HoustonEngineering Inc.

JD 18 – Hydraulic Assistance to Viewers

Joint County Ditch Board

HEI#: 1940-001

ENGINEER'S REPORT

JOINT COUNTY DITCH BOARD
JD-18 HYDRAULIC ASSISTANCE TO VIEWERS

May 2013

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision, and that I am a duly Licensed Engineer under the laws of the State of Minnesota.

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List of Data on Digital Data CD

- Shapefile: Swift_Flooded_ Acres_quarterquarter (Attributed with 10-year Acres Flooded: As Built, Current, Pre Project, and Pre Project plus 4 feet)
- Shapefile: Kandiyohi_Flooded_ Acres_Parcels (Attributed with 10-year Acres Flooded: As Built, Current, Pre Project, and Pre Project plus 4 feet)
- Shapefile: Chippewa_Flooded_ Acres_Parcels (Attributed with 10-year Acres Flooded: As Built, Current, Pre Project, and Pre Project plus 4 feet)
- Shapefile: AsBuilt_10yr_SCS_FloodPoly
- Shapefile: Current_10yr_USGS_FloodPoly
- Shapefile: PreProject_10yr_MNDOT_FloodPoly
- Shapefile: PreProject_plus4_10yr_MNDOT_FloodPoly
- Shapefile: Current_2yr_USGS_FloodPoly
- Shapefile: AsBuilt_2yr_MNDOT_FloodPoly
- Shapefile: PreProject_2yr_MNDOT_FloodPoly
- PDF: Scanned Plan Set

INTRODUCTION

The Joint County Ditch #18 Board (Board) has appointed Viewers to complete a Redetermination of Benefits on the ditch. The Viewers of Joint County Ditch #18 have requested that Houston Engineering Inc. provide hydraulic analysis and floodplain mapping of the 10-year flood along Ditch #18. The viewers have requested that hydraulic analysis and floodplain mapping be completed of the ditch in order to allow quantification of the 10-year water surface elevation; and to determine the extents of the associated floodplain along the ditch for the As Built Condition and the Pre-Project Condition.

In 1954 the Soil and Conservation Service (SCS, now NRCS), began a watershed project in the JD #18 basin. The project was constructed around 1960 including a channel improvement in a reach of approximately 30 miles, construction of two flood retarding reservoirs and other land management measures. The system of structures and land management measures was designed to eliminate flooding in the watershed from 1-year to 10-year events.

1 DATA

Several sources of data were used to develop the hydrology, hydraulic models, and floodplain mapping for both the as built condition and pre-construction condition.

- The "Judicial Ditch 18, Chippewa River Tributaries and Hawk Creek Watershed Protection Project, Shakopee Creek Watershed" plan set. (As Built Plans) This plan set is dated June 1956.
- 2010 MN DNR LiDAR data for Swift, Chippewa, and Kandiyohi Counties.
- Minnesota Historical Aerial Photographs available from the John R. Borchert Map Library. Photographs from the 1930's and 1950's were available for the area and utilized.
- NRCS Study – Watershed Rehabilitation, Shakopee Lake Dam. This study of the Shakopee Lake structure was completed in December 2007 and includes a HEC-HMS hydrologic model of the current watershed.
- MN DNR, Pre-settlement Vegetation data
- USDA-NRCS, Hydrologic Soil Groups
- USGS, National Land Cover Database 2006
- USDA-SCS, Hydrology Guide for Minnesota
- Minnesota Department of Transportation, Drainage Manual, St. Paul, MN July 1, 1963
- USGS- Lorenz, D.L., Sanocki, C.A., and Kocian, M.J., 2009, Techniques for estimating the magnitude and frequency of peak flows on Small Streams in Minnesota based on data through water year 2005: U.S. Geological Survey Scientific Investigations Report 2009–5250, 54 p. http://streamstats.usgs.gov/

2 HYDROLOGY

1) SCS DESIGN HYDROLOGY

The hydrology developed in 1956 utilized Meyers curves #3 and #4 to develop uncontrolled discharges along JD18. These curves are based on the basin characteristic of drainage area. Time of concentration was calculated and a hydrograph was developed and routed through the Florida lake structure, utilizing a storage curve for the lake and a spillway discharge curve.

The resulting hydrograph was used for the uncontrolled area upstream of Florida Lake, Meyer's curves and the peak discharges were then used to determine an adjusted drainage area at Florida Lake. This adjusted drainage area is equal to the uncontrolled drainage area that would result in the same discharge

using Meyer's curves. Any additional drainage area at points downstream from Lake Florida was added to this working drainage area and Meyer's curves were again used to determine the discharge. A hydrograph was developed at Swan Lake and again routed through the lake and structure. The same methods were used to calculate peak discharges downstream of Swan Lake and Shakopee Lake.

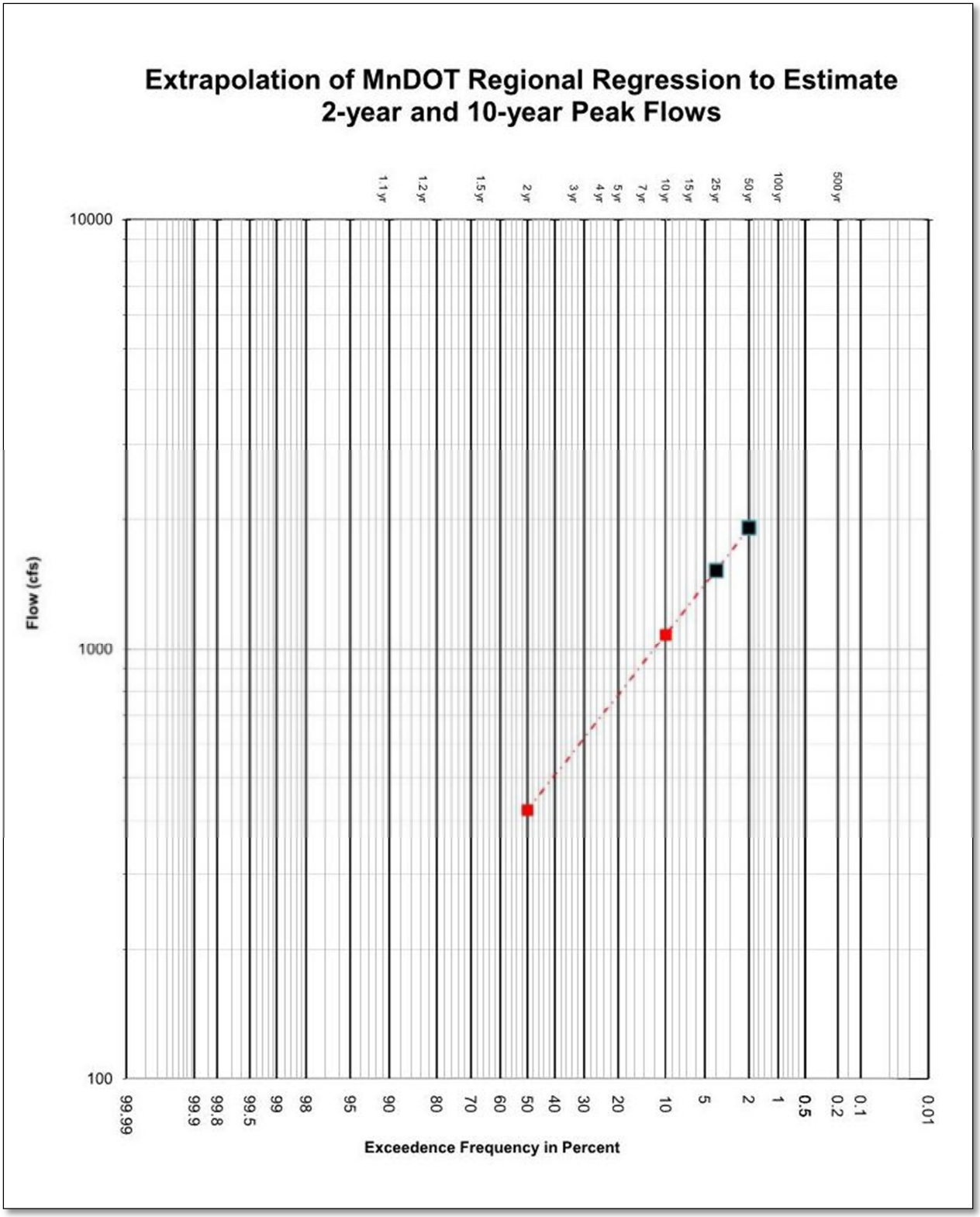
Meyer's curves are now out of print and unavailable. The drainage area and design 10-year and 25-year discharges are shown in the as built plan set for numerous points along JD18.

