2-D or not 2-D

XP-SWMM in an Urban Environment

Thomas Johnson, PE, CFM

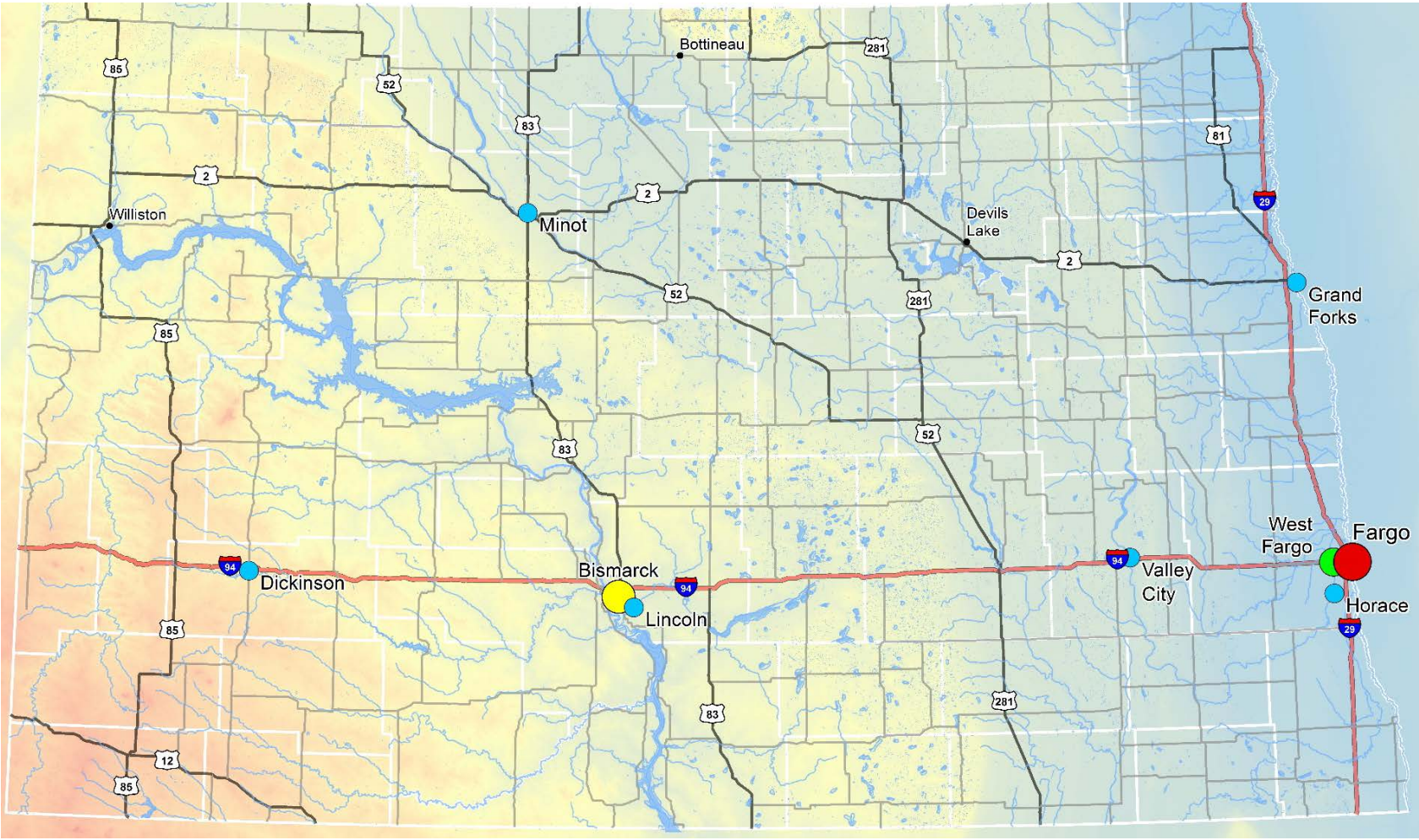
Association of Montana Floodplain Managers

March 9, 2017

ACKERMAN ESTVOLD

NORTH DAKOTA - TERRA INCOGNITA

Certified Floodplain Managers in ND



Continental
Divide
Elev. 1490

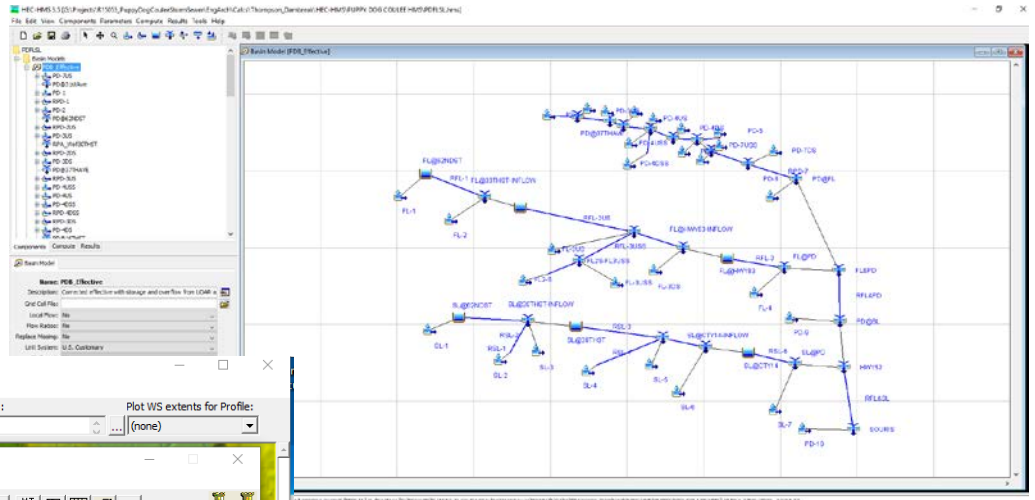
What is Modeling?

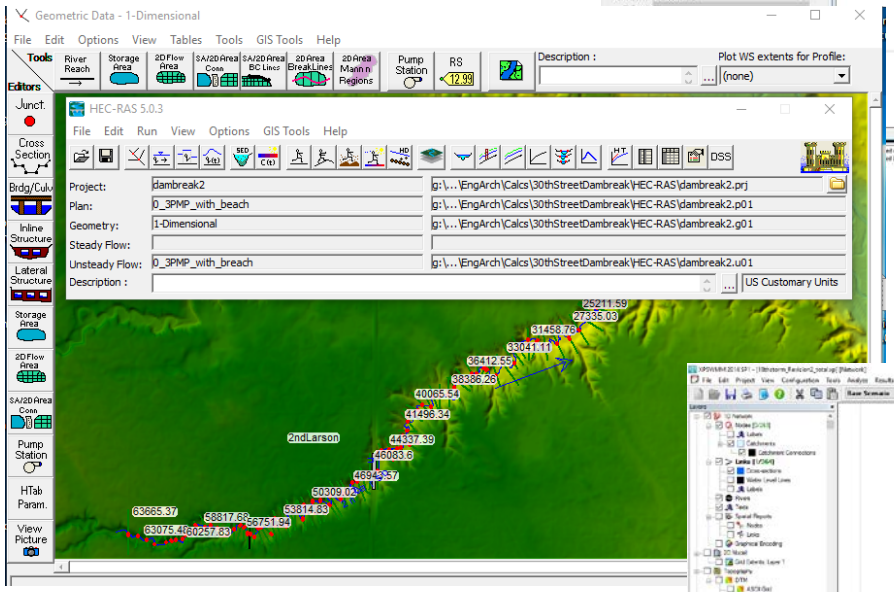
What is Modeling?

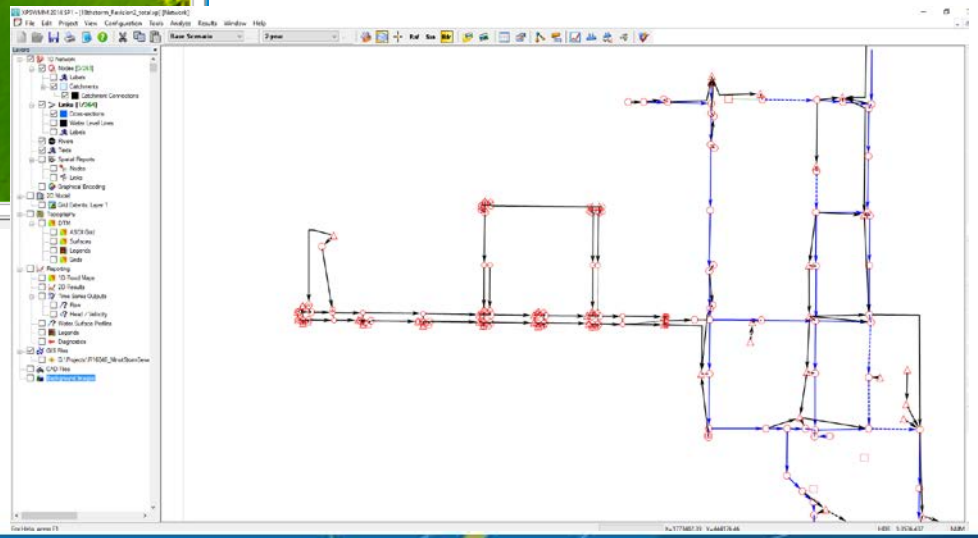
$$\overbrace{\underbrace{\frac{\partial \mathbf{u}}{\partial t}}_{\text{Variation}} + \underbrace{(\mathbf{u}\cdot\nabla)\mathbf{u}}_{\text{Convection}}}^{\text{Inertia (per volume)}} \overbrace{- \underbrace{\nu\nabla^2\mathbf{u}}_{\text{Diffusion}} = \underbrace{-\nabla w}_{\text{Internal source}}}^{\text{Divergence of stress}} + \underbrace{\mathbf{g}}_{\text{External source}}.$$

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u} = -\frac{1}{\rho}\nabla\bar{p} + \nu\nabla^2\mathbf{u} + \frac{1}{3}\nu\nabla(\nabla\cdot\mathbf{u}) + \mathbf{g}.$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A} + g\,I_1\right) + g\,A\,(S_f - S) - g\,I_2 = 0,$$

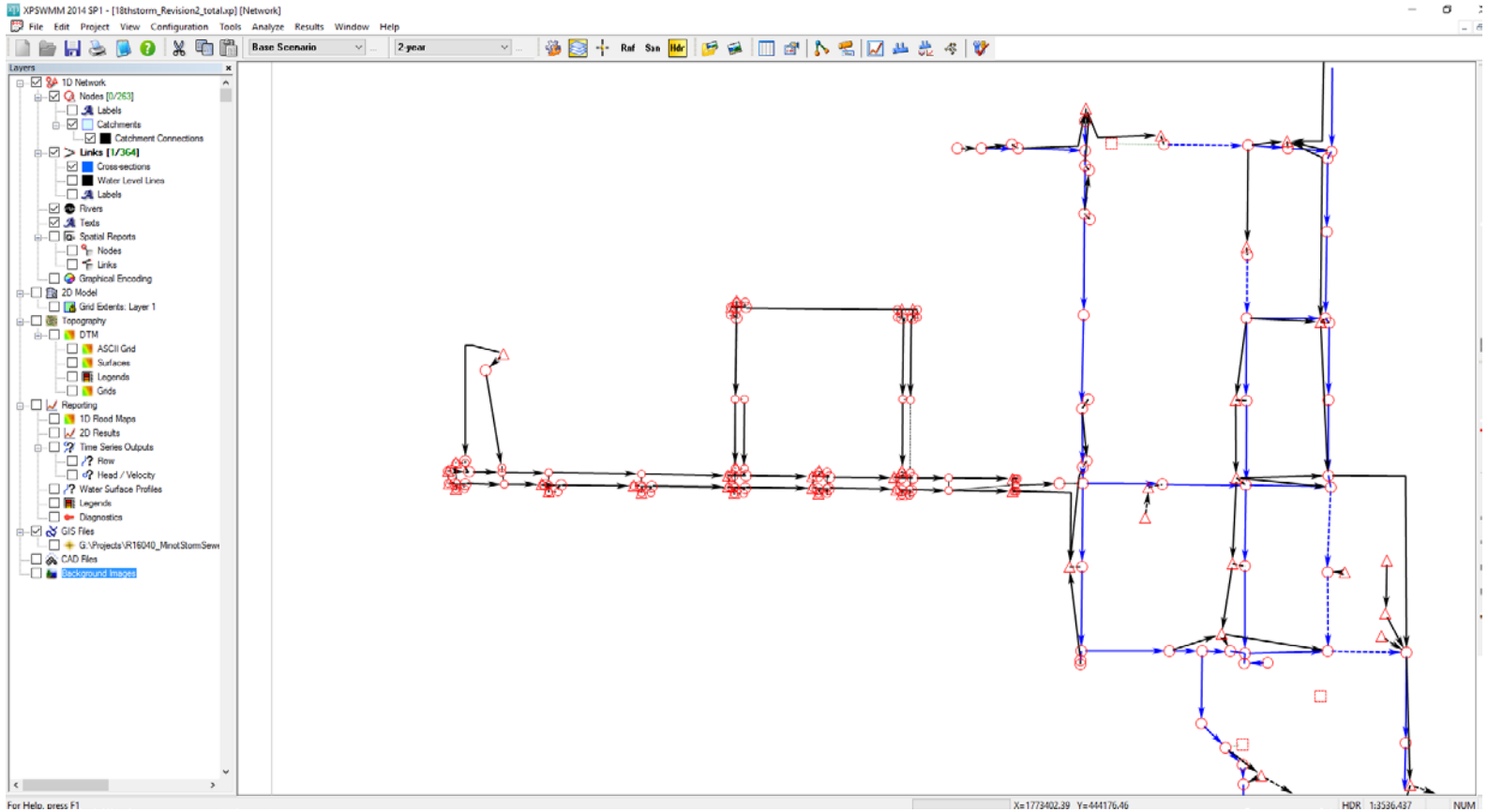




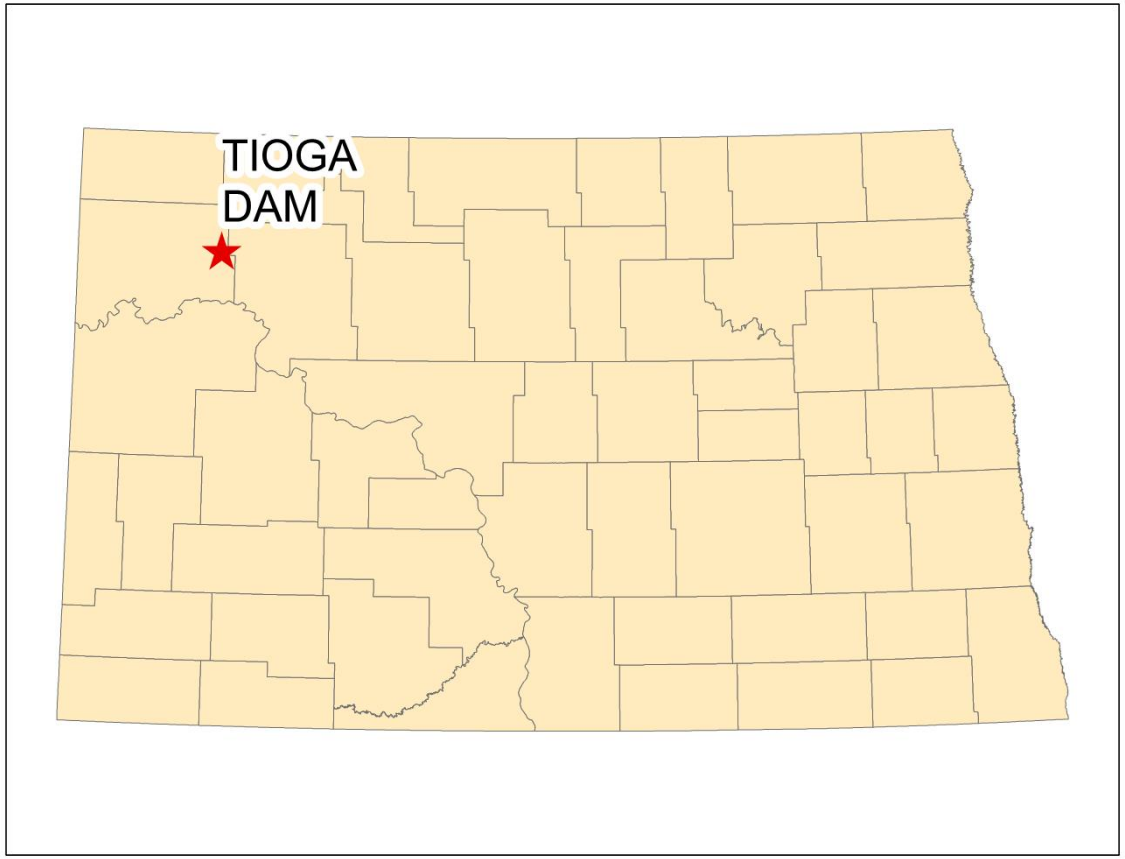


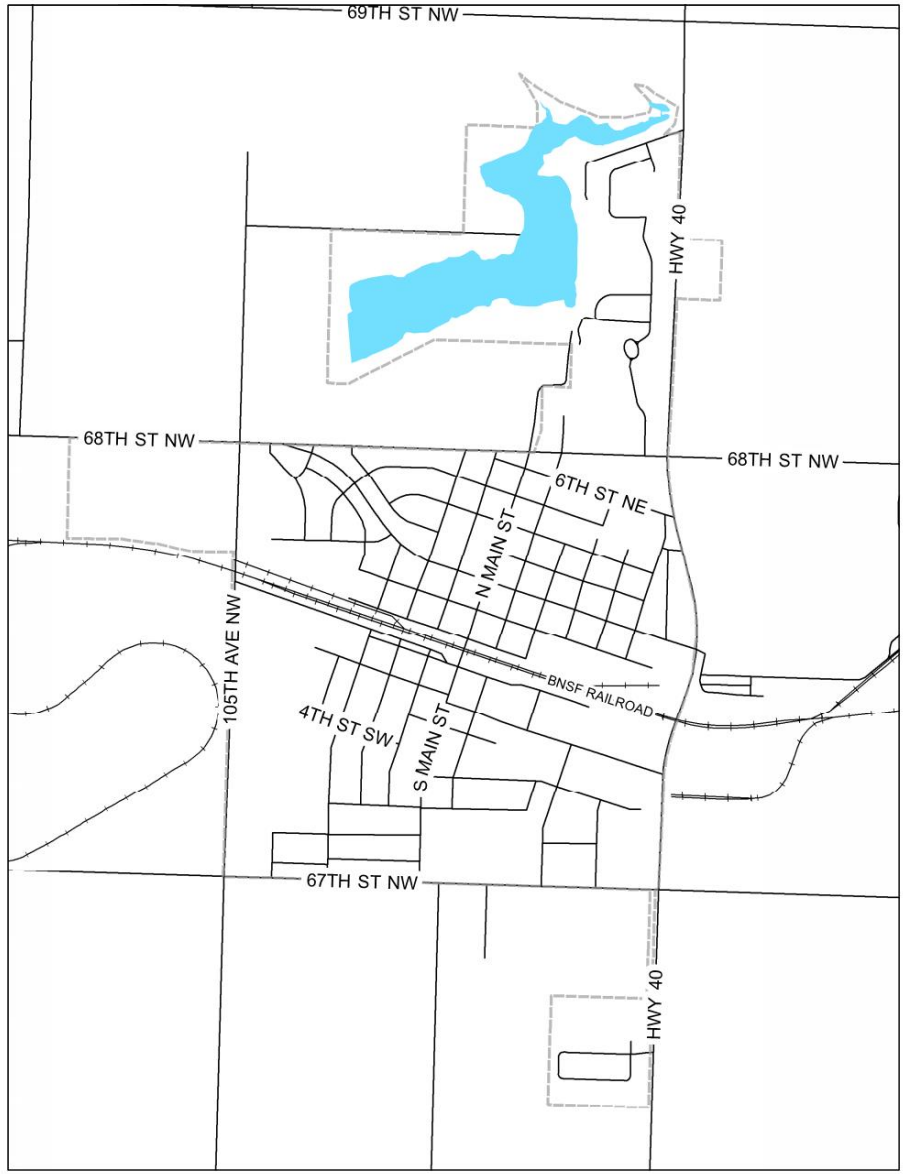
XP-SWMM Notes

- Proprietary Software Package
- Combines hydrology and hydraulics
- Nodes and Links
- TuFlow



Tioga Dam Breach
2-Dimensional Approach





- Originally Purpose – Water Supply
  Contributing Area = 5.9 sq mi

  Primary embankment - 39 feet
  5 Saddle levees (as high as 24 ft)
  Drop manhole an 18- inch pipe primary spillway
  Earthen Auxiliary Spillway – Activated in 50-year storm

FIGURE 2

PLAN VIEW OF DAM
EMERGENCY ACTION PLAN
TIOGA DAM

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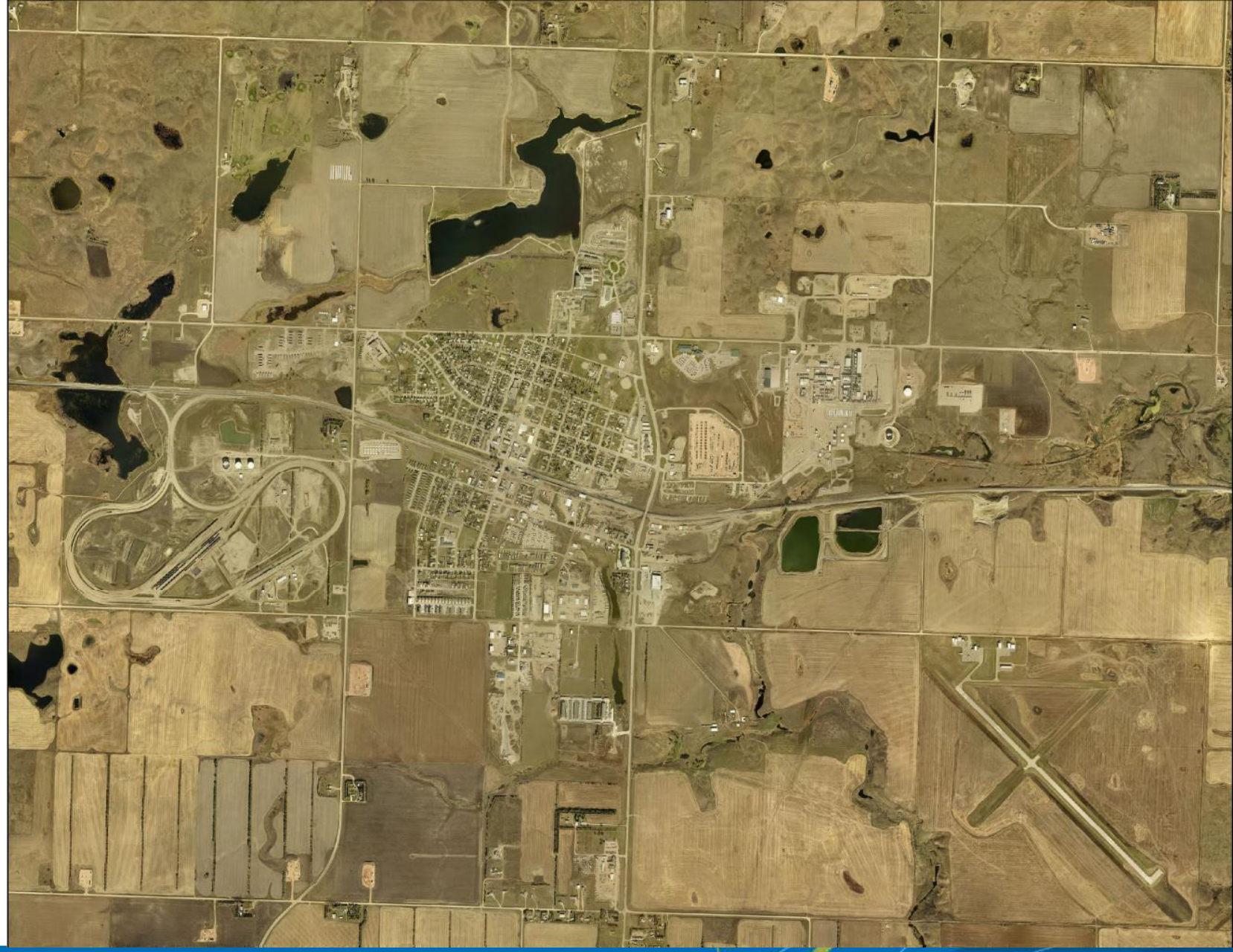
701.837.8737 · www.ackerman-estvold.com
Minot, ND | Williston, ND

Project Name: EMERGENCY ACTION PLAN TIOGA DAM	
Project No: R16038	
Scale:	1" = 400'
Date:	09/06/2016
Drawn By:	CFE
Appr. By:	TRJ

Dam and reservoir located north of Tioga.



