HYDROLOGIC AND HYDRAULIC ANALYSIS

OF THE

GUN RIVER WATERSHED

PREPARED FOR:
ALLEGAN CONSERVATION DISTRICT

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TABLE OF CONTENTS

LIST OF TABLES

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

SUMMARY

Hydrologic and hydraulic analyses were performed for the Gun River in Allegan and Barry Counties as an additional study component of the Gun River Watershed Management Plan. An understanding of the hydrologic and hydraulic characteristics of the Gun River Watershed (Watershed) is consistent with the goal of reducing nonpoint source pollution. The information provided by this study is related to nonpoint source pollution issues in the following ways.

- Determination of the 100-year floodplain will reduce the risk of new development locating not only buildings, but septic systems and other potentially hazardous facilities where they may be inundated by flood waters, thus causing health concerns and/or transport of the associated pathogens/toxics.

- Storm water design criteria adapted at the county level that incorporates stream protection volume for all headwater streams based on numerous urban storm water studies and supported by the conclusions of this analysis, will help maintain more stable channel forming flows and reduce the amount of sediment deposited in the waters of the state from accelerated streambank erosion.

- An understanding of the hydrology of a watershed, the hydraulics of a river or stream and the effects that proposed land use changes and Best Management Practices (BMPs) may have on flow rates, volumes, and velocities is directly related to surface water quality by virtue of maintaining the dynamic equilibrium of the stream and preventing degradation of the water body.

Conclusions from the Hydrologic and Hydraulic (H&H) Analysis of the Gun River are be summarized as follows:

- Overall, the Gun River appears to be relatively stable due to the “non-flashy” nature of the Watershed.

- The hydrology of the Watershed is such that development upstream of Gun Lake will have minimal impact of the Gun River due to the large amount of storage available in Gun Lake. Low, broad hydrographs are characteristic of the discharge from Gun Lake (i.e., the upper watershed).

- The most significant contribution to the Gun River downstream of Gun Lake is via three major tributaries that enter at about midpoint along the Gun River. The large contribution of discharge from Greggs Brook, Orangeville Drain, and Fenner Creek will actually cause reverse flow in the upper portion of the Gun River during flood events. However, the land use trend over the last 40 years (as

indicated on land cover maps) has been from intense agricultural use toward more fallow and open space, which would tend to result in lower runoff rates and volumes.

- The most significant changes in land use between existing zoning and future land use plans are in the lower portion of the Watershed in Otsego and Gun Plain Townships. However, urban sprawl is occurring throughout the Watershed regardless of current zoning that indicates an agricultural use.

- The only structures that would be expected to overtop during the 100-year flood are the approaches to the bridges at 9th Street and 106th Avenue. However, it is apparent from the water surface profiles that the culverts at 116th and 118th Avenues cause the greatest rise in water surface elevations and directly impact the predicted elevation of the floodplain upstream.

The primary benefit of this study is the following information provided through the analysis, which can be used by decision makers in the Watershed.

- In regard to county storm water design criteria, a storm water detention policy release rate restriction of 0.06 cubic feet per second (cfs) per acre was determined to keep the post development flows and water surface elevations at the same levels as predevelopment for a 25-year flooding event. The analysis was completed for development in Gun Plain and Otsego Townships and the City of Plainwell only, since future land use maps indicated an increase in development density within these governmental units.

  Follow up: Re-zoning for urban development us actively taking place in Martin Township as well. The Allegan County Drain Commissioner is considering updates to county standards that call for a detention basin release rate of 0.13 cfs per acre for a 100-year storm. A special policy statement for the Gun River Watershed could be included in the county standards.

- Analysis performed assuming a 0.13 cfs per acre detention basin release rate during a 25-year storm (based on anticipated Allegan County standards), indicated that peak flow rates and volumes increase during a 2-year “bankfull” event. Therefore, stream protection volume requirements should also be incorporated into the counties’ rules. One suggested method (for circumstances where infiltration is not possible) is based on providing extended detention for the 1.5-year storm.

  Follow up: Draft rules of the Allegan County Drain Commissioner contain provisions for stream protection volume.

- The HEC-RAS model may be used to evaluate improvements to hydraulic structures, construction or removal of levies (spoil banks), and other proposed scenarios. Base flows and peak flow rates for a range of storm frequencies are provided for use in sizing hydraulic structures (bridges, culverts, and weirs) in accordance with county drain and the Michigan Department of Environmental Quality (MDEQ) requirements, or for sizing certain streambank stabilization or fish habitat structures.

  Follow up: Specific scenarios have already been requested by local engineering firms, and the model has been modified for use in these independent projects to evaluate the impact of various landform changes on the system hydraulics. Results will be used to obtain regulatory permits for proposed developments.

- The map of flood hazard zones may be integrated with the Allegan County Geographic Information System (GIS), and used to regulate development within the floodplain. Maps are provided as Figures 8A-8F.

- This work may be used to expedite regular participation in the Federal Emergency Management Agency (FEMA) Flood Insurance Program for Otsego and Gun Plain Townships through a partnership between Allegan County and FEMA. At a minimum, this information should be provided to FEMA when Allegan and Barry Counties are scheduled for floodplain map updates as part of FEMA's Floodplain Mapping Update Program.

It is important that this effort on behalf of the Gun River not stop here if water resource goals are to be met for both the Gun River and Lake Allegan, which has a Total Maximum Daily Load for phosphorous. Implementation of low impact development techniques should be pursued along with quantitative storm water design criteria for flood control, which is substantiated by the modeling performed during this study. BMPs for water quality should be included in county storm water rules and township land use ordinances.

INTRODUCTION

This Hydrologic and Hydraulic (H&H) study was completed as part of the U.S. Environmental Protection Agency, Clean Water Act, Section 319 grant project - Gun River Watershed Planning (2000-0164).

The Gun River Watershed is located in rural Allegan and Barry Counties and encompasses 107 square miles of agricultural, urban, and forested land. A watershed map is shown in Figure 1. The Gun River originates at Gun Lake, which is 4.2 square miles in surface area, and is located in Yankee Springs Township in Barry County. From Gun Lake, the Gun River flows 14.6 miles south-southwest to its confluence with the Kalamazoo River in Section 24 of Otsego Township in Allegan County. A 12-mile section of the northern (upstream) portion of the Gun River is an established intercounty drain.

The overall goal of the Section 319 grant project is to develop a watershed management plan to improve water quality and aquatic habitat in the Watershed. The H&H analyses provide quantitative information in regard to flood-frequency discharges and water surface elevations, delineation of the 100-year floodplain, and evaluation of storm water detention policies in the downstream urbanizing areas of the Watershed. This work is related to the nonpoint source goals in the following ways:

- Determination of the 100-year floodplain will reduce the risk of new development locating not only buildings, but septic systems and other potentially hazardous facilities where they may be inundated by flood waters, thus causing health concerns and/or transport of the associated pathogens/toxics.

- Storm water design criteria adapted at the county level that incorporates stream protection volume for all headwater streams based on numerous urban storm water studies and supported by the conclusions of this analysis, will help maintain more stable channel forming flows and reduce the amount of sediment deposited in the waters of the state from accelerated streambank erosion.

- An understanding of the hydrology of a watershed, the hydraulics of a river or stream, and the effects that proposed land use changes and BMPs may have on flow rates, volumes, and velocities is directly related to surface water quality by virtue of maintaining the dynamic equilibrium of the stream and preventing degradation of the water body.

HISTORY

The most recent study of the Gun River was completed in March 1985. This study was commissioned by the Gun River Intercounty Drainage Board in response to a flooding event in June 1978. The objectives of the 1985 study were to determine the hydraulic capacity of the Gun River and the source of the 1978 flooding, evaluate improvement alternatives for reducing the flood stage, and make specific recommendations for flood relief, soil erosion control, channel stabilization, and protection of fish habitat. George Palmiter’s river restoration techniques were recommended as a way to meet these goals. This method involved increasing the channel capacity by removing obstructions and downed trees in the Gun River channel and protecting the channelbanks with vegetative structures.

Engineering studies were also completed between 1979 and 1982 by Alpha Engineering and Nordlund, Dunlap & Associates, Inc. They proposed channel deepening and widening along with an overflow structure and flood by-pass. These improvements were never completed.

METHODOLOGY

HYDROLOGIC ANALYSIS

Hydrologic analysis is performed using a computational model to determine storm water discharges from individual subbasins for various frequency rainfall events. The software used for the hydrologic model is the U.S. Army Corps of Engineers program HEC-HMS. This program computes subbasin hydrographs (a relationship between flow rate and time for a particular rainfall event), which are used as inputs into a hydraulic model to compute river hydrographs, flow velocities, and water surface elevations. The initial analysis is completed based on current land use conditions in the Watershed. Storm water detention alternatives to minimize negative impacts from projected future land use changes are also evaluated.

LAND USE

The Watershed continues to experience changes in land use. Between 1978 and 1996 the trend has been from cultivated to fallow/open land and an increase in residential areas scattered throughout the Watershed. In general, the reduction in runoff associated with the conversion of agricultural to open land uses tends to negate the impact of additional runoff associated with impervious surfaces in the residential areas.

The most dramatic differences between existing and future land use occurs in Otsego and Gun Plain Townships where the greatest amount of residential and commercial development is expected. However, for numerous reasons, concerns with urban sprawl should continue to be aggressively addressed throughout all rural and agricultural areas.

MODEL DEVELOPMENT

The Watershed is subdivided into 12 major subbasins. A hydrologic subbasin map is included in Appendix 1. Figure 2 shows these subbasins in relation to the HEC-HMS model schematic. The Watershed and subasin boundaries are based on the MDEQ delineation. All areas providing flow into Gun Lake are included in a single subbasin because the Gun Lake dam provides an effective hydraulic control, and a more detailed analysis of this area was not required. The areas within the Watershed that are not included in these 12 subbasins are assumed to be non-contributing.

HYDROLOGIC PARAMETERS

The HEC-HMS model uses Soil Conservation Service (SCS) loss computations, Clark unit hydrographs, and constant monthly base flows. The rainfall distribution is an SCS Type II with rainfall depths from *Bulletin 71 - Rainfall Frequency Atlas of the Midwest* (Illinois State Water Survey, 1992). An aerial adjustment factor of 0.932 is used for a 100-square-mile watershed.

BASE FLOW

The MDEQ monthly mean flow rates for the Gun River, at the Kalamazoo River, are used as an estimate of baseflow. The monthly mean values are then distributed among the subbasins by area. Baseflow amounts are shown in Table 1.

Table 1 - Monthly Base Flows for the Gun River (cfs)

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
120th Avenue	62	67	88	88	67	57	38	32	33	38	49	62
114th Avenue	85	92	120	120	92	78	51	44	45	51	66	85
110th Avenue	95	103	135	135	103	87	58	49	51	58	74	95
9th Street	112	121	158	158	121	102	68	58	60	68	87	112
Kalamazoo River*	120	131	171	171	131	110	73	62	64	73	94	120

*MDEQ data complied through 2001

CURVE NUMBER

Curve Numbers (CN) are based on available GIS soils and land cover data as included in Appendix 1. The Allegan County soils data is taken from the State Soil Geographic (STATSGO) database and the land cover is taken from the 1978 Michigan Resource Information System (MIRIS) database. For Barry County the Soil Survey Geographic (SSURGO) database is used for soils data and the 1983 MIRIS database is used for land cover information. ArcView 3.2 is used to create a database file providing areas for all combinations of land cover and a hydrologic soil group for each subbasin. The area averaged CN is then computed using a spreadsheet. Two CN estimates are produced for each subbasin. A high value and a low value are computed based on drained and undrained conditions in soils with dual soil group designations. The more conservative, higher value is used in the model.

TIME OF CONCENTRATION

The time of concentration for each subbasin is computed using the method outlined in *Computing Flood Discharges for Small Ungaged Watersheds* (Sorrel, 2001). A number of flow paths are identified in each subbasin. The distance and elevation drops are determined using MapTech USGS mapping software. A spreadsheet is used to compute the time of concentration from the map information. The storage coefficient for the Clark unit hydrograph is set equal to the time of concentration.

ADJUSTMENTS FOR PERCENT PONDING

Adjustments are made in the time of concentration to account for ponding in the subbasins. These adjustments are based on Equation 9.1 in *Computing Flood Discharges for Small Ungaged Watersheds*. The new time of concentration is one that reproduces the reduced peak discharges utilizing Equation 9.1 directly. To determine the percentage of ponding in each subbasin, the GIS database is used to generate a file of wetland areas. The percentage of ponding is then computed using a spreadsheet.

TIME OF CONCENTRATION FOR BASINS ALONG RIVER

The subbasins that drain by lateral runoff include Gun Dam, Otsego-Plainwell, Bellingham, Reno, Monteith, Scott-Whitcomb, and Sutherland. The times of concentration for these basins are based on overland and waterway flow until runoff reaches the Gun River.

GUN LAKE

Gun Lake is modeled as a reservoir in HEC-HMS (indicated with triangle in Figure 2). The characteristics are given in terms of Elevation-Area-Outflow data. For simplicity, it is assumed that the lake area does not change appreciably with elevation (model runs show less than a 1-foot elevation change). The outflow is determined using the weir formula.

FUTURE LAND USE

Otsego and Gun Plain Townships each have development plans, which set goals for future land use. A future land use map is included in Appendix 1. The Otsego Township Comprehensive Plan completed in 1998 sets land use goals for the year 2020. Gun Plain Township also provided a future land use map. These future land uses affect both the SCS CN and the time of concentration. As more land is developed, a larger portion of the rainfall runs off (higher CN) and it takes less time to reach the outlet of the subbasin. The future land use maps are used to determine an updated CN using the same procedure as that for the existing land use. The time of concentration is reduced using the following method. An equivalent totally impervious fraction is computed from the existing and future CN. If CN_1 is the existing curve number and CN_2 is the future then this impervious fraction, f, is as follows:

$$f = \frac{CN_2 - CN_1}{100 - CN_1}$$

It is then assumed that the flow time is reduced by 50% over the same fraction of the flow path. If t_{c1} is the current time of concentration then the future value, t_{c2}, is computed as follows:

$$t_{c2} = t_{c1}(1 - f/2)$$

STORM WATER DETENTION

Storm water detention essentially increases the time of concentration for a given subbasin. A simple method to compute this effect is to add a fraction of the detention pond release time, t_R, to the subbasin time of concentration. If the detention basin outlet hydrograph is modeled as triangular with a peak outflow equal to the release rate restriction, then the release time can be estimated by equating inflow volume (using SCS curve number method) to outflow volume (based on area under outflow hydrograph). The result is:

$$t_R = 2\frac{SRO}{R}$$

where *SRO* is the surface runoff based on SCS computations and *R* is the release rate restriction. If *R* has units of cfs/acre and *SRO* has units of inches, then t_R has units of hours (1 cfs = 1 ac in/hr).

