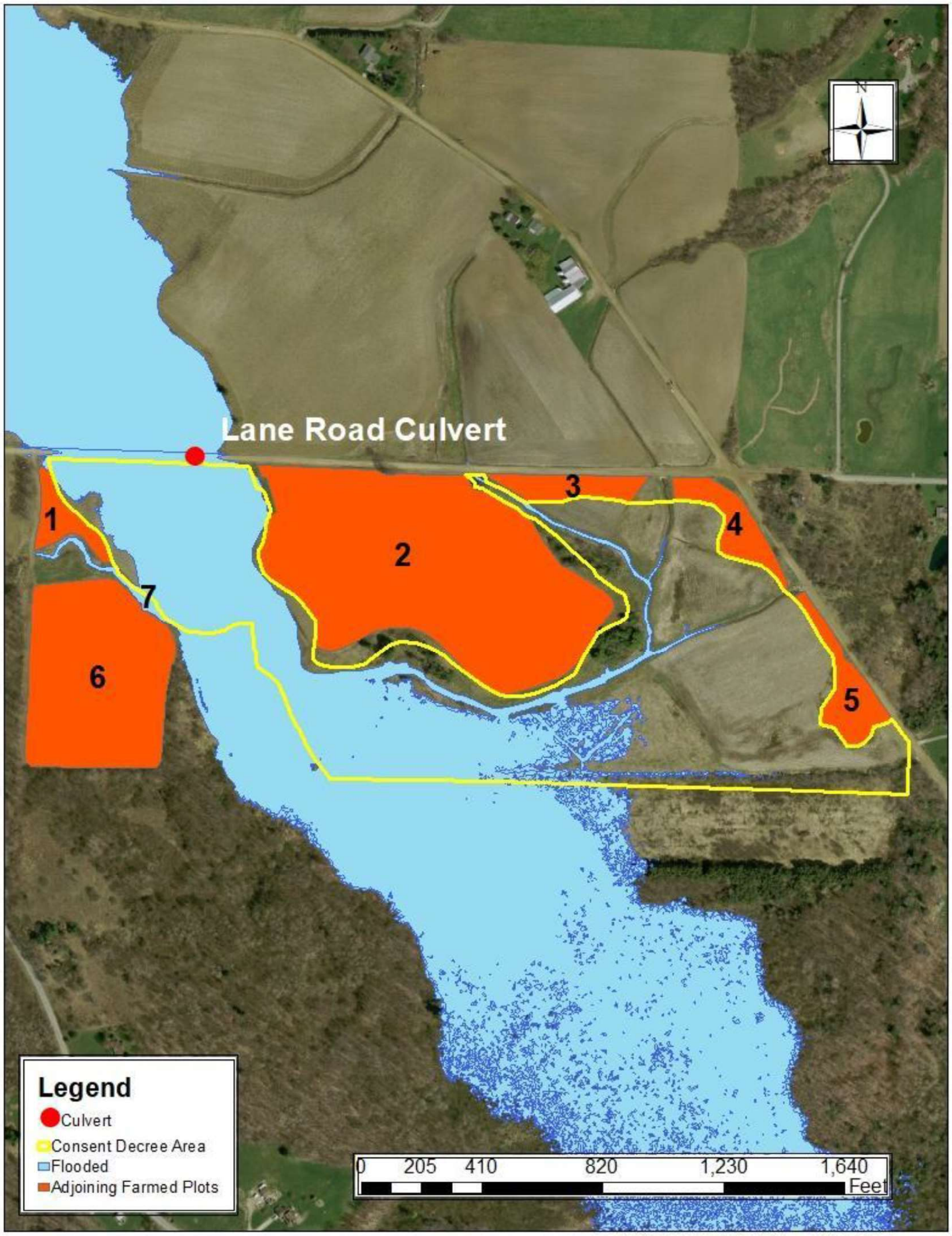
[2] Overtopping roadway

Fig. 27. Scenario 5 - Flooded surface for 10-year return period.[18]