The following table shows the as built design discharges computed by the SCS in 1956.

2) MNDOT DRAINAGE MANUAL

We used the Minnesota Department of Transportation regional regression equations published in 1963 as an estimate of the pre-project flows within the project watershed. The MnDOT Drainage Manual published in 1963 included regional regression equations for estimating 50-year peak flows based upon the region of the State, the drainage area and watershed characteristics. The manual also provides a factor to determine the 25-year design peak flow as a function of the 50-year flow. For the Central Lakes Region regression equation, a K value of 90 was selected due to the following description: "Relatively flat agricultural lands to gently rolling timberlands with considerable storage in ponds, swamps or lakes." A copy of the MnDOT Drainage Manual Central Lakes regression chart is included in Appendix A. We also determined the 2-year and 10-year peak flow estimates based upon linear extrapolation on a log-normal plot of the 25-year and 50-year flows. **Figure 1** provides a graphical example of the 2-year and 10-year extrapolation technique.

Figure 1: Extrapolation of MnDOT Regional Regression



3) USGS REGRESSION EQUATIONS AND STREAM STATS (2009)

We have used the USGS regional regression equations published in 2009 as an estimate of the current peak flows within the project watershed. The USGS report "Techniques for Estimating…Peak Flows on Small Streams in Minnesota…" USGS SIR 2009-5250 contains the most recent USGS regression equations for Minnesota. The equations for the project area (Region D) utilize the following basin characteristics to estimate peak stream flow for a range of design flood events: drainage area, main-channel slope, percent lake area, and generalized mean annual runoff. Minnesota Stream Stats, an interactive website application, was used to determine the watershed characteristics for use in the regression equations and to calculate the discharges at various points along the reach. **Table 1** shows the resultant discharge estimates and basin characteristics.

Table 1: Basin Characteristics and USGS Discharges

Location	DA*	SLOPE*	LAKE*	RUNOFF*	2yr	10yr
DS Swan Lake	104	4.44	11	3.79	197	556
Hwy 104	108	7.1	10.52	3.79	199	562
Hwy 12	125	3.79	9.1	3.77	224	642
Section Line of 1 and 6	141	3.62	8.1	3.75	248	720
DS Shakopee Lake	202	4.06	5.86	3.68	373	1120
Hwy 29	256	3.9	4.64	3.62	463	1430
Confluence with Chippewa River	319	3.63	3.72	3.56	556	1760

**DA, drainage area in square miles; SLOPE, main-channel slope in ft./mile; LAKE, percent area lakes and ponds; RUNOFF, generalized mean annual runoff in MN 1951-85*

4) HYDROLOGY COMPARISON AND DISCUSSION

The discharges calculated using the 1963 MNDOT regression equations were used to represent pre-project flows. The SCS As built flows (1960) were used to represent the condition at the time of construction. The USGS (2009) flows were used to simulate the current peak flows.

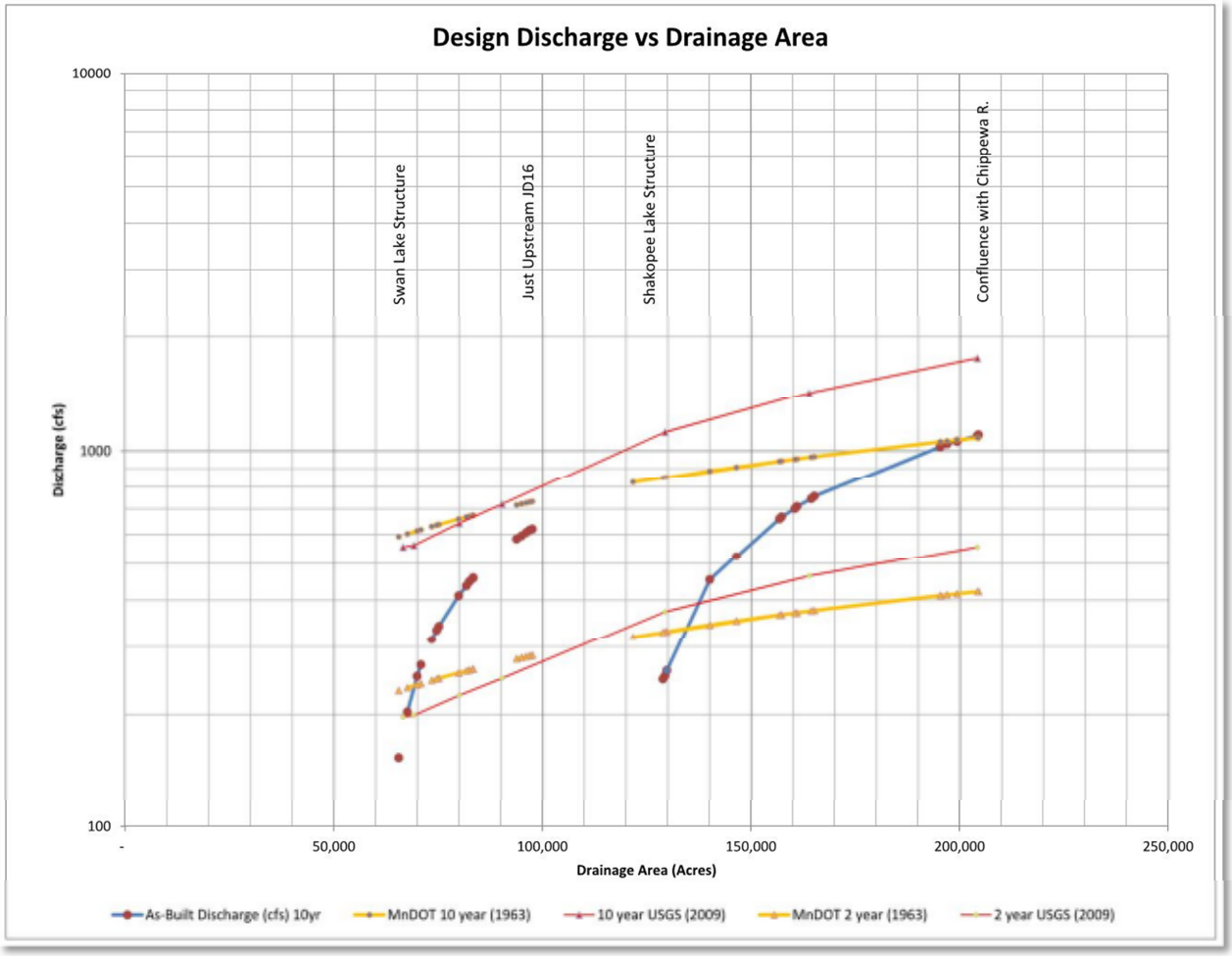
The USGS regressions equations may provide a conservative estimate of the current 2-year and 10-year peak flows along JD 18, since the Shakopee Lake and Swan Lake flood control reservoirs are not specifically considered in the regional regression equations—except as part of the lakes and pond area regression parameter.