The time of concentration for each subbasin can now be increased by a fraction of this release time. To determine the appropriate fraction, detailed modeling was performed on the Otsego-Plainwell subbasin. As a result of this modeling, the following expression is developed for the time to be added to the subbasin time of concentration to account for basin-wide detention:

$$t_A = c\frac{SRO}{R}$$

(t_A in hours, *SRO* in inches, and *R* in cfs/acre). In this expression c is a parameter that varies with the release rate. Values used for specific release rates are given in Table 2.

Table 2 - Coefficients for Time of Concentration Increases

R [cfs/acre]	C
0.05	0.44
0.10	0.41
0.20	0.19
0.30	0.04

HYDRAULIC ANALYSIS

Hydraulic analysis is performed to predict flow rates, velocities, and water surface elevations in the Gun River. This analysis uses the US Army Corps of Engineers computer program HEC-RAS. The recent release of this computer program is able to model time varying flows. Instead of using steady state flow rates based on peak hydrograph values from the hydrologic analysis, this version of the program takes the subbasin hydrographs, as determined by HEC-HMS, and accurately combines and routes the hydrographs in a downstream progression along the river system. The model is also able to account for available storage in the floodplain.

DATA ACQUISITION

Several types of information are needed for the hydraulic model. River cross-sections need to be described at regular intervals. These cross-sections require position/elevation data extending to both sides of the Gun River up to the 100-year flood elevations. They also require information about the roughness (Manning's n) of the stream and the floodplain. In addition to river cross-sections, information is needed about all of the stream crossings (culverts and bridges) along the length of the Gun River.

Many of the Gun River cross-sections were obtained from the plans completed in 1982, by Alpha Engineering. Since these improvement plans were never completed, it was concluded that the existing cross-sections surveyed at that time are still accurate, although the cross-sections extend only to the top of the Gun River bank. Two-foot contour maps were used to extend these cross-sections to the 100-year floodplain elevation. The contour maps were made available by the Allegan County GIS department. Construction drawings for many of the crossings were obtained from the Allegan County Road Commission (ACRC) as well as the Michigan Department of Transportation (MDOT). Information for the culverts in the upstream reaches was obtained from the 1982 plans. The culvert data was also field verified. Stream roughness characteristics were determined by visual field survey. Additional river cross-sections were also obtained by field surveys. These are described in the next section.

FIELD SURVEY

Detailed survey work was performed by Fishbeck, Thompson, Carr & Huber, Inc. (FTC&H) in December 2001. The major focus of this work was the lower reaches of the Gun River (114th Avenue to the confluence with the Kalamazoo River). Several tasks were performed in this detailed survey.

- River stationing from the 1982 Alpha Engineering project was used for consistency, which set Station 0+00 at the 11th Street bridge.

- All of the bridge crossings were surveyed between the confluence with the Kalamazoo River and 114th Avenue. Surveyors determined roadway elevations, bridge opening information, and channel cross-section information.

- Elevation reference marks were placed and recorded at each crossing. These can be used for future flood elevation determination and are included in Appendix 4.

- Photographs were taken at each crossing.

- Stream cross-sections were surveyed between the confluence with the Kalamazoo River and 11th Street, since this reach of the Gun River was not surveyed in 1982.

- Six channel cross-sections were surveyed to provide comparison with the 1982 Alpha Engineering data. These cross-sections generally matched within 0.5 feet accuracy.

A Global Positioning System (GPS) was used to establish accurate elevations at every surveyed cross-section. Figure 3 shows the locations of several key cross-sections and river station numbering used.

CALIBRATION

Calibration involves comparing the model results with a measured flooding event to make sure that results are reasonable. On April 8 and April 9, 2002, 1.55 inches of rainfall was measured by the ACRC. Between 9 a.m. and 10 a.m. on April 9, 2002, photographs were taken at many of the stream crossings and are included in Appendix 2. HEC-HMS is used to model this rainfall event. The 1.55 inches of rain are distributed according to the recorded time distribution at the Kalamazoo/Battle Creek Airport. The HEC-RAS model is run using the HEC-HMS computed subbasin hydrographs. The computed water surface elevations are then compared to those measured at five stream crossings. Adjustments are then made to the Manning's "n" value until a reasonable match is obtained. Table 3 gives the results of this calibration.

Table 3 - Results of Model Calibration

Location	River Station	Measured Water Surface Elevation [ft]	Predicted Water Surface Elevation [ft]	Difference (Measured - Predicted) [ft]
114th Street	363+12	729.1	729.2	-0.1
2nd Avenue (middle)	333+29	727.9	727.6	+0.3
2nd Avenue (south)	298+00	725.9	726.0	-0.1
7th Street	120+58	717.4	717.6	-0.2
9th Street	73+61	715.7	715.6	+0.2
10th Street	34+29	713.3	712.9	+0.4

RESULTS

HYDROLOGIC ANALYSIS

EXISTING CONDITIONS

The initial program runs for the hydrologic model were made for existing land use conditions and the 100-year, 24-hour storm. This storm is modeled to occur on the first day of March (highest base flow conditions as shown in Table 1). Table 4 provides both the input parameters and the computed peak flows from each of the subbasins.

Table 4 - Hydrologic Model Parameters and Results - Current Land Use

Subbasin Name	Effective Drainage Area [mi^2]	Curve Number	Time of Concentration [hr]	100-year Peak Flow [cfs]	Time to Peak [hr]
Gun Lake Basin	27.36	65	37.8	687	48.0
Gun Lake (dam outlet)		-	-	188	109.0
Gun Dam	4.43	65	15.4	240	27.0
Greggs Brook	7.46	68	15.0	462	27.5
Orangeville Drain	11.39	64	28.9	350	40.0
Fenner Creek	5.11	72	17.9	315	30.5
Culver Drain	4.07	75	15.5	310	27.0
Sutherland Drain	4.22	80	12.7	437	24.0
Monteith Drain	4.93	72	26.1	222	37.0
Otsego-Plainwell	13.06	66	25.9	465	37.0
Scott-Whitcomb Drain	5.15	63	16.1	251	30.0
Bellingham Drain	3.83	68	4.4	600	16.0
Reno Drain	9.13	65	15.3	497	27.0

The previous hydrologic analysis of the Gun River, completed by FTC&H in 1985, listed peak flow rates from Orangeville Drain, Greggs Brook, and Fenner Creek accounting for channel hydraulic limitations. The values for Greggs Brook and Fenner Creek compare favorably with the current analysis as shown in Table 5. The current analysis for Orangeville Drain predicts a peak flow rate 35% lower than the 1985 analysis.

Table 5 - Comparison of Peak Flow Rates

Subbasin Name	Maximum Flow Rate [cfs]		% Difference from 1985 Analysis
	Current Analysis	1985 Analysis	
Greggs Brook	462	465	-0.6%
Orangeville Drain	350	537	-34.8%
Fenner Creek	315	300	+5.0%

Hydrographs from three of the subbasins are compared in Figure 4 to highlight the differences in their hydrologic response: Gun Lake basin (at Gun Lake Dam outlet), Fenner Creek, and Bellingham Drain. The location of these subbasin hydrographics is shown on 1D in Appendix 1. Gun Lake basin is the largest of the 12 subbasins and therefore releases the largest volume of water. As a result, the area under the hydrograph is the greatest for this subbasin. Storm water draining from the Gun Lake basin is stored in Gun Lake and then released slowly due to the controlling effect of Gun Lake Dam. The peak flows therefore occur later and storm water is released over a longer period of time. The center of the Bellingham subbasin is closer to the Gun River than the center of Fenner Creek. Bellingham therefore has a shorter time of concentration resulting in an earlier peak in the hydrograph. The water draining from Bellingham is released more quickly than any of the other subbasins resulting in a higher peak flow rate.

A watershed that is “flashy” is one that drains quickly, resulting in hydrographs that peak early and have relatively large peak flows. Flashiness is usually associated with watersheds that have steep slopes or quickly drained surfaces. Highly urbanized watersheds show this behavior. Figure 4 indicates that the Bellingham subbasin is more flashy than the other two presented. The Gun River basin as a whole is not flashy. Peak flow rates and times from the 24-hour, 100-year rainfall event are given in Table 6. All of the peaks occur well after the end of rainfall, between 30 and 108 hours. The earlier peaks at 110th and 118th Avenues reflect the impact of the Bellingham subbasin at 110th Avenue and Fenner Creek at 118th Avenue. The peak at 122nd Avenue is due to the slower release of water from Gun Lake dam.

Table 6 - Peak Flow Rates and Times (100-year, 24-hour Rainfall Event)

Location	River Station	Peak Flow Rate [cfs]	Time to Peak [hr]
122nd Avenue	-133+14	191	108
118th Avenue	475+18	1,190	34
114th Avenue	363+12	1,256	42
110th Avenue	220+50	1,491	30
10th Street	34+29	1,872	42
106th Avenue	-133+14	2,175	46

FUTURE LAND USE

The hydrologic model was also used to predict flow rates under future land use conditions to evaluate alternative detention basin release rate policies for the 25-year rainfall event, as well as the effect of those policies on the 2-year storm event. These frequencies were selected based on the following rational.

Allegan County has previously adopted storm water criteria that requires detention of up to the 25-year storm with an allowable release rate equal to the undeveloped 3-year runoff, typically equating to 0.20 cfs per acre. Based on our review of watershed protection literature, we would also recommended the 25-year frequency rainfall as the flood control event over the 100-year frequency rainfall since it is more cost-effective and the emphasis for the 100-year event should be on floodplain preservation. The 2-year event was also selected as representative of the bankfull or channel forming flow event that is most closely related to channel stability.

Tables 7 and 8 compare peak flow rates and runoff volumes for the 25-year storm and the 2-year storm, respectively, for both existing and future land use conditions. Note that no changes are seen in the upper portions of the Watershed since the most significant land use changes were assumed to occur in Otsego and Gun Plain Townships.

Table 7 - Hydrologic Model Results - Future Land Use Conditions (25-Year)

	25-Year Peak Flow Rate [cfs]			Runoff Volume [acre-ft]		
Subbasin Name	Existing Conditions	Future Conditions	% Change	Existing Conditions	Future Conditions	% Change
Gun Lake Basin	340	340	0	3,533	3,533	0
Gun Dam	115	115	0	581	581	0
Greggs Brook	234	234	0	1,033	1,033	0
Orangeville Drain	167	167	0	1,436	1,436	0
Fenner Creek	166	166	0	784	784	0
Culver Drain	169	169	0	664	664	0
Sutherland Drain	259	291	+12%	725	763	+5%
Monteith Drain	106	125	+18%	848	904	+7%
Otsego-Plainwell	208	280	+35%	1,295	1,519	+17%
Scott-Whitcomb Drain	122	164	+34%	751	833	+11%
Bellingham Drain	304	366	+20%	583	623	+7%
Reno Drain	239	239	0	1,178	1,178	0
Total for Gun River, Mouth	**1,412**	**1,537**	**+9%**	**13,411**	**13,829**	**3%**

Table 8 - Hydrologic Model Results - Future Land Use Conditions (2-Year)

	2-Year Peak Flow Rate [cfs]			Runoff Volume [acre-ft]		
Subbasin Name	Existing Conditions	Future Conditions	% Change	Existing Conditions	Future Conditions	% Change
Gun Lake Basin	93	93	0	2,191	2,191	0
Gun Dam	24	24	0	364	364	0
Greggs Brook	53	53	0	623	623	0
Orangeville Drain	40	40	0	900	900	0
Fenner Creek	43	43	0	462	462	0
Culver Drain	47	47	0	384	384	0
Sutherland Drain	82	96	+17%	394	416	+6%
Monteith Drain	29	35	+21%	538	565	+5%
Otsego-Plainwell	42	64	+52%	629	723	+15%
Scott-Whitcomb Drain	27	40	+48%	519	550	+6%
Bellingham Drain	57	77	+35%	372	390	+5%
Reno Drain	50	46	0	731	720	0
Total for Gun River, Mouth	**432**	**473**	**+9%**	**8,106**	**8,287**	**+2%**

Results of the future land uses analysis are also illustrated in Figures 5 and 6, which compare flow rates along the entire length of the Gun River under existing and future conditions for both the 25-year and the 2-year rainfall events. This figure shows the peak flow rate at each location along the length of the Gun River. Higher flow rates occur closer to the confluence with the Kalamazoo River. The flow rate jumps occur at the locations where the major tributaries feed into the Gun River.

The analysis indicates that the runoff rates from the lower subbasins would increase by as much as 35% for the 25-year storm and by 52% for the 2-year storm, as seen in Tables 7 and 8. Because no changes were assumed for the upper subbasins, the impact of the increased runoff rates from the lower subasins is less dramatic on total discharges for the Gun River. Tables 7 and 8 indicate that the result of future development is an increase in flow rates at the downstream end of 9%. The total volume differences in the Gun River are even smaller, being on the order of 2% to 3%.

STORM WATER DETENTION

A common approach to reducing the impact of future development is to require all new developments to detain storm water runoff. Storm water detention rules are usually based on specific release rate restrictions. Several Michigan counties require that detention basin release rates be limited to 0.13 cfs per acre for the 25-year storm. The hydraulic model was used to estimate the effect of such a release rate restriction.

The "flood control volume" is only one component of an overall storm water management program that addresses water quality, stream protection, groundwater recharge, potential groundwater contamination areas (hotspots), water resource based zoning, and preservation of natural hydrologic features. For this reason, the hydraulic model was also used to evaluate the effect of anticipated storm water detention policies on the 2-year storm.

FLOOD CONTROL

Several release rate restrictions were modeled to determine the impact of detention on peak flow rates in the Gun River. Initially, detention was assumed in the lower five subbasins: Otsego-Plainwell, Monteith, Scott-Whitcomb, Sutherland, and Bellingham (Figure 2). As a result of these runs it was discovered that detention can actually increase the peak flow rates along the reach of the Gun River between 110th and 112th Avenue (inflow reaches for Sutherland and Bellingham subbasins). This is likely due to the impact of having the peaks from these two subbasins combine with flows from Culver Drain further upstream. The impact was modest (5% increase at the highest detention release rates). It was determined to be small enough to not warrant separate storm water design criteria such as no detention zones or an alternative flood control volume release rate.

The final runs considered detention in the lower three subbasins (i.e., only those areas contributing downstream of 110th Avenue). The results of modeling the effect of various detention release rate restrictions is given in the Table 9.