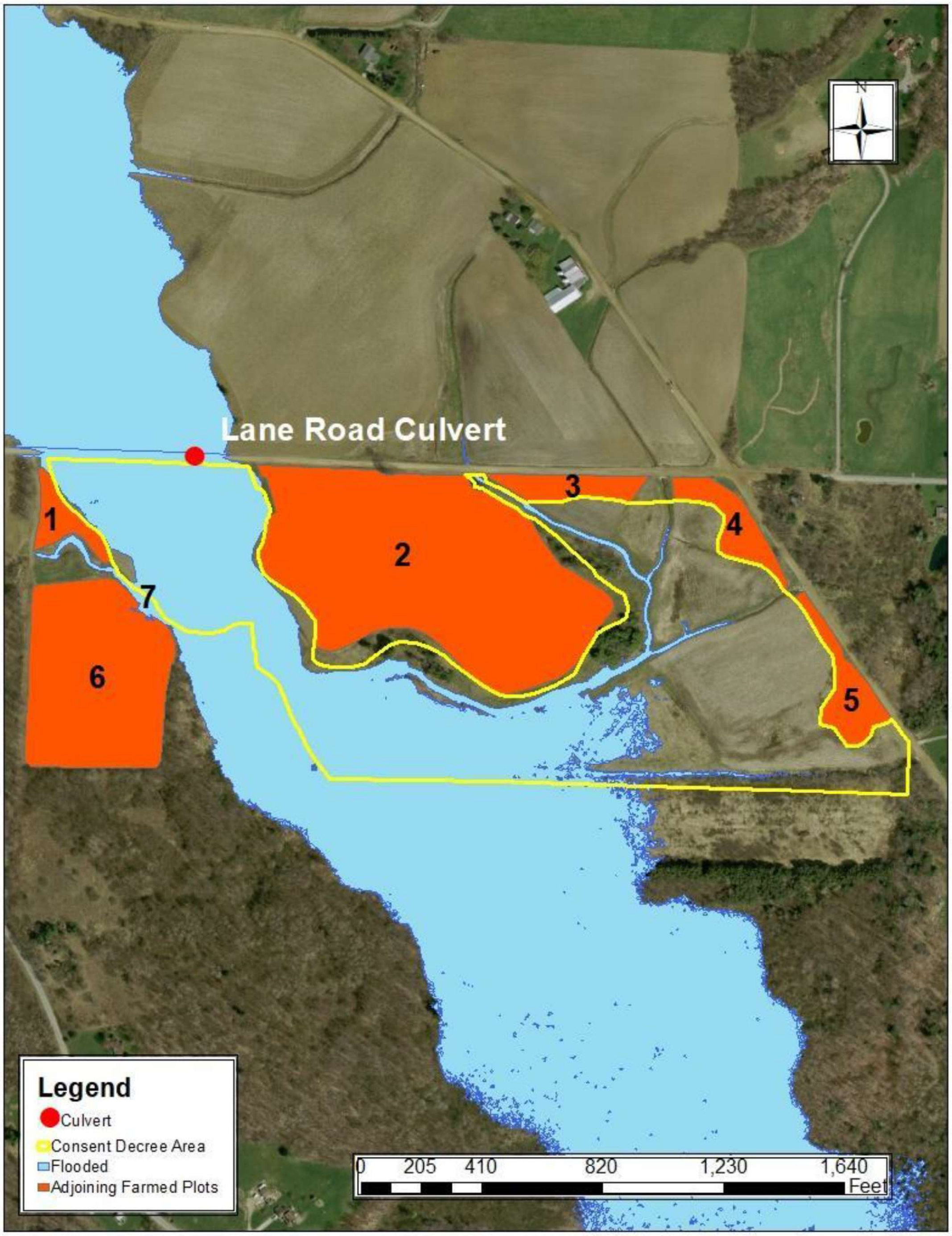
[18] Small portions of plots 1, 6, and 7, totaling 0.0148 ac (0.0615% of the total adjoining acreage), experience flooding at this return period.