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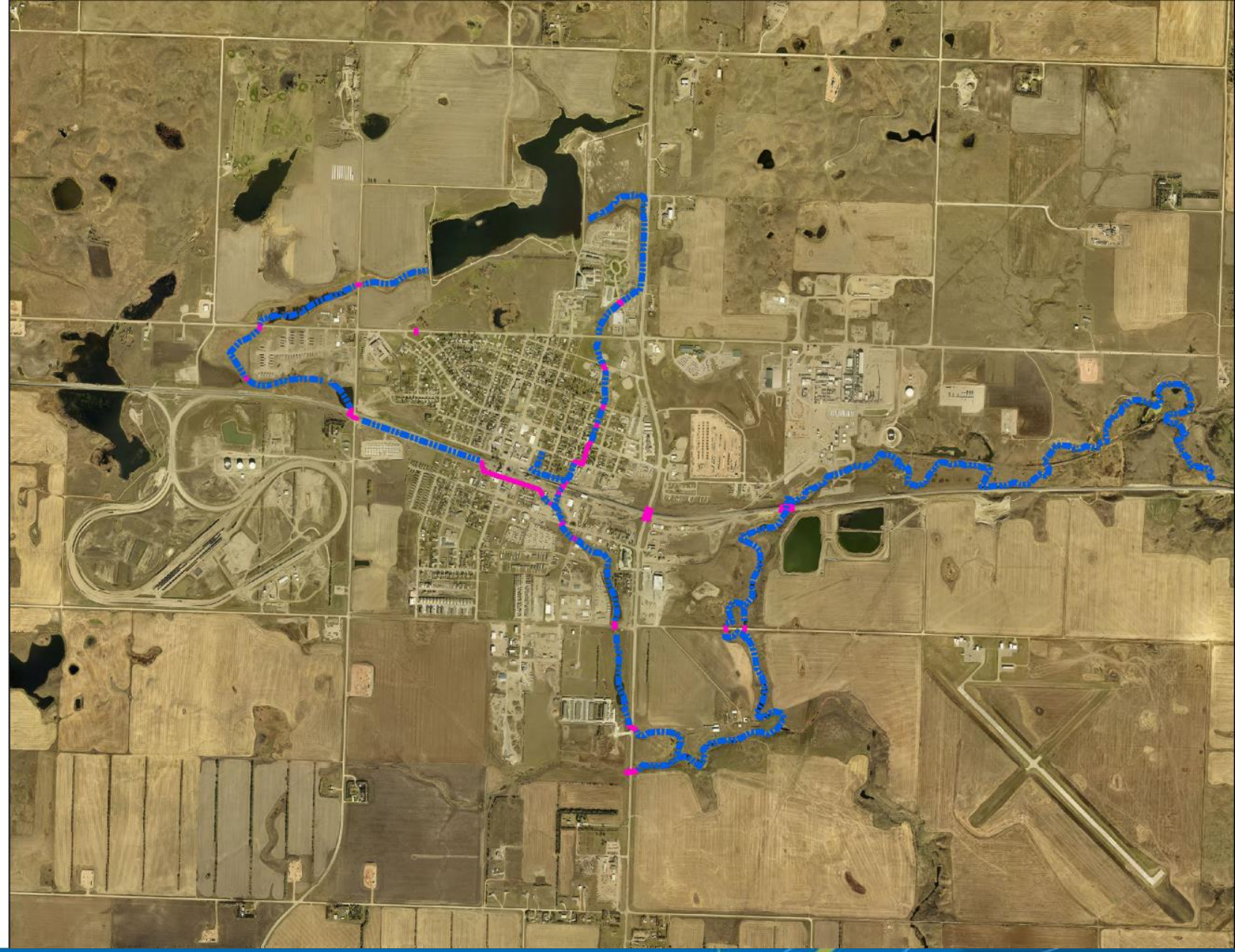
Channels, storm sewers and culverts convey normal discharge through town. No controlled discharge to the west.



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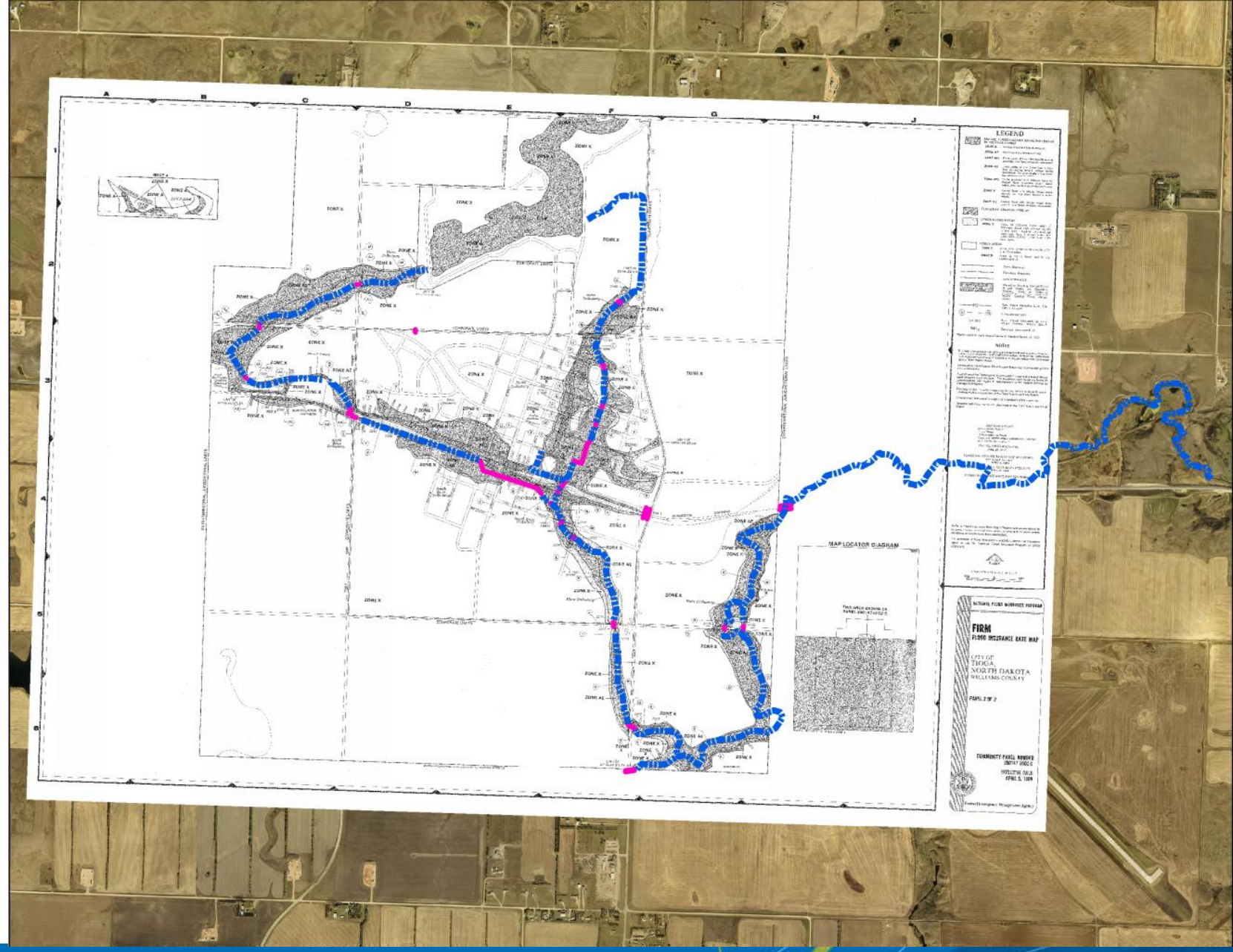
FIRM (1988)



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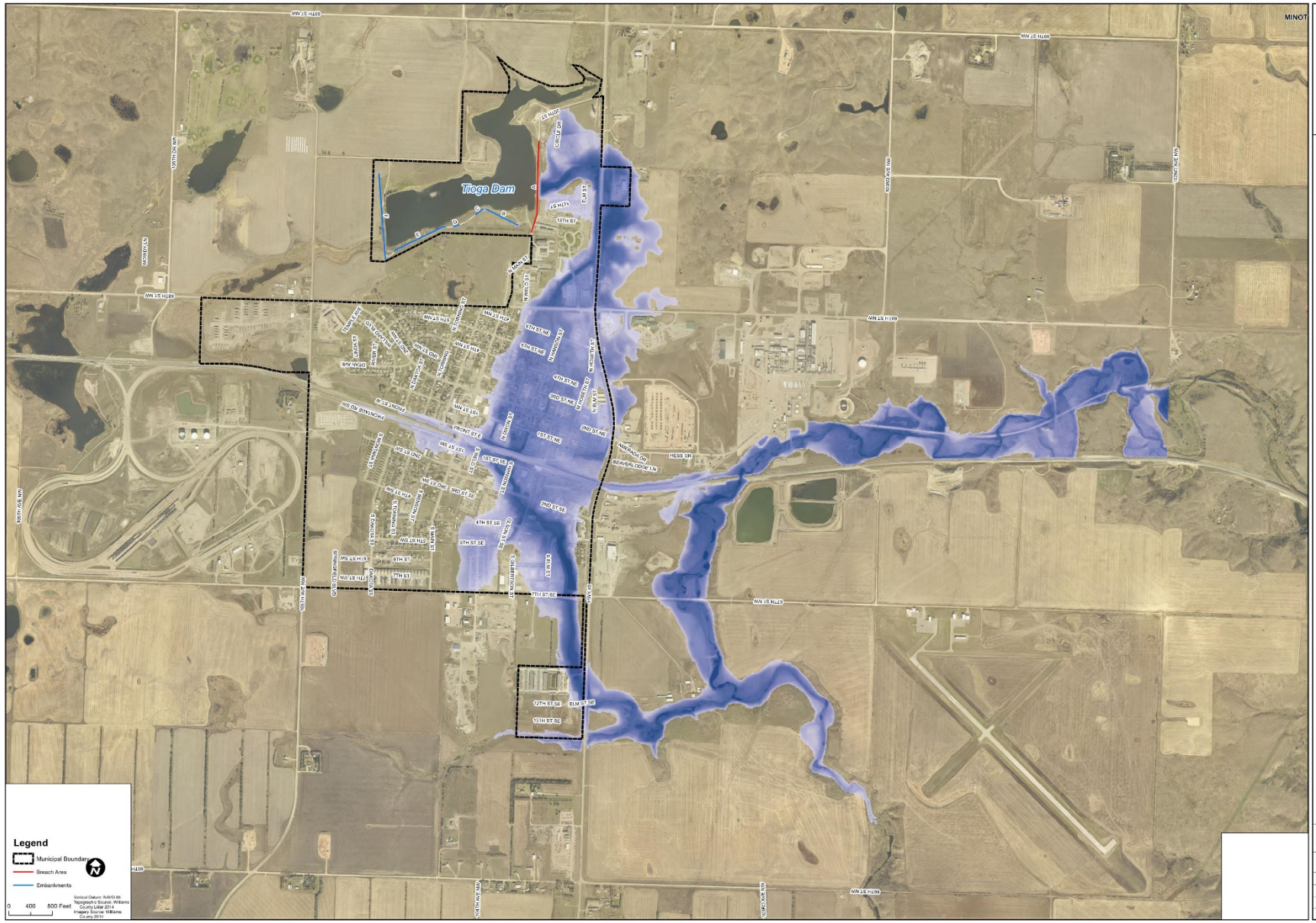
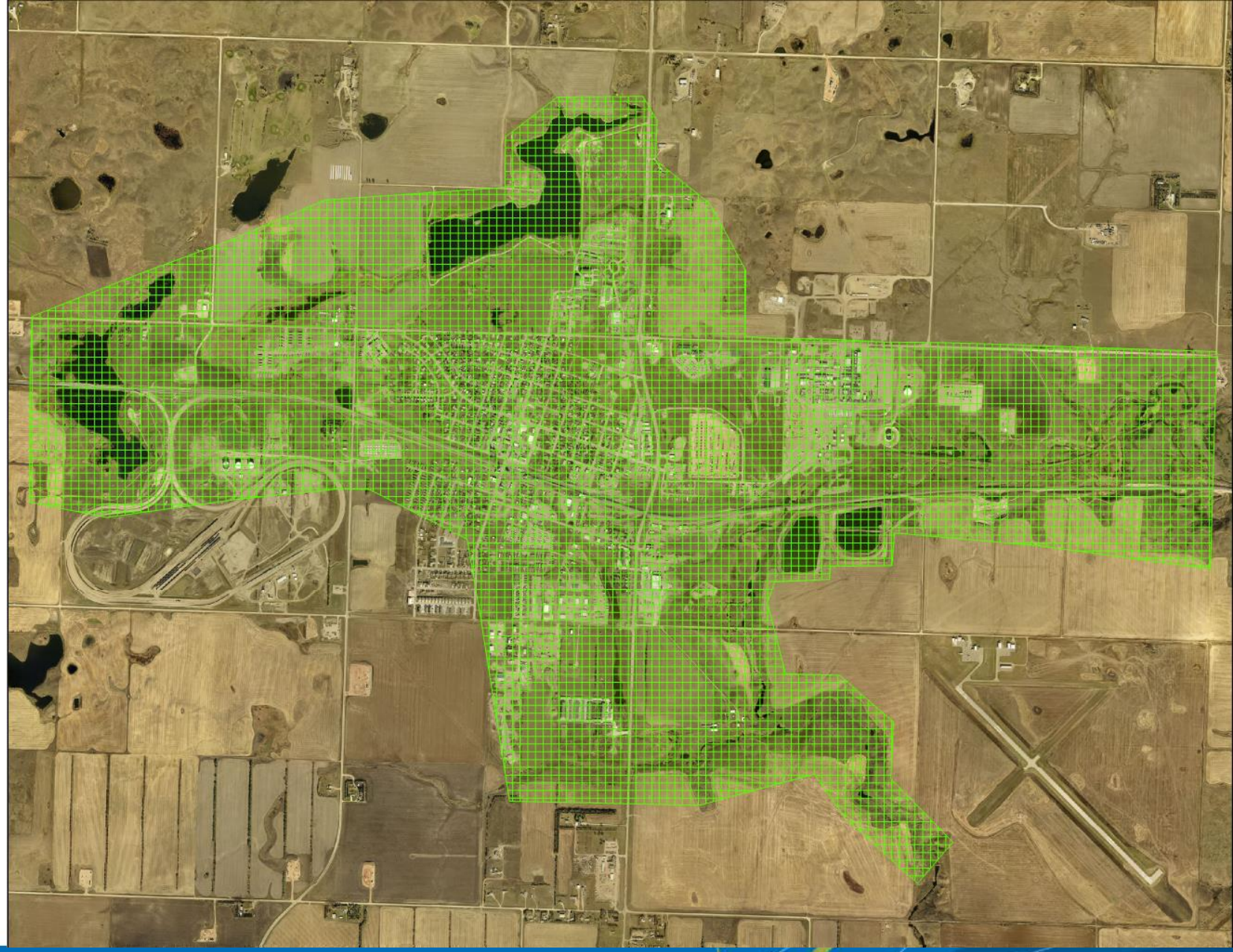
Purpose is to produce inundation maps as part of an Emergency Action Plan (EAP) based on dam breach hydrograph



Build model in stages

- Mesh



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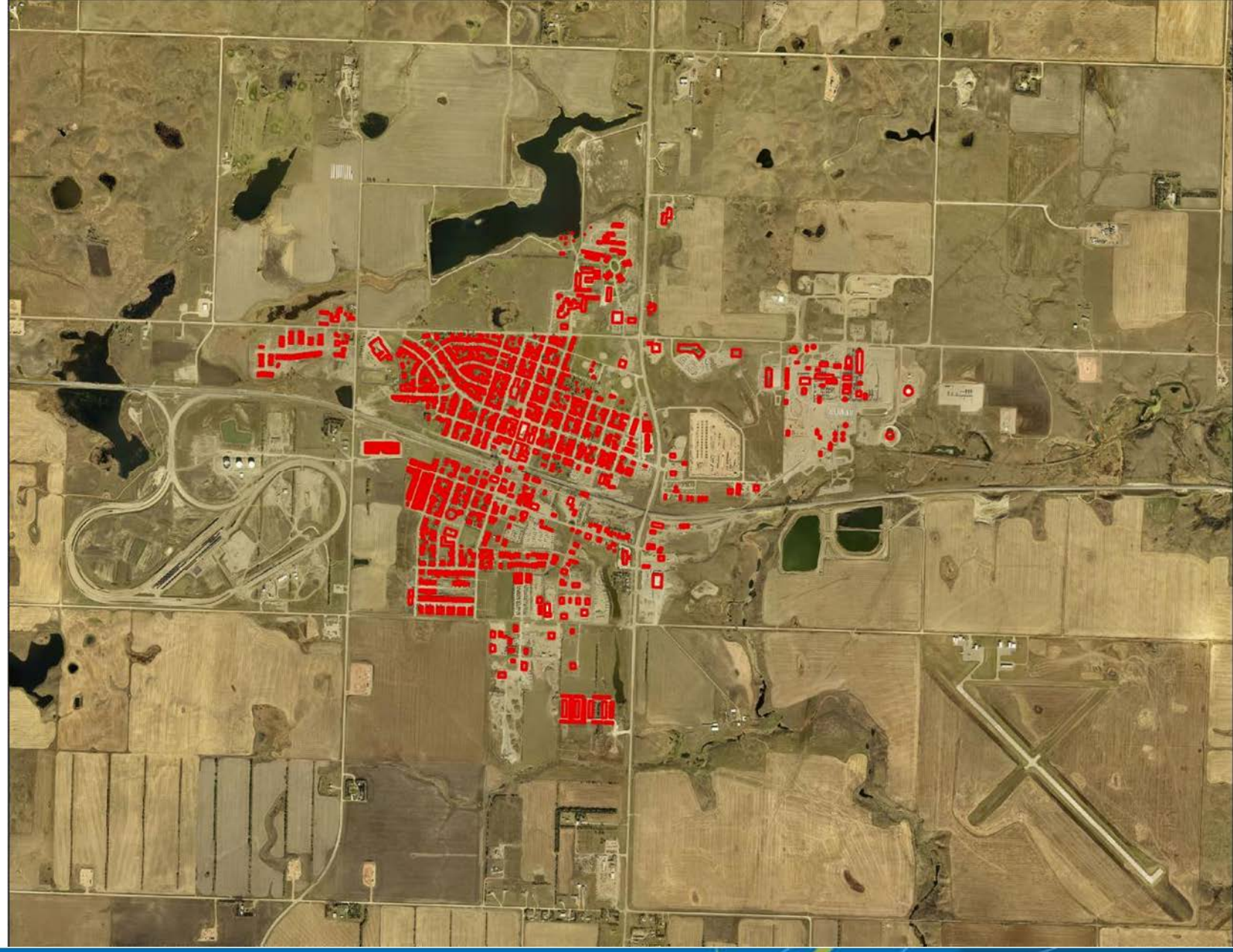
Build model in stages

- Mesh
- Buildings



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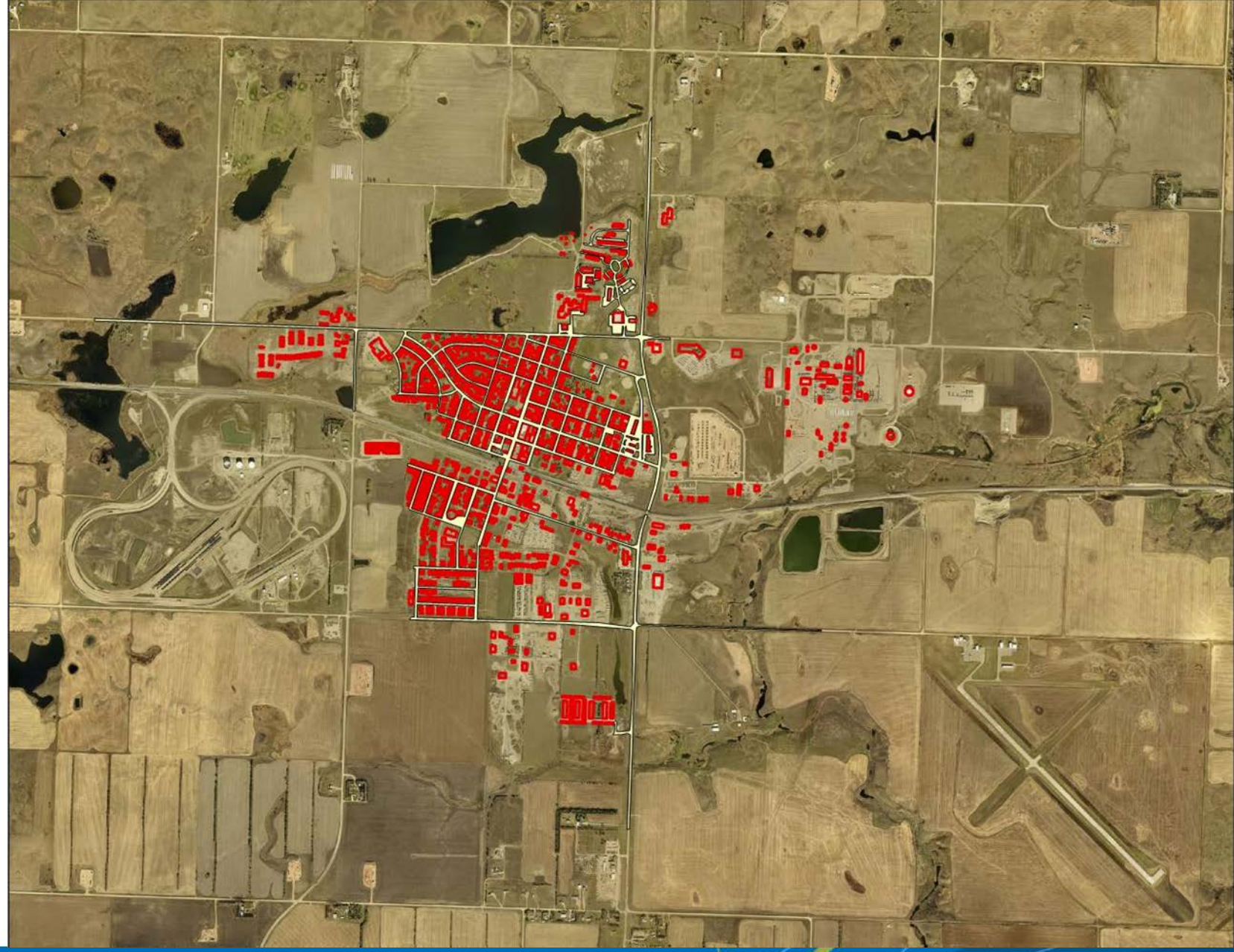
Build model in stages

- Mesh
- Buildings
- Streets



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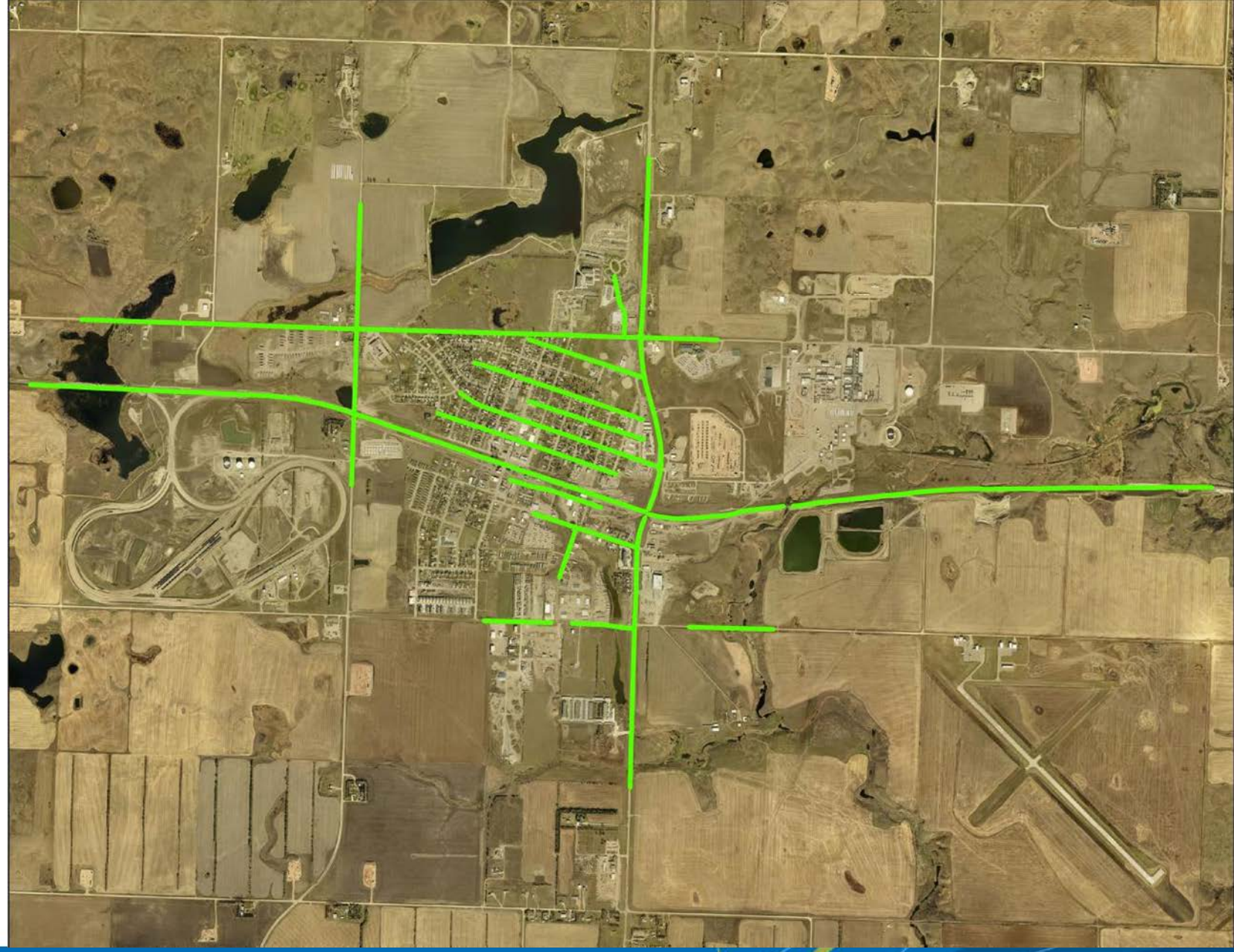
Build model in stages

- Mesh
- Buildings
- Streets
- Breaklines (Ridges)



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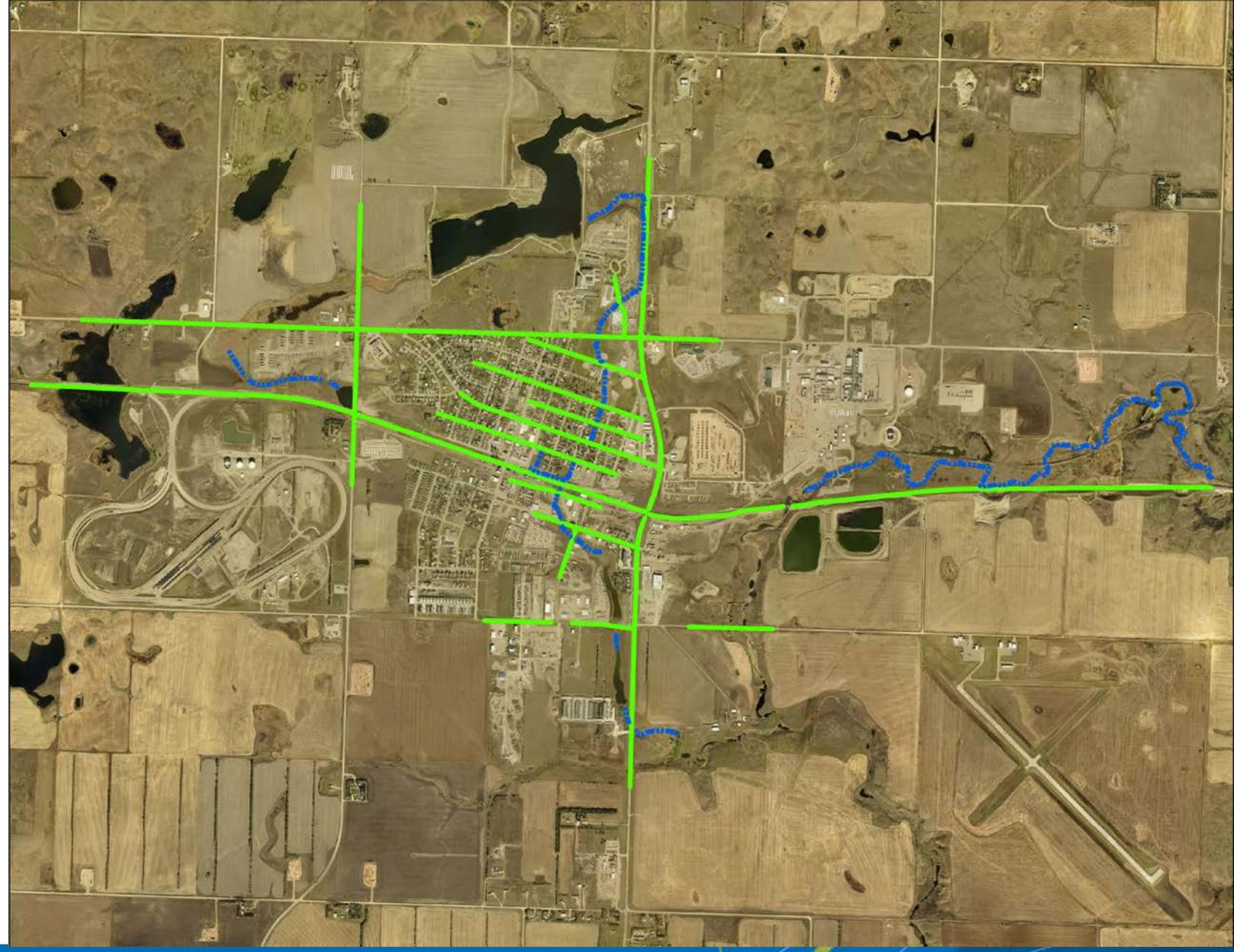
Build model in stages