Table 9 - Peak 25-Year Flow Rates and Water Surface Elevations (WSE) with Detention

Condition or Release Rate	106th Avenue		11th Street		10th Street		7th Street	
	Q_P [cfs]	WSE [ft]	Q_P [cfs]	WSE [ft]	Q_P [cfs]	WSE [ft]	Q_P [cfs]	WSE [ft]
Existing	1,412	701.24	1,331	709.04	1,269	716.12	1,222	721.98
Future	1,537	701.46	1,433	709.16	1,349	716.23	1,283	722.02
0.20 cfs/acre	1,522	701.44	1,420	709.14	1,338	716.22	1,274	722.02
0.13 cfs/acre	1,496	701.39	1,397	709.11	1,320	716.20	1,258	722.01
0.06 cfs/acre	1,419	701.26	1,329	709.04	1,265	716.12	1,218	721.98

This analysis shows that a detention release rate restriction of 0.20 cfs per acre (past practice used in Allegan County) has only a minor impact on reducing future peak flow rates in the Gun River. A value of 0.06 cfs per acre keeps the future peak flows at the existing levels. Using this value, the peak flows at 106th Avenue are delayed 2 hours from those under existing conditions and 4 hours from those under future conditions. Since any amount of detention reduces the peak flow rates, the model does not indicate a need for no-detention zones in these lower subbasins.

The actual flow rate increase in the Gun River associated with the future land use condition is rather small (about 9% at 106th Avenue). As a result, the potential for an increase in flooding associated with future land use conditions is also small. The largest water surface increase associated with the future land use (without detention) is 0.24 feet at 106th Avenue.

Several counties have adopted a detention release rate restriction of 0.13 cfs per acre and present recommendations from outside consultants are for the Allegan County Drain Commissioner’s office to adopt this value for use on a county-wide basis. This value will keep the water surface increase associated with future land use conditions to less than 0.1 foot at every location except 106th Avenue where the increase is 0.15 feet.

Stream Protection

In the previous section, storm water detention is proposed for flood control. Storm water detention can also be used for protecting the stream banks during more frequent events. This usually requires designing the detention facility with multiple release rate criteria. Analysis completed using the Gun River model indicates that if the only release criterion is the 0.13 cfs per acre proposed for flood protection, peak flow rates and volumes will still increase during the 2-year bank full storm. This is shown clearly in Figure 6 where the peak flow rates do not return to predevelopment levels under the 0.13 cfs per acre requirement established for flood protection. To provide for stream bank protection, a second set of detention requirements is needed. An important part of these detention criteria is controlling storm water volume and flow rate which are directly related to sediment transport and shear stress on the channel bank. As seen in Table 8, without the use of infiltration or interception, storm water volumes are predicted to increase by about 2% for the Gun River, but much higher for tributary watercourses from the individual subbasins.

Several methods have been proposed for establishing criteria for stream protection. One method is “two year control” where the post-development peak discharge rates are held to the pre-development rates for the two-year event. Some studies have indicated that this method may actually exacerbate erosion since banks are exposed to erosive velocities for a longer duration. Another approach, where infiltration is not feasible, is to design the detention facility to hold the 1 to 2 year event for a period of 24 hours (i.e. there should be a 24 hour lag between the centriods of the inflow and outflow hydrographs). This extended detention approach releases the runoff in such a gradual manner that critical erosive velocities would seldom be exceeded in downstream channels.

FTC&H has done extensive detention basin modeling to establish release rate criteria for stream protection. A stream protection release rate has been determined which, if used, will detain the 1.5 year runoff for the required 24 hours. The results of this work has been used to establish storm water detention rules for neighboring counties. A detailed description of this work can be found in Appendix 6.

This release rate needed for stream protection is a function of the soil type in the drainage area and the degree of imperviousness in the associated development. Release rates restrictions and required detention storage volumes can be expressed in several ways and at several levels of detail. Figure 4 in Appendix 6 shows the release rate (in cfs/acre) and required storage volume (in cubic feet [cft]/acre) as a function of the developed Curve Number. An alternative to this (also described in Appendix 6) gives the release rate as a function of the hydrologic soil group and the number of impervious acres in the development. This approach applied to Allegan county gives the following results:

- Hydrologic soil group A: 0.026 cfs and 3,000 cft storage per impervious acre
- Hydrologic soil group B: 0.034 cfs and 4,000 cft storage per impervious acre
- Hydrologic soil group C: 0.051 cfs and 5,800 cft storage per impervious acre
- Hydrologic soil group D: 0.059 cfs and 5,800 cft storage per impervious acre

A third method assumes that developments with A and B soils will use infiltration to reduce peak flows. Using the lower release rate for soil groups C and D gives a value of 0.05 cfs per impervious acre along with 5,800 cft of storage per impervious acre. It should be noted that runoff from the pervious portion of the development is still included in the volume recommendations above. This approach just uses the number of impervious acres to predict the volume needed to detain runoff from the entire site.

HYDRAULIC ANALYSIS

The calibrated model was used to predict the flow rates and water surface elevations for the 2 -, 5-, 10-, 25-, 50-, and 100-year flood events. The peak flow rates, maximum water surface elevations, average channel velocity, flow area, and water surface top width computed for each of these events at the river cross-sections surveyed in 1985 and 2001 are tabulated in Appendix 3. The resulting flood profiles for the 10-year through 100-year rainfall frequencies are shown in Figures 7A through 7F. The 100-year flood hazard zone is shown in Figures 8A through 8F.

Appendix 4 provides detailed crossing data. It includes photographs, HEC-RAS generated crossing tables, and HEC-RAS computed stage and flow hydrographs. The hydrographs clearly show the reverse flow that takes place during large storm events upstream of the confluence of Orangeville Drain, Greggsbrook, and Fenner Creek. This phenomena is illustrated by the hydrographs at Patterson Road and 122nd Avenue, which indicate that peak stage is reached at approximately 3 hours (by the higher, earlier downstream flows shown in the hydrograph at 120th avenue) before the peak flow from upstream comes through at about 5.5 hours.

The Allegan County GIS department provided detailed maps of elevations within the flood hazard zone to be used for future mapping and planning projects. These maps are included in Appendix 5.

The road crossings that are expected to flood during a 100-year event are 9th Street and 106th Avenue by 0.2 feet and 0.3 feet respectively. In both cases the flows will pass over the approach road. (See Appendix 5 for elevations.) The farm lane south of 122nd Avenue also shows overtopping by 0.6 feet.

CONCLUSIONS

Peak flow rates from the hydrologic analysis compare well with those computed in the 1985 report for the Greggs Brook, Fenner Creek, and Orangeville Drain subbasins. Overall, the Gun River appears to be a relatively stable channel due to the “non-flashy” nature of the Watershed as a whole. Annual maintenance due to fallen trees and log jams is ongoing, but not found to be excessive.

The upper portion of the Watershed, which drains into Gun Lake, is characterized by residential and recreational uses. Future development in this area will have minimal impact on the Gun River because of the storage available in Gun Lake. The middle portion of the Watershed is characterized by agricultural uses. Significant runoff volumes enter the Gun River by way of three major tributaries: Greggs Brook, Orangeville Drain, and Fenner Creek. Peak flows entering the Gun River from these three tributaries have been known to back up into the upper portion. Here there has been a trend toward fallow/open land uses which should result in lower flow rates. The lower portion of the Watershed in Otsego and Gun Plain Townships is characterized by increasing urban development as indicated in future land use plans, although urban sprawl is occurring throughout the watershed. This development could have a significant impact on the amount of runoff entering the Gun River.

Comparisons of existing and future flow rates show the impact of development in the lower part of the Watershed. The peak flow rates in the Gun River for a 25-year storm could be expected to increase by 9% and runoff volumes by 3%. Without effective storm water management measures, these increased flow rates and volumes will increase flood elevations in the Gun River. A storm water detention policy release rate restriction of 0.06 cfs per acre was determined to keep the post development flow and water surface elevation at the same levels as predevelopment for a 25-year flooding event. The analysis was completed for development in Gun Plain and Otsego Townships and the City of Plainwell only, since future land use maps indicated an increase in development density within these governmental units.

Results show that storm water detention criteria directed at controlling larger flood events (25-year storm) are not effective for smaller channel forming events (2-year storm). Therefore, separate design criteria is needed to protect the integrity of tributary streams from increases in runoff rates and volumes typically associated with urban development. A suggested method (when infiltration is not possible) is outlined in Appendix 6.

The hydraulic analysis provides predictions of river hydraulic characteristics (i.e., flow rates, water surface elevations, velocities, etc.) during storm events. Flooding is expected on the approaches at 9th Street and 106th Avenue during the 100-year event. This has the potential of causing damage or increasing maintenance of these road surfaces. None of the other publicly owned bridge or culvert crossings are predicted to be overtopped.

It is apparent from the water surface profiles that the culverts at 116th and 118th Avenues cause the greatest rise in water surface elevations and directly impact the predicted elevation of the floodplain upstream.

BENEFITS OF THIS STUDY

The information from this study may be used by decision makers in the Watershed to protect water quality and quality of life. Some important uses include:

- Allegan County may use this study to support a special storm water policy that allows no more than a 0.06 cfs per acre discharge rate to the Gun River from Gun Plain and Otsego Townships and the City of Plainwell to mitigate the impact of future development on flood discharges.

- Barry and Allegan Counties my use this study to support a storm water policy that calls for stream protection via infiltration and/or extended detention.

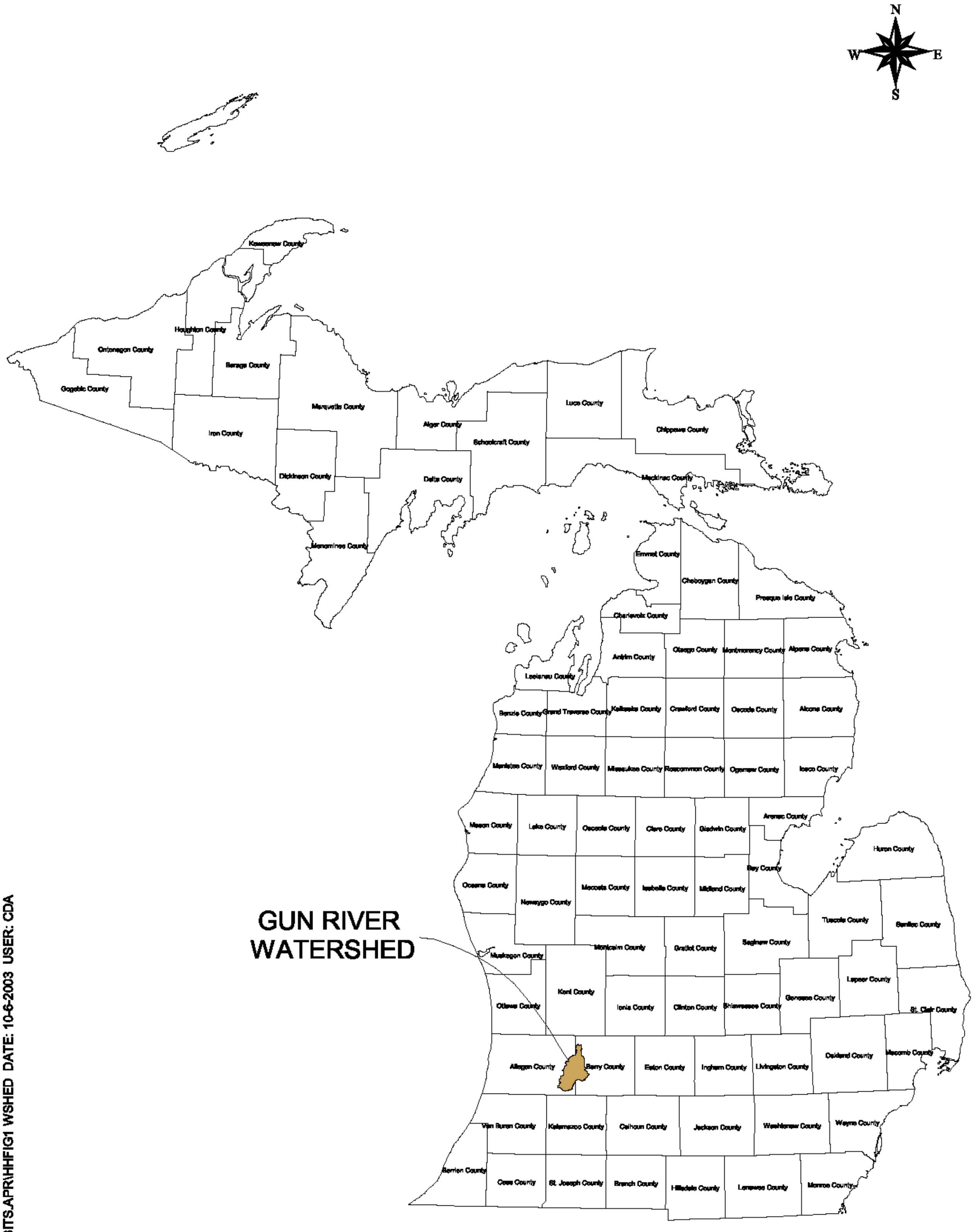
- The HEC-RAS model may be used to evaluate improvements to hydraulic structures, construction or removal of levies (spoil banks), and other proposed scenarios. Base flows and peak flow rates for a range of storm frequencies are provided for use in sizing hydraulic structures (bridges, culverts, and weirs) in accordance with county drain and the MDEQ requirements, or for sizing certain streambank stabilization or fish habitat structures.

- The map of flood hazard zones may be integrated with the Allegan County GIS. It could then be more readily available for building inspectors to regulate development within the floodplain. This will allow for protection of the natural floodplain. Maps are provided in Figures 8A through 8F.

- The hydrologic and hydraulic analyses, along with the resulting flood profiles and flood hazard zone maps may be used to expedite regular participation in the FEMA Flood Insurance Program. This is done through the FEMA's Cooperating Technical Partners Program. The result of this partnership will be the creation of a Flood Insurance Rate Map and lower flood insurance premiums. This process has already been started with requests from Otsego and Gun Plain Townships to Mr. Eric Berman *(now Mary Jo Mullen)* of the FEMA Region 5, who has indicated that this process should continue at the county level in cooperation with the Allegan County GIS department and Dr. Jeroen Wagendorp. Since initial meetings in 2002, the FEMA has initiated a statewide floodplain mapping update program. The information contained in this report should be provided to the FEMA when Allegan and Barry Counties are scheduled for county-wide floodplain mapping updates.