Table 2 below summarizes the resultant hydrologic data from all the methods described above. **Figure 2** compares 10-year design flows developed using the as built discharges calculated by SCS in 1956, the 2-year and 10-year peak flows determined using the MnDOT regional regression equation of 1963, and 2-year and 10-year peak flows determined using the current USGS regression equations of 2009.

Table 2: Hydrology

		Pre Project Condition		As Built Condition	Current Condition	
Location	**Actual Drainage Area (Acres)**	**MNDOT (1963)**	**MNDOT (1963)**	**As Built SCS (1956)**	**USGS (2009)**	**USGS (2009)**
		10yr	**2yr**	**10yr**	**10yr**	**2yr**
Downstream Reach						
53+29	204,416	1083	422	1103	1760	556
56+35	204,218	1082	421	1099		
85+00	199,271	1068	416	1060		
113+57	196,890	1062	413	1044		
154+00	195,341	1057	411	1035		
201+90	195,226	1057	411	1026		
220+00	165,082	967	376	755		
251+27	164,359	965	376	744	1430	463
271+00	160,928	954	371	710		
330+61	160,455	953	371	701		
334+00	157,232	942	367	667		
438+62	121,629	822	320			
467+53	156,755	941	366	659		
544+02	146,407	907	353	524		
561+96	140,045	886	345	453		
590+70	129,735	851	331	260		
645+64	129,357	850	331	252		
693+78 Shakopee Lake Structure	128,813	848	330	247	1120	373
A Reach						
842+42	97,533	732	285	620		
857+00	96,854	729	284	616		
898+36	96,061	726	282	607		
955+08	94,934	721	281	595		
972+00	93,744	716	279	584	720	248
1005+00 End A reach						
B reach						
1217+98	83,376	673	262	458		
1247+82	83,235	673	262	456		
1287+58	82,416	669	260	447		
1336+28	81,718	666	259	436		
1379+72	79,882	658	256	411	642	224
1390+00	75,152	637	248	342		
1425+50	74,602	635	247	334		
1441+30 End of B Reach	73,418	629	245	314		
C Reach						
1551+48	70,826	618	240	269	562	199
1611+20	69,923	613	239	251		
1660+00	67,574	602	234	203		
1702+50 Swan Lake	65,520	593	231	153	556	197

Figure 2: Design Discharge vs. Drainage Area



5) UPSTREAM WATERSHED CHANGES IN LANDUSE

Changes in landuse in the upper watershed, both prior and post construction of the project can impact the volume of water downstream. A large portion of the watershed has changed since settlement from prairie to cultivated crops. To quantify these impacts, SCS curve numbers for the watershed were calculated. The following data was used to calculate a pre-settlement and current curve numbers:

- MN DNR, Pre-settlement Vegetation data
- USDA-NRCS, Hydrologic Soil Groups
- USGS, National Land Cover Database 2006
- USDA-SCS, Hydrology Guide for Minnesota

Curve number calculations were performed using ArcGIS software. A soil hydrologic group classification layer and land use data were utilized along with the methods outlined in the Hydrology Guide for Minnesota to compute the curve numbers. The DNR Pre-settlement vegetation layer and USGS National Land Cover Layers were used for pre-settlement and current curve number calculations respectively. Soils with dual hydrologic soil groups were assumed to be drained for current calculations and undrained for pre-settlement calculations. **Table 3** shows the prevalence of land cover type and the curve numbers used for each soil type for the pre-settlement curve number calculations.

Table 3: Presettlement Curve Numbers

Pre-settlement Vegetation	SCS Cover Type	Acres	Percent	SCS Curve Number By Soil Type			
				A	B	C	D
Wet Prairie	Meadow (All type D)	28638	14.0%	78	78	78	78
Lakes (open water)	Water Surfaces	8839	4.3%	100	100	100	100
Oak openings and barrens	Woods	9087	4.5%	36	60	73	79
Brush Prairie	Average: Meadow and Brush	351	0.2%	32.5	57	70.5	77.5
Prairie	Meadow	155401	76.2%	30	58	71	78
Big Woods - Hardwoods (oak, maple, basswood, hickory)	Woods	1590	0.8%	36	60	73	79

Table 4 shows the prevalence of land cover type and the curve numbers used for each soil type for the current curve number calculations.

Table 4: Current Curve Numbers

Land Use/ Land Cover	SCS Cover Type	Acres	Percent	SCS Curve Number By Soil Type			
				A	B	C	D
Open Water	Water Surfaces	9530	4.67%	100	100	100	100
Developed, Open Space	Developed Open Space	7596	3.73%	49	69	79	84
Developed, Low Intensity	Low Density Residential	1552	0.76%	47	65	76	82
Developed, Medium Intensity	Medium Density Residential	149	0.07%	54	70	79	84
Developed, High Intensity	High Density Residential	30	0.01%	70	81	87	90
Barren Land	Fallow	98	0.05%	77	86	91	94
Deciduous Forest	Woods	6237	3.06%	36	60	73	79
Evergreen Forest	Woods	185	0.09%	36	60	73	79
Mixed Forest	Woods	10	0.00%	36	60	73	79
Shrub/Scrub	Meadow	1452	0.71%	30	58	71	78
Grassland/Herbaceous	Meadow	2731	1.34%	30	58	71	78
Pasture/Hay	Pasture	10750	5.27%	49	69	79	84
Cultivated Crops	Row Crops, C&T <2% Slope	156956	76.97%	62	71	78	81
Woody Wetlands	Meadow (All type D)	715	0.35%	78	78	78	78
Emergent Herbaceous Wetlands	Meadow (All type D)	5916	2.90%	78	78	78	78

The NRCS Study reports that lands in the watershed were 64% agricultural as of the 1955 work plan. The current watershed is 77% agricultural. As shown in the previous tables the major change between presettlement to current landuse is the change from prairie to cultivated crops and undrained to drained soil conditions.