- Mesh
- Buildings
- Streets
- Breaklines (Ridges)
- Gullies (Streams)



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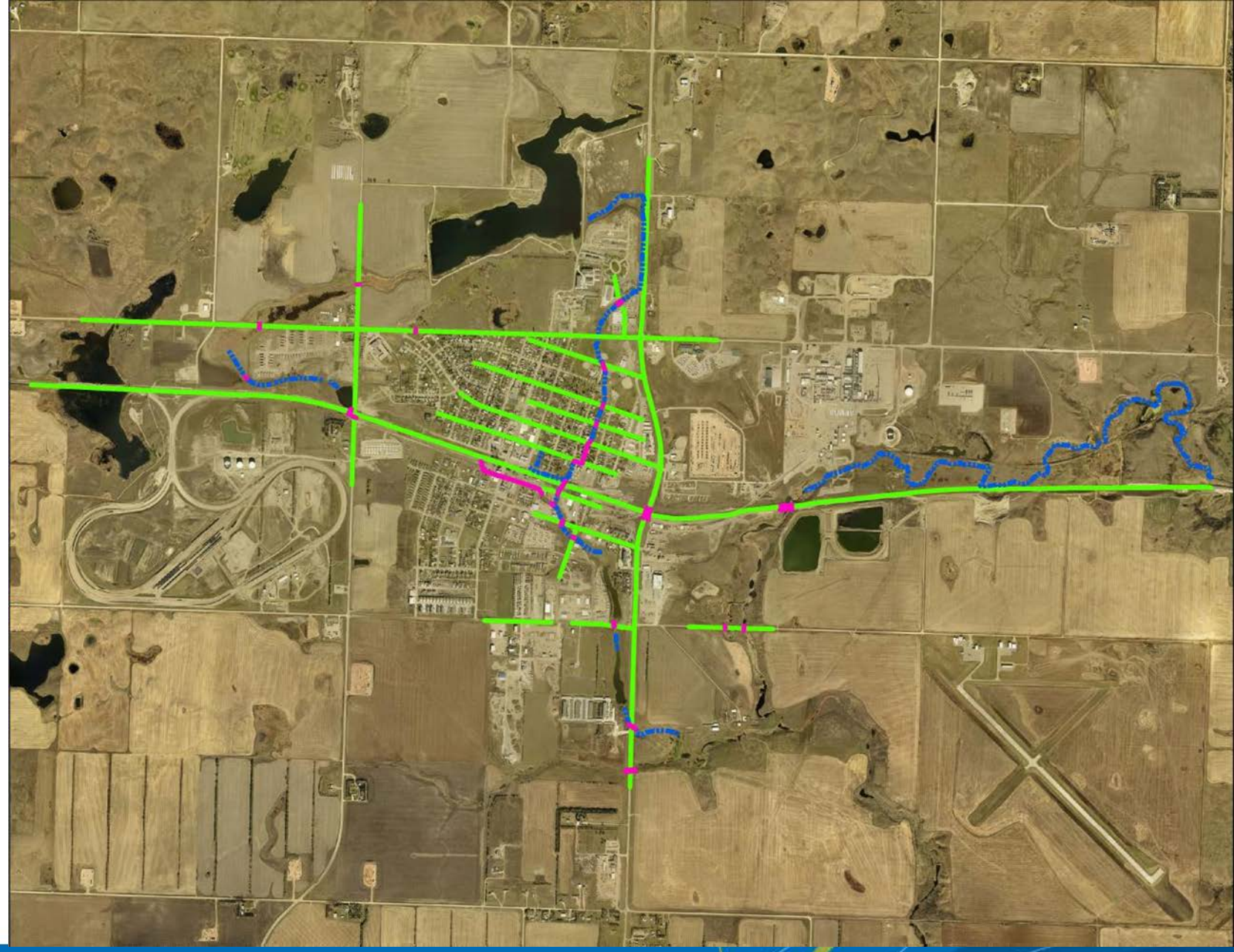
Build model in stages

- Mesh
- Buildings
- Streets
- Breaklines (Ridges)
- Gullies (Streams)
- Culverts / Bridges



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xpswmm 2012 - [Tioga_PMP_Breach_A-2.xp] [Network]

File Edit Project View Configuration Tools Analyze Results Window Help

Base Scenario

Layers

- 2D Model
  - Grid Extents: Layer 1 [0/1]
  - Active Areas: Layer 1 [0/1]
  - Inactive Areas
  - 1D / 2D Interfaces
  - 1D / 2D Connections
  - Landuse
    - Buildings [0/1490]
    - Streets [0/74]
    - Grass [0/1]
- Topography
  - Breaklines
    - Gullies: Layer 1 [0/24]
    - Ridges: Layer 1 [0/19]
  - DTM
    - Surfaces
      - E:\Tioga_backup\Tioga_2D
    - Legends
      - E:\Tioga_backup\Tioga_2D
- Reporting
  - 1D Flood Maps
  - 2D Vectors (Flow)
  - 2D Maps (Water Depth)
  - Time Series Outputs
    - Flow
      - DS Plant [0/1]
      - US County Line [0/1]
      - 67th St SW - East [0/1]
      - CR 40 North [0/1]
      - CR 40 South [0/1]
      - Signal Road West [0/1]
      - Signal Road East [0/1]
      - 4th Street NE [0/1]
      - 2nd Street NE [0/1]
      - RR West [0/1]
      - RR Central [0/1]
      - RR East [0/1]
      - 2nd Street SE [0/1]
      - 67th ST SW - West [0/1]
    - Head / Velocity
  - Water Surface Profiles
  - Legends
  - Diagnostics
    - E:\Tioga_backup\Tioga_2D\Tio
- GIS Files
- CAD Files
- Background Images
  - G:\Projects\R16038_TiogaDamEAP\

XPS 1D/2D Simulation

```
Configuration Parameter: VERT_WALLS=ON
Configuration Parameter: SUBCATCHMENT_RES=ON
Configuration Parameter: SCSIADEPTH=ON
Configuration Parameter: SCSIADEPTH=ON
Current Directory:  C:\XPS\XPSWMM~1
Engine Name: C:\XPS\XPSWMM~1\SWMMEN~2.EXE
Input File : E:\Tioga_backup\Tioga_2D\Tioga_PMP_Breach_
A-2.XP
Engine Version: 12.0
```

Don't Show Model Status

Exit at Simulation End

Time Step #	439
Time (hrs)	0.1
Time Used	1.3
Time Left	529.25
Efficiency	5.6740

Model Adjustment

Courant Factor | Courant Factor 1.00000 | Apply

1D Results

Max. Node Iterations	1	Node	Node102	# Nodes Not Converged	0
Max. Flow Change	0.00000	Conduit	Link1	Surcharged	0
Min. Time Step	1.00	Conduit	Link1	Flooded	0
				# Conduits with Normal Flow	0

xpswmm - Solve...

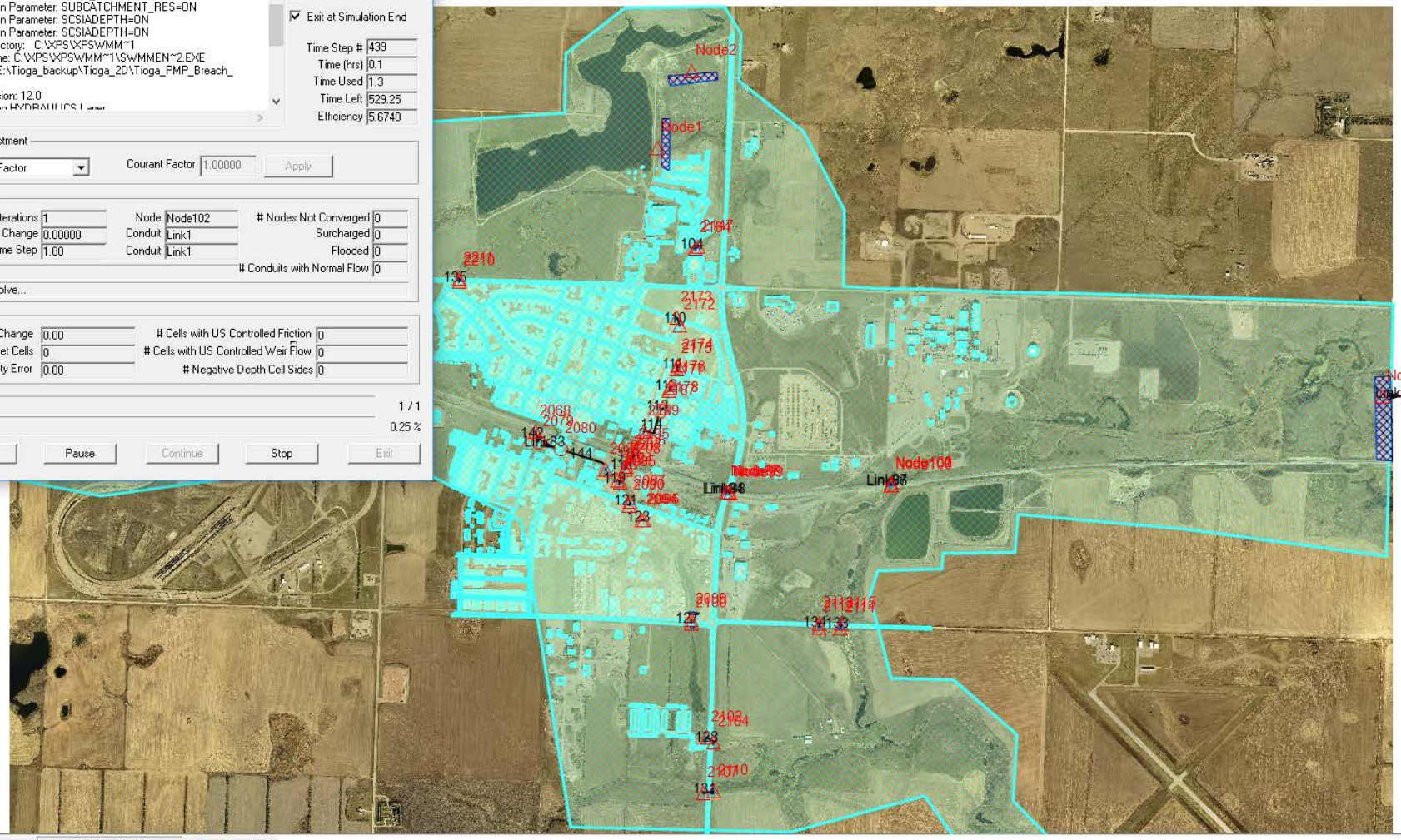
2D Results

Volume Change	0.00	# Cells with US Controlled Friction	0
# Wet Cells	0	# Cells with US Controlled Weir Flow	0
Continuity Error	0.00	# Negative Depth Cell Sides	0

1 / 1

0.25 %

Start | Pause | Continue | Stop | Exit



0:00:00:00

X=1378094.62 Y=525862.88 HDR 1:17707.198 NUM OVR

Ask me anything

5:28 PM 10/29/2016

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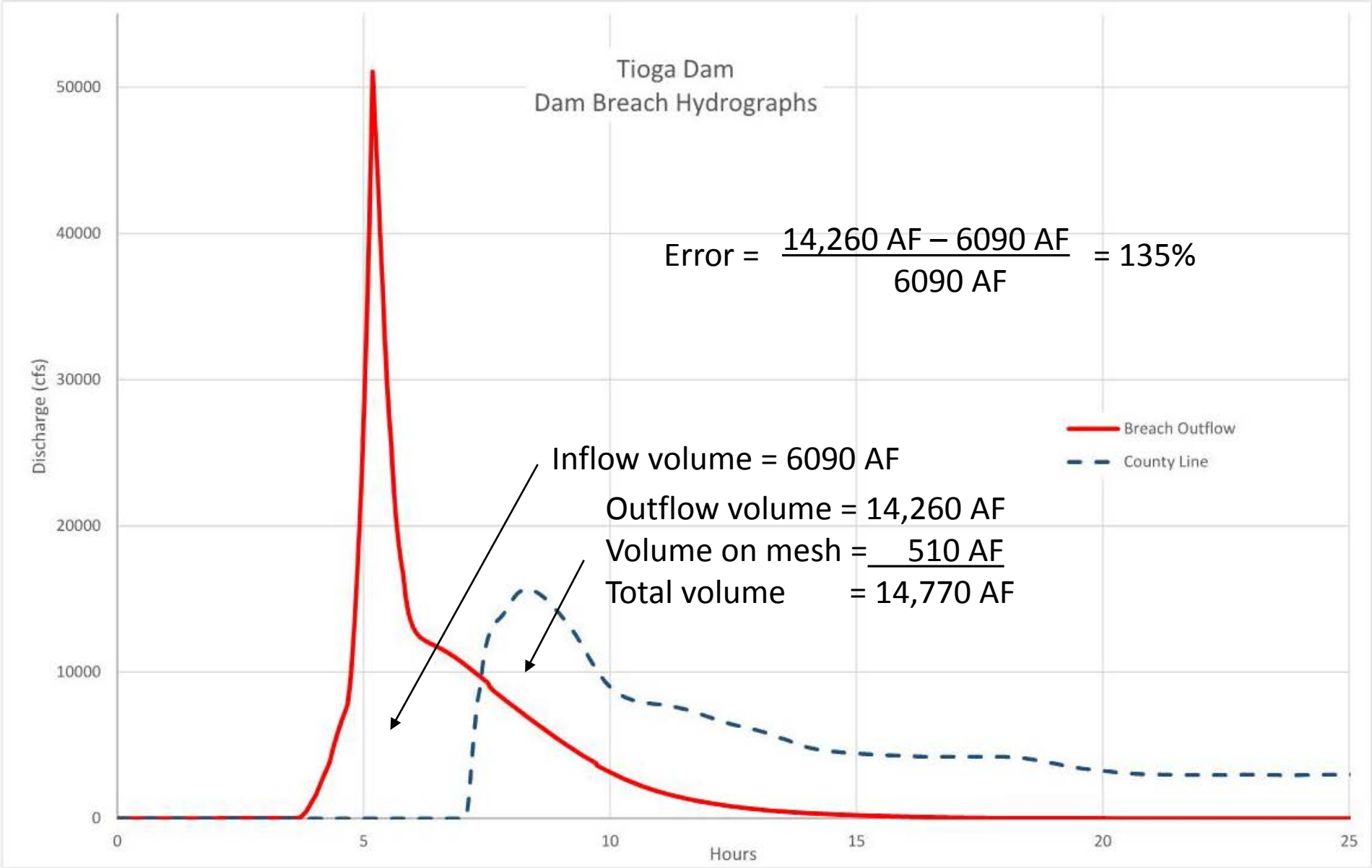
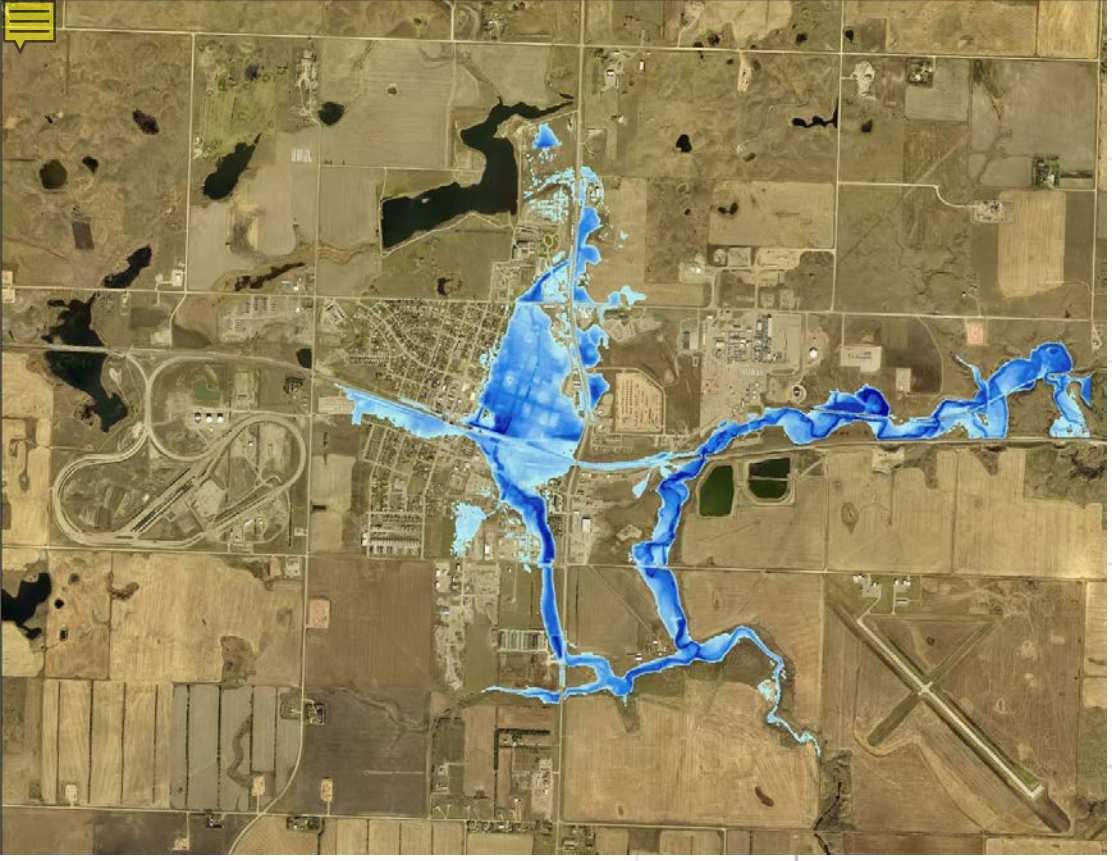
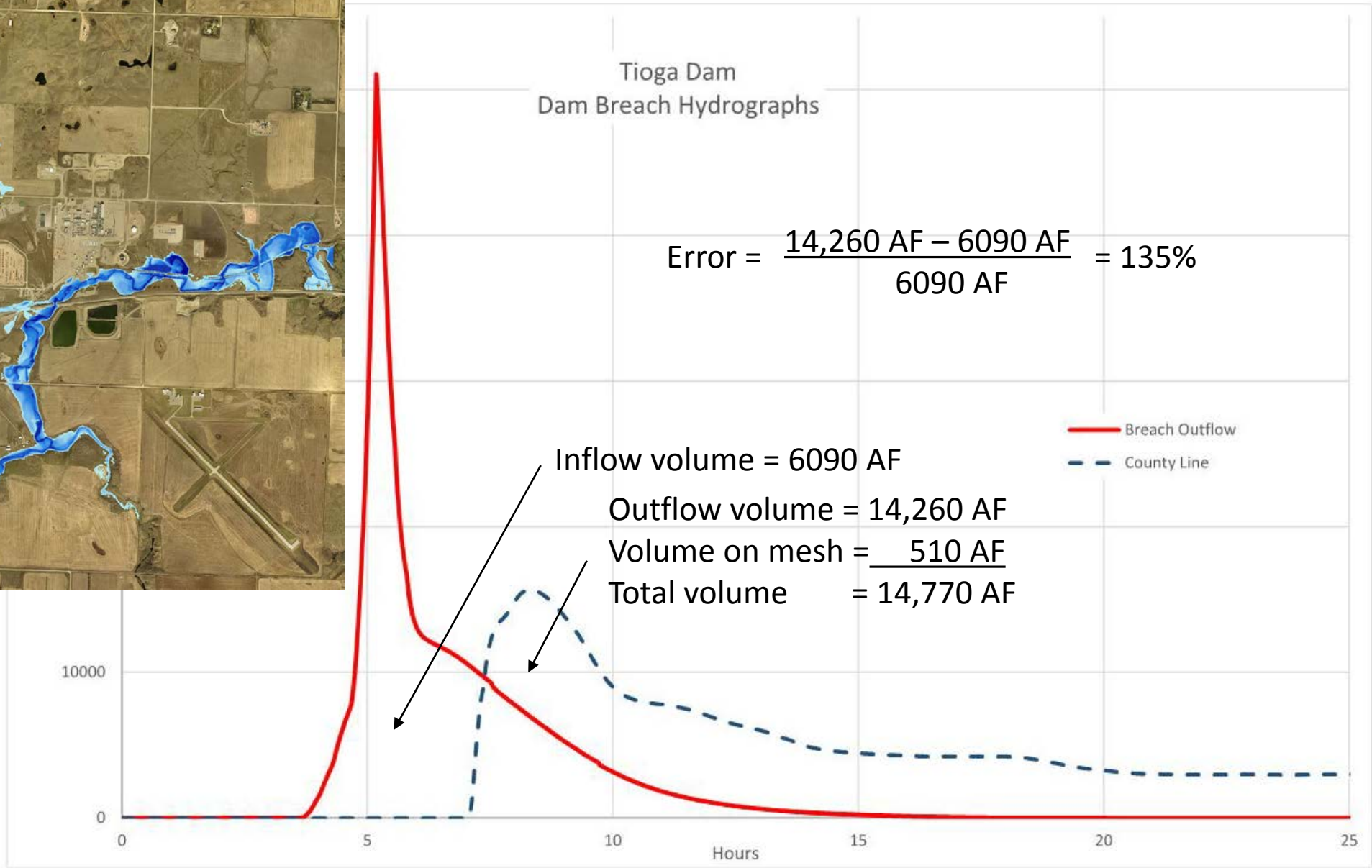
Celebration

Continuity and Intermediate Cross Sections



$$\text{Error} = \frac{14{,}260\ \text{AF} - 6090\ \text{AF}}{6090\ \text{AF}} = 135\%$$