STEERING COMMITTEE INPUT

The Watershed Steering Committee has expressed a desire to do everything possible from a urban development perspective. Examples include educating developers and city/township review officials in low impact development techniques. Provisions to allow for low impact development storm water criteria could be included in county storm water rules and township land use ordinances to maintain as close as possible the pre-development hydrology of the site for water quality and stream protection, while also allowing for cleansing overbank or flood flows in the natural watercourses (without increasing flooding).



D:\WORK\01339\PROJECT\GUN_EXHIBITS.APR\HHFIG1 WSHED DATE: 10-6-2003 USER: CDA

DATA SOURCES: MICHIGAN FRAMEWORK
VERSION 1B, PROJECTED TO MICHIGAN SPCS
NAD 27, FEET.

WATERSHED MAP

Fishbeck, Thompson, Carr & Huber
Engineers • Scientists • Architects
Grand Rapids, Michigan

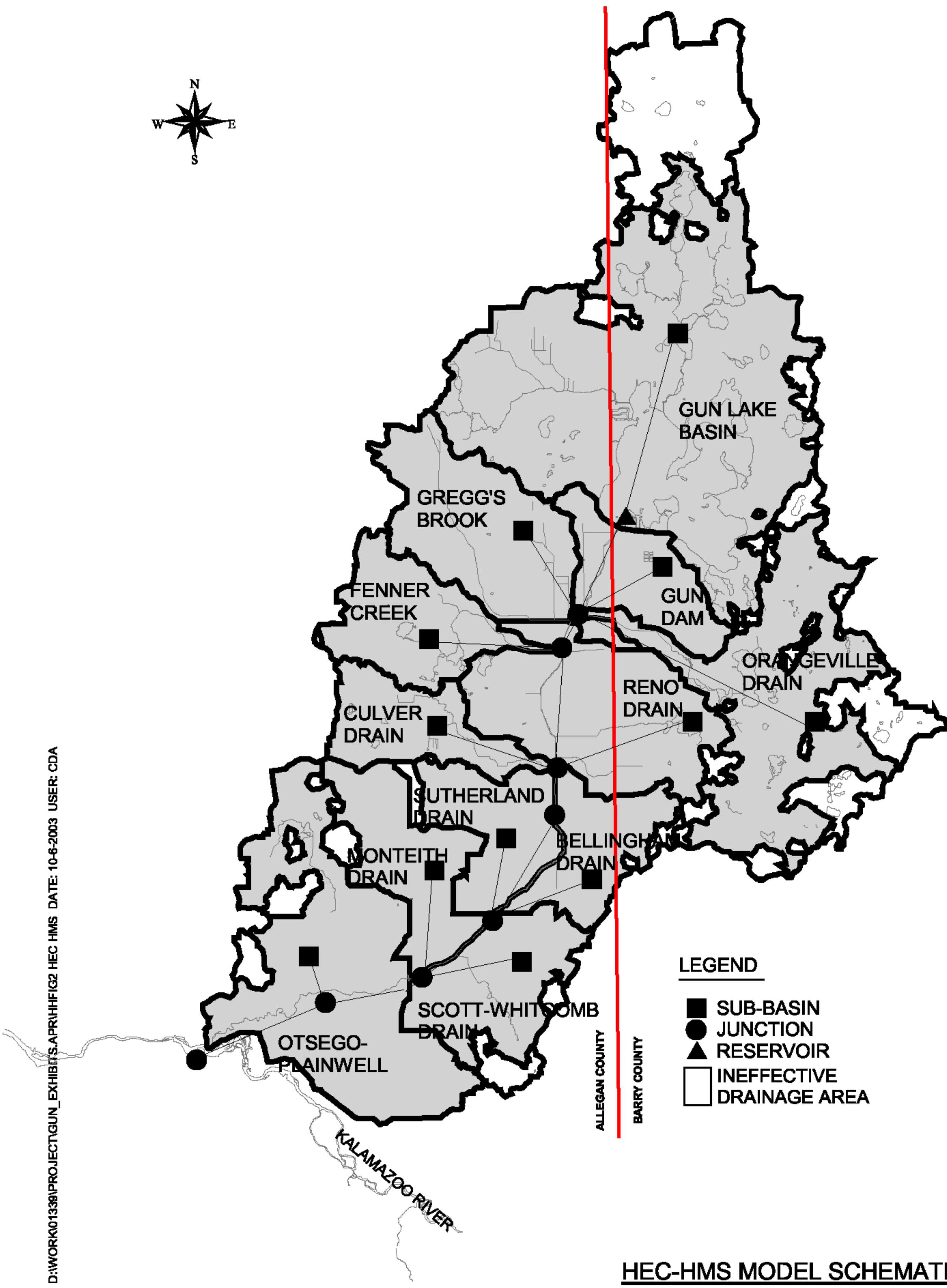
ftc&h

Allegan Conservation District
Allegan County, Michigan

Hydrologic and Hydraulic Analysis
of Gun River

PROJECT NO.
G01339

FIGURE NO.
1



D:\WORK\01339\PROJECT\GUN_EXHIBITS.APR\HHFIG2 HEC HMS DATE: 10-6-2003 USER: CDA

HEC-HMS MODEL SCHEMATIC

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Grand Rapids, Michigan

Allegan Conservation District
Allegan County, Michigan

Hydrologic and Hydraulic Analysis of Gun River

PROJECT NO. G01339

FIGURE NO. 2

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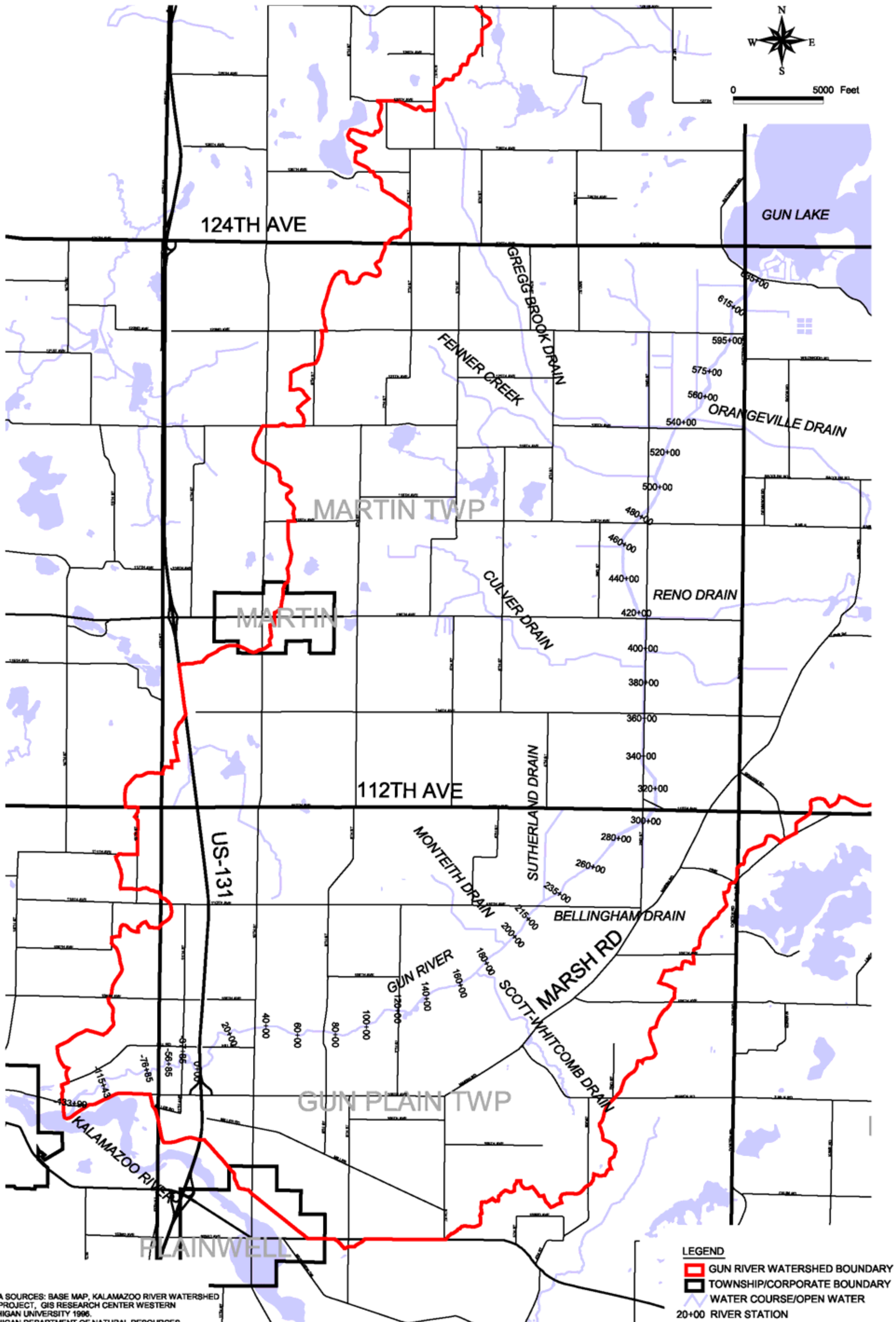


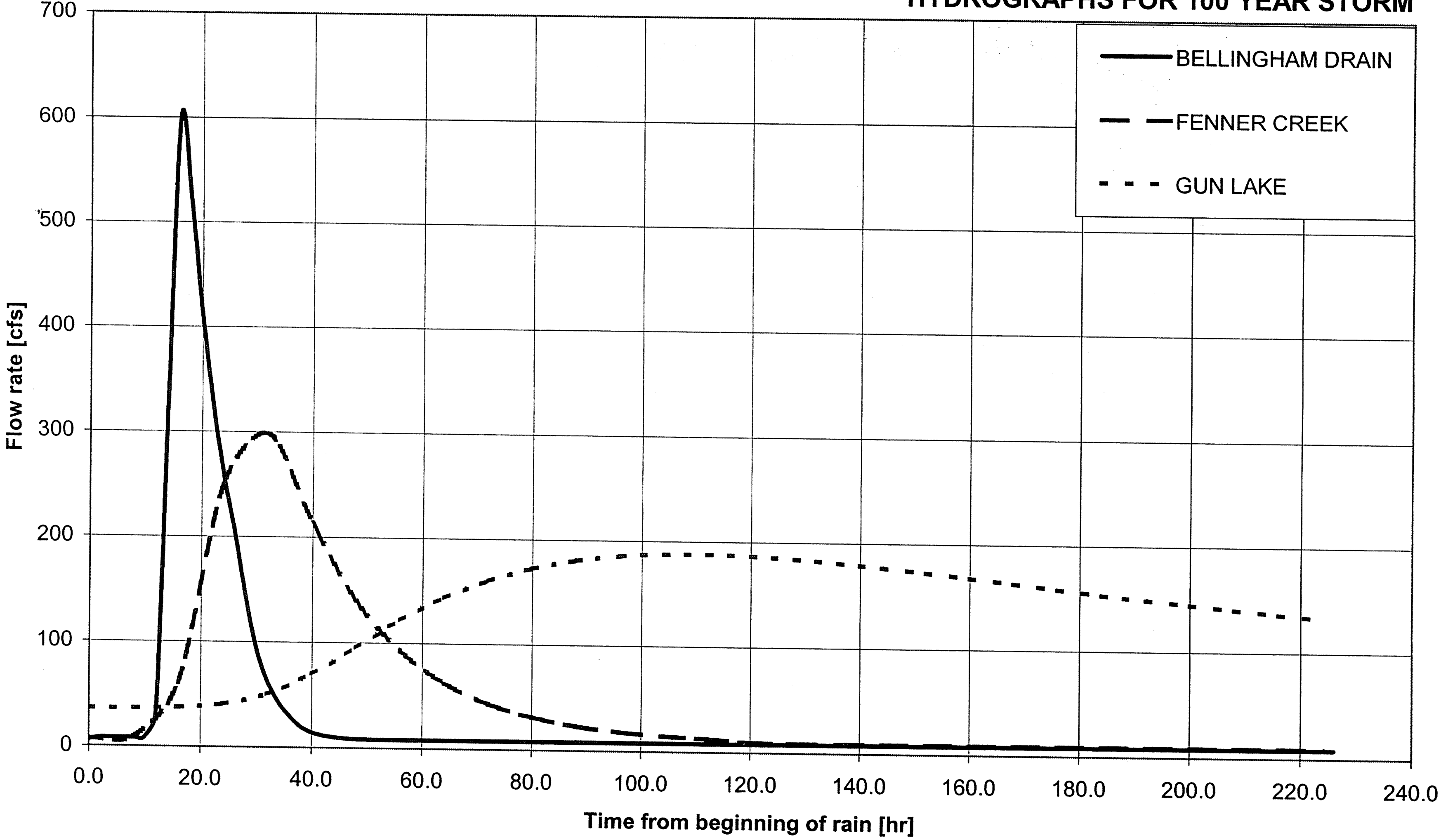
DATA SOURCES: BASE MAP, KALAMAZOO RIVER WATERSHED GIS PROJECT, GIS RESEARCH CENTER WESTERN MICHIGAN UNIVERSITY 1996.
MICHIGAN DEPARTMENT OF NATURAL RESOURCES MIRIS, 1978, SPCS NAD 27, US FEET.
WATERSHED DELINEATION, MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY GIS, DIGITAL SHEDS, 2001.