Curve numbers for the As built project condition were computed based upon the runoff expected at Florida Lake, Swan Lake and Shakopee Lake for the 10-year, 25-year, 50-year and 100-year events. **Table 5** lists the curve numbers we computed for the drainage area to each lake based upon the as built plan design runoff and the corresponding precipitation depth.

Table 5: As Built Curve Numbers

Design Event	Design Runoff (inches) (I-F)	Precipitation P from TP 40 (inches)	CN (by trial)	S = (1000-10*CN)/CN	Runoff Q = ((P - .2*S)^2)/(P + .8*S) (inches)	Difference (inches)
Florida Lake				Sheets 81, 82 and 83 of 89		
10-year	1.07	4.0	66	5.15	1.09	0.02
25-year	1.25	4.6	63	5.87	1.26	0.01
50-year	1.5	5.2	61	6.39	1.49	-0.01
100-year	1.74	5.75	60	6.67	1.76	0.02
Swan Lake				Sheets 84, 85 and 86 of 89		
10-year	1.07	4.0	66	5.15	1.09	0.02
25-year	1.25	4.6	63	5.87	1.26	0.01
50-year	1.5	5.2	61	6.39	1.49	-0.01
100-year	1.74	5.75	60	6.67	1.76	0.02
Shakopee Lake				Sheets 87, 88 and 89 of 89		
10-year	0.71	4.0	59	6.95	0.71	0.00
25-year	0.83	4.6	56	7.86	0.84	0.01
50-year	1.0	5.2	54	8.52	1.02	0.02
100-year	1.2	5.75	53	8.87	1.23	0.03

An average curve number for the watershed was calculated by averaging all the curve numbers within the watershed, weighted by area. **Table 6** displays the resultant average curve numbers. The As built curve numbers were taken from the above table, using the 10-year frequency. **Figure 3** and **Figure 4** show the pre-settlement and current curve numbers spatially.

Table 6: Summary of Calculated Curve Numbers

Location	Confluence with Chippewa River	Shakopee Lake	Swan Lake	Florida Lake
Area (sq. mi.)	318.6	202.4	103.8	71.1
Pre-settlement	68.9	69.5	71.3	72.2
As Built Plans	NA	59	66	66
Current	71.9	72.3	73.3	73.5

Figure 3: Presettlement Curve Numbers

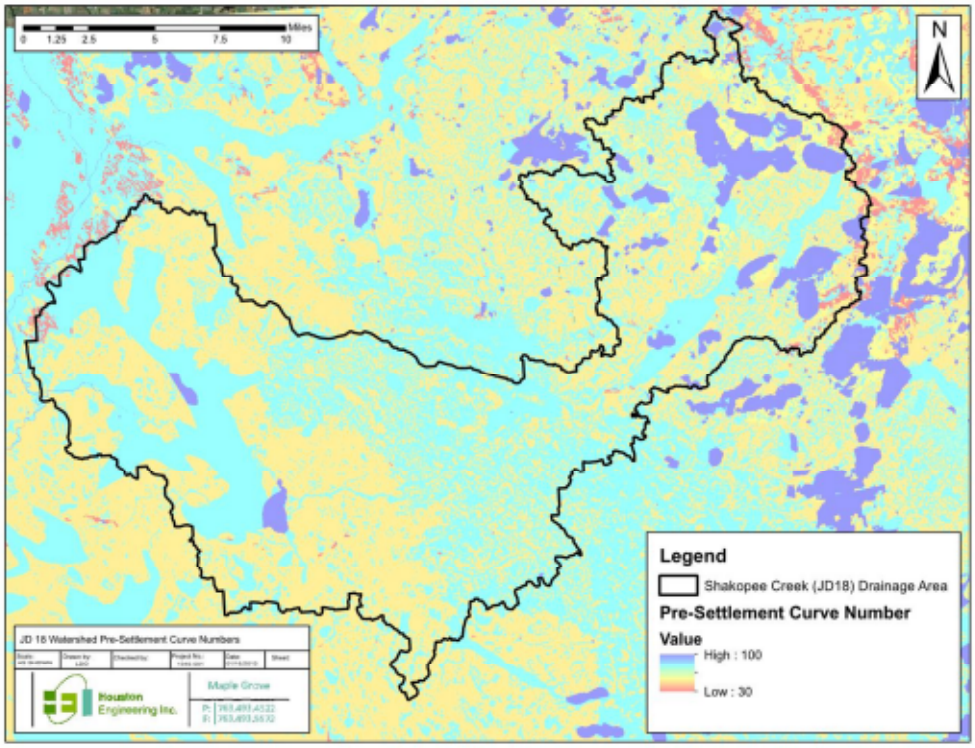
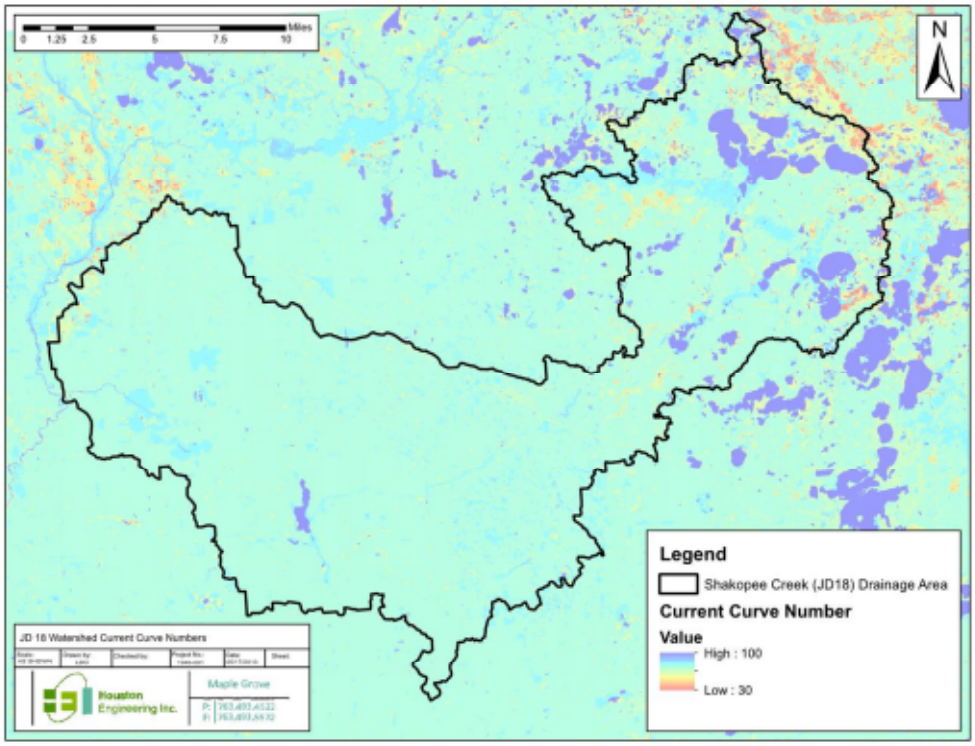


Figure 4: Current Curve Numbers



The SCS Runoff method was used to determine an average runoff for the basin based on 24-hr rainfall for various frequencies shown in the Hydrology Guide for MN. The SCS method uses the following equations:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Where:

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

$$P \geq 0.2S, else\ Q = 0$$
$$Q = Direct\ Runoff\ (in.)$$
$$P = Rainfall\ (in.)$$
$$CN = SCS\ Curve\ Number$$

Table 7 shows the direct runoff values calculated using the SCS method.