Fig. 28. Scenario 5 - Flooded surface for 100-year return period.[19]



[19] Small portions of plots 1, 6, and 7, totaling 0.0336 ac (0.1394% of the total adjoining acreage), experience flooding at this return period.

Fig. 29. Scenario 5 - Flooded surface for 1,000-year return period.[20]



[20] Small portions of plots 1, 2, 6, and 7, totaling 0.0636 ac (0.2641% of the total adjoining acreage), experience flooding at this return period.

Table 18. Adjoining plot flooding for Scenario 5.

Return Period (years)	Flooded Area (ac)	Fraction of Plot Area %	Average Depth (ft)	Maximum Depth (ft)	Maximum Duration (hours)
2	None	N/A	N/A	N/A	N/A
5	0.0034	0.0141	0.50	0.61	1.33
10	0.0148	0.0615	0.66	0.89	1.75
25	0.0229	0.0949	0.74	1.01	2.17
50	0.0294	0.1220	0.82	1.21	2.42
100	0.0336	0.1394	0.88	1.41	2.67
500	0.0464	0.1926	1.09	1.78	3.58
1000	0.0636	0.2641	1.28	1.97	4.17

F. Scenario 6 - Severe Conditions

35. Results for the most severe scenario (Elk Creek flowing at bankfull conditions, no beaver dams, and wetter-than-average soil moisture) are given in Table 19 and depicted in Figs. 30-32. Despite the severity of this scenario, there are no major differences from Scenario 5 in terms of flooding in the adjoining plots (Table 20); flooded area remains small (0.0636 ac and less), average depth of flooding is 1.28 ft and less, and the same four plots (1, 2, 6 and 7) are predicted to be affected by flooding. Flooded duration is increased over the previous scenario (to a maximum of 4.92 hours) as a result of the simulated bankfull conditions at the onset of rainfall.

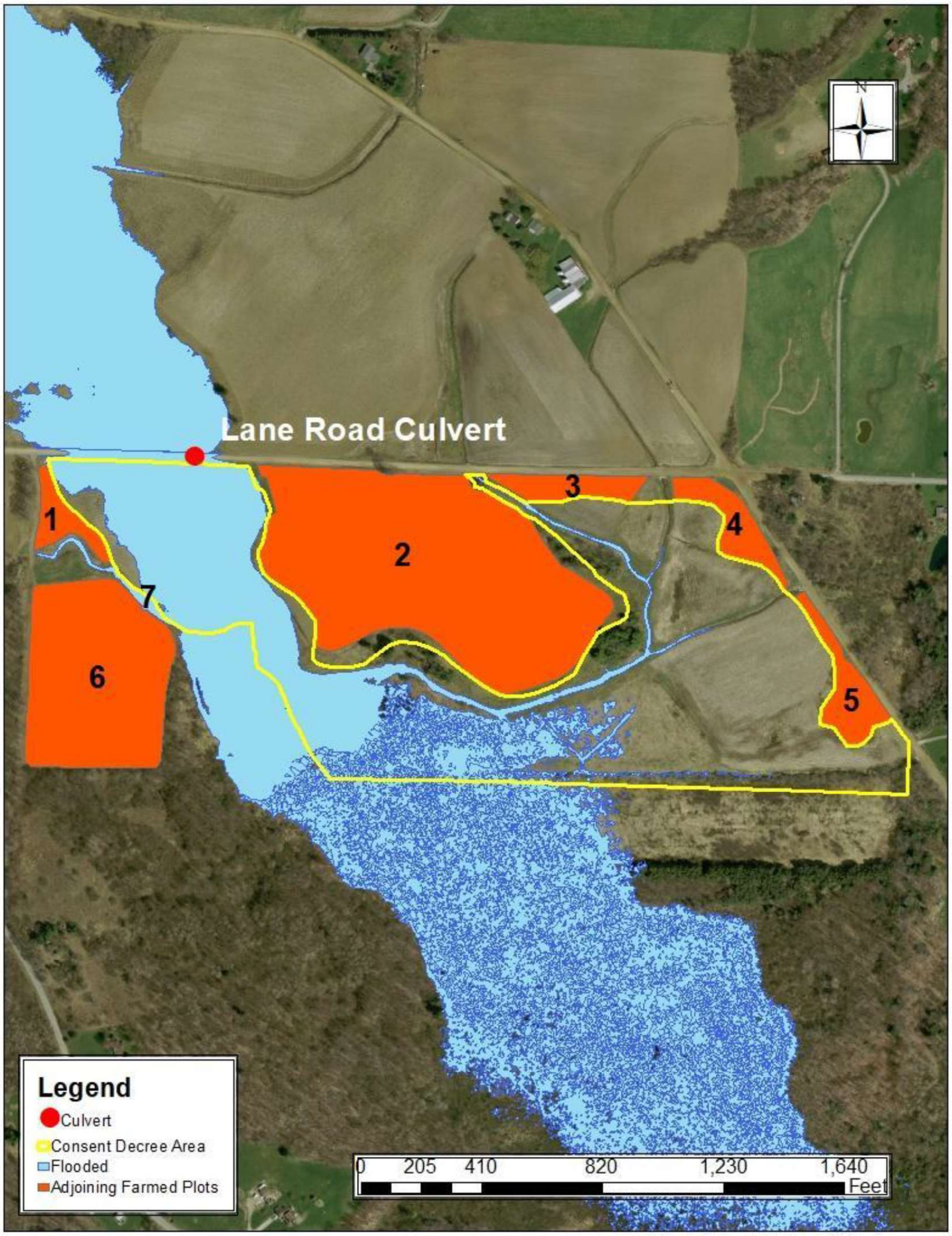
Table 19. Simulation results for Scenario 6 (Elk Creek flowing at bankfull conditions, no beaver dams, higher-than-average soil moisture). Data are peak culvert discharges and maximum upstream water surface elevation (WSE).