HEC-RAS CROSS SECTION MAP

PROJECT NO. G01339 / FIGURE NO. 3	Allegan Conservation District Allegan County, Michigan Hydrologic and Hydraulic Analysis of Gun River	Fishbeck, Thompson, Carr & Huber Engineers • Scientists • Architects Grand Rapids, Michigan

D:\WORK\01339\PROJECT\GUN_EXHIBITS.APR\HHFIG4 HYDRO DATE: 10-6-2003 USER: CDA

HYDROGRAPHS FOR 100 YEAR STORM



HYDROGRAPHS

PROJECT NO.	G01339
FIGURE NO.	4

Allegan Conservation District
Allegan County, Michigan

Hydrologic and Hydraulic Analysis of Gun River

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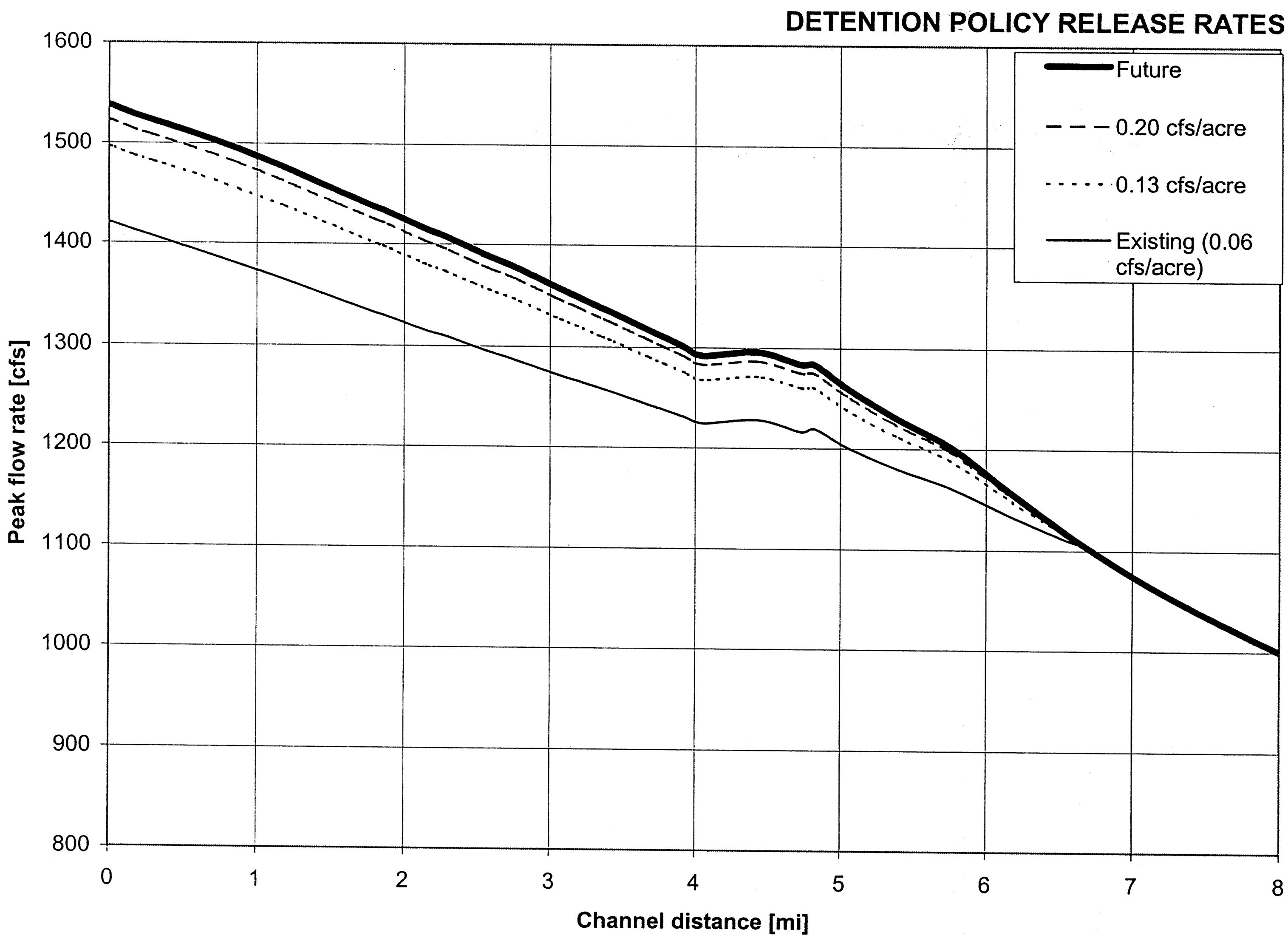
D:\WORK\01339\PROJECT\GUN_EXHIBITS.APR\HHFIG5 25YR DATE: 10-6-2003 USER: CDA



EXISTING AND FUTURE
25 YEAR FLOW RATES

PROJECT NO. G01339

FIGURE NO. 5

Allegan Conservation District
Allegan County, Michigan

Hydrologic and Hydraulic Analysis of Gun River

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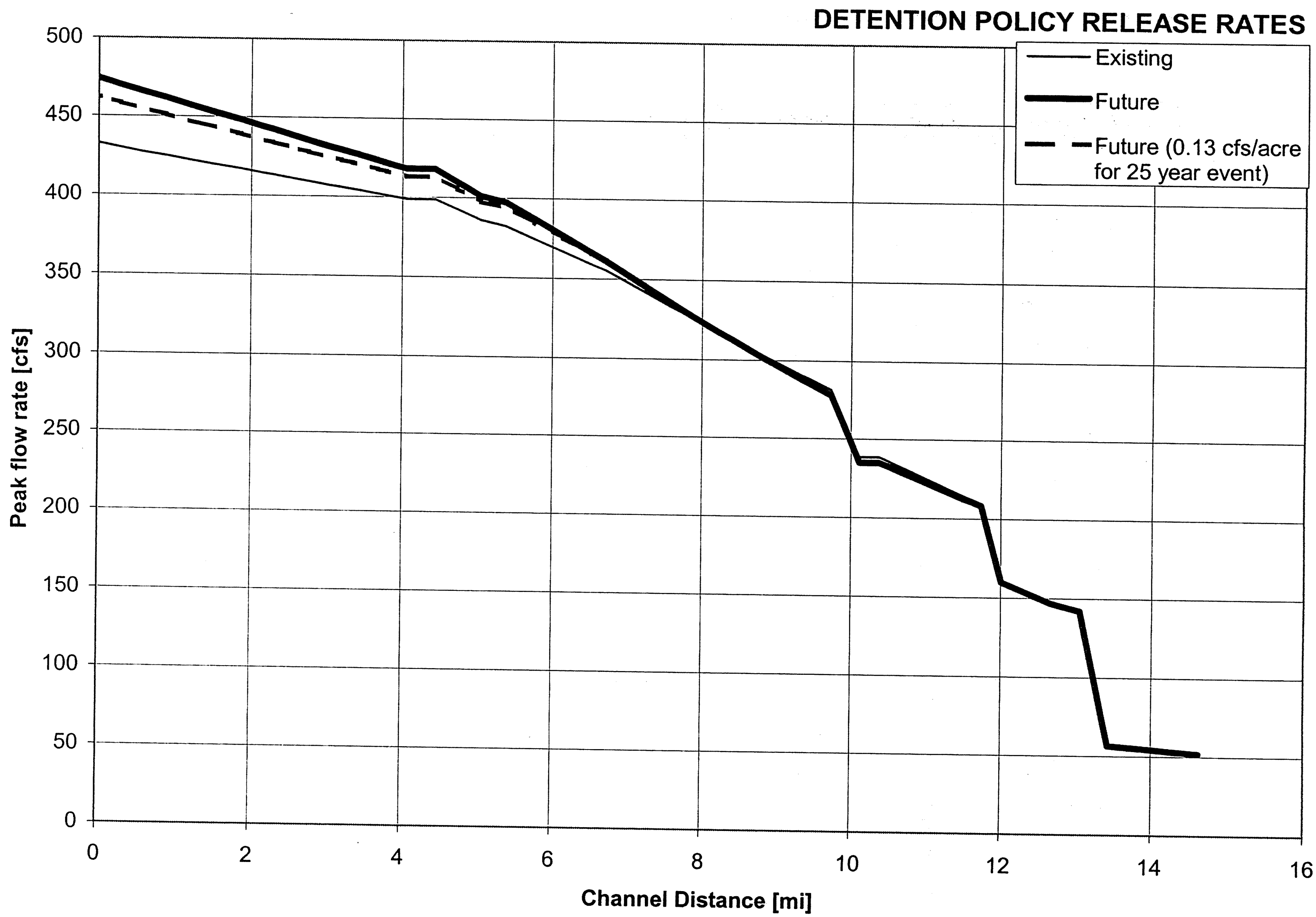
D:\WORK\01339\PROJECT\GUN_EXHIBITS.APR\HHFIG6 2YR DATE: 10-6-2003 USER: CDA



EXISTING AND FUTURE
2 YEAR FLOW RATES

PROJECT NO. G01339

FIGURE NO. 6

Allegan Conservation District
Allegan County, Michigan

Hydrologic and Hydraulic Analysis of Gun River

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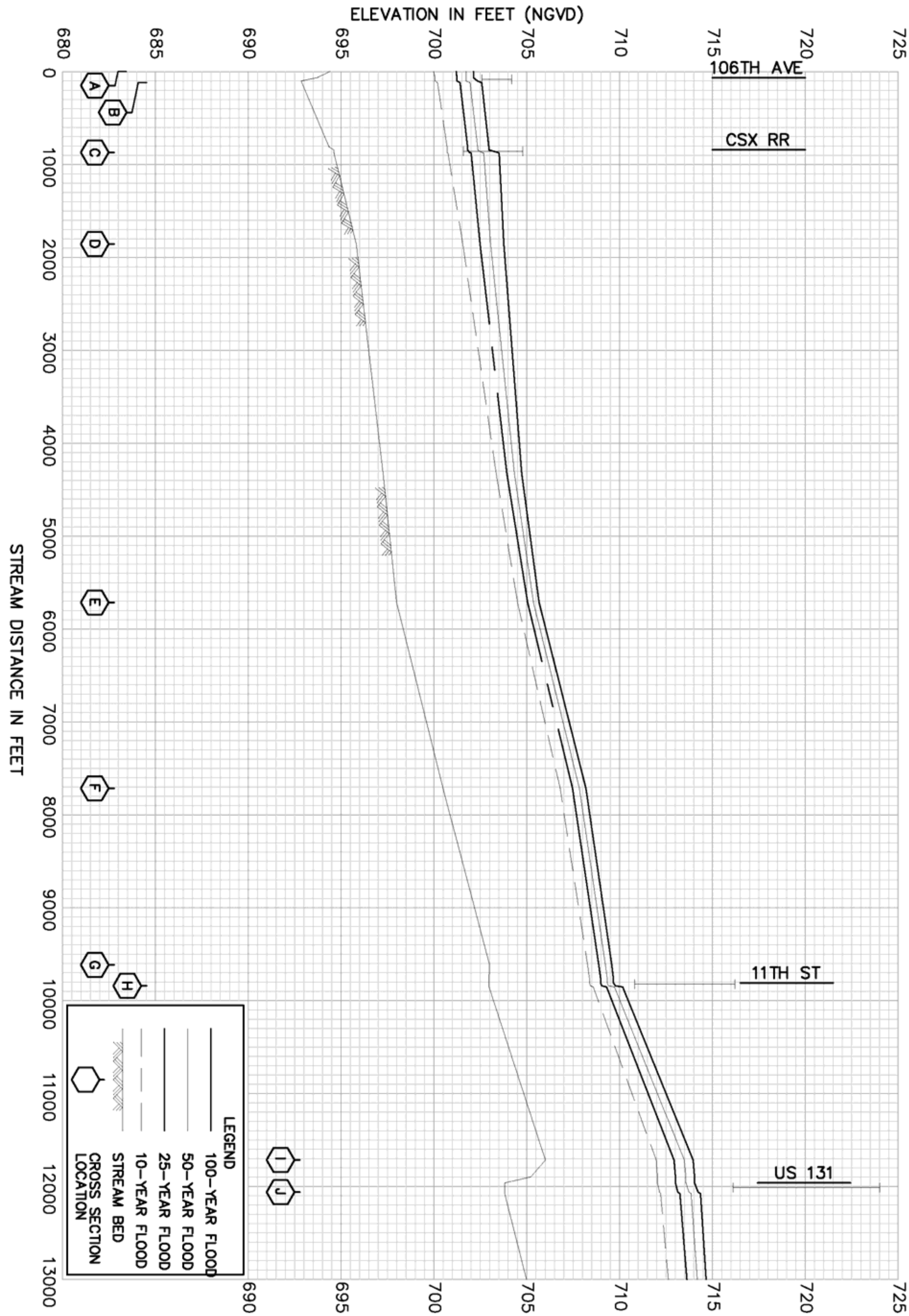
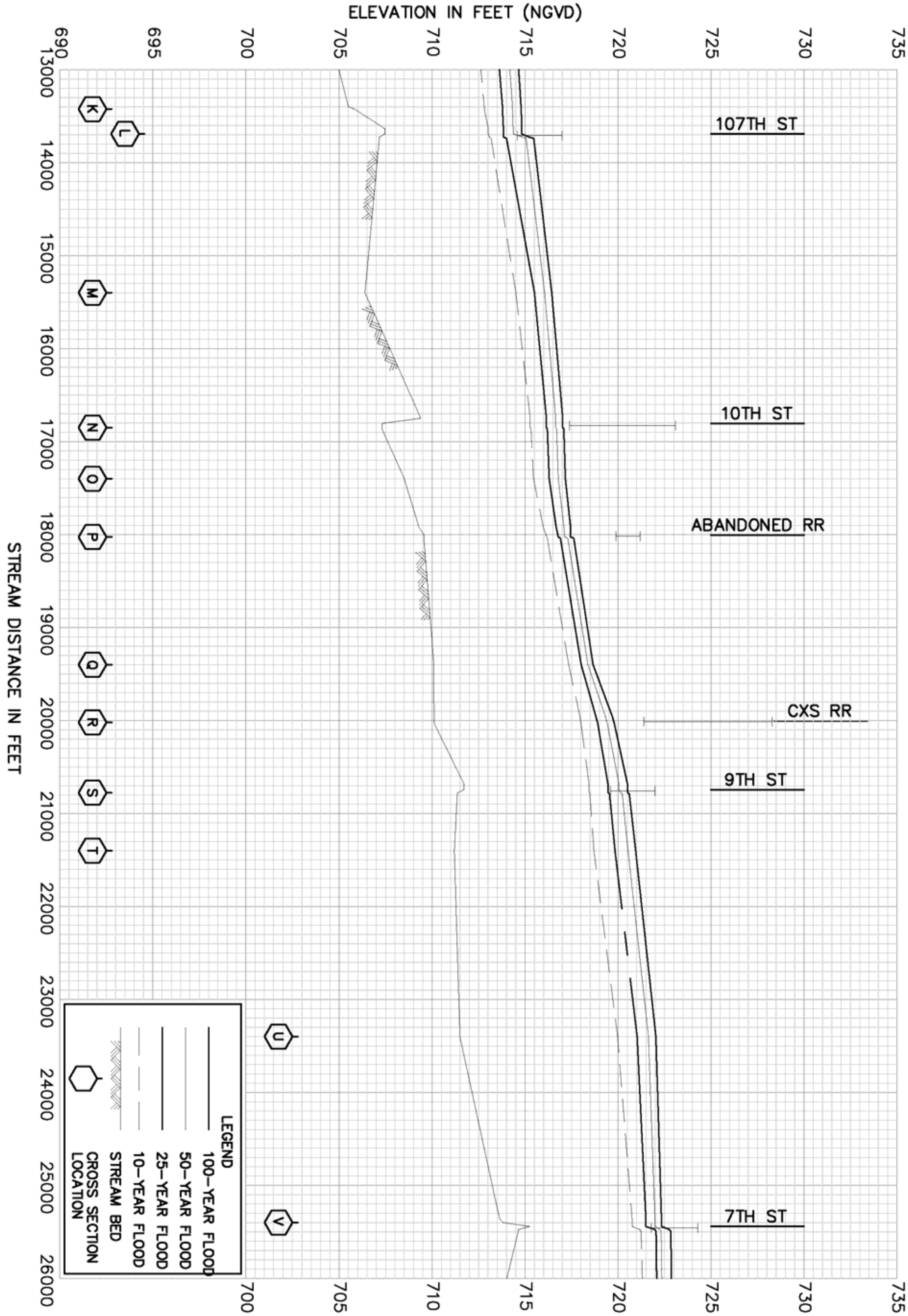