Table 7: Runoff

Location		Average CN	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
	24-yr Rainfall (in.) (MN Hydrology Guide)		2.2	2.6	3.4	4.0	4.6	5.2	5.8
Florida Lake	Pre-settlement Runoff (in.)	72.2	0.39	0.59	1.07	1.47	1.91	2.37	2.85
	Current Runoff (in.)	73.5	0.43	0.64	1.14	1.56	2.01	2.48	2.97
	Increase:		11%	9%	7%	6%	5%	5%	4%
Swan Lake	Pre-settlement Runoff (in.)	71.3	0.36	0.55	1.02	1.41	1.84	2.29	2.77
	Current Runoff (in.)	73.3	0.42	0.64	1.13	1.55	1.99	2.46	2.95
	Increase:		18%	15%	11%	9%	8%	7%	7%
Shakopee Lake	Pre-settlement Runoff (in.)	69.5	0.31	0.49	0.92	1.30	1.71	2.14	2.60
	Current Runoff (in.)	72.3	0.39	0.59	1.07	1.48	1.92	2.38	2.86
	Increase:		28%	22%	17%	14%	12%	11%	10%
Chippewa River	Pre-settlement Runoff (in.)	68.9	0.29	0.46	0.89	1.26	1.66	2.09	2.55
	Current Runoff (in.)	71.9	0.38	0.55	1.01	1.40	1.83	2.28	2.75
	Increase:		30%	24%	18%	15%	13%	12%	11%

This shows that during a 10-yr 24-hr rainfall the volume of runoff in the watershed has increased by 15% based on changes in landuse between the pre-settlement condition and the current watershed condition.

3 HYDRAULICS

An HEC-RAS hydraulic model (version 4.1.0) was developed to determine the water surface profiles in the JD 18 channel for various design flood events. Topography for the HEC-RAS model came from a combination of data from the 1956 plan set, and LIDAR developed in 2010 by the MN DNR.

Manning's "n" values for the constructed channel reaches were set to match the plans, 0.028 and 0.032 accordingly. Any previously channelized stream or ditch reaches used Manning's "n" values of 0.032. Non-channelized stream reaches used "n" values of 0.045. All overbanks used a Manning's n value of 0.07 to reflect shallow floodplains and agricultural landuses.

Structures at Swan Lake and Shakopee Lake were added to the model using as built data and the 1956 plan set. No other crossings were simulated, as they were assumed to have a negligible effect on the 2-year and 10-year water surface elevation profiles.

A conversion of 0.6 ft was used to convert the 1956 plan set elevations in NGVD29, to NAVD88. For example, NGVD29 elevation + 0.6 = NAVD88 elevation

1) AS BUILT GEOMETRY

The 1956 plan set included channel slopes, bottom widths, channel bottom elevations, manning's n-values and side slopes for the constructed channel. The channel modification tool in HEC-RAS was used to combine the constructed channel with the cross section station-elevation data developed from LiDAR. Areas where the channel was not modified as part of the 1956 project were copied from the pre-construction geometry.

The As built alignment and reach lengths were developed based on LiDAR using HEC-GeoRAS (Version 10).

2) PRE-CONSTRUCTION GEOMETRY

Topography for the HEC-RAS model came from a combination of data from the 1956 plan set, and LIDAR developed in 2010 by the MN DNR. At some bridge crossings, pre-construction cross sections are shown in the 1956 plan set. These cross sections were entered into HEC-RAS at the appropriate station. At 100 foot intervals, the interpolation tool in HEC-RAS was used to interpolate channel shape. This channel was combined with the cross section station-elevation data developed from LiDAR. Channel bottoms were adjusted to reflect the existing channel bottom shown on the profile in the 1956 plan set. Several cross sections exist upstream from cross section data available at structures. For these, a generalized channel was used, and adjusted to match the existing channel bottom in the 1956 plan set.

The pre-construction alignment and reach lengths were developed based on Minnesota historical aerial photographs available from the John R. Borchert Map Library. Photographs from the 1930's and 1950's were available for the area and utilized to digitize a pre-construction alignment using HEC-GeoRAS (Version 10).

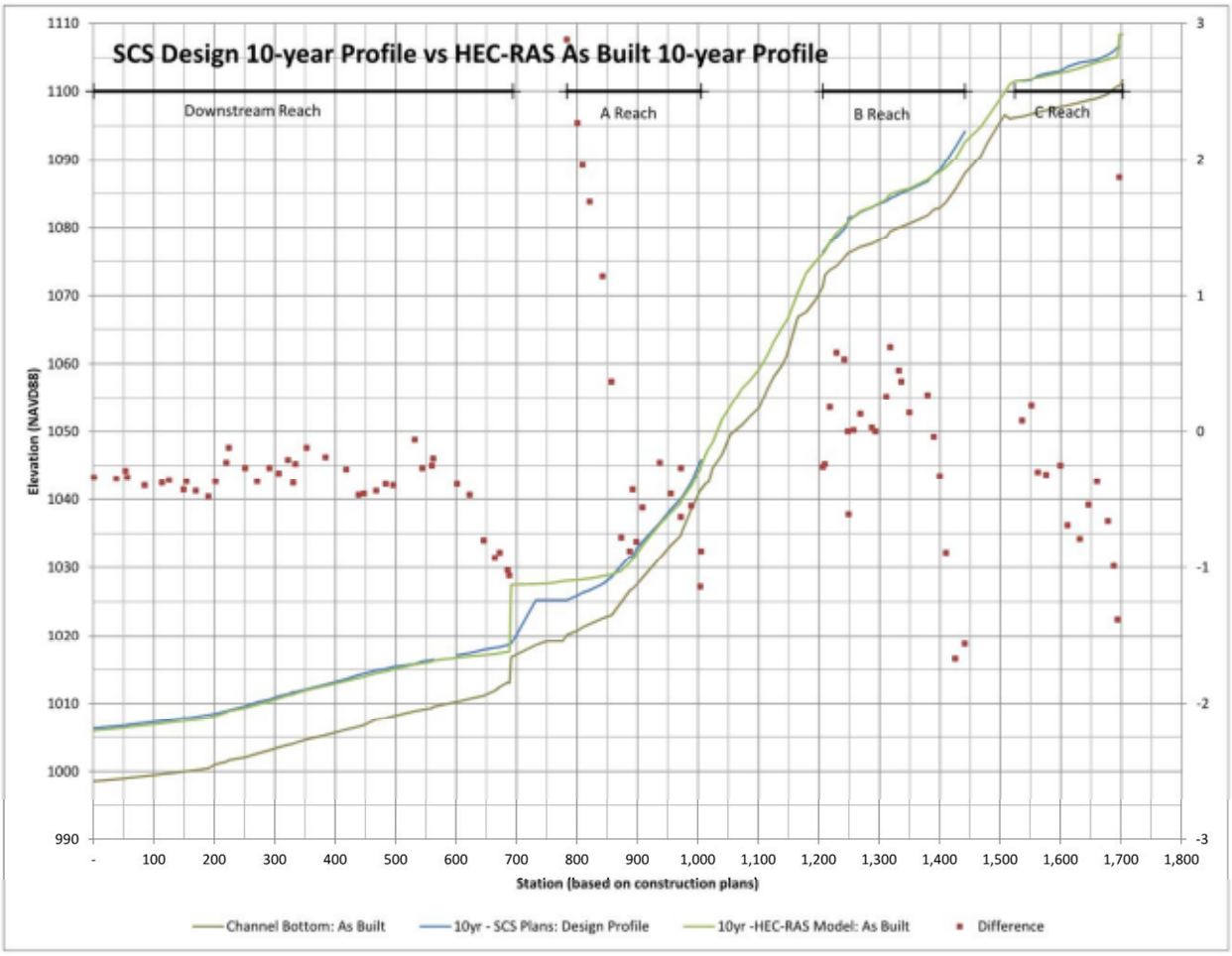
In some areas, spoil banks or earthen berms appeared along the channel on the LiDAR. In areas that were non-channelized prior to the 1956 plans, these berms were deleted and the floodplain was extended flat. In areas that were channelized prior to 1956, the berms were left as cut from LiDAR.