Error = $\frac{14{,}260 \text{ AF} - 6090 \text{ AF}}{6090 \text{ AF}}$ = 135%

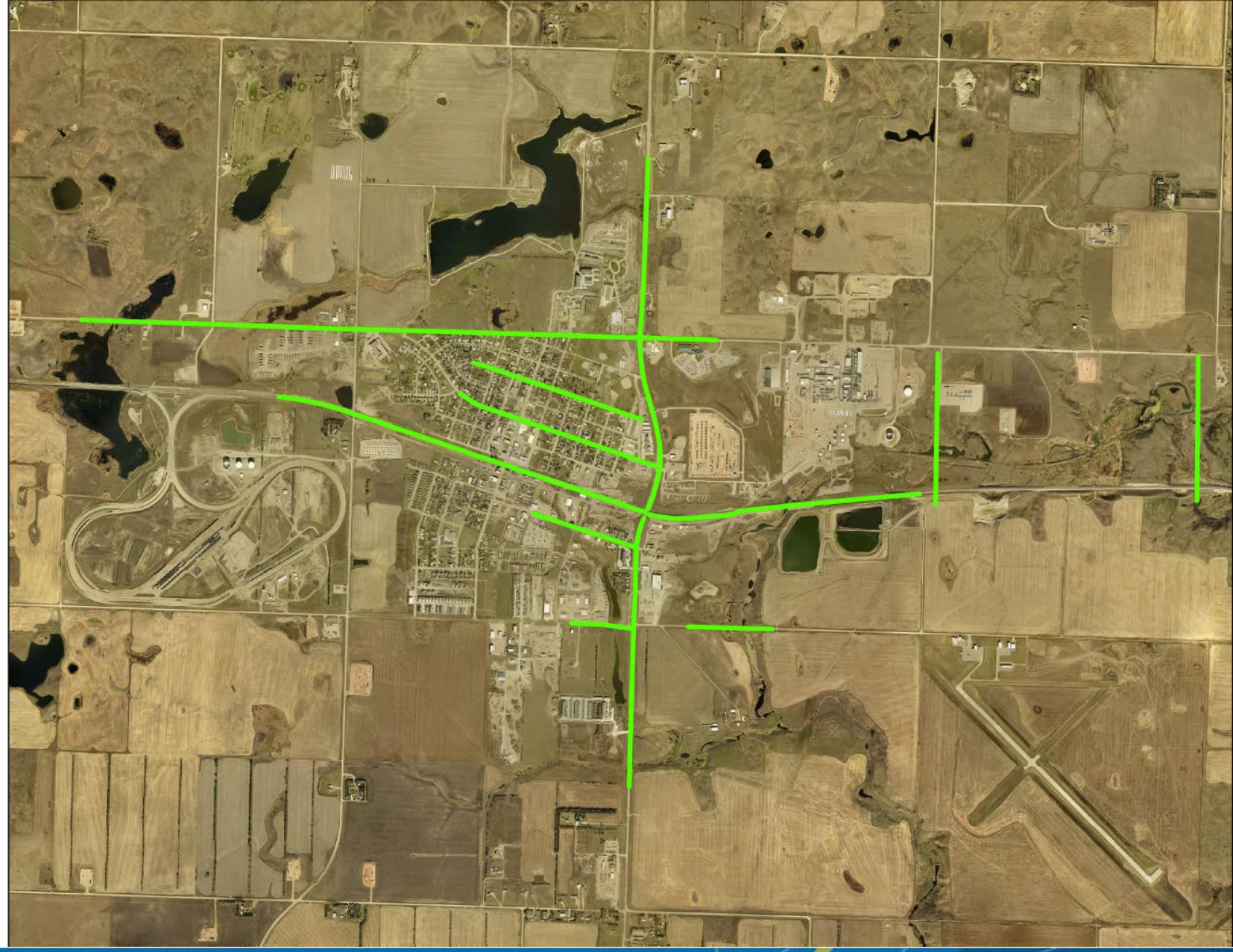
Inflow volume = 6090 AF

Outflow volume = 14,260 AF

Volume on mesh = 510 AF

Total volume = 14,770 AF

Continuity and Intermediate Cross Sections



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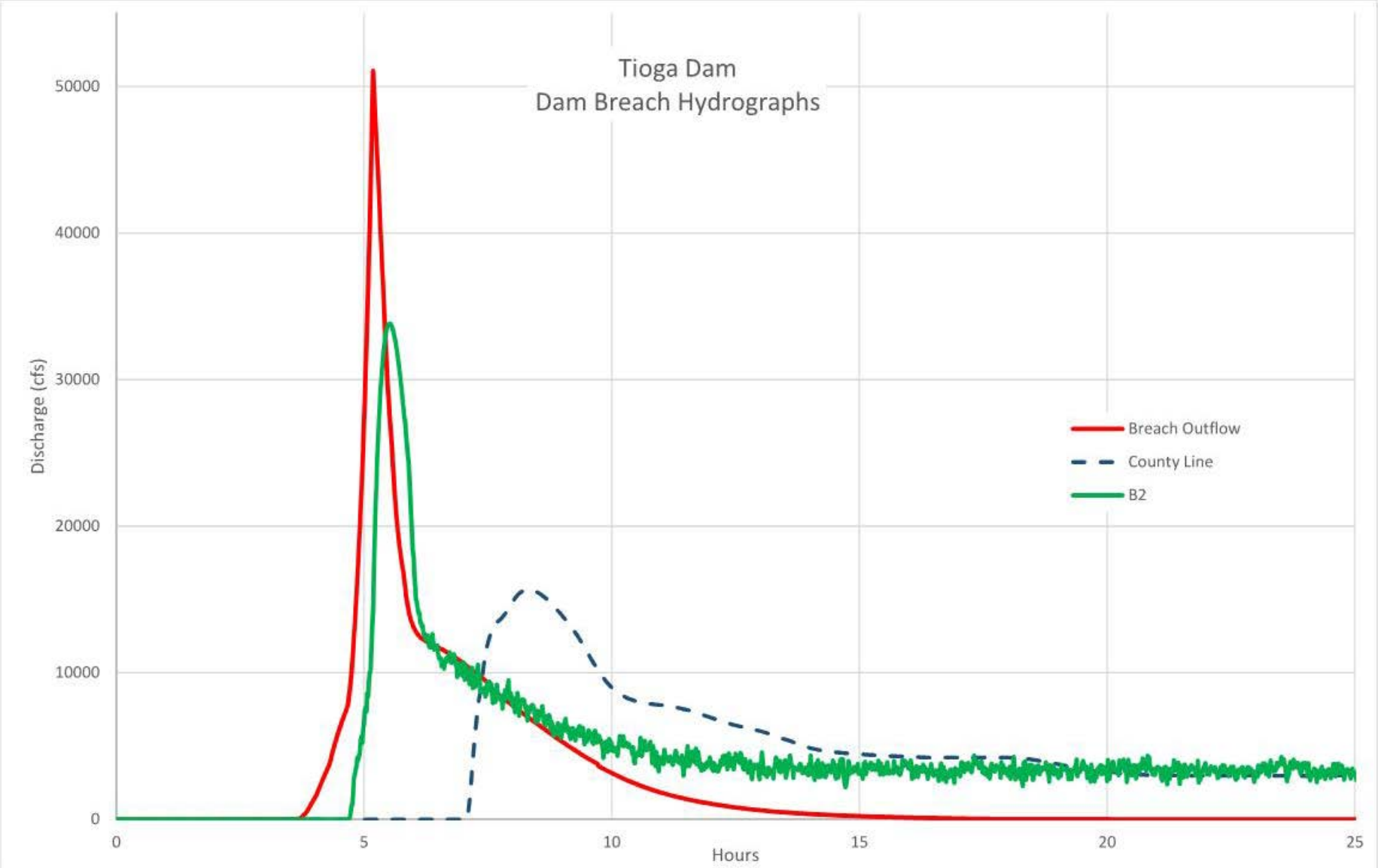
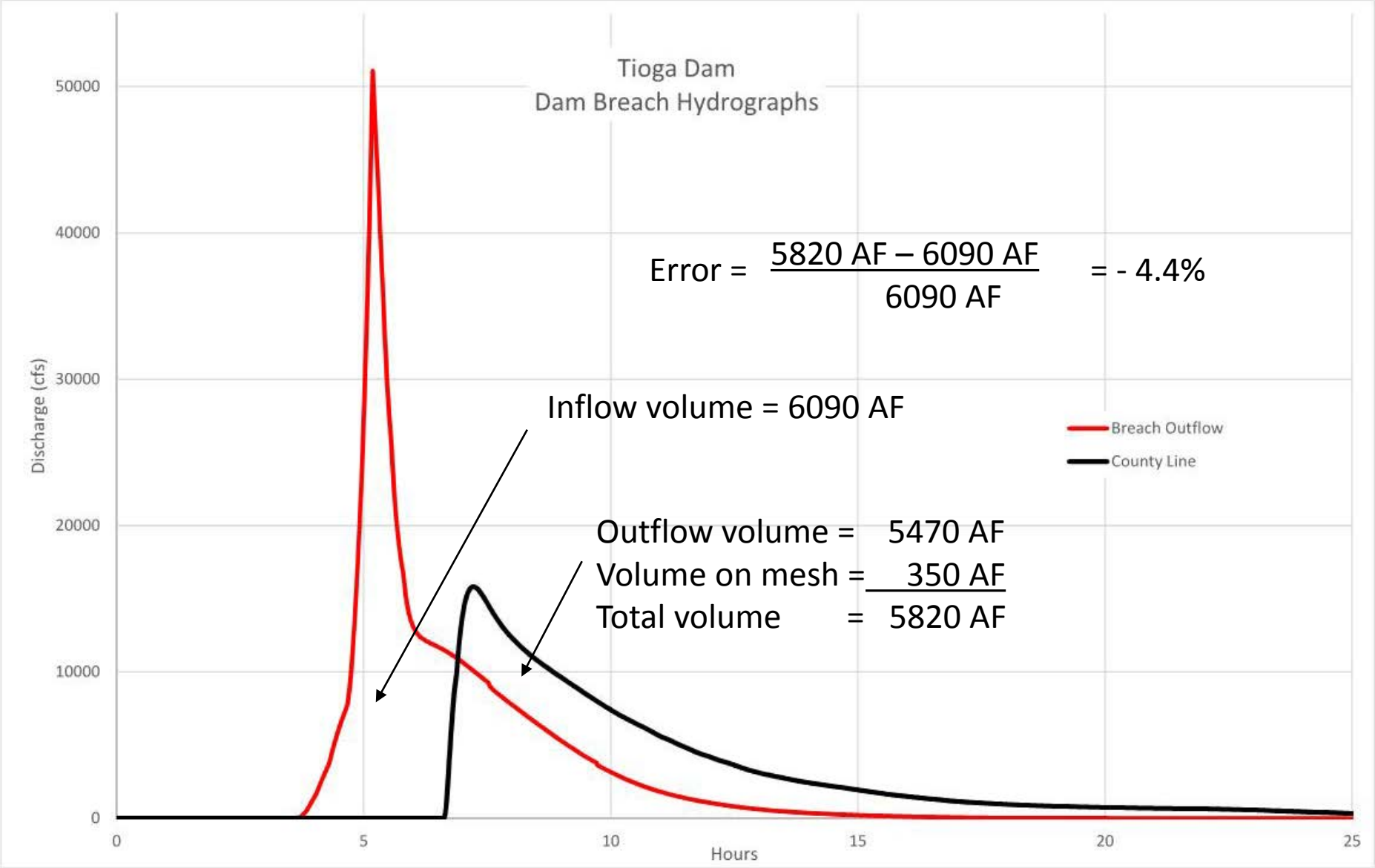
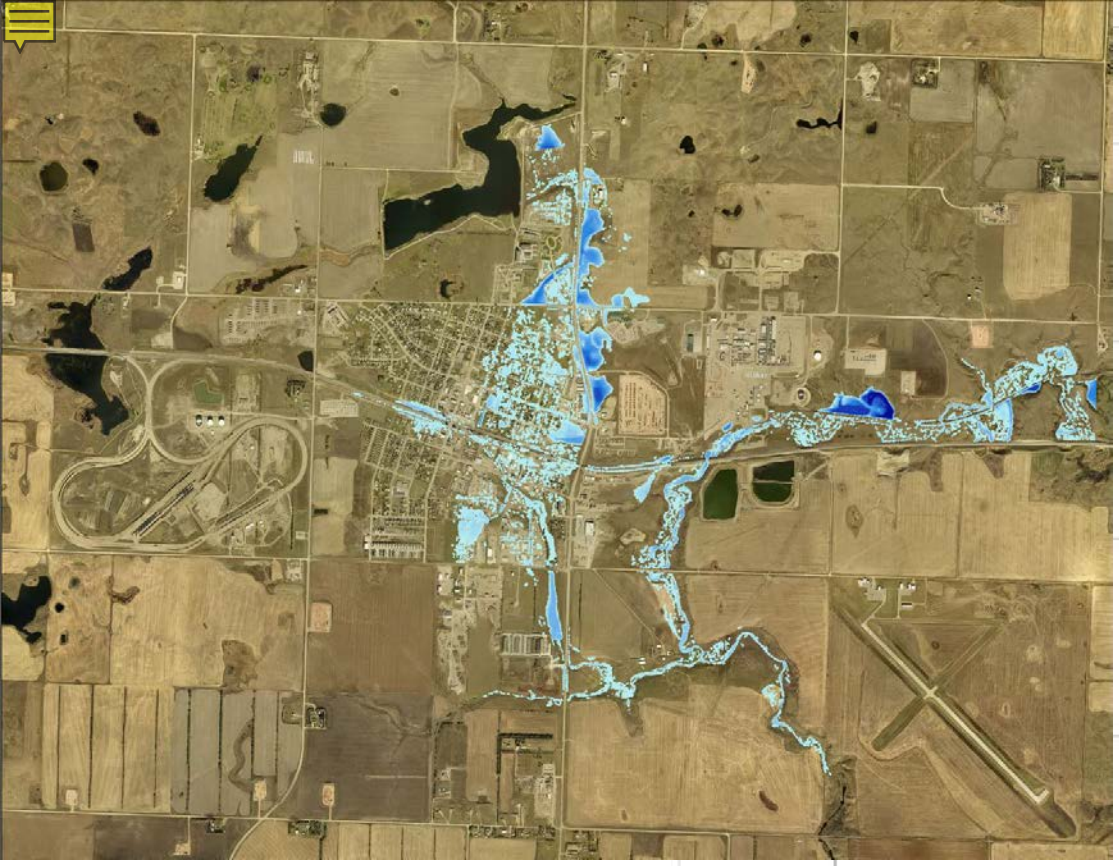
Continuity and Intermediate Cross Sections

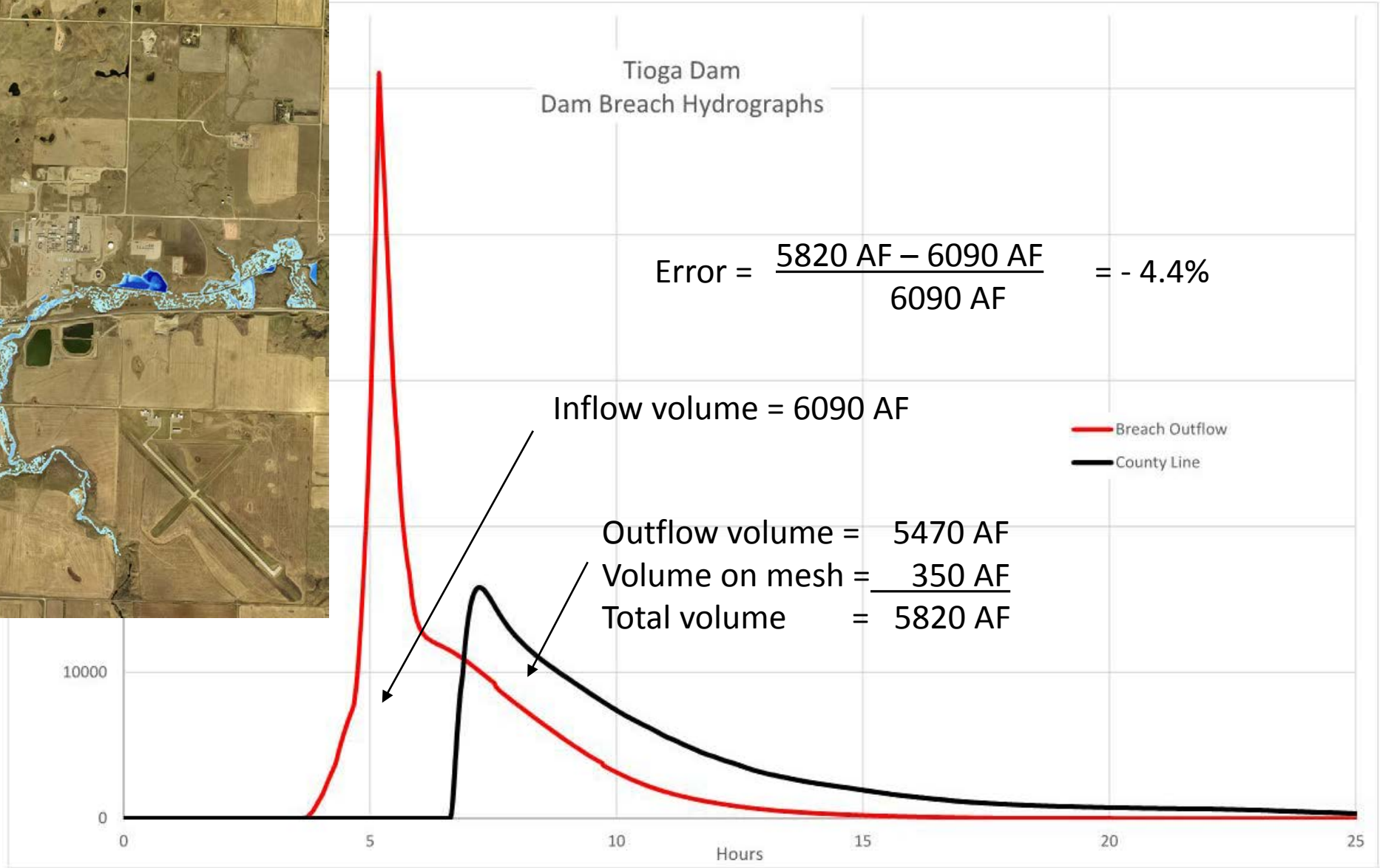


Continuity and Intermediate Cross Sections



$$\text{Error} = \frac{5820\ \text{AF} - 6090\ \text{AF}}{6090\ \text{AF}} = -4.4\%$$



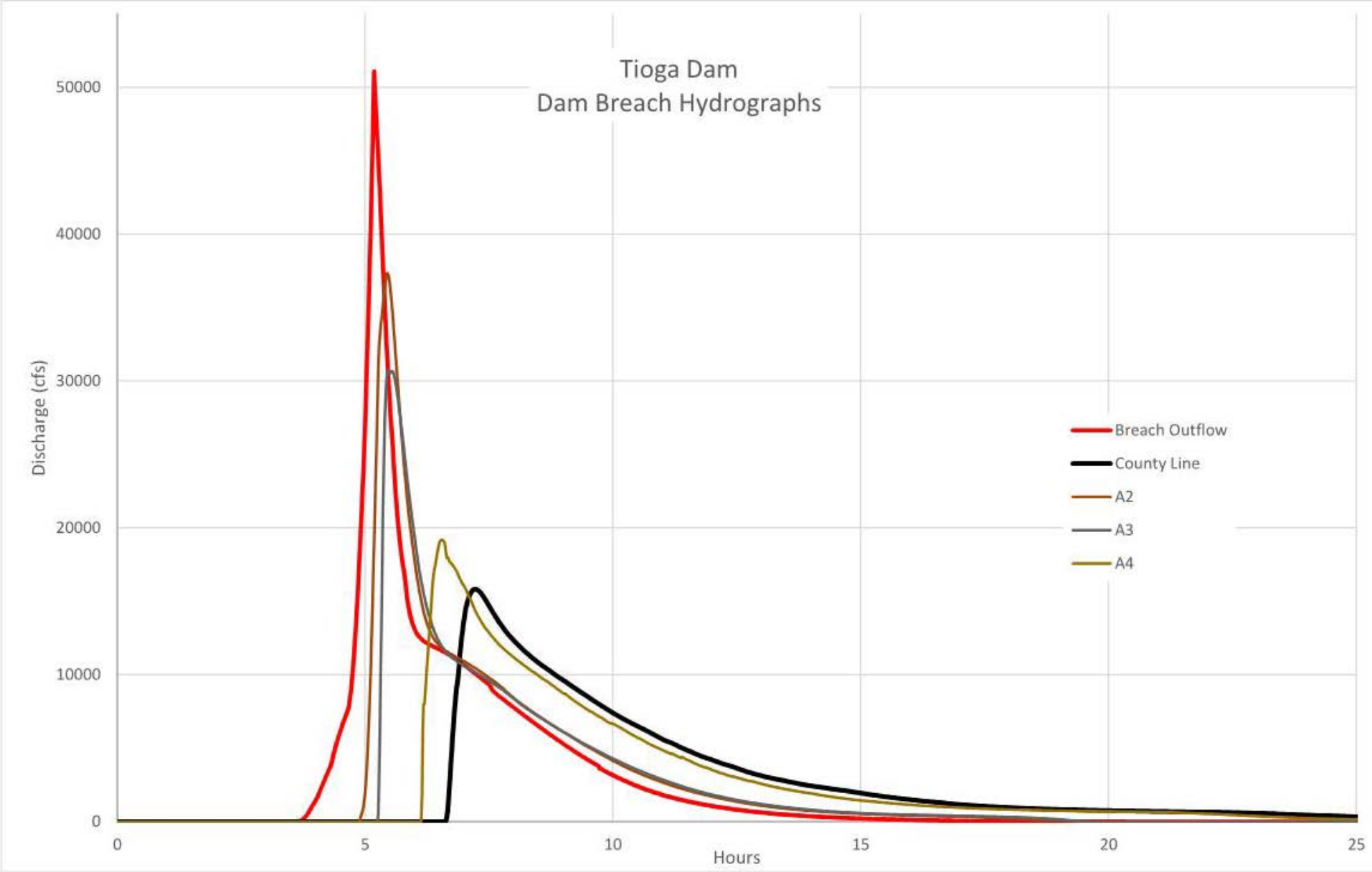


Error = $\frac{5820\text{ AF} - 6090\text{ AF}}{6090\text{ AF}}$ = - 4.4%

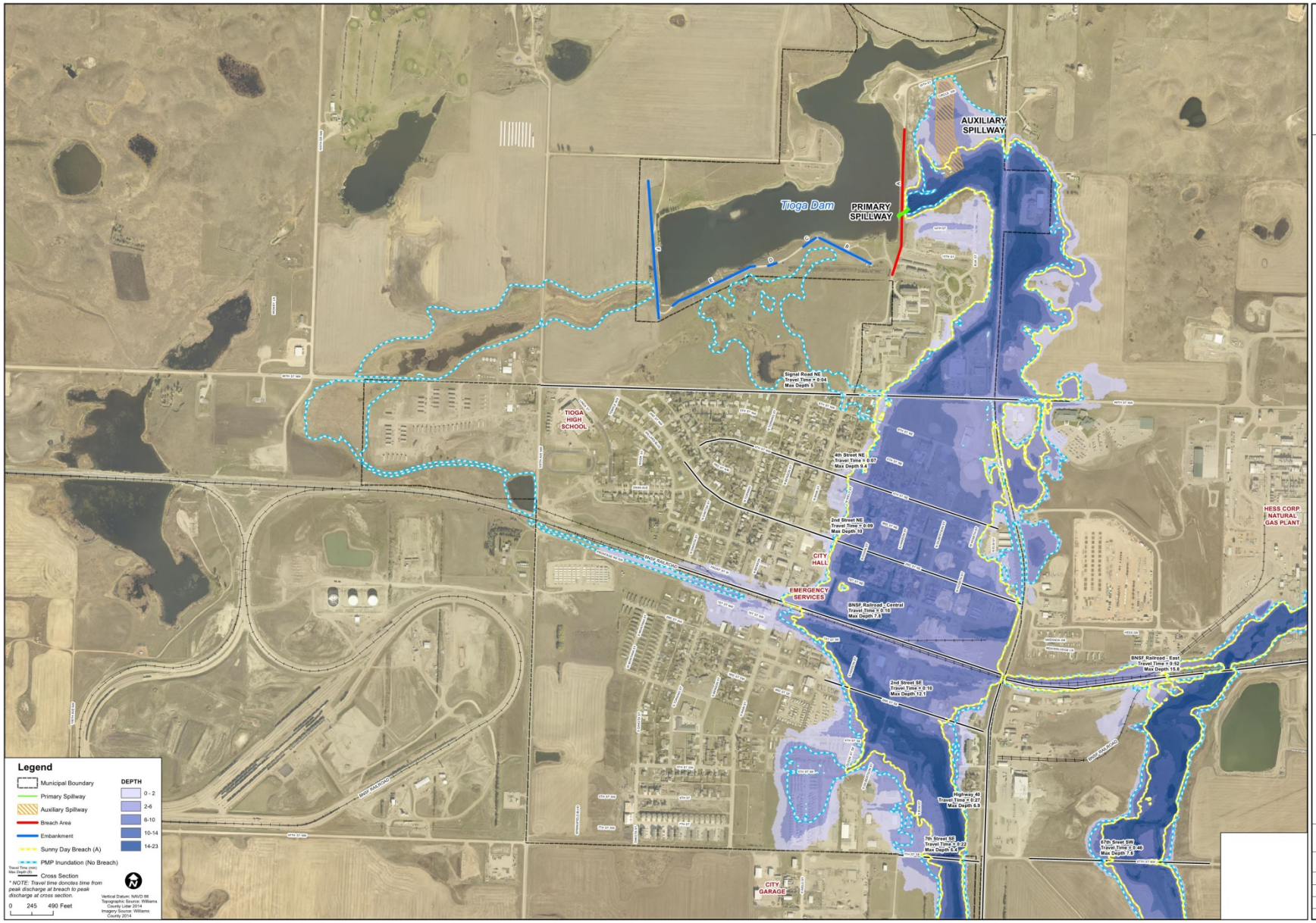
Inflow volume = 6090 AF

Outflow volume = 5470 AF
Volume on mesh = 350 AF
Total volume = 5820 AF

Continuity and Intermediate Cross Section



LESSON LEARNED - Continuity



FLOOD INUNDATION MAP
EMERGENCY ACTION PLAN
TIOGA DAM
PMP BREACH - EMBANKMENT A (1 of 2)

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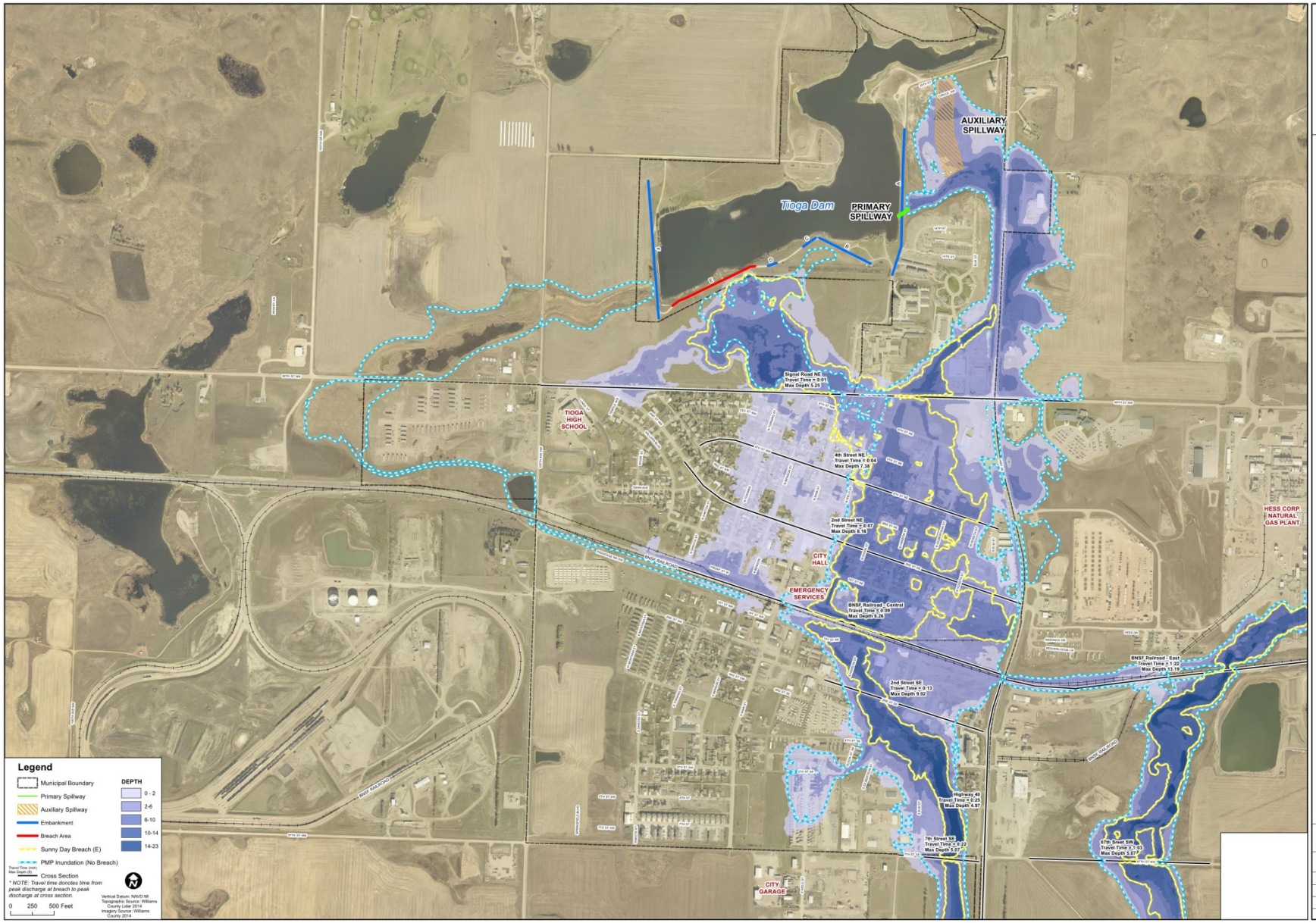
Minot, ND | Williston, ND

Project Name:	EMERGENCY ACTION PLAN TIOGA DAM
Project No:	R16038
Scale:	1" = 500'
Date:	07/05/2016
Drawn By:	CFE
Appr. By:	TRJ



FLOOD INUNDATION MAP
EMERGENCY ACTION PLAN
TIOGA DAM
PMP BREACH - EMBANKMENT E (1 of 2)

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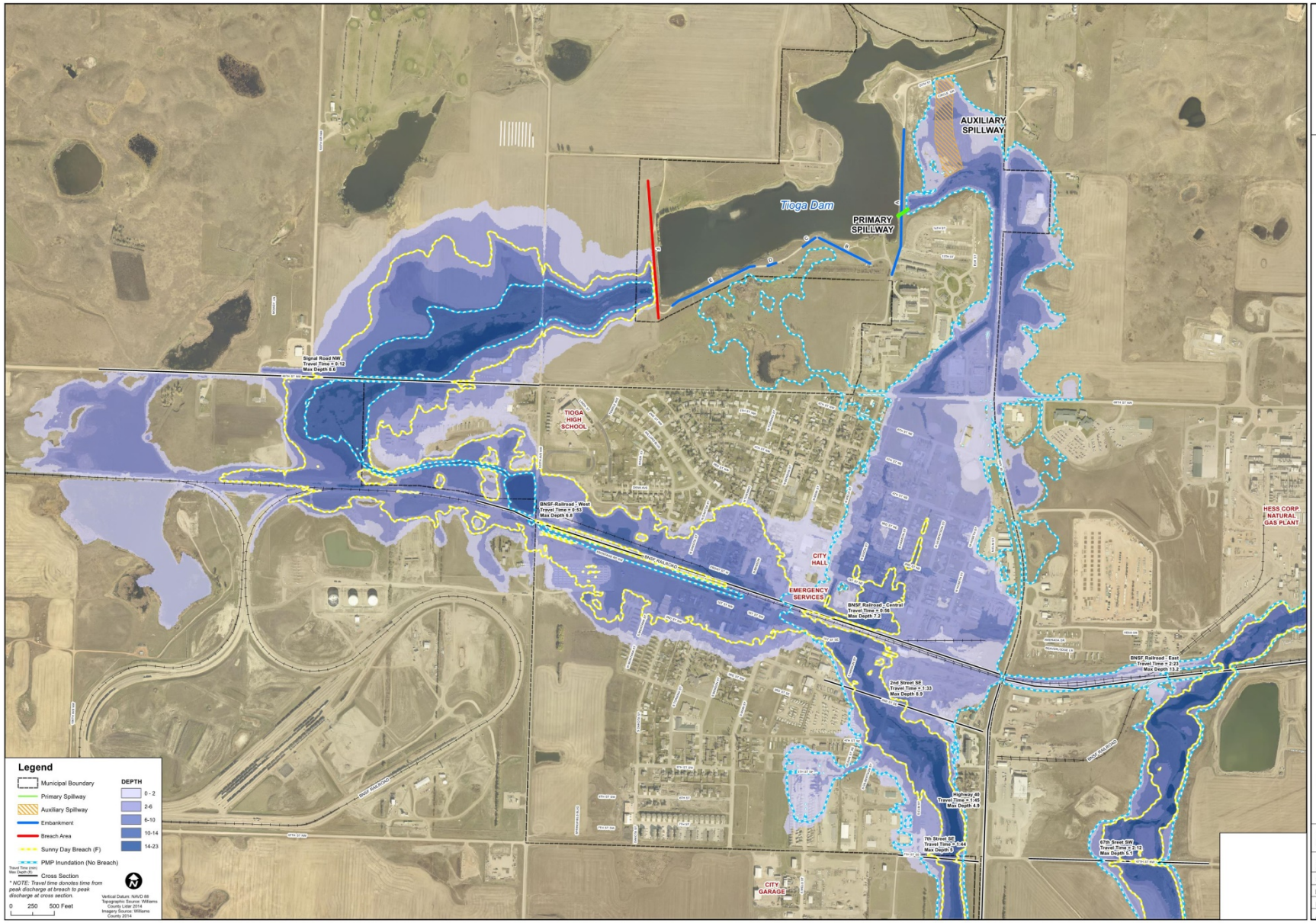
Project Name:	EMERGENCY ACTION PLAN TIOGA DAM
Project No:	R16038
Scale:	1" = 500'
Date:	07/05/2016
Drawn By:	CFE
Appr. By:	TRJ



FLOOD INUNDATION MAP
EMERGENCY ACTION PLAN
TIOGA DAM
PMP BREACH - EMBANKMENT F (1 of 2)

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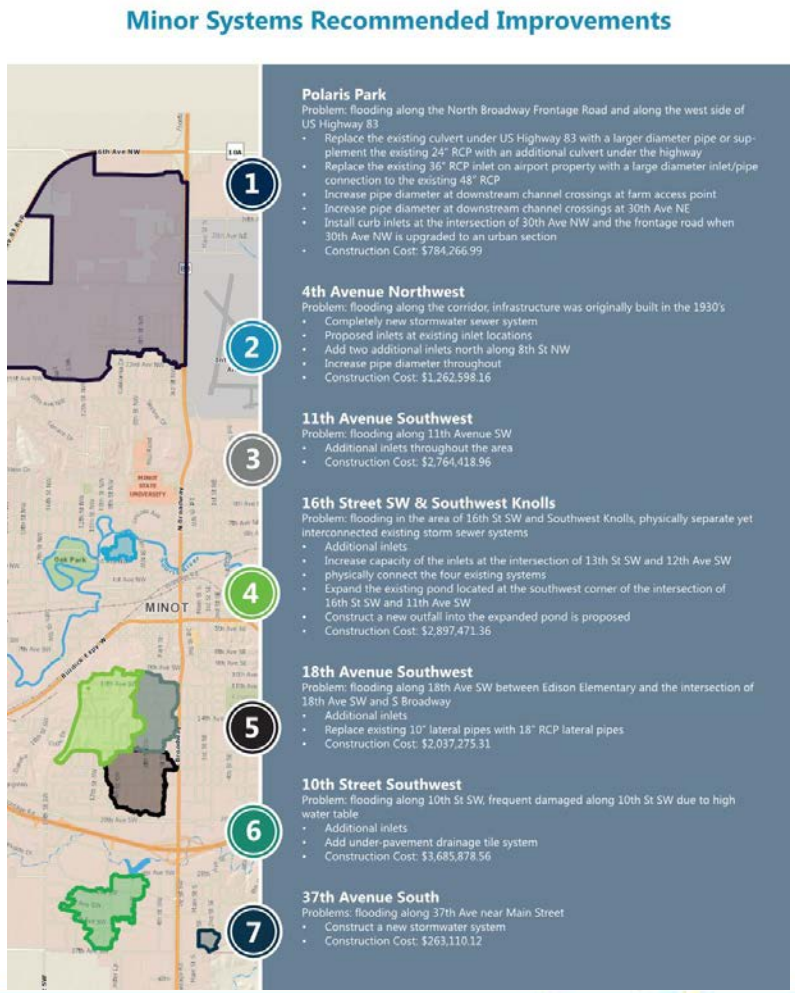
Minot, ND | Williston, ND

Project Name:	EMERGENCY ACTION PLAN TIOGA DAM
Project No:	R16018
Scale:	1" = 500'
Date:	07/05/2016
Drawn By:	CFE
Appr. By:	TRJ

18th Avenue Southeast Storm Sewer

- City of Minot Storm Water Management Plan – 2015
- Seven Minor Systems Improvements
- 18th Avenue Southwest is one of those recommended improvements



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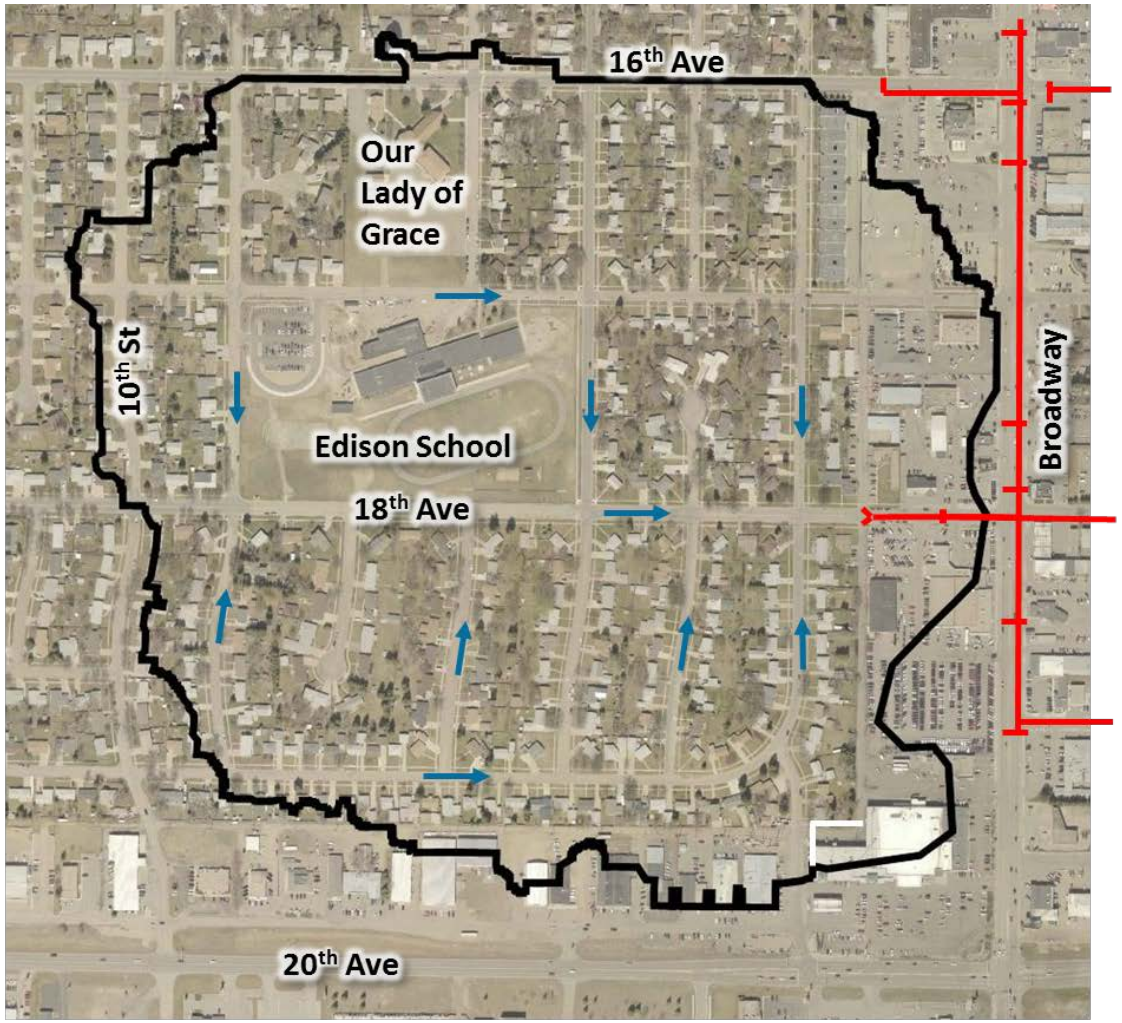
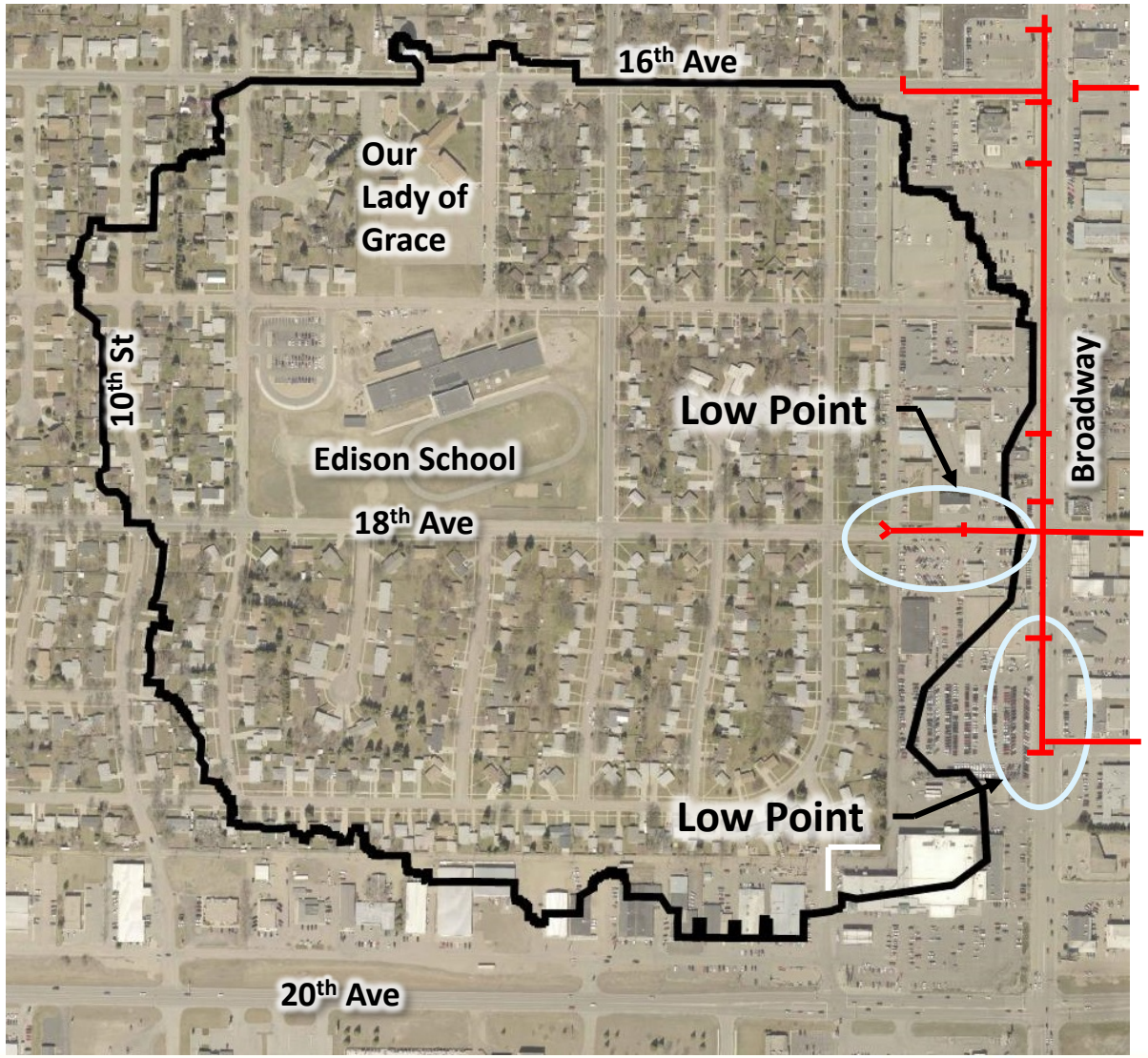
18th Avenue Southeast Storm Sewer

- Tributary area
  Approx. 138 acres
- Topography
- Overland flow routes



- Existing Storm Sewer Limitations



To Puppy Dog Coulee

Design Criteria

2-year storm for residential, 5-year storm for commercial

Local streets: 6-inch depth in gutter, spread to crown

Gravity flow during design storm

3fps < Velocity in Pipe < 20 fps

Check 100-year storm , 6-inch above crown maximum depth

Hydrology

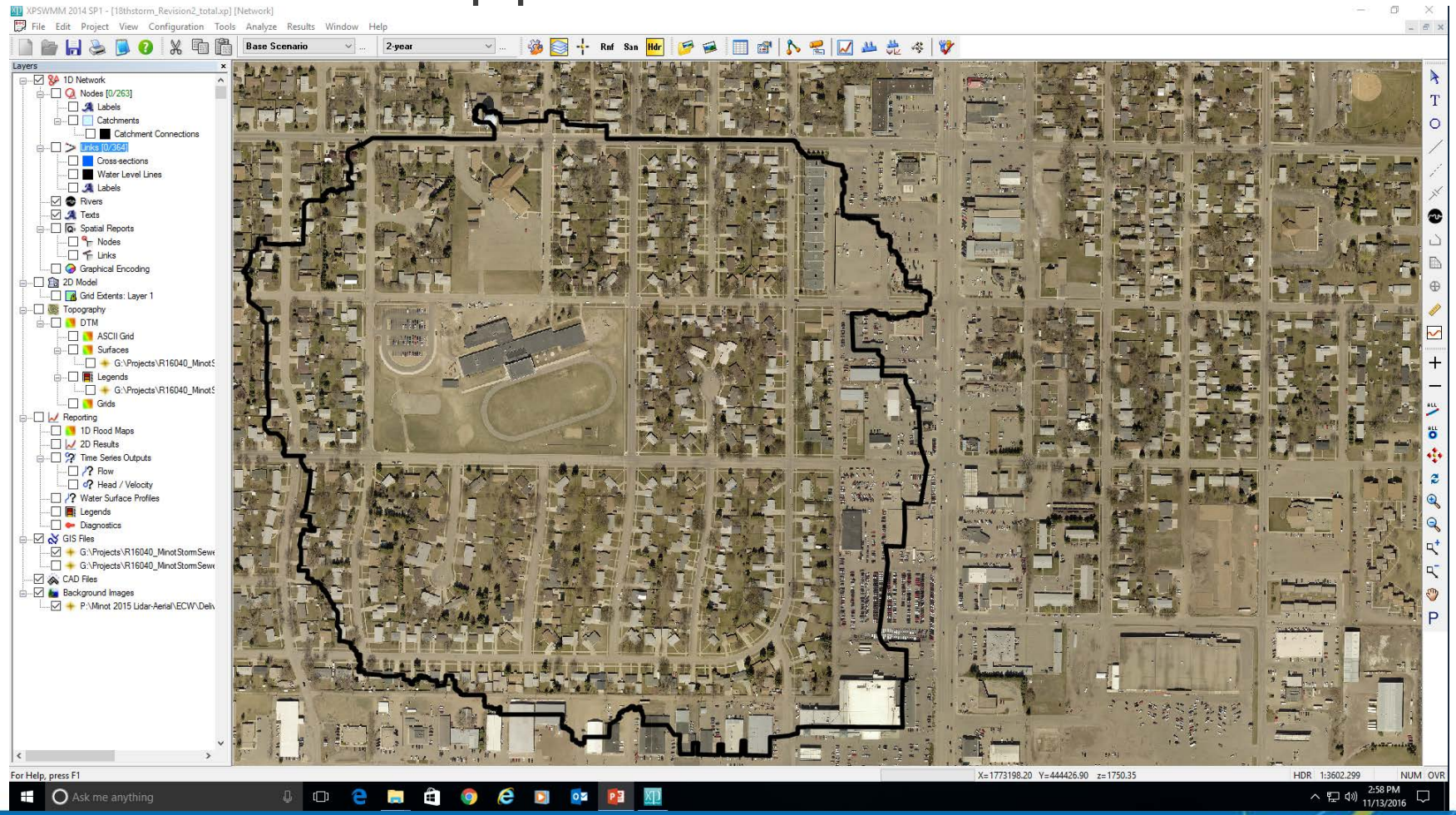
NRCS Curve Number

Velocity Method (NEH)

NRCS Type II

NOAA Atlas 14

18th Avenue Southeast Storm Sewer 1-Dimensional Approach



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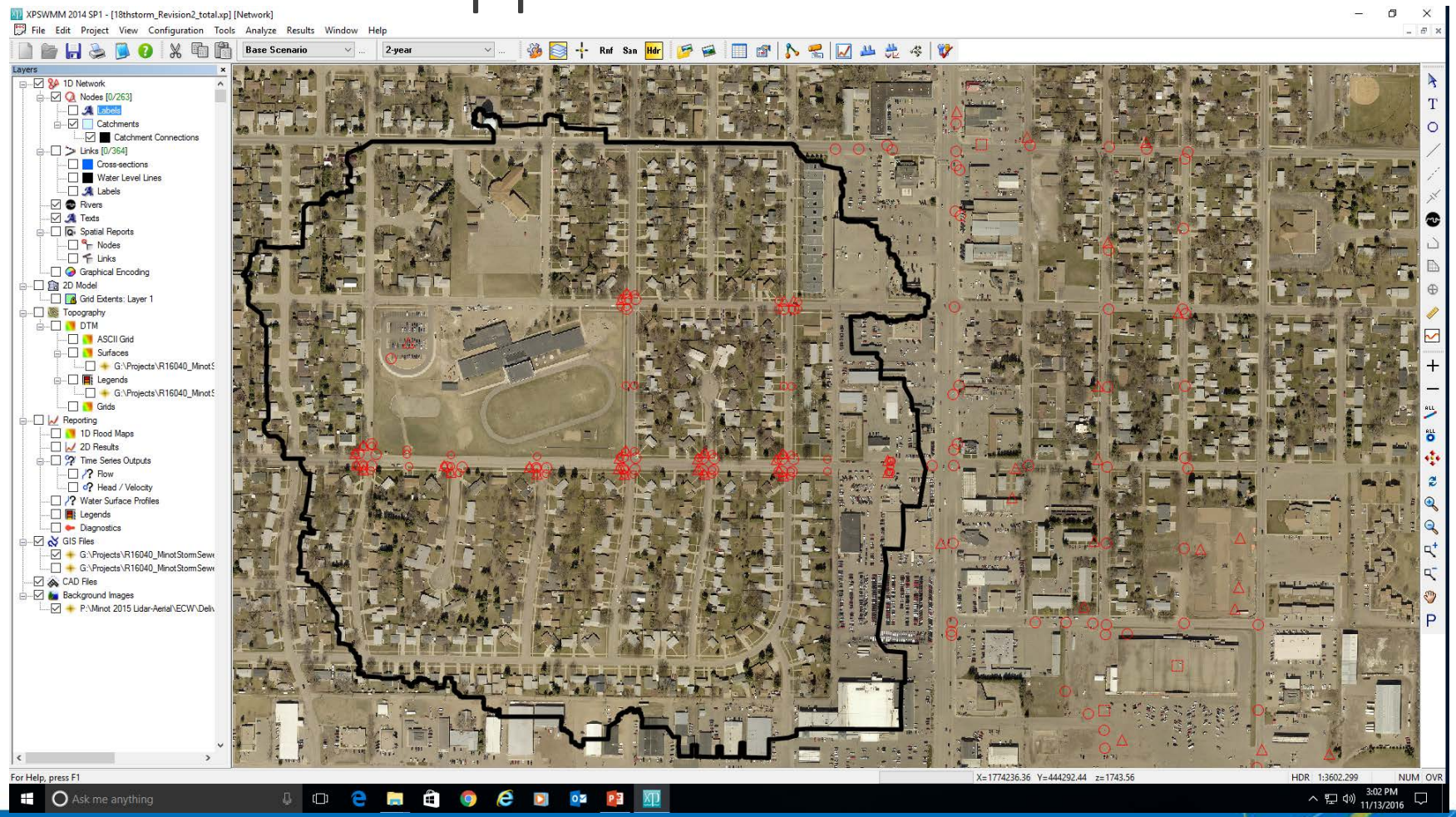
18th Avenue Southeast Storm Sewer 1-Dimensional Approach



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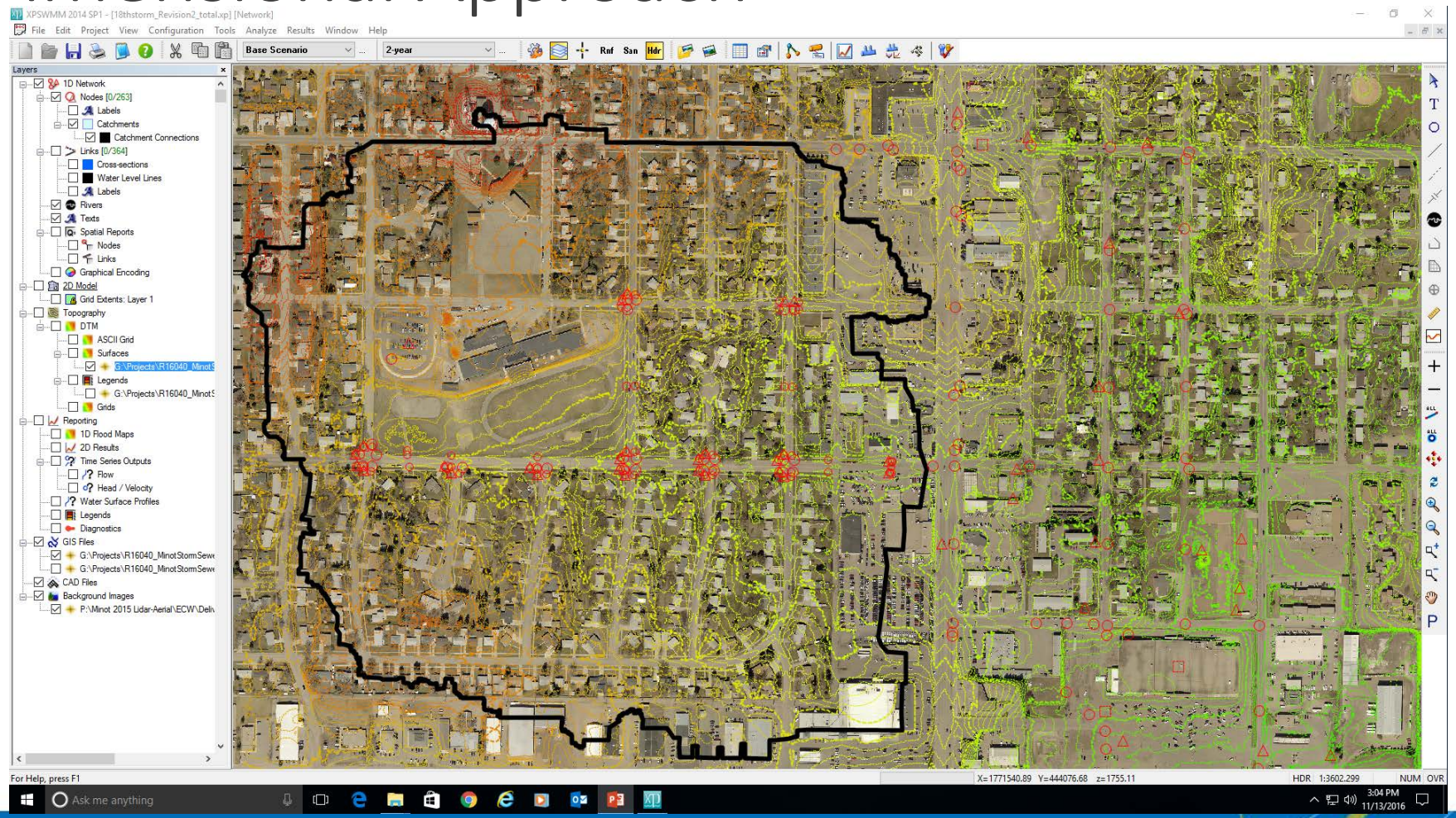
18th Avenue Southeast Storm Sewer 1-Dimensional Approach



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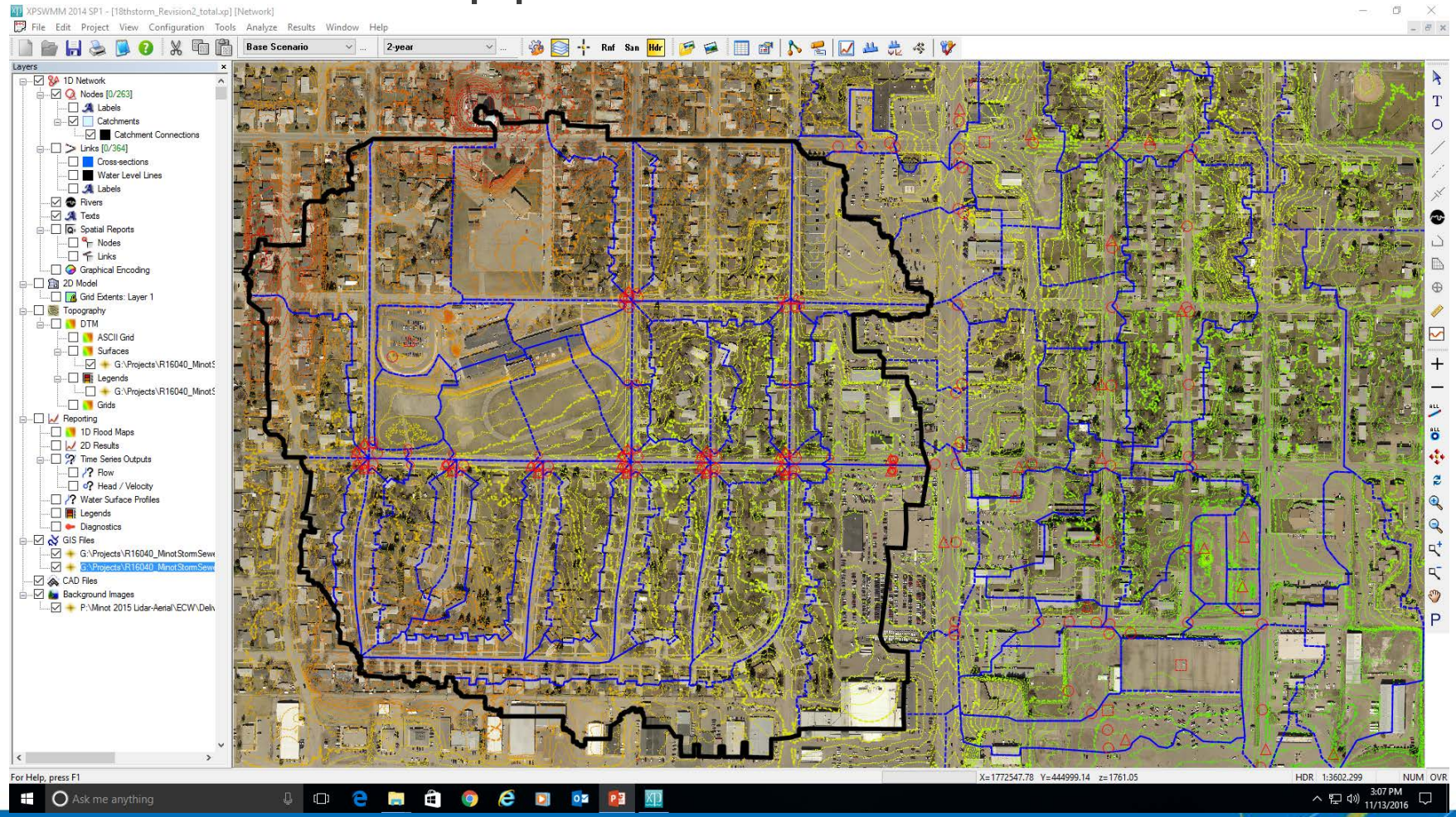
18th Avenue Southeast Storm Sewer 1-Dimensional Approach



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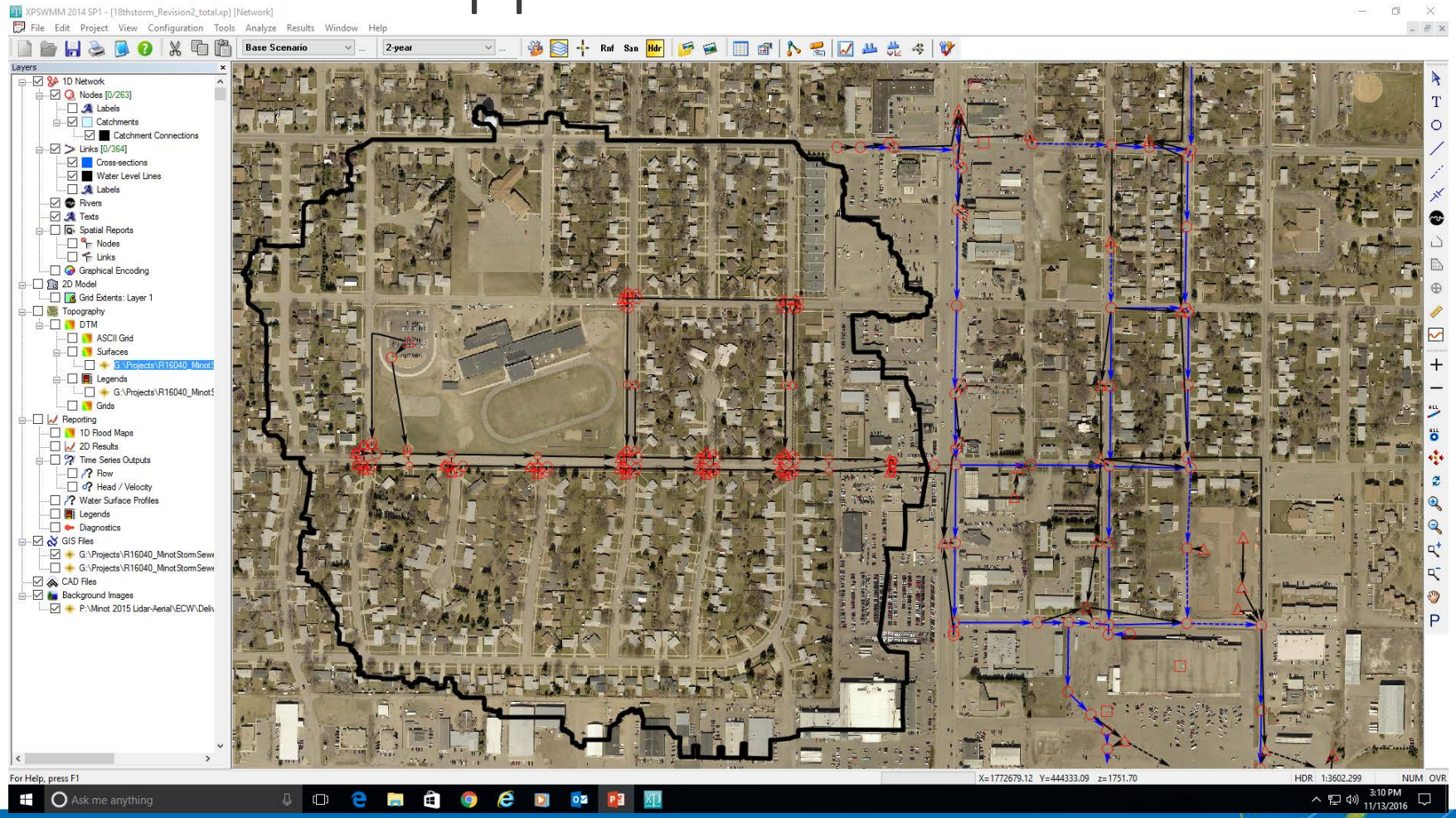
18th Avenue Southeast Storm Sewer 1-Dimensional Approach



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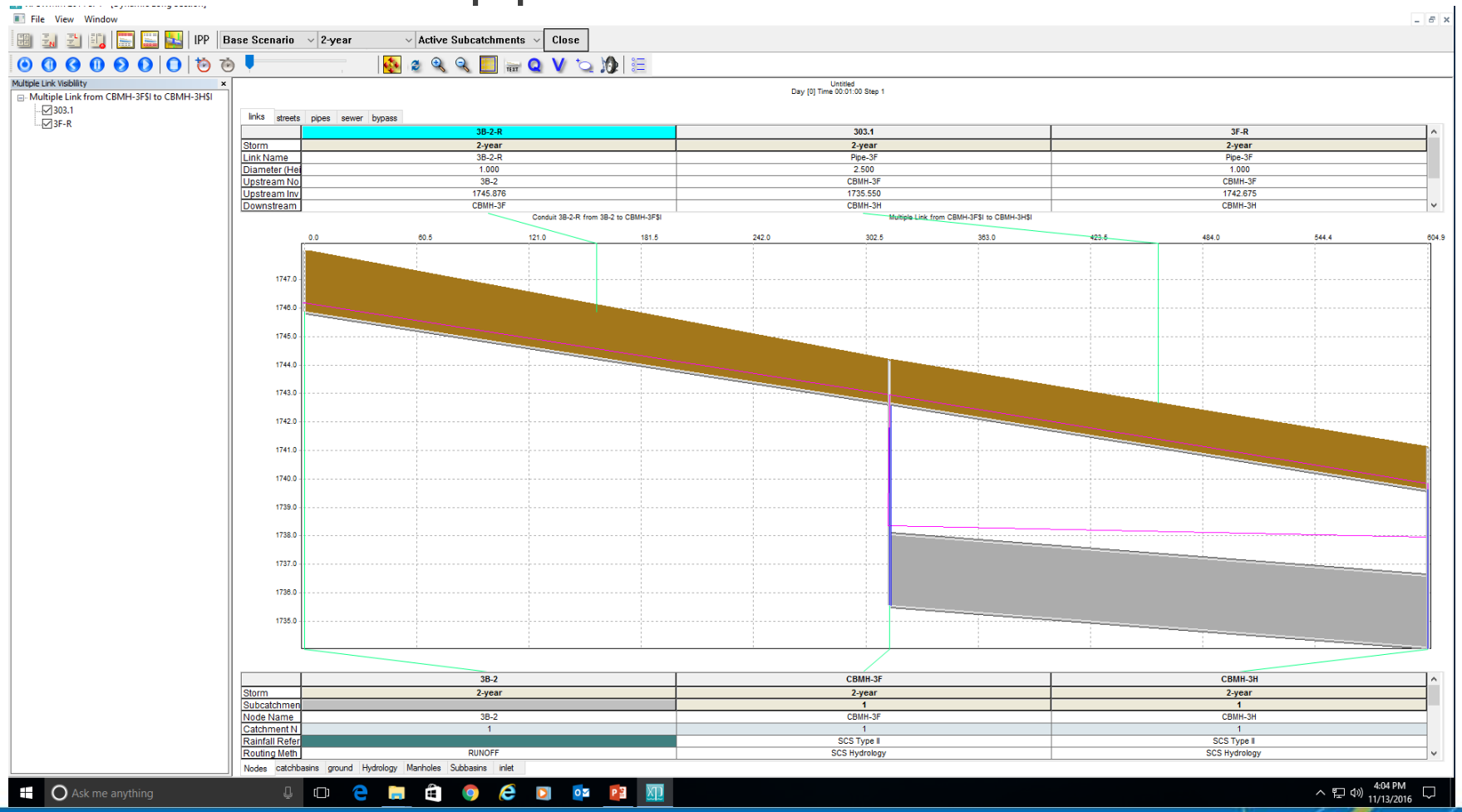

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1-Dimensional Approach

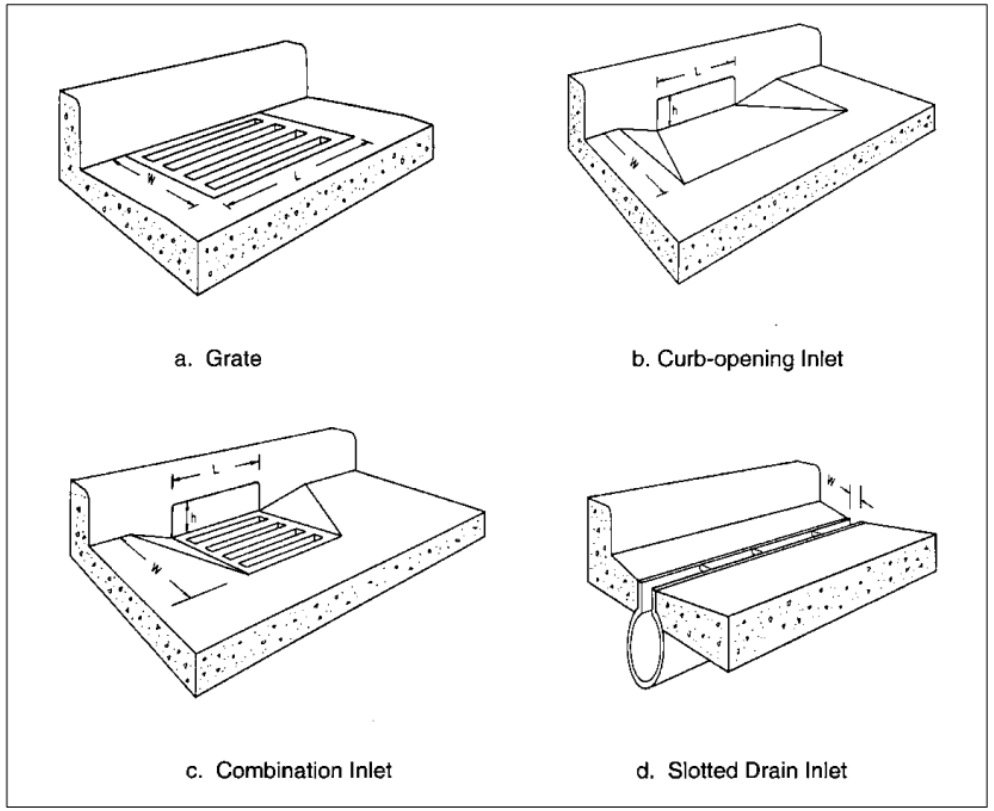
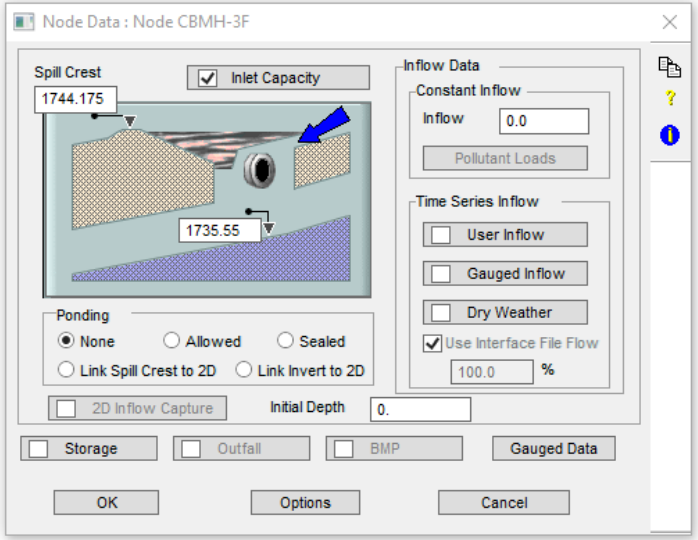
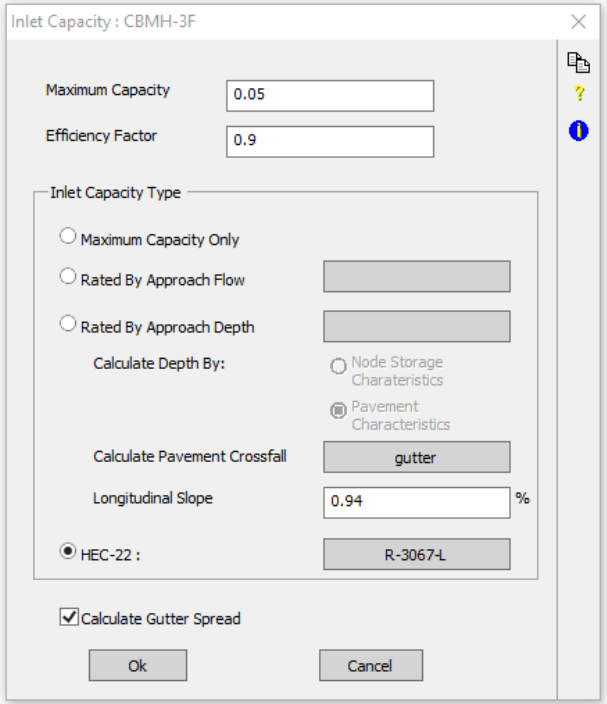
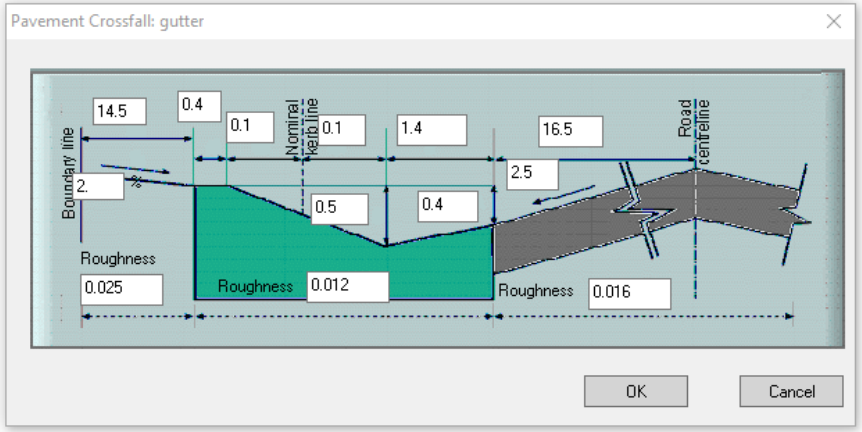


Figure 4-4. Classes of storm drain inlets.







1-Dimensional Approach

Inlet: **Neenah R-3295-2**
Grate: **Type C**
Reduction Factor: **0.7**

Depth-Flow Rating Curve

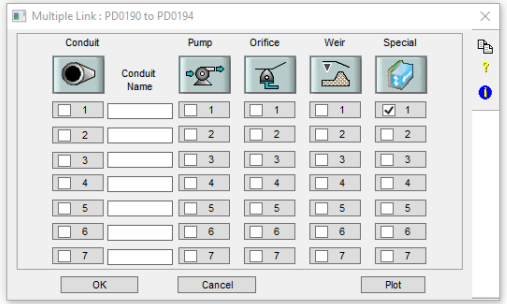
Depth (ft)	Flow rate: Grate (Neenah)* (CFS)	Curb Opening** (CFS)	Combined (CFS)	Reduced Combined (CFS)	Flow Type
0	0.0	-	0.0	**0.0**	Weir
0.1	0.9	-	0.9	**0.6**	Weir
0.2	2.6	-	2.6	**1.8**	Weir
0.3	4.8	-	4.8	**3.4**	Weir
0.4	7.3	-	7.3	**5.1**	Weir
0.5	10.3	-	10.3	**7.2**	Weir
0.6	11.7	6.5	18.2	**12.7**	Transition
0.7	13.6	7.2	20.8	**14.5**	Transition
0.8	15.6	7.8	23.4	**16.4**	Transition
0.9	19.2	8.4	27.6	**19.3**	Orifice
1	20.2	8.9	29.1	**20.4**	Orifice
1.5	24.8	11.3	36.1	**25.3**	Orifice
2	28.6	13.3	41.9	**29.3**	Orifice
2.5	32.0	15.0	47.0	**32.9**	Orifice
3	35.0	16.5	51.5	**36.0**	Orifice
4	40.4	19.2	59.6	**41.7**	Orifice
5	45.2	21.5	66.7	**46.7**	Orifice

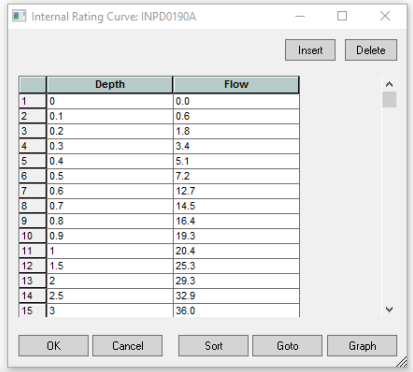
*Flow rates and flow types for grates are from Neenah Foundry online Weir & Orifice Calculator

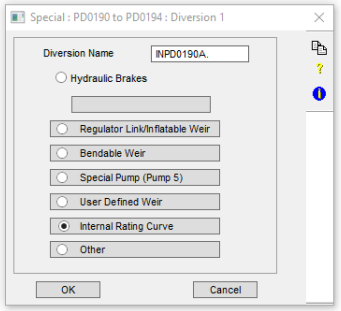
**Flow rates for curb openings are calculated from FHWA HEC-22 Equation 4-31a: $\mathbf{Q=C_o hL(2gd_o)^{0.5}}$

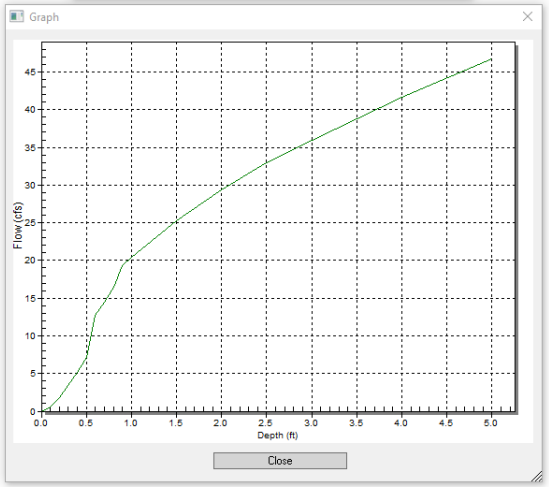
FHWA HEC-22 Equation 4-31a variables

Symbol	Equation	Value	Units	Description
C_o=		**0.67**	-	Orifice Coefficient
g=		**32.2**	ft/s^2	Acceleration of Gravity
h=		**0.33**	ft	Curb Opening Height
L=		**5.52**	ft	Curb Opening Length
d_o=	depth-(h/2)	**Variable**	ft	Head at Center of Curb Opening

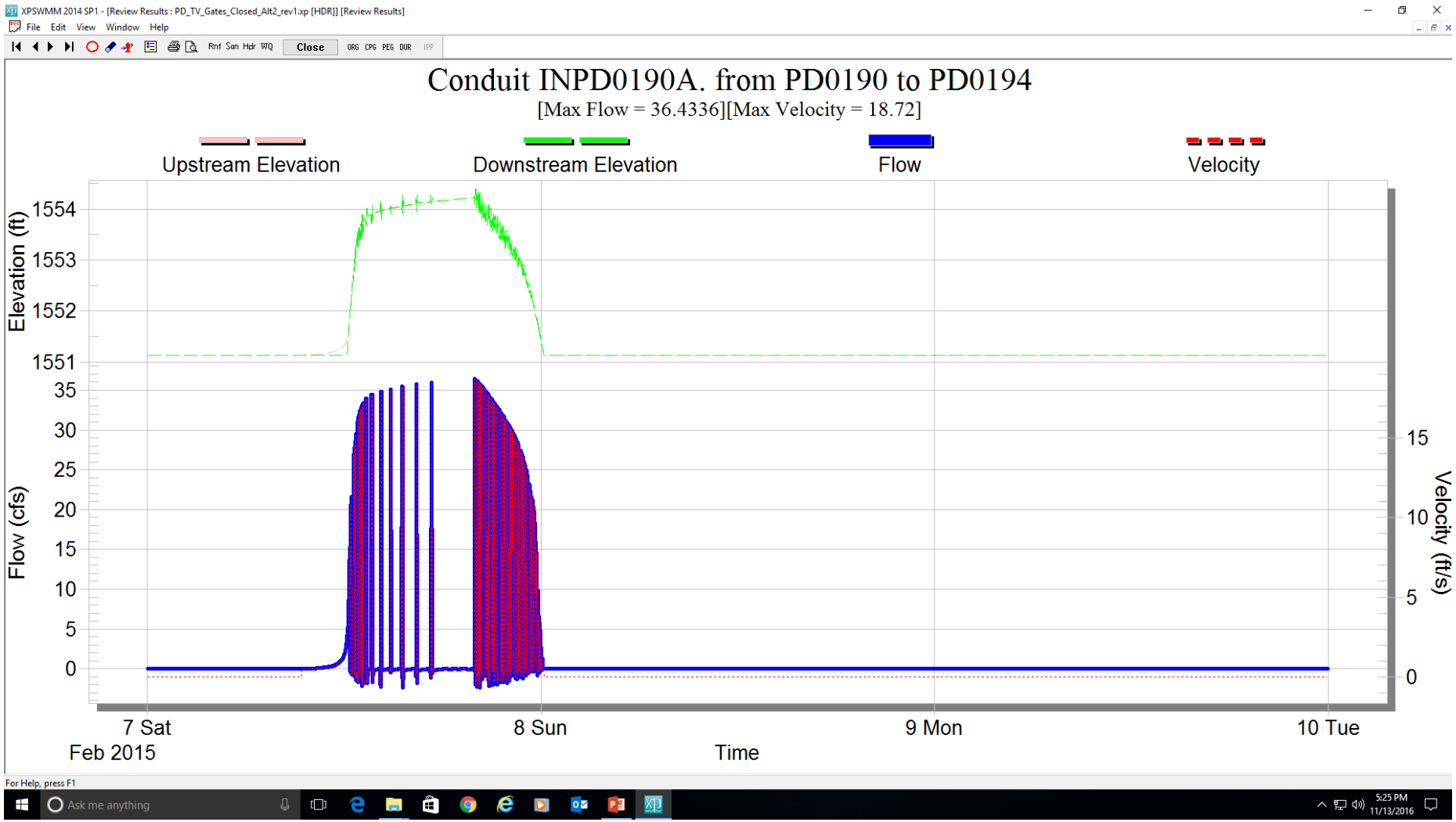








1-Dimensional Approach



1-Dimensional Approach

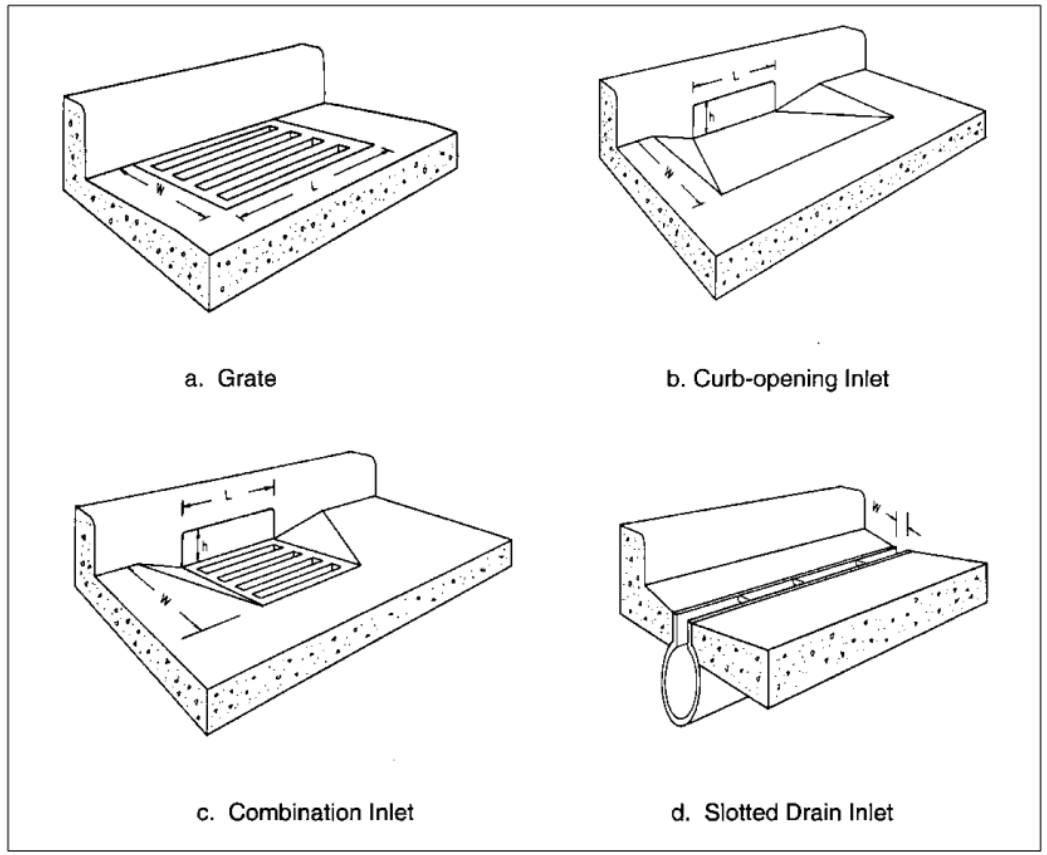


Figure 4-4. Classes of storm drain inlets.

The standard orifice equation is:

Qo = Co·Ao· Sqrt(2·g·h)

where, Co = discharge coefficient (a function of the type of opening and the length of the orifice tube),

Ao = cross-sectional area of the orifice,

g = gravitational acceleration, and

h = the hydraulic head on the orifice.

Values of Co and Ao are specified by the user. To convert the orifice to a pipe, the program equates the orifice discharge equation and the Manning pipe flow equation, i.e.,
(m/n)·A·R2/3·Sqrt(So) = Co·Ao·Sqrt(2·g·h) (36)

where m = 1.486 for U.S. customary units and 1.0 for metric units, and So is the bed slope.

The orifice conduit is assumed to have the same diameter or depth, D, as the orifice and to be nearly flat, the invert on the discharge side being set 0.01 ft (3 mm) lower than the invert on the inlet side. In addition, for a sump orifice, the pipe invert is set by the program 0.96·D below the junction invert so that the orifice conduit is flowing full before any outflow from the junction occurs in any other pipe. For side outlet orifices, the user specifies the height of the orifice invert above the junction floor.

1-Dimensional Approach

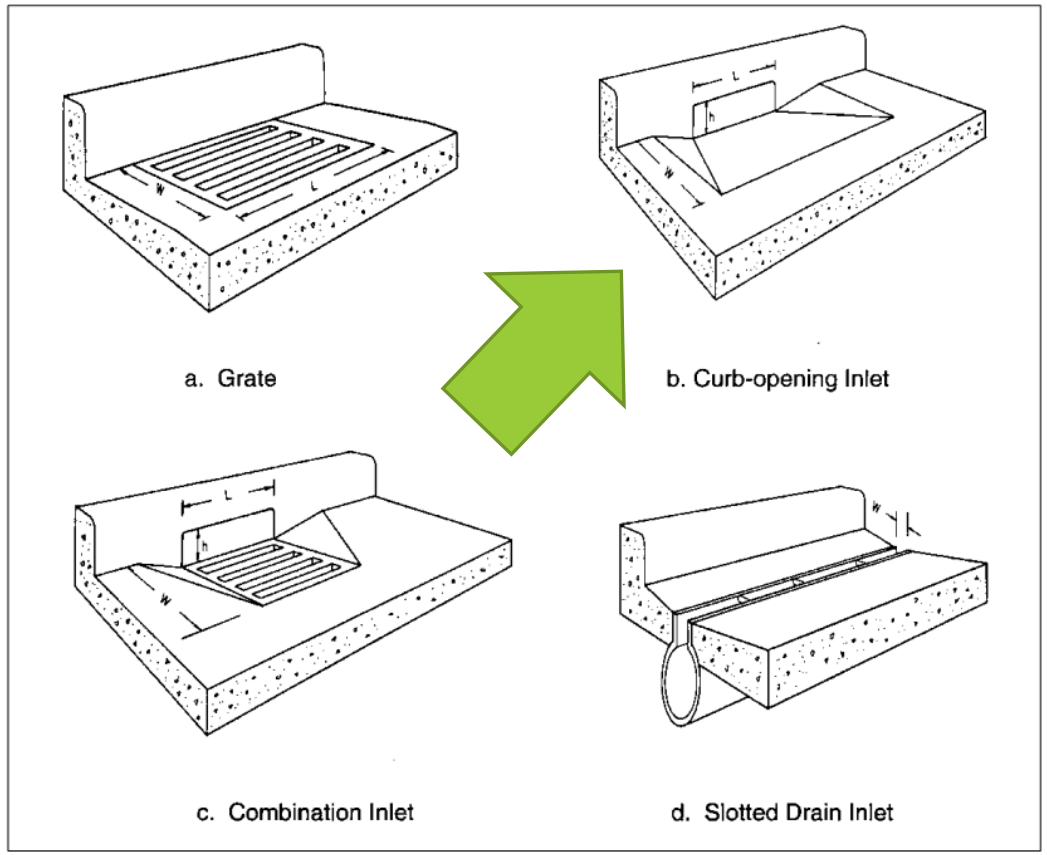


Figure 4-4. Classes of storm drain inlets.

DESIGN MEMORANDUM

Note: This form must be used for project calculations and original to be placed in project files.

ACKERMAN ESTVOLD

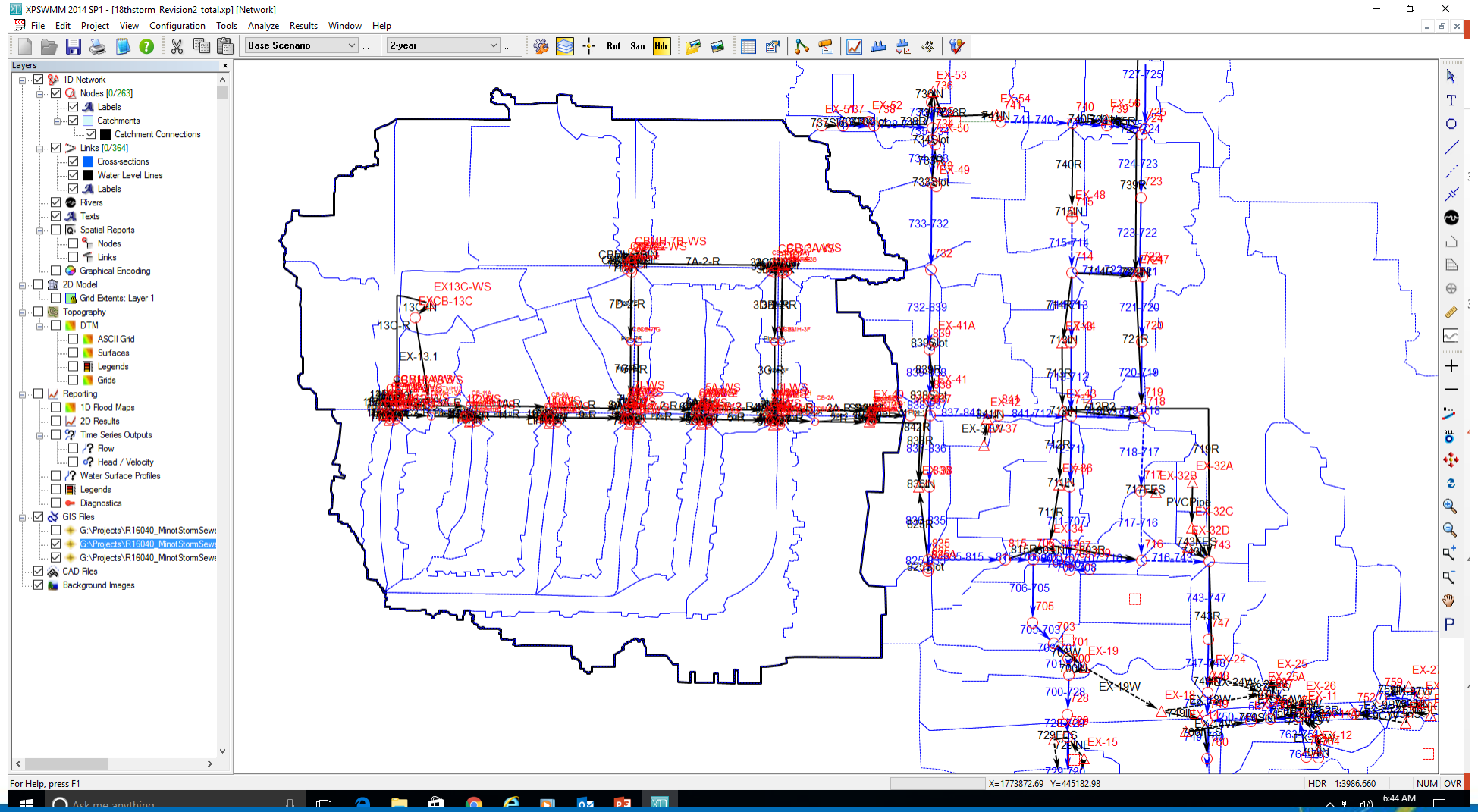
CLIENT			
City of Minot		PROJECT NO.	PAGE
PROJECT		R16007	1
Minot Storm Sewer District 122		PREPARED BY	FILE NO.
SUBJECT		DPW	R16040
Orifice equivalents of common catchbasins.		CHECKED BY	DATE
			8/5/2016

References:

1. Neenah Website
2. Spreadsheets from Houston

NDDOT Type	**2**	Grate Area	1.60	SF
Neenah Equivalent	**R-3067-C**	Curb Cut Length	2.90	ft
		Curb Cut Height	0.33	ft
		Grate Perimeter	5.80	ft
		Total area	2.56	SF
		80% of Area	**2.05**	**SF**
		Assumed Orifice Height	**0.353**	**ft**

1-Dimensional Approach



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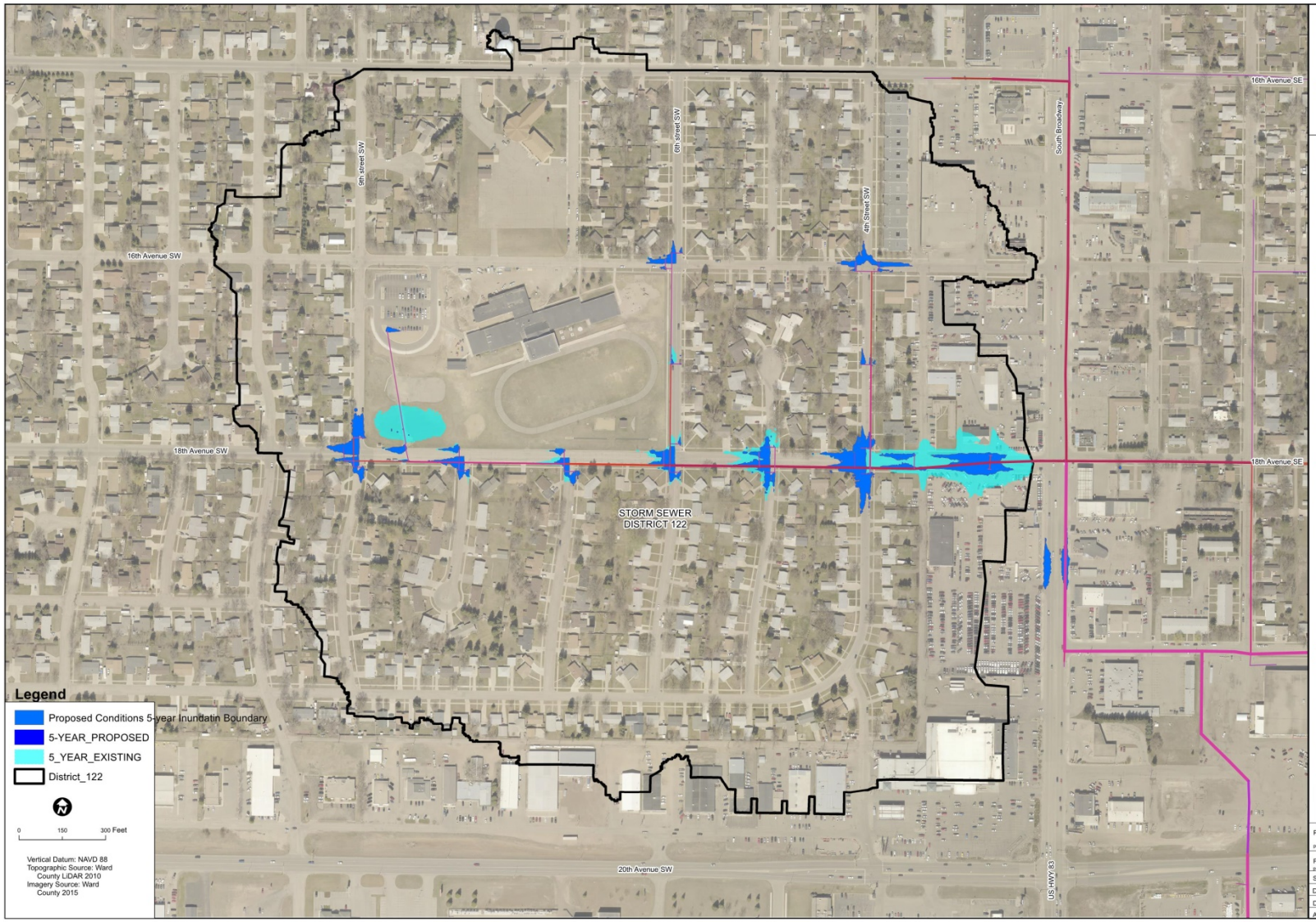

EXHIBIT 5

City of Minot

STORM SEWER DISTRICT 122
18th AVENUE SW
5-YEAR STORM

ACKERMAN ESTVOLD
1907 17th Street Southeast · Minot, ND 58701
701.837.8737 · www.ackerman-estvold.com
Minot, ND | Williston, ND

Project Name: project name	
Project No: project number	
Scale:	1" = 100'
Date:	00/00/0000
Drawn By:	AAA
Appr. By:	AAA

ACKERMAN ESTVOLD

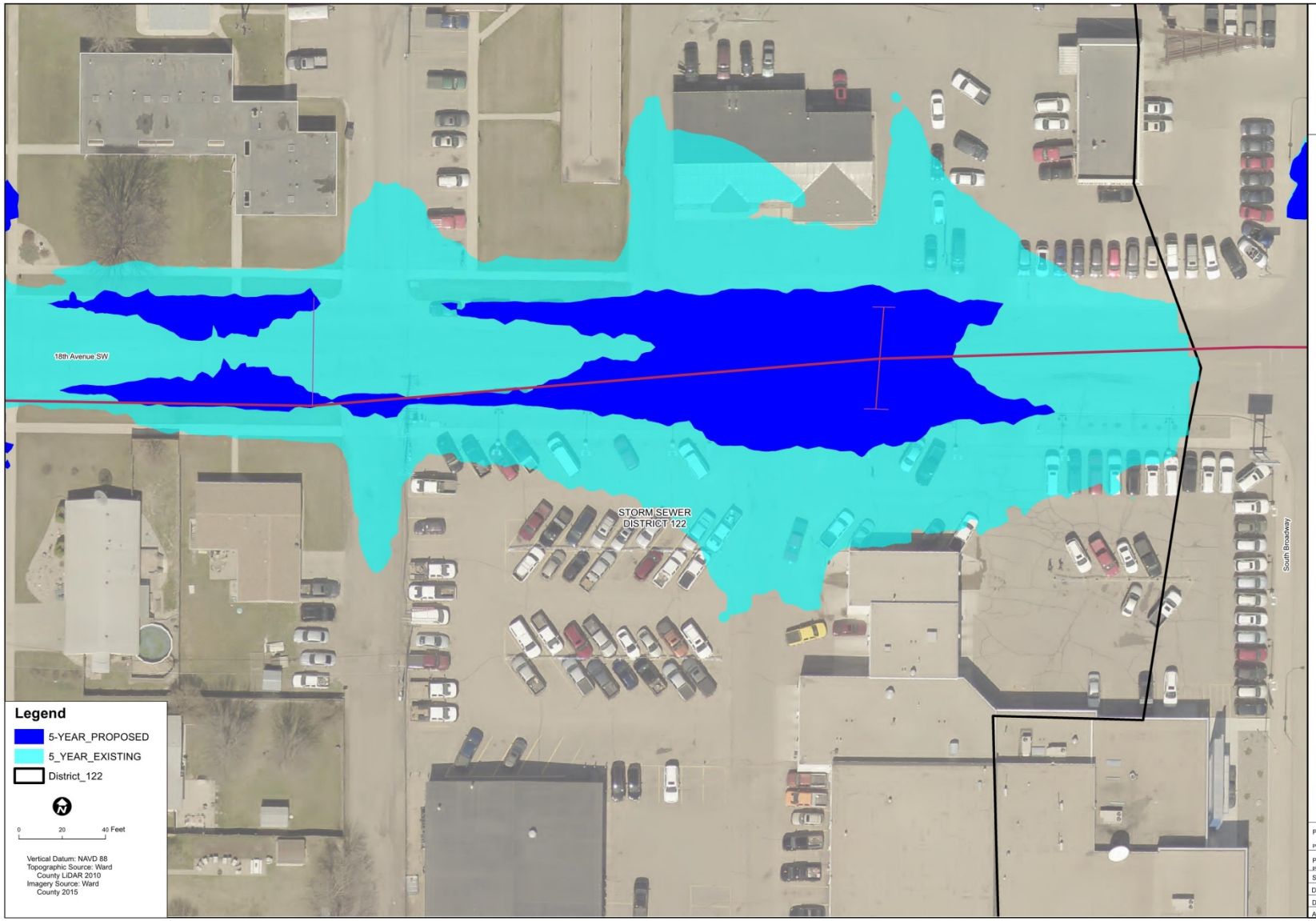

EXHIBIT 6

City of Minot

STORM SEWER DISTRICT 122
18th AVENUE SW
5-YEAR STORM

ACKERMAN ESTVOLD
1907 17th Street Southeast - Minot, ND 58701
701.837.8737 - www.ackerman-estvold.com
Minot, ND | Williston, ND

Project Name:	project name
Project No:	project number
Scale:	1" = 100'
Date:	00/00/0000
Drawn By:	AAA
Appr. By:	AAA

ACKERMAN ESTVOLD

Minot Daily News

BREAKING NEWS Storm-related closure announcements

Sewer project reviewed

Minot considers scrapping 18th Avenue SW storm sewer project

Jill Schramm/MDN Shown Wednesday looking west from Broadway, 18th Avenue Southwest is scheduled for storm sewer work this year, but city council members may decide to cancel the project.

A committee is recommending the Minot City Council drop plans for a storm sewer project on 18th Avenue Southwest because many residents of the area don't want it.

Minot Daily News

BREAKING NEWS Storm-related closure announcements

City wise to heed residents' wishes

There aren't that many occasions when city government can be hyper-responsive to the desires of a particular neighborhood. Generally, situations are of greater import, have a broader impact or are entwined in complex planning, preventing city government from being able to react.

Some Minot residents have come out opposed to a storm sewer project in their neighborhood around 18th Avenue SW. The plan has been in place there for years, just now reaching the point where the city is looking at getting it underway.

Residents who object say that there is no need to invest the money (most of it coming from a special assessment) in the project because street flooding hasn't been a prohibitive problem there. In response, the council's Finance and Improvement Committee is recommending against kicking off the project.

Good for residents to speak up and good for the committee members to take public will into consideration. Hopefully, the call from residents accurately reflects the situation and is not inspired just by cost.

The residents opposed to the project need also be accountable, though. Resources will now be directed elsewhere and if this project suddenly becomes desirable, it should have lost its place in the queue. That's the risk of this kind of community involvement. Hopefully this position is well

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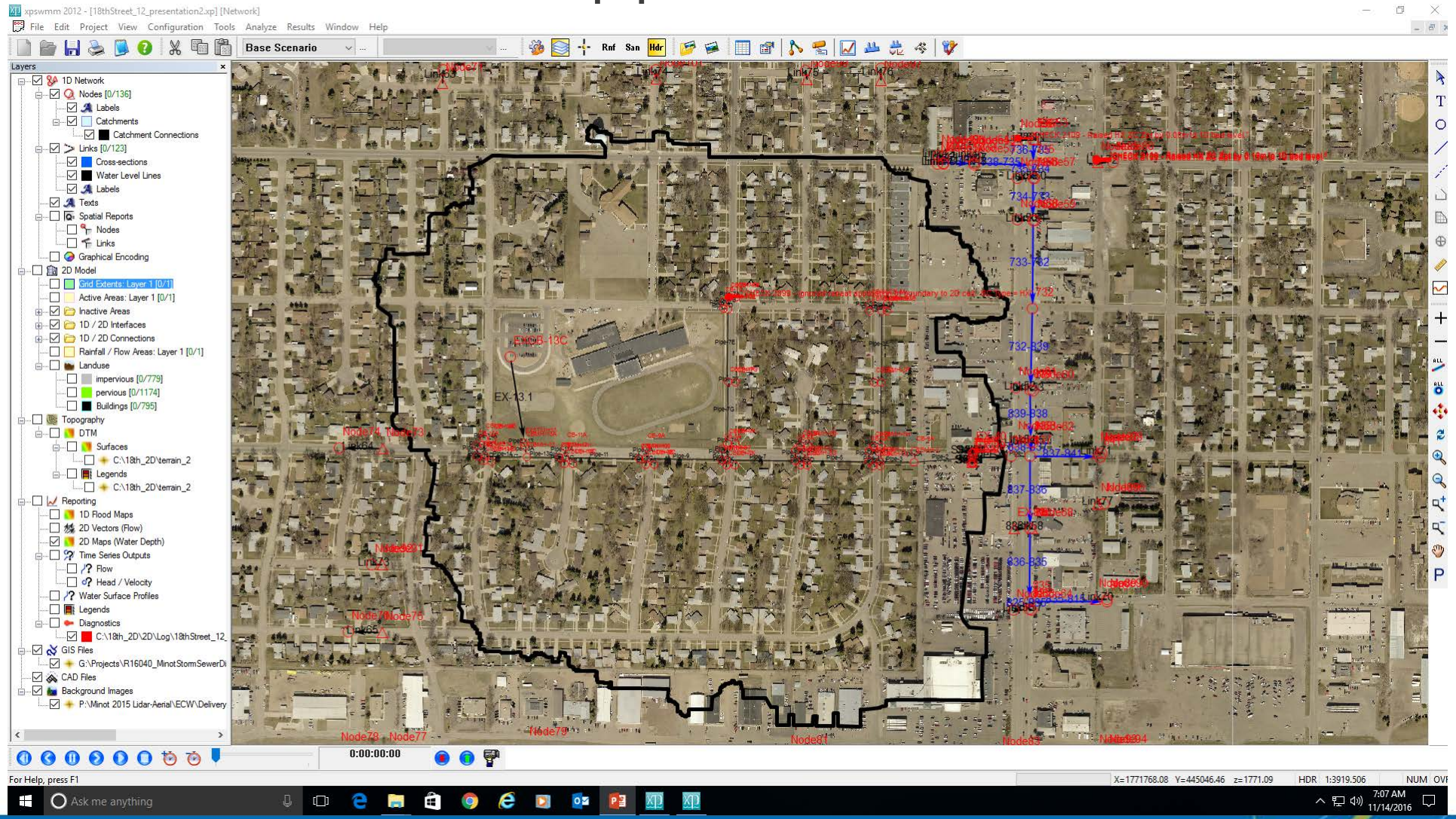
18th Avenue Southeast Storm Sewer

June 4, 2014 Rainfall Event

ACKERMAN ESTVOLD

2-Dimensional Approach



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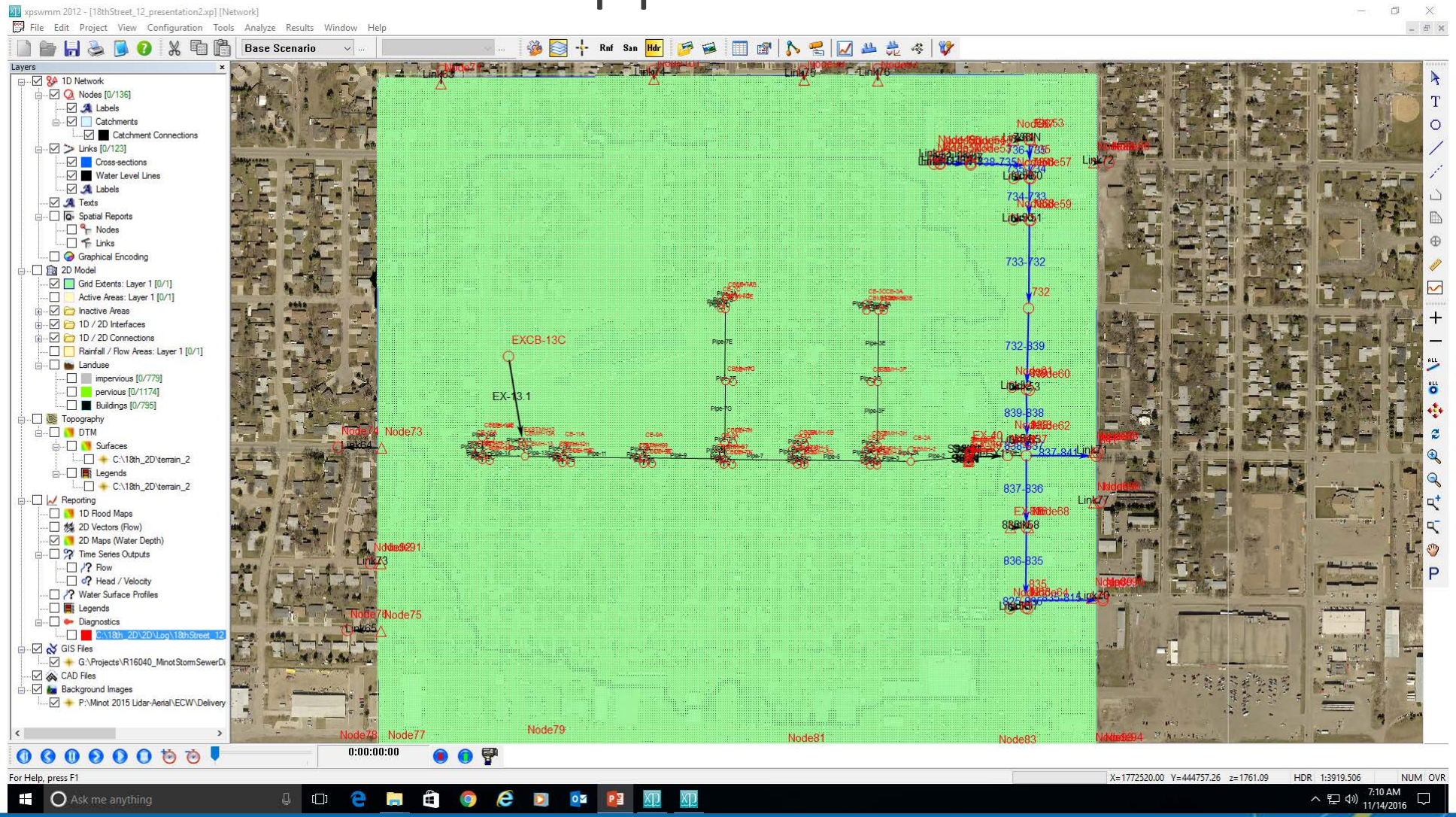
2-Dimensional Approach



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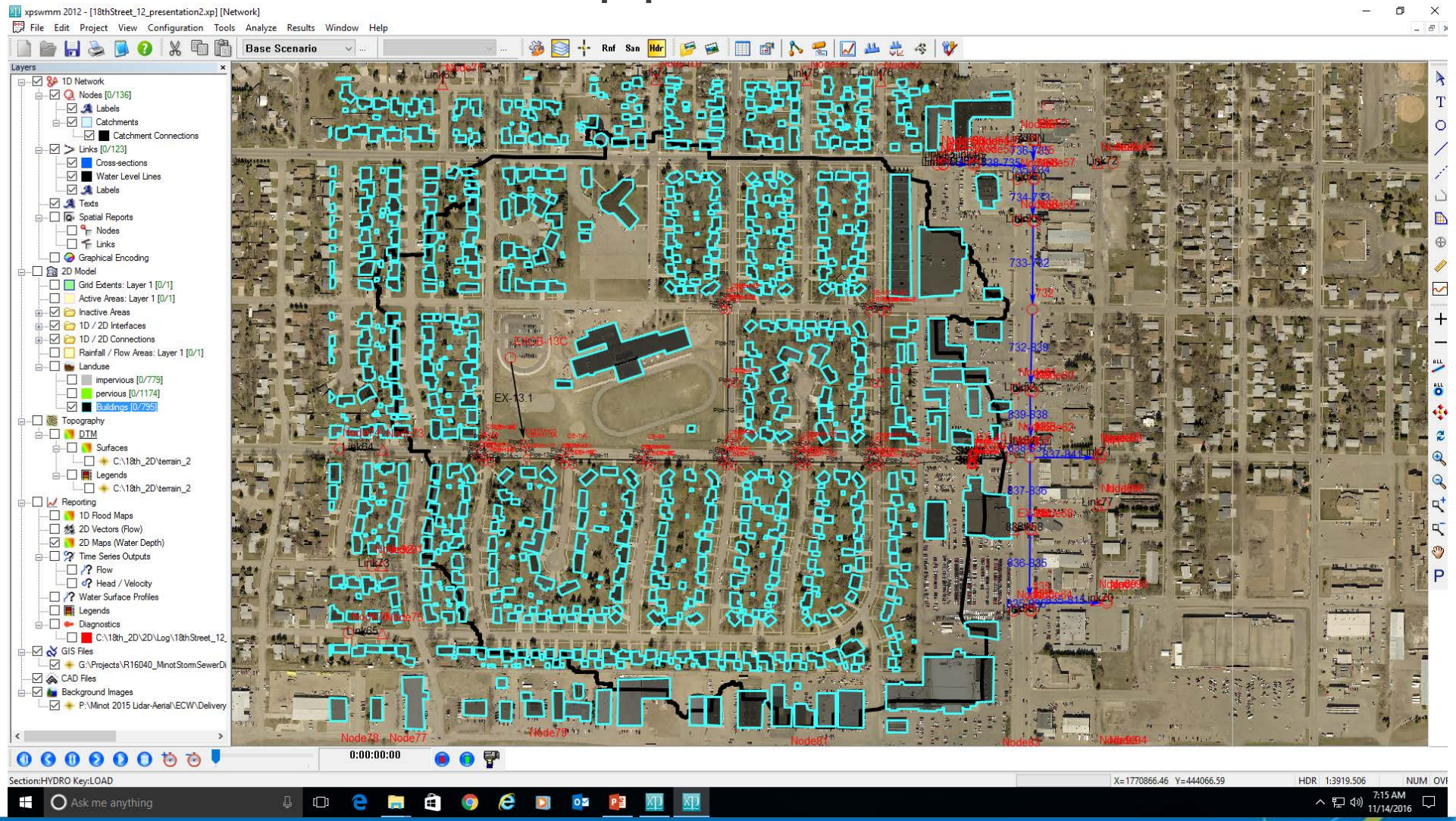
2-Dimensional Approach



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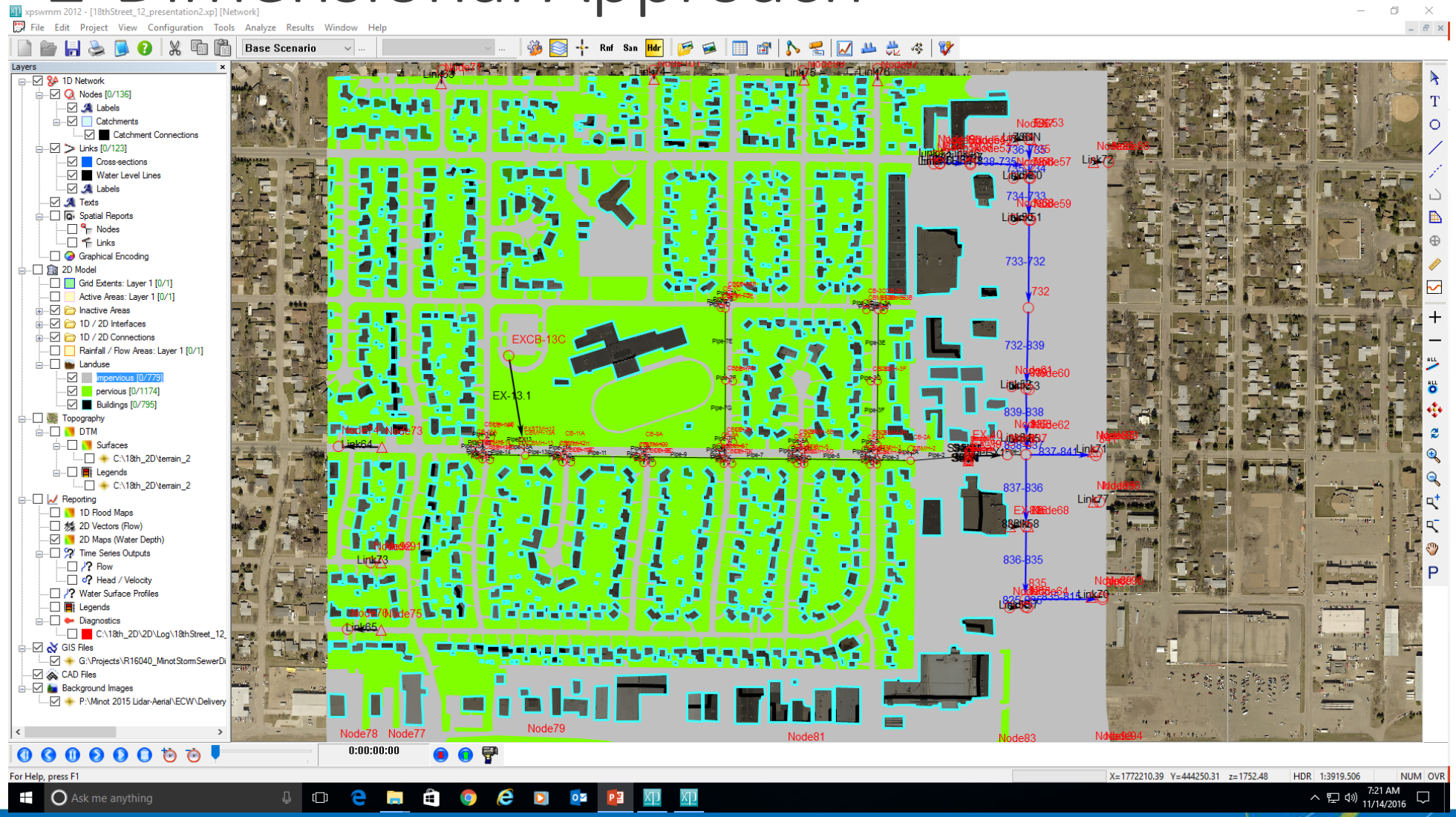
2-Dimensional Approach



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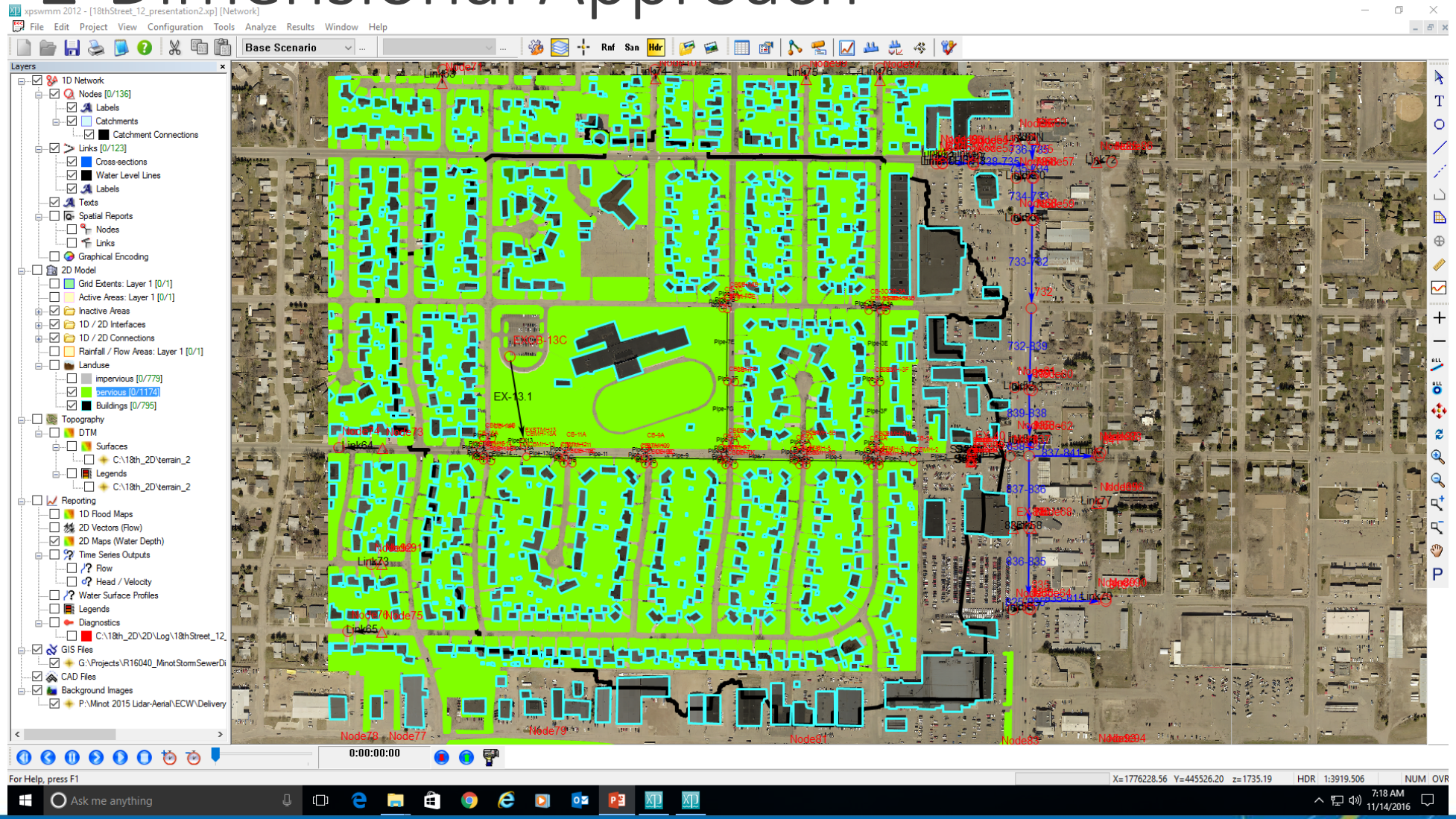
2-Dimensional Approach



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Inlets

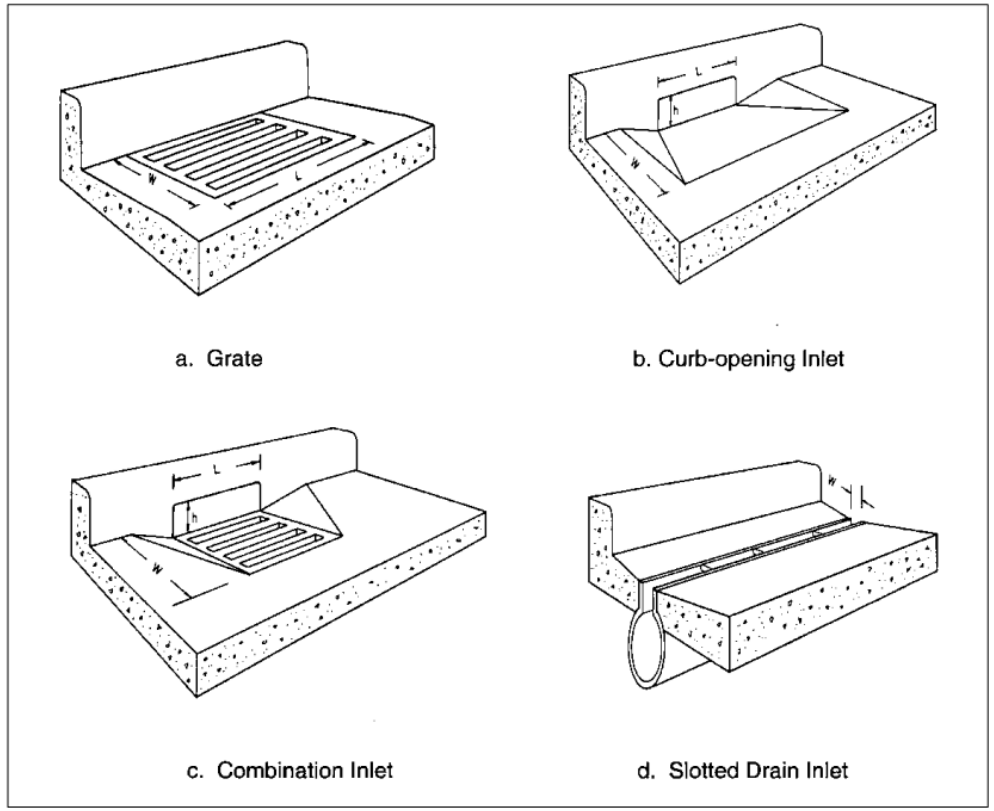
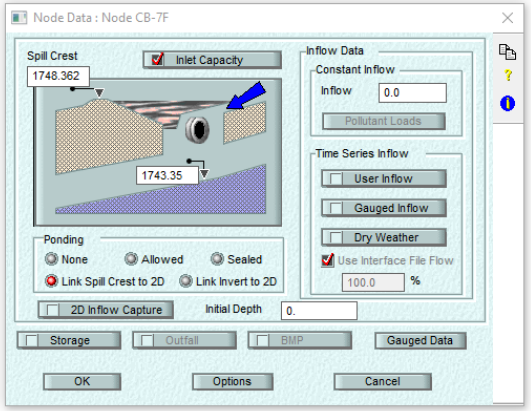
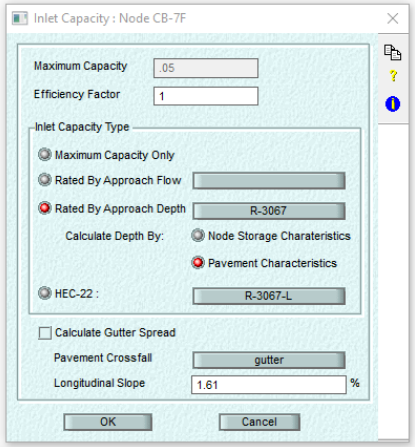
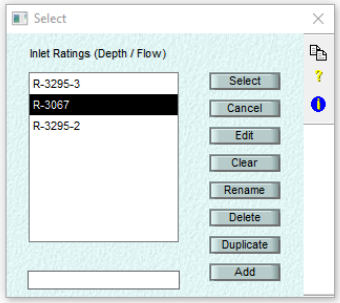
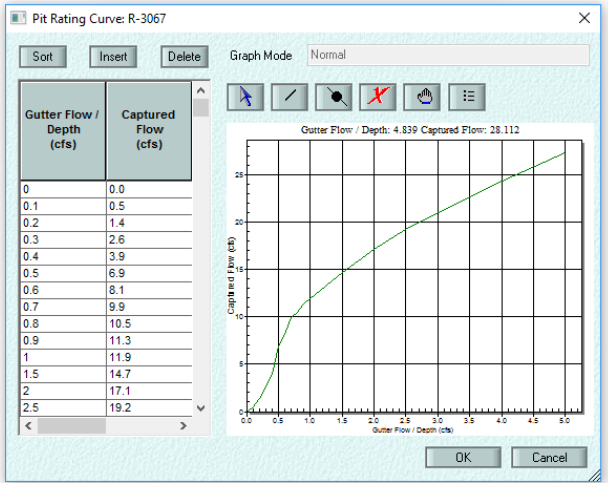


Figure 4-4. Classes of storm drain inlets.

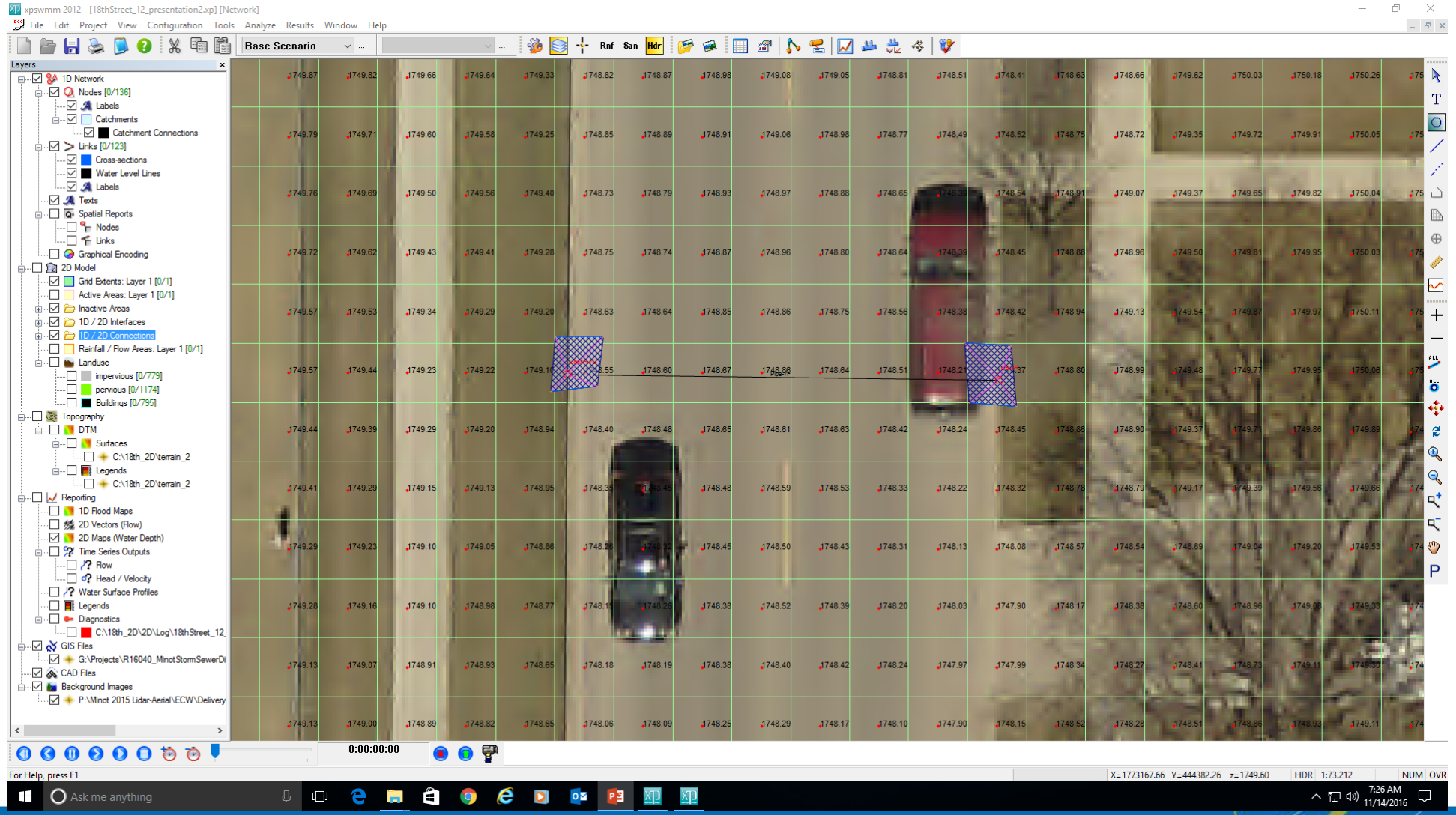








Inlets



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Inlets

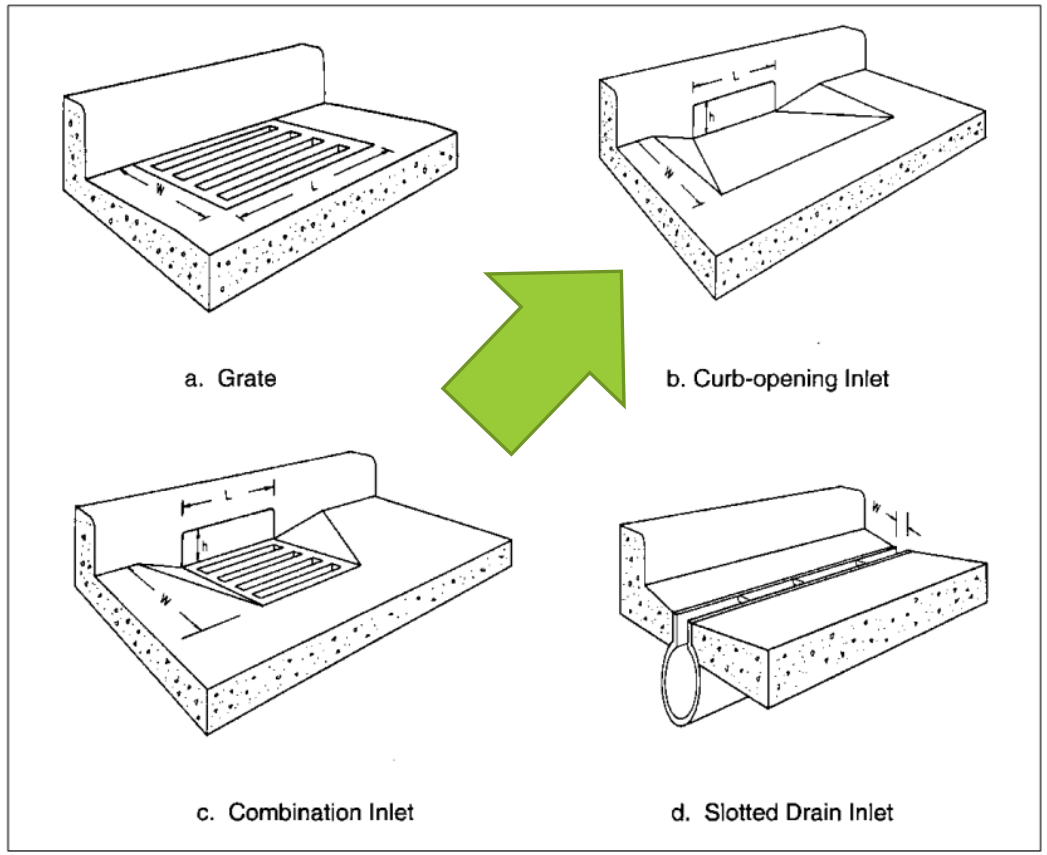


Figure 4-4. Classes of storm drain inlets.

DESIGN MEMORANDUM

Note: This form must be used for project calculations and original to be placed in project files.

ACKERMAN ESTVOLD

CLIENT			
City of Minot		PROJECT NO.	PAGE
PROJECT		R16007	1
Minot Storm Sewer District 122		PREPARED BY	FILE NO.
SUBJECT		DPW	R16040
Orifice equivalents of common catchbasins.		CHECKED BY	DATE
			8/5/2016

References:

1. Neenah Website
2. Spreadsheets from Houston

NDDOT Type	**2**	Grate Area	1.60	SF
Neenah Equivalent	**R-3067-C**	Curb Cut Length	2.90	ft
		Curb Cut Height	0.33	ft
		Grate Perimeter	5.80	ft
		Total area	2.56	SF
		80% of Area	**2.05**	**SF**
		Assumed Orifice Height	**0.353**	**ft**

Hydrology

Rain on Grid