FLOOD PROFILES OF THE GUN RIVER

PROJECT NO G01339 FIGURE NO 7A	**Allegan Conservation District** Allegan County, Michigan Hydrologic and Hydraulic Analysis of Gun River	**Fishbeck, Thompson, Carr & Huber** Engineers • Scientists • Architects Grand Rapids, Michigan (616) 575-3824



FLOOD PROFILES OF THE GUN RIVER

PROJECT NO G01339 FIGURE NO **7B**	**Allegan Conservation District** Allegan County, Michigan Hydrologic and Hydraulic Analysis of Gun River	ftc&h **Fishbeck, Thompson, Carr & Huber** Engineers • Scientists • Architects Grand Rapids, Michigan (616) 575-3824

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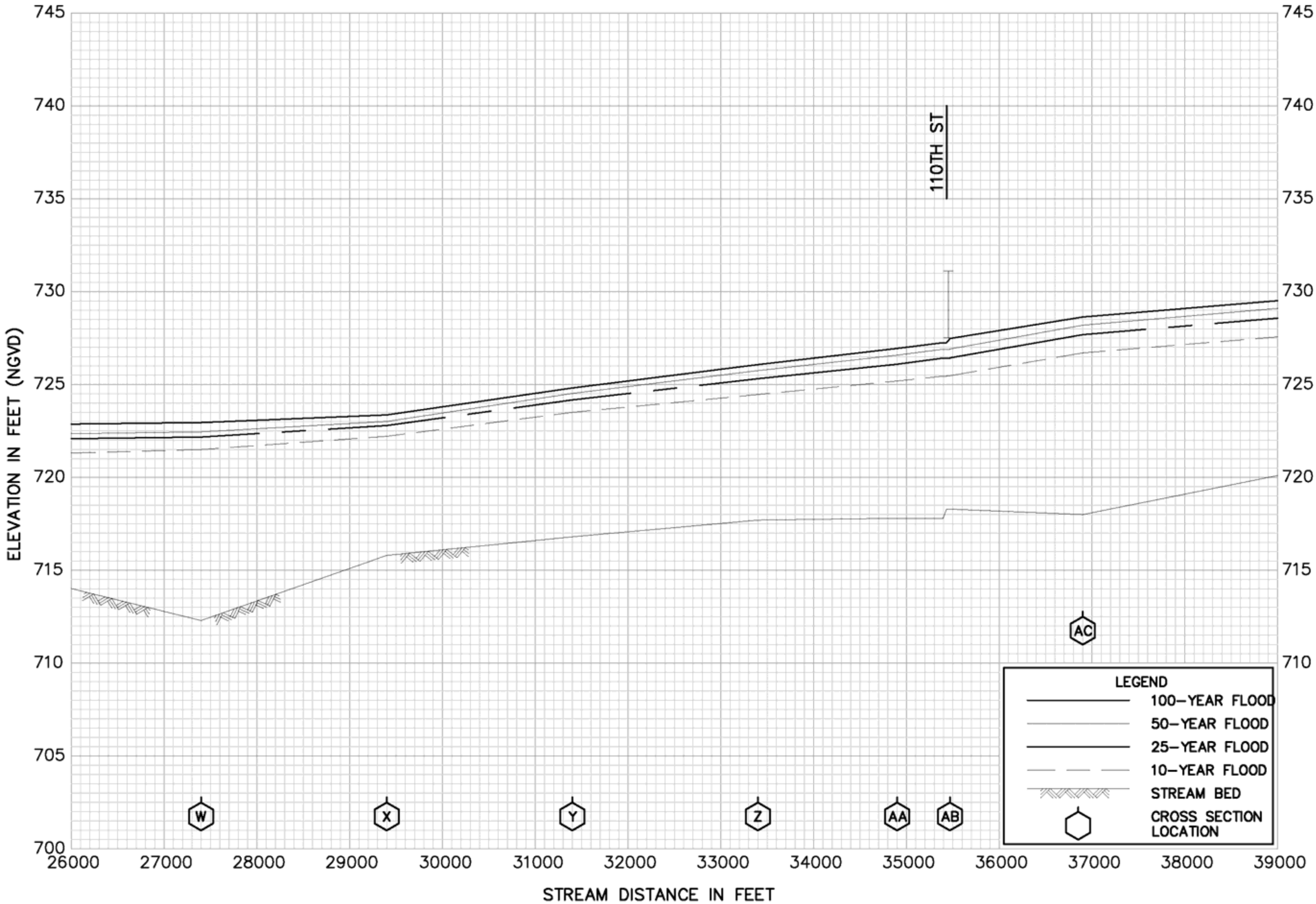

FLOOD PROFILES OF THE GUN RIVER

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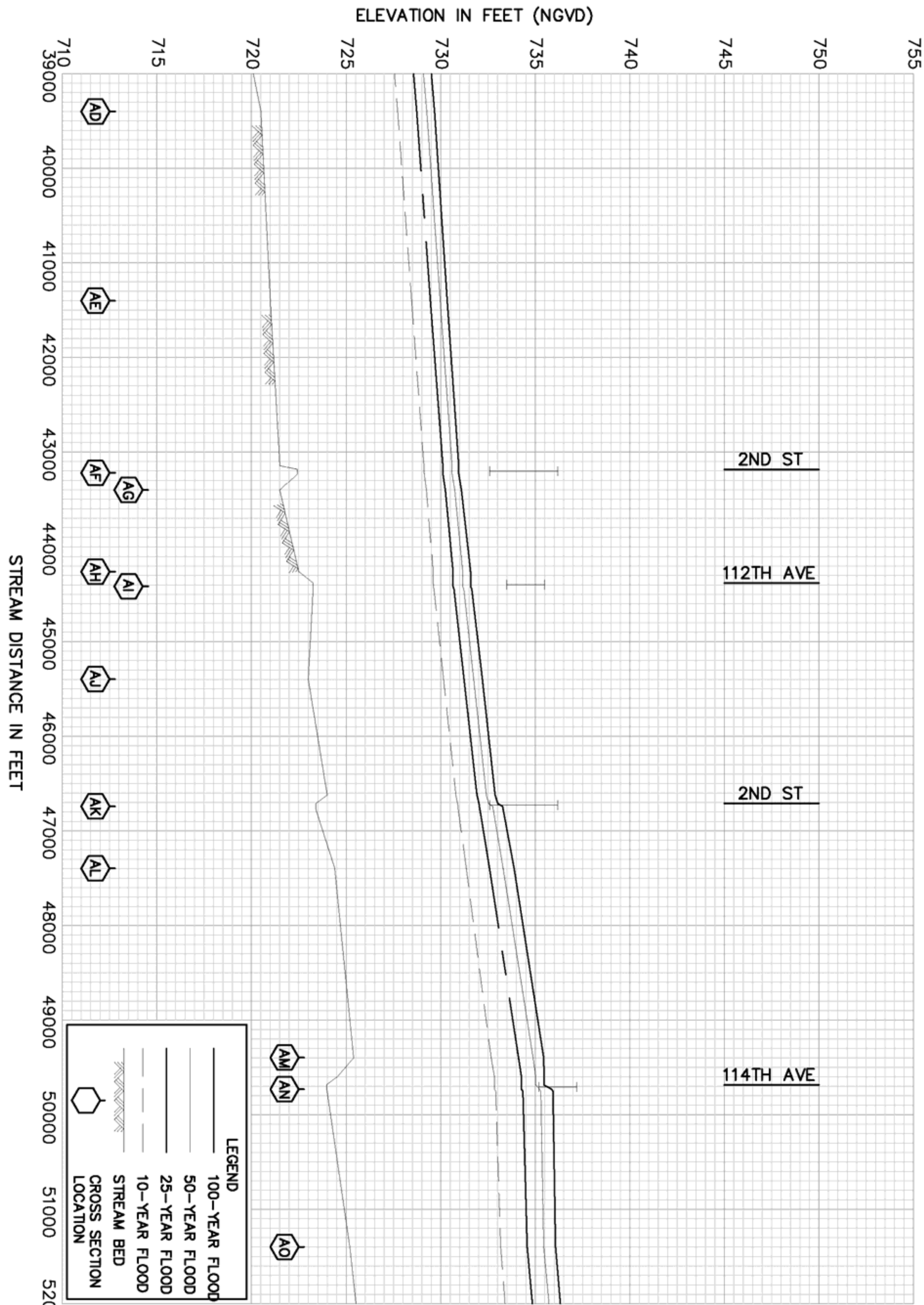
Allegan Conservation District
Allegan County, Michigan
Hydrologic and Hydraulic Analysis of Gun River

PROJECT NO. G01339
FIGURE NO. **7C**



FLOOD PROFILES OF THE GUN RIVER

FIGURE NO 7D

PROJECT NO G01339

Allegan Conservation District

Allegan County, Michigan

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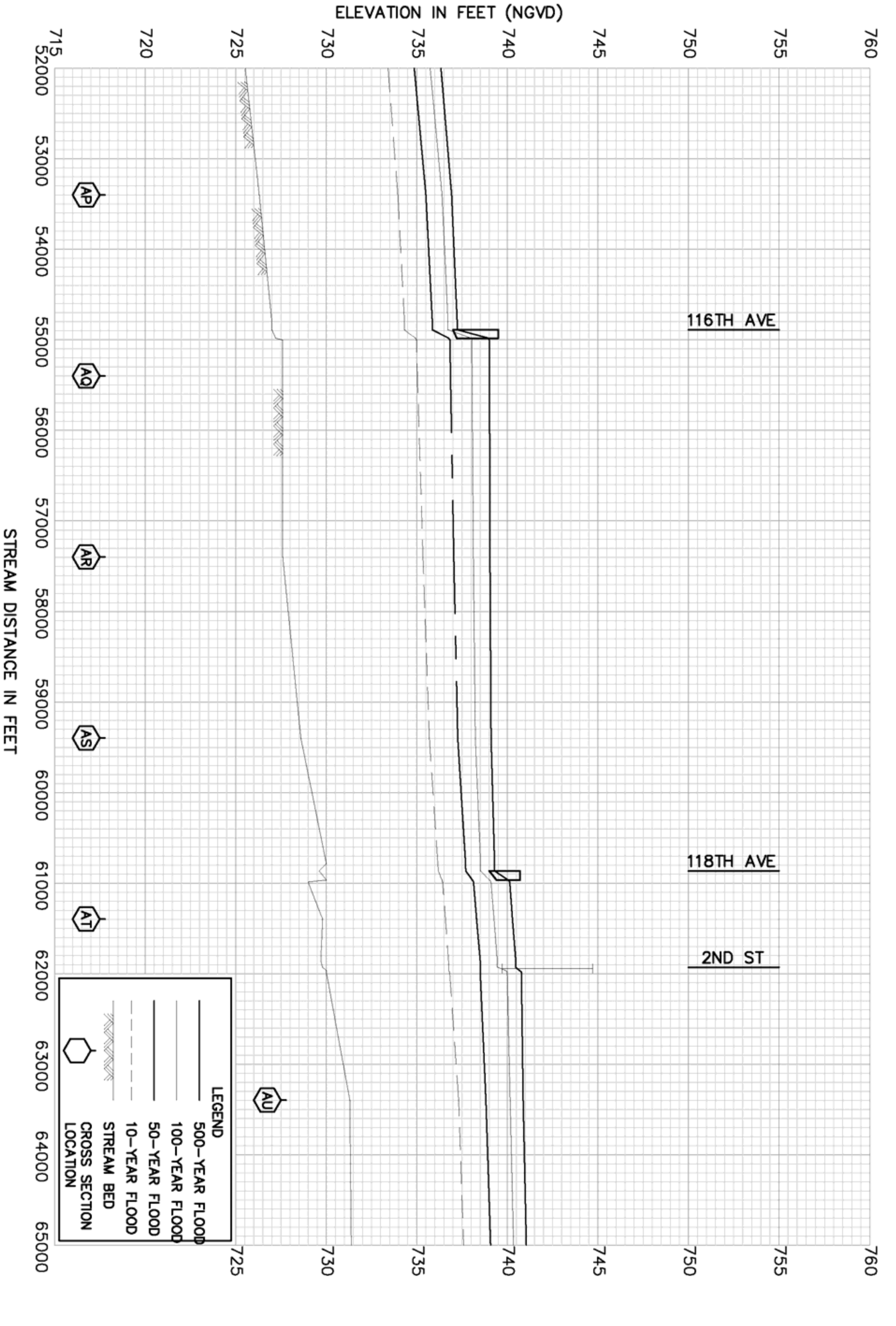

FLOOD PROFILES OF THE GUN RIVER

PROJECT NO. G01339
FIGURE NO. 7E

Allegan Conservation District
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Hydrologic and Hydraulic Analysis of Gun River