4 RESULTS

1) WATER SURFACE PROFILES

Several comparisons were made to confirm that the HEC-RAS calculated profiles are reasonable. First the calculated as built 10-year profile was compared to the SCS design 10-year profile. **Figure 5** below shows this comparison.

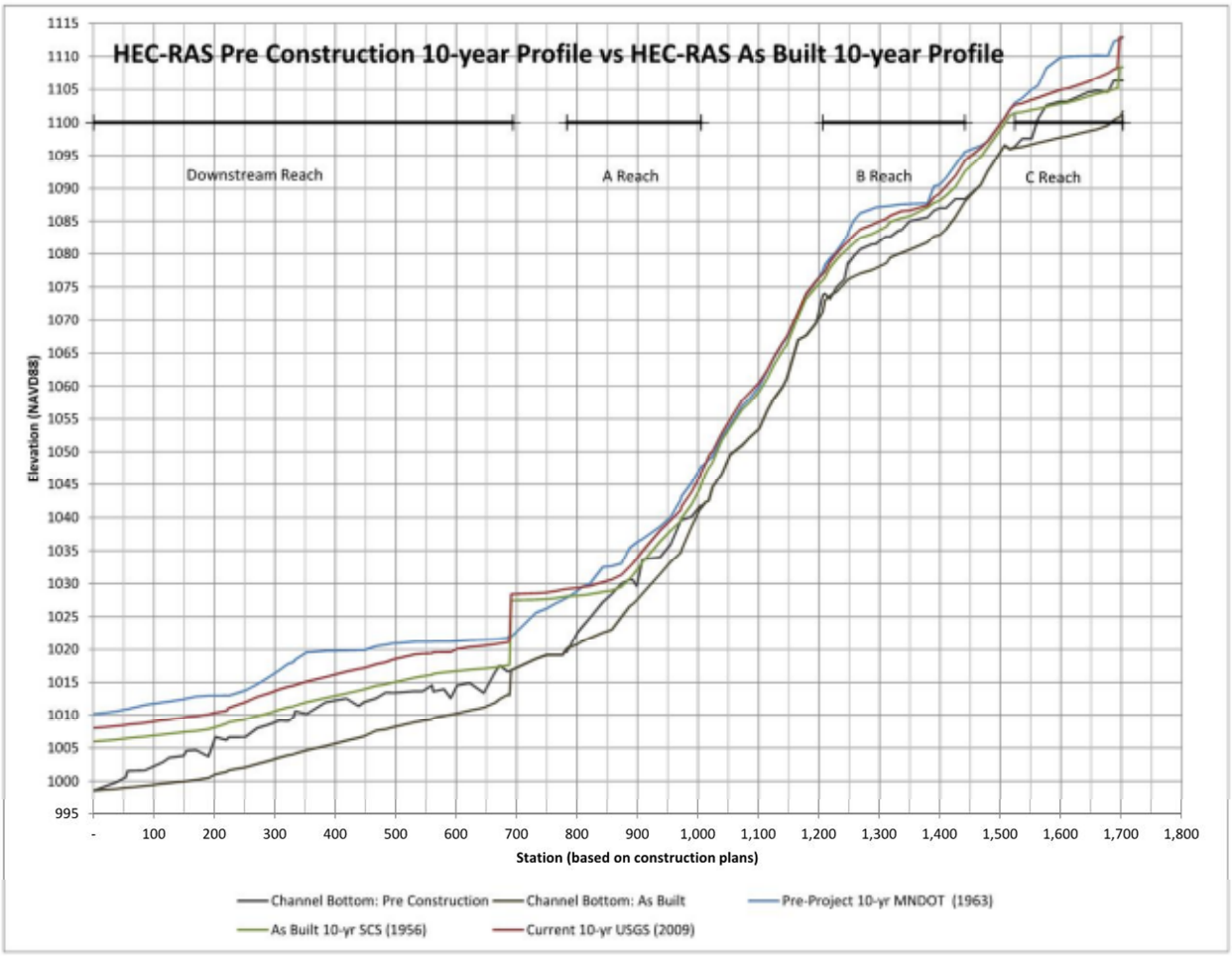
Figure 5: SCS Design Profile vs. HEC-RAS As Built Profile



Generally water surfaces were calculated within half a foot of the SCS design profile on the As built plans (61 of 89 points of comparison were within ½ foot--69%), with the largest differences near the Shakopee Lake and Swan Lake reservoir structures.

Figure 6 compares the preconstruction and as built 10-year profiles produced using HEC-RAS.

Figure 6: Pre Construction vs. As Built (HEC-RAS 10-year Profiles)



2) 10-YEAR FLOODPLAIN MAPPING

The floodplain was mapped using the water surface elevations calculated in HEC-RAS using the discharges discussed previously. Four ten-year events were mapped: 10-year pre-construction, 10-year as built, 10-year current, and 10-year pre-construction plus 4 feet. The Viewers requested that we determine elevations of the 10-year pre-project condition flood plus 4 feet for use in their analysis of drainage benefits and damages. The two year pre-construction, as built, and current condition were also mapped. As 2-year as built discharges were not calculated by the SCS, the 2-year MnDOT discharges were used to develop the 2-year as built profile. Cross sections from the model were used to produce a Triangulated Irregular Network (TIN) representing the water surface elevation, which was then compared to LiDAR to create depth grids and flood polygons. In some areas cross sections were extended to provide mapping in backwater areas. The resultant flood polygons were manually refined to remove small pooling areas not connected to the channel flooding. The results of this floodplain mapping are shown in **Figure 7**, **Figure 8**, **Figure 9**, and **Figure 10.** The flood polygons are also included as Shapfiles in the Digital Data CD.