Return	Lane Road Culvert		Sharp Road Culvert	
Period (years)	Peak Discharge (ft^3/s)	WSE (ft)	Peak Discharge (ft^3/s)	WSE (ft)
2	329	1223.2 [1,2]	181	1221.6
5	677	1223.8 [1,2]	319	1222.6 [2]
10	921	1224.0 [1,2]	599	1223.0 [2]
25	1263	1224.2 [1,2]	1075	1223.3 [2]
50	1552	1224.3 [1,2]	1493	1223.6 [2]
100	1873	1224.5 [1,2]	1925	1223.8 [2]
500	2739	1224.8 [1,2]	3118	1224.2 [2]
1000	3171	1225.0 [1,2]	3689	1224.4 [2]

[1] Flooding in at least one adjoining plot.

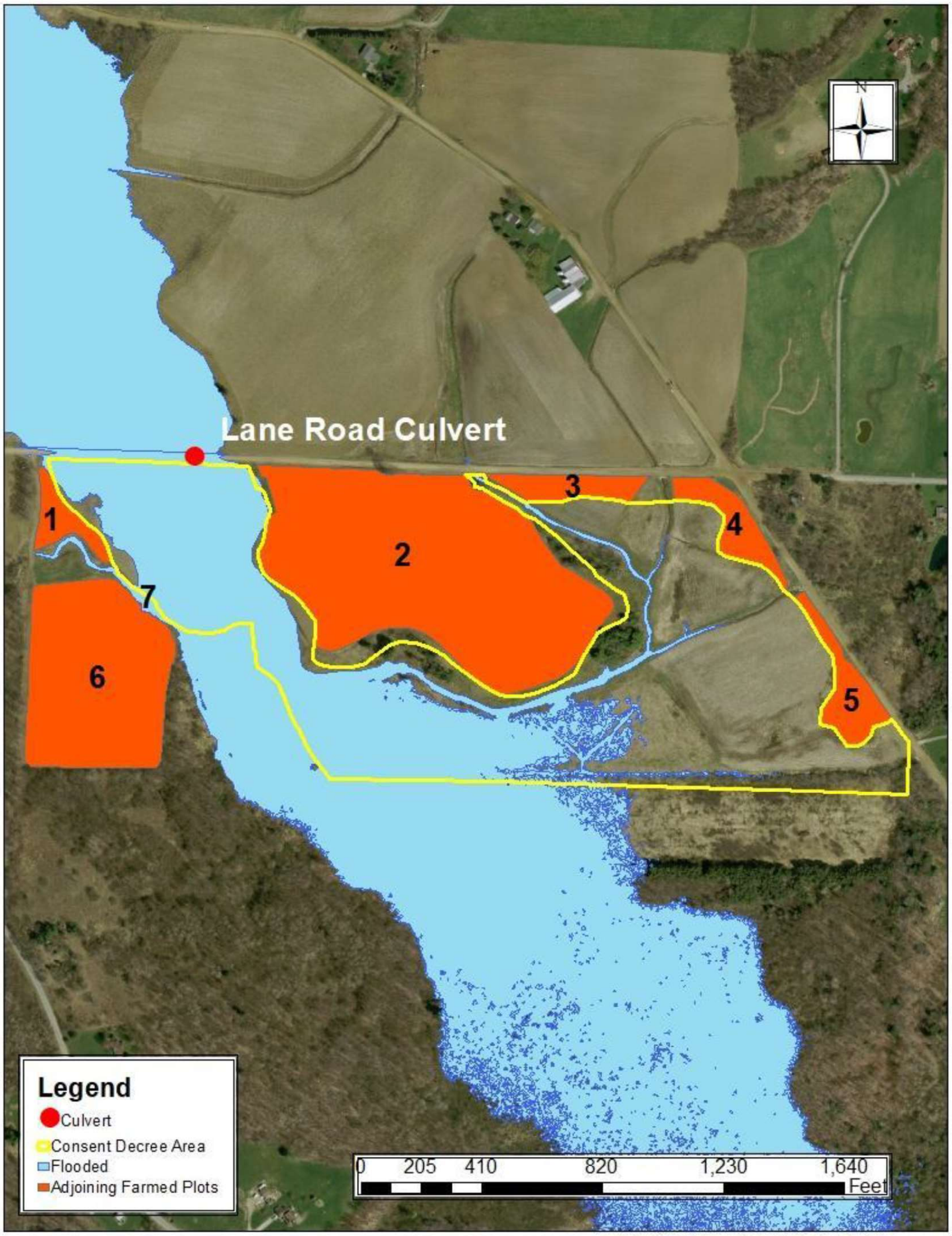
[2] Overtopping roadway

Fig. 30. Scenario 6 - Flooded surface for 10-year return period.[21]



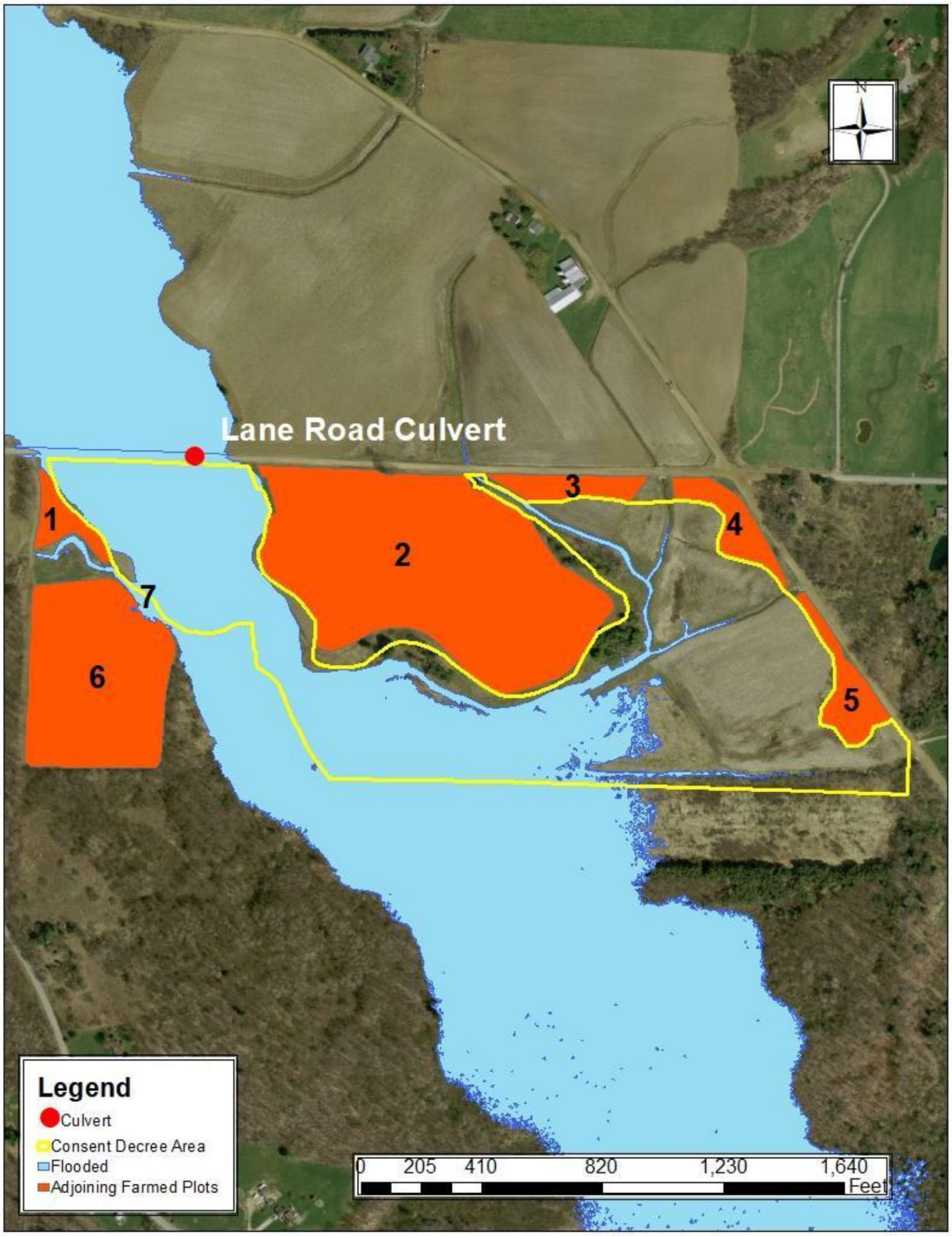
[21] Small portions of plots 1, 6, and 7, totaling 0.0188 ac (0.0782% of the total adjoining acreage), experience flooding at this return period.

Fig. 31. Scenario 6 – Flooded surface for 100-year return period.[22]



[22] Small portions of plots 1, 6, and 7, totaling 0.0336 ac (0.1394% of the total adjoining acreage), experience flooding at this return period.

Fig. 32. Scenario 6 – Flooded surface for 1,000-year return period.[23]



[23] Small portions of plots 1, 2, 6, and 7, totaling 0.0636 ac (0.2641% of the total adjoining acreage), experience flooding at this return period.

Table 20. Adjoining plot flooding for Scenario 6.

Return Period (years)	Flooded Area (ac)	Fraction of Plot Area %	Average Depth (ft)	Maximum Depth (ft)	Maximum Duration (hours)
2	0.0000	0.0000	0.00	0.00	0.60
5	0.0094	0.0392	0.61	0.77	1.50
10	0.0188	0.0782	0.70	0.94	1.92
25	0.0256	0.1077	0.78	1.11	2.33
50	0.0294	0.1220	0.82	1.21	2.75
100	0.0336	0.1394	0.88	1.41	2.92
500	0.0464	0.1926	1.09	1.78	4.33
1000	0.0636	0.2641	1.28	1.97	4.92

VII. Conclusions

36. I considered a multitude of scenarios in evaluating flooding upstream of the Lane Road Culvert, especially flooding of plots adjoining the CDA. The scenarios collectively describe a spectrum of conditions, ranging from hypothetical modifications of current conditions ("EcoStrategies" Model) to quite severe conditions.

37. My consistent finding has been that very little farmed land adjoining the CDA, if any, floods under any conditions. "Improvements" such as removing existing beaver dams or, if it were a practical option, lowering the Sharp Road Culvert, do nothing to reduce flooding and, in the case of beaver dam removal, exacerbates it.

38. Under Scenarios 1-4 (average soil moisture), no adjoining farmland is predicted to flood at return periods of less than 25 years. Even at return periods of 1,000 years, only a maximum of 0.0336 acres of the approximately 24.1 total adjoining plot acreage (less than one-quarter of one percent of the total upland acreage adjoining the CDA) is predicted to flood. Flooded depths under these conditions are predicted to average 0.89 ft and less, with maximum depths of 1.41 ft.

39. Under Scenarios 5-6 (above-average soil moisture), at least some adjoining farmland is predicted to flood at all return periods considered (except for Scenario 5, 2-year return period). However, even at a return periods of 1,000 years, only 0.0636 acres (equivalent to an area of roughly 50 ft by 50 ft), at most, of the approximately 24.1 total adjoining plot acreage (roughly one-quarter of one percent of the total upland acreage adjoining the CDA) is predicted to flood. This is equivalent to "buffer area" extending roughly 3.5 inches outside the entire perimeter (including the southern border) of the CDA. Flooded depths under Scenarios 5 and 6 are predicted to average 1.28 ft and less, with maximum depths of 1.97 ft.

40. In his answer to the United States' Second Set of Interrogatories Directed to Robert Brace, Defendant Robert Brace asserts that "periodic ongoing surface flooded occurred on or around the edge of the Consent Decree area, expanding out into the upland portion of the Murphy Farm and the adjacent Homestead Farm by approximately five to ten feet." Answer to Interrog. No. 2. This assertion is not supported by my modeling analysis. A buffer area of 5 ft. extending beyond the CDA, for example, would encompass 1.1 ac – this is more than 17 times the modeled findings for the most severe conditions at a 1,000 year return period. Additionally, a more significant buffer area of 10 ft, would encompass 2.2 ac – this is more than 30 times the modeled findings for the most severe conditions at a 1,000 year return period.

41. The flooded conditions identified as a result of HEC-HMS modeling are very transient. To use Scenario 6 (the most severe conditions) as an example, simulations indicate that

no adjoining upland acreage will experience flooding for more than 4.92 hours. Flooded durations were shorter for other scenarios.

42. Finally, for return periods greater than 10 years, the peak flow estimates produced in this study are likely to be higher – especially at the higher return periods – than would be actually observed. Moreover, "dryer-than-average" soil moisture conditions (as defined in the context of NRCS runoff estimation methods) are much more likely to exist (66% of the time) than "wetter-than-average" (13% of the time) or even "average" soil moisture conditions (21%). Rare flooding events are thus likely not to be as severe in reality as estimated in this study.

43. Summarizing these findings, flooding under severe conditions is judged to affect a relatively miniscule amount of adjoining farmland and to a very modest degree. In view of the substantial time (days) often required for soil trafficability to be restored following heavy rainfall, the flooding itself would likely have no significant impact on land use or any immediately-following, customary anthropogenic activities. The finding that severe conditions are assessed as having little impact on adjoining farmland flooding might seem contrary to intuition, but this is only a reflection of the physics of the situation. Water surface elevations upstream of Lane Road during flooding are largely dictated by the crest of the road itself, and flooding in adjoining plots is dictated by the superior elevations of the adjoining plots relative to Lane Road, the CDA, and Elk Creek. Nature finds it difficult to overcome these two important variables.