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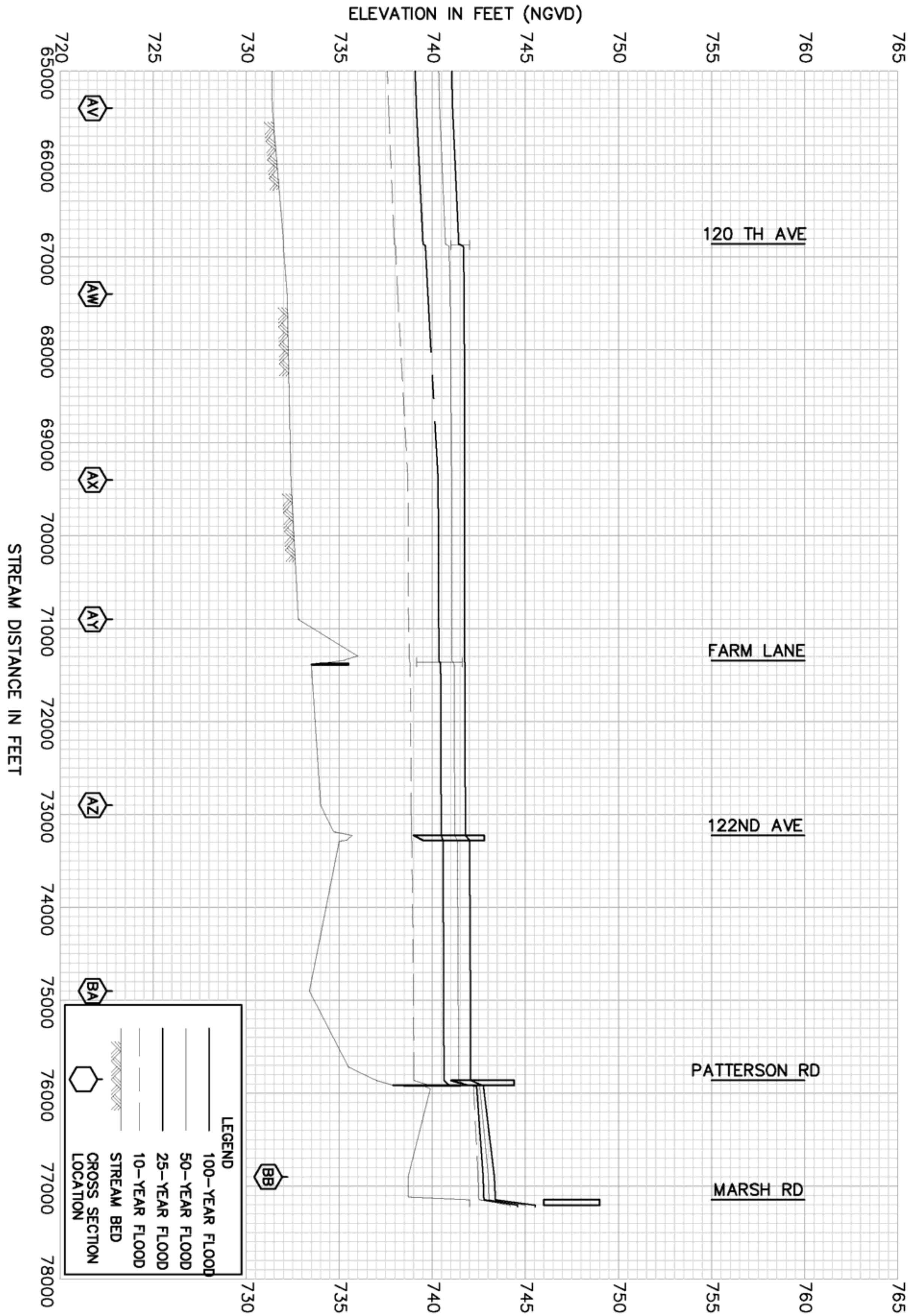

FLOOD PROFILES OF THE GUN RIVER

PROJECT NO. G01339	FIGURE NO. 7F

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Hydrologic and Hydraulic Analysis of Gun River

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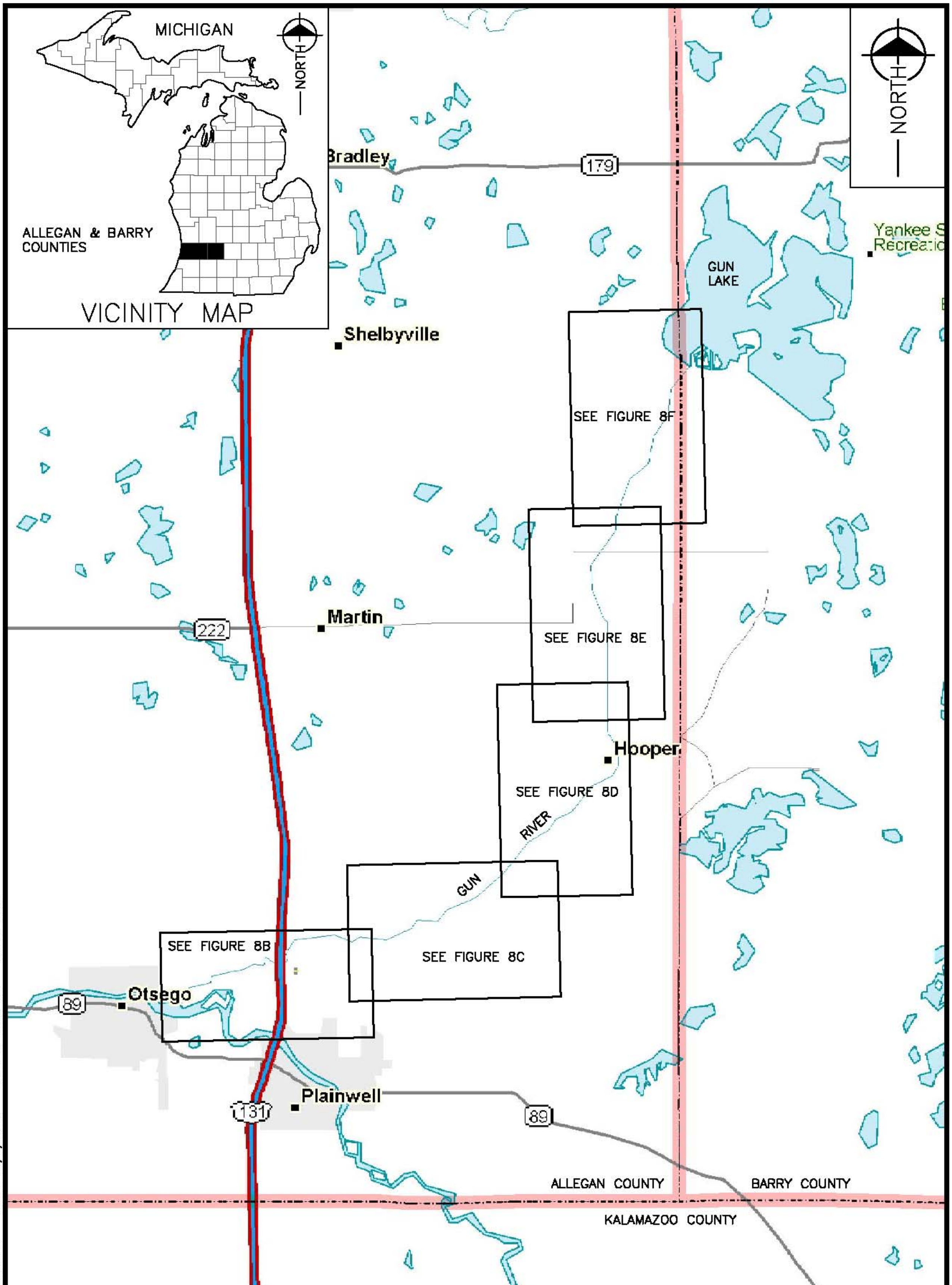

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VERSION 3.0.0
DATED: 2002

OVERVIEW MAP

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Allegan Conservation District
Allegan County, Michigan

Hydrologic & Hydraulic Analysis of Gun River

PROJECT NO. G01339
FIGURE NO. **8A**

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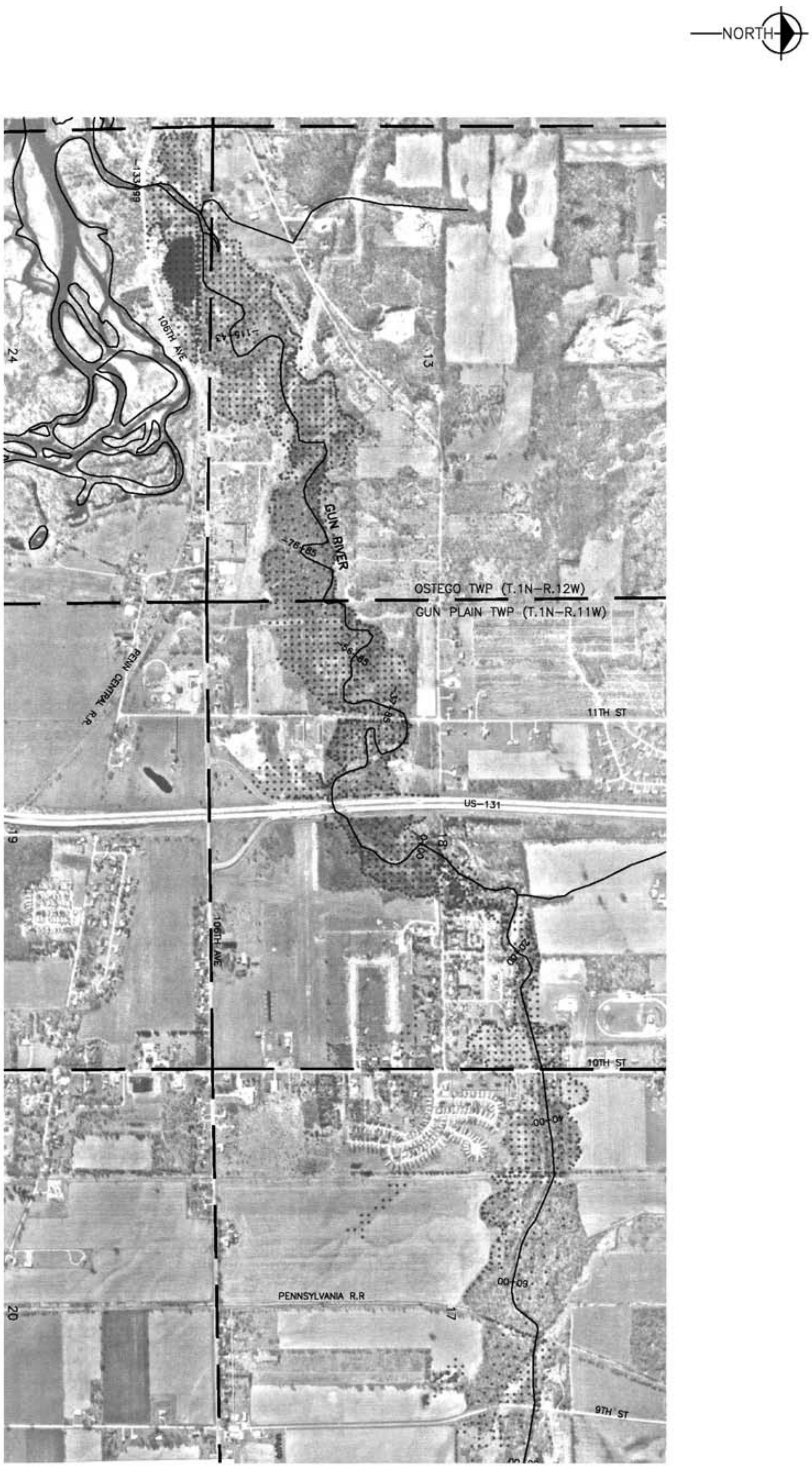

LEGEND

- WATERCOURSES
- SECTION LINES
- 100 YEAR FLOOD HAZARD ZONE
- 20+00 RIVER STATION

0 1,200 2,400

Scale: 1" = 1,200'

100-YEAR FLOOD HAZARD ZONE

PROJECT NO. G01339 FIGURE NO. 8B	**Allegan Conservation District** Allegan County, Michigan Hydrologic & Hydraulic Analysis of Gun River	**Fishbeck, Thompson, Carr & Huber** Engineers • Scientists • Architects Grand Rapids, Michigan (616) 575-3824

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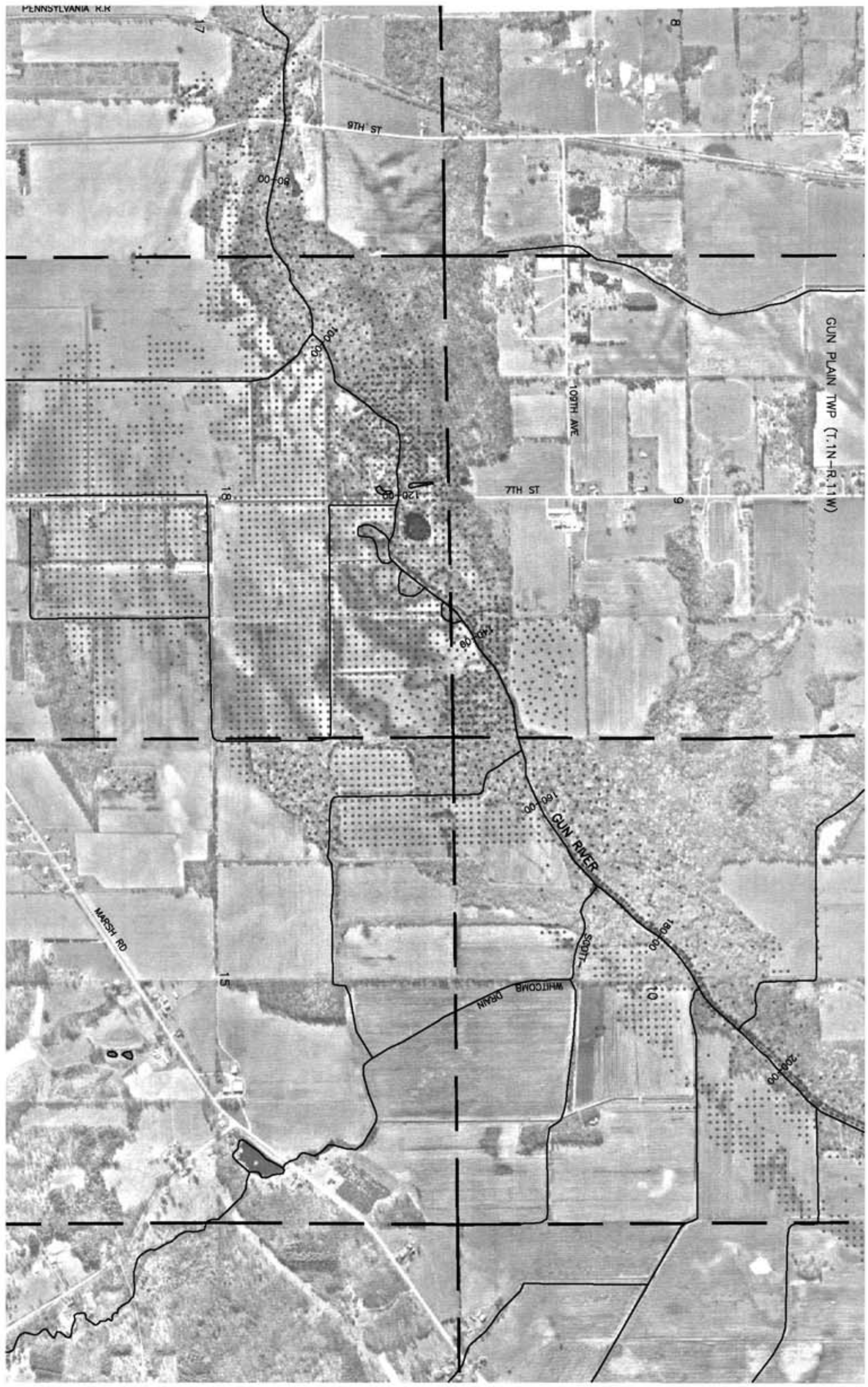
NORTH