Figure 7: Pre Project vs. Pre Project plus 4 feet Flood Mapping

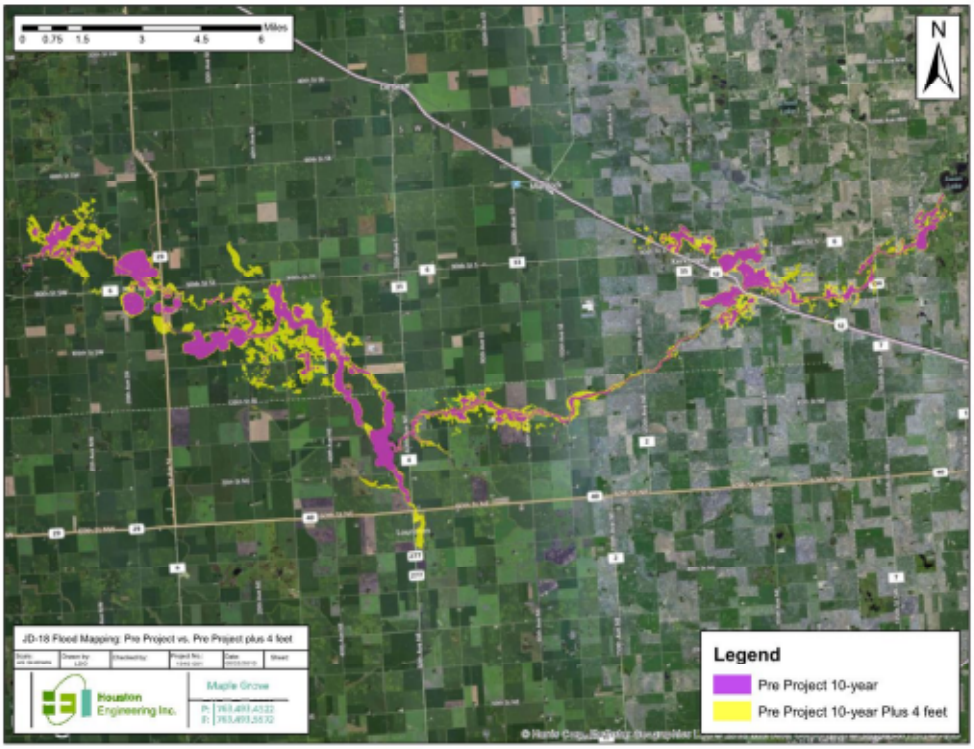


Figure 8: Pre Project vs. As Built Flood Mapping

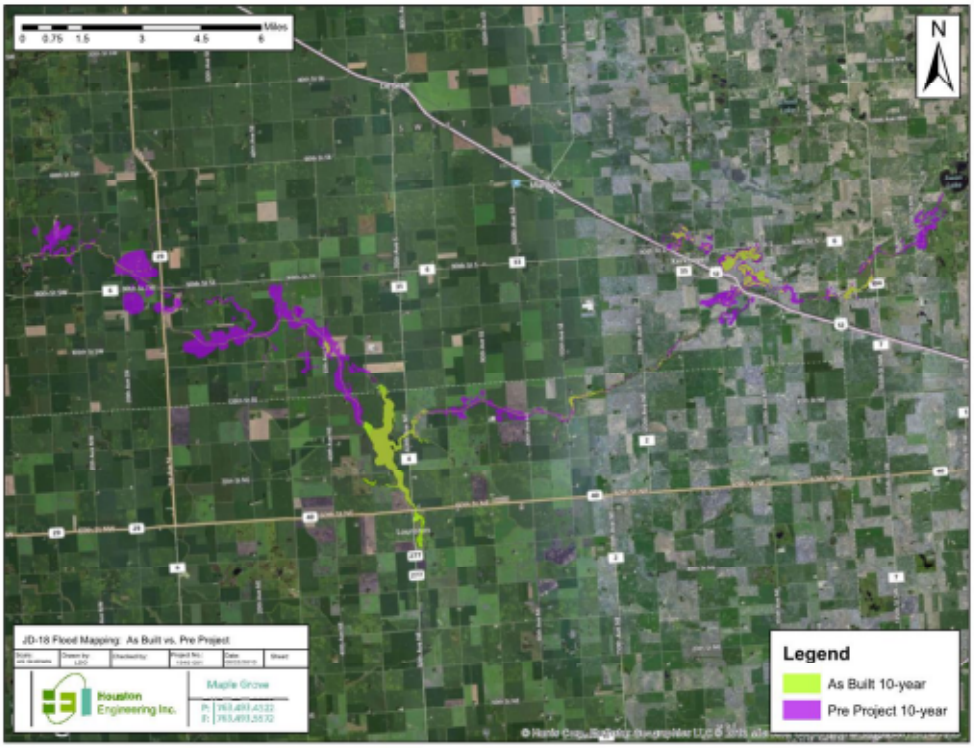


Figure 9: As Built vs Current Flood Mapping

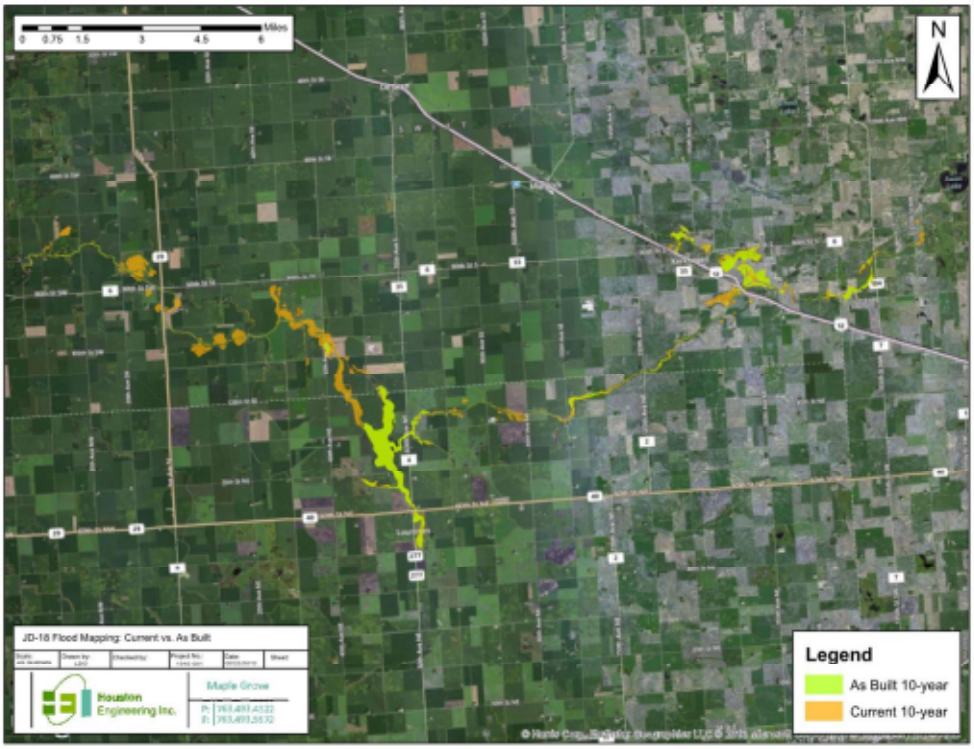
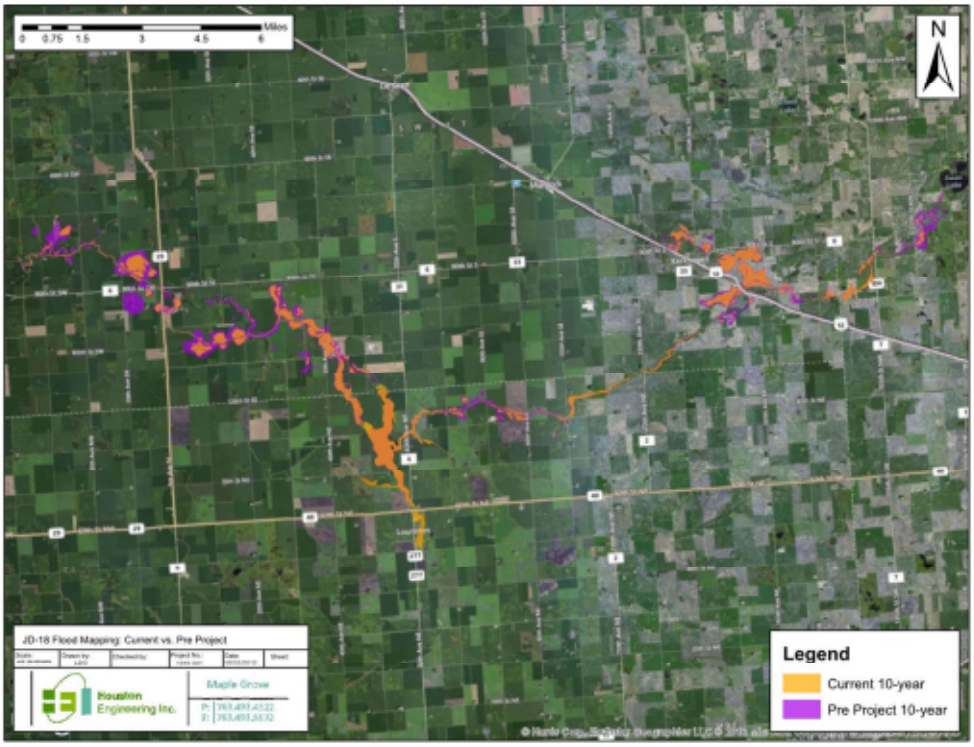
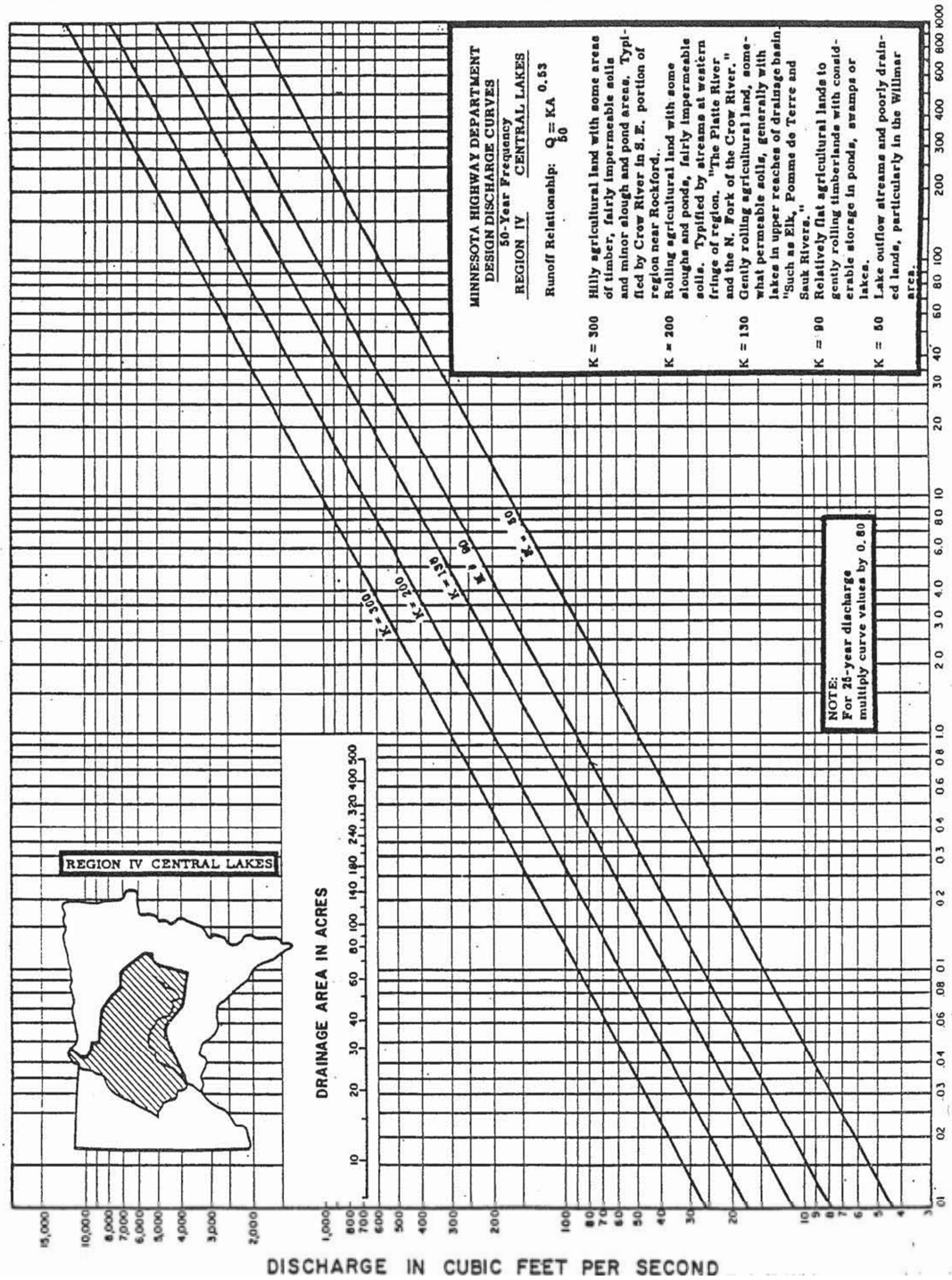


Figure 10: Current vs. Pre Project Flood Mapping



1) CROSS REFERENCED FLOODPLAIN TO PARCEL DATA

These flood polygons were overlaid with parcel data for Chippewa and Kandiyohi Counties, and quarter quarter section data for Swift County. Each parcel or quarter quarter section within the flooding area is attributed with an acres flooded for each of the three mapped scenarios. Shapefiles with this data are included in the Digital Data CD.

APPENDIX A

JULY 1, 1963 DRAINAGE MANUAL FIG E 5-295.223