LEGEND

- WATERCOURSES
- SECTION LINES
- 100 YEAR FLOOD HAZARD ZONE
- 20+00 RIVER STATION

0 1,200 2,400

Scale: 1" = 1,200'

100-YEAR FLOOD HAZARD ZONE

PROJECT NO. G01339 FIGURE NO. 8C	**Allegan Conservation District** Allegan County, Michigan Hydrologic & Hydraulic Analysis of Gun River	ftc&h	**Fishbeck, Thompson, Carr & Huber** Engineers • Scientists • Architects Grand Rapids, Michigan (616) 575-3824

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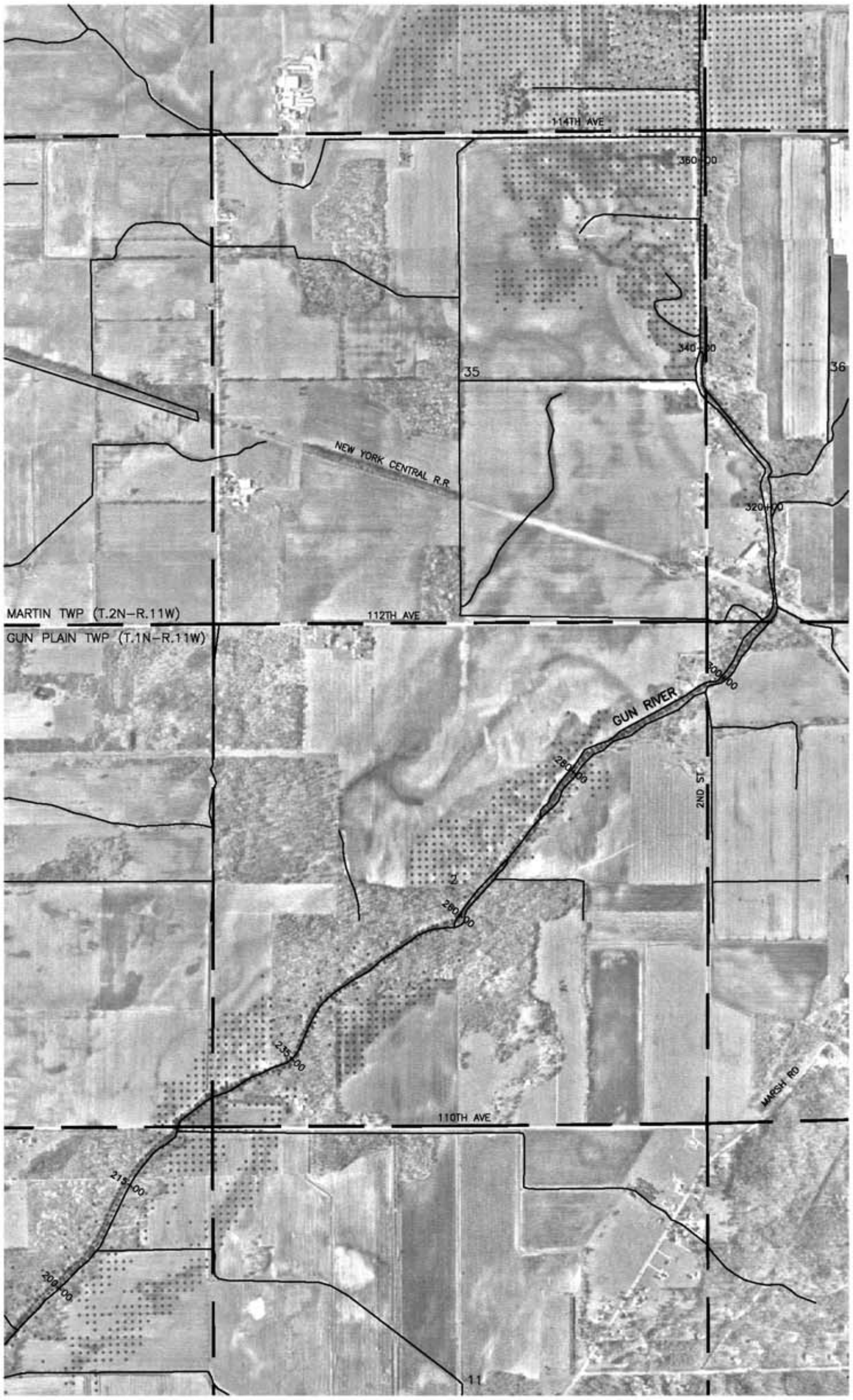
NORTH



LEGEND

- WATERCOURSES
- SECTION LINES
- 100 YEAR FLOOD HAZARD ZONE
- 20+00 RIVER STATION

0 1,200 2,400

Scale: 1" = 1,200'

100-YEAR FLOOD HAZARD ZONE

FIGURE NO. 8D	PROJECT NO. G01339	**Allegan Conservation District** Allegan County, Michigan Hydrologic & Hydraulic Analysis of Gun River	**Fishbeck, Thompson, Carr & Huber** Engineers • Scientists • Architects Grand Rapids, Michigan (616) 575-3824

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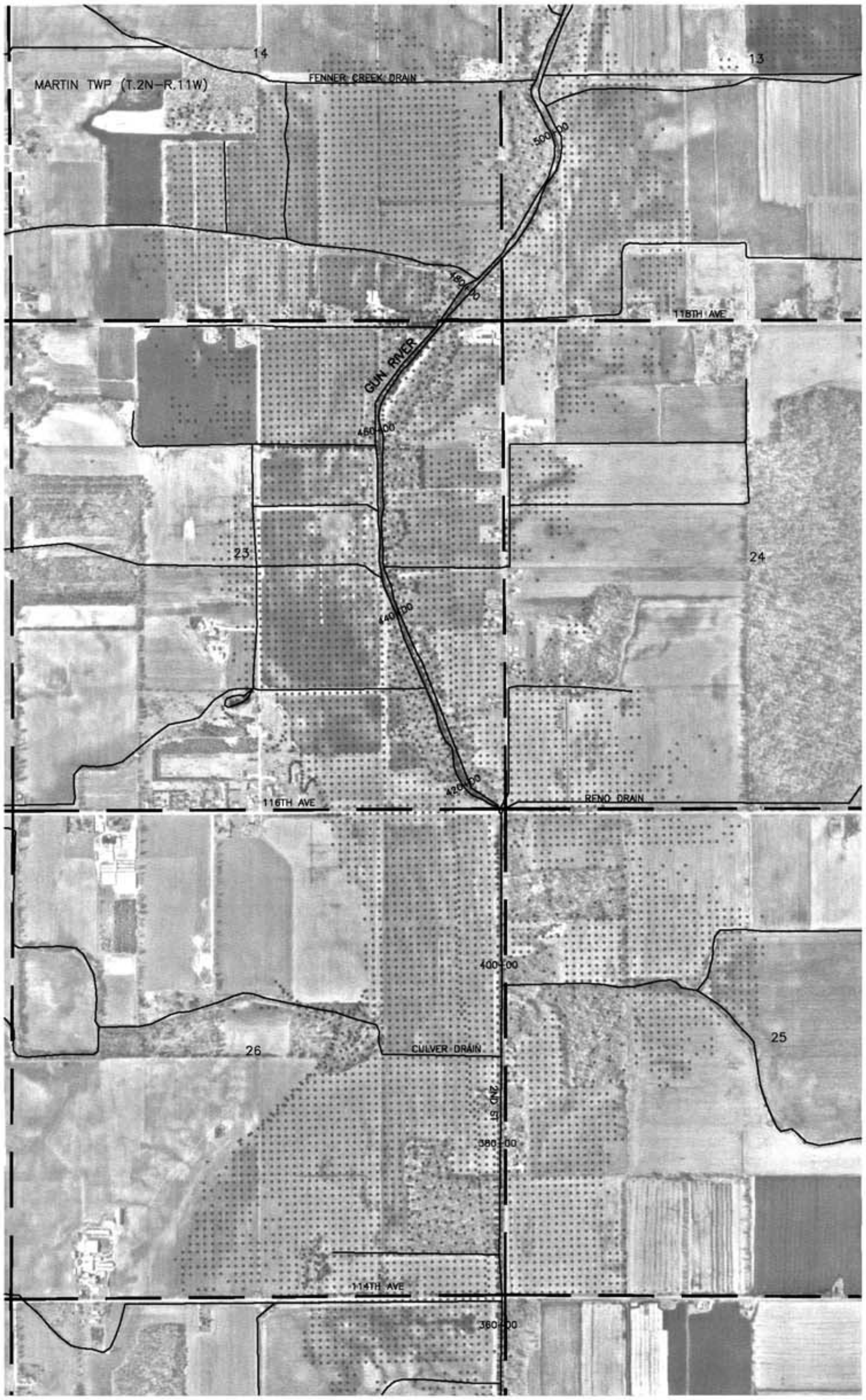
NORTH



LEGEND

— WATERCOURSES

— — SECTION LINES

100 YEAR FLOOD HAZARD ZONE

20+00 RIVER STATION

0 1,200 2,400

Scale: 1" = 1,200'

100-YEAR FLOOD HAZARD ZONE

FIGURE NO. 8E

PROJECT NO. G01339

Allegan Conservation District
Allegan County, Michigan

Hydrologic & Hydraulic Analysis of Gun River

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PLOT INFO: N:\01339\CD\Z00101339.DWG DATE: 10/7/2003 TIME: 2:12:53 PM USER: CDA

DATA SOURCES: PHOTOGRAPH &
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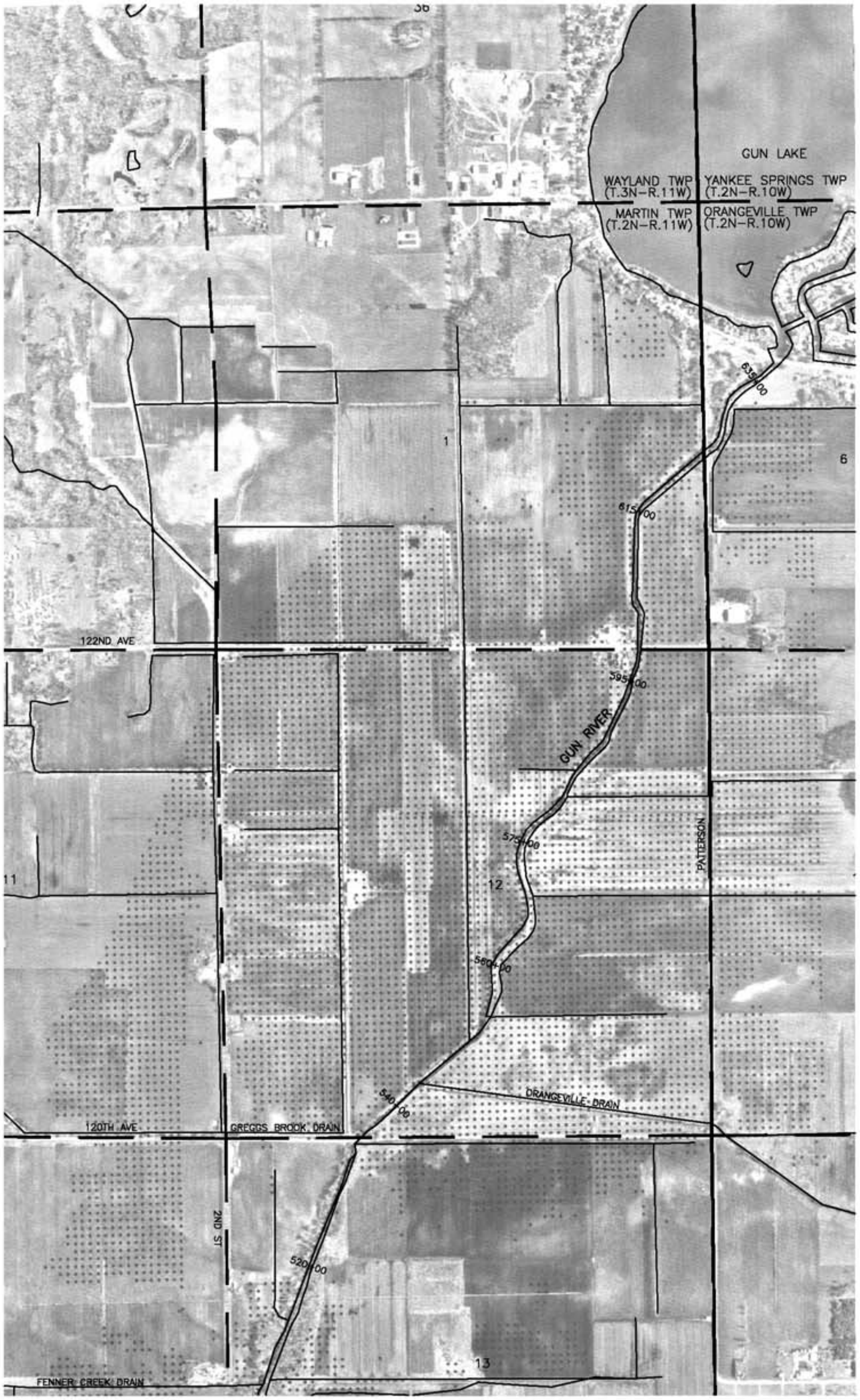
PROVIDED BY ALLEGAN COUNTY GIS.
RIVER AND SECTION LINES,
MICHIGAN FRAMEWORK VERSION 2A.

NORTH



LEGEND

- WATERCOURSES
- SECTION LINES
- 100 YEAR FLOOD HAZARD ZONE
- 20+00 RIVER STATION

0 — 1,200 — 2,400

Scale: 1" = 1,200'

100-YEAR FLOOD HAZARD ZONE

PROJECT NO. G01339 FIGURE NO. 8F	**Allegan Conservation District** Allegan County, Michigan Hydrologic & Hydraulic Analysis of Gun River	ftc&h Fishbeck, Thompson, Carr & Huber Engineers • Scientists • Architects Grand Rapids, Michigan (616) 575-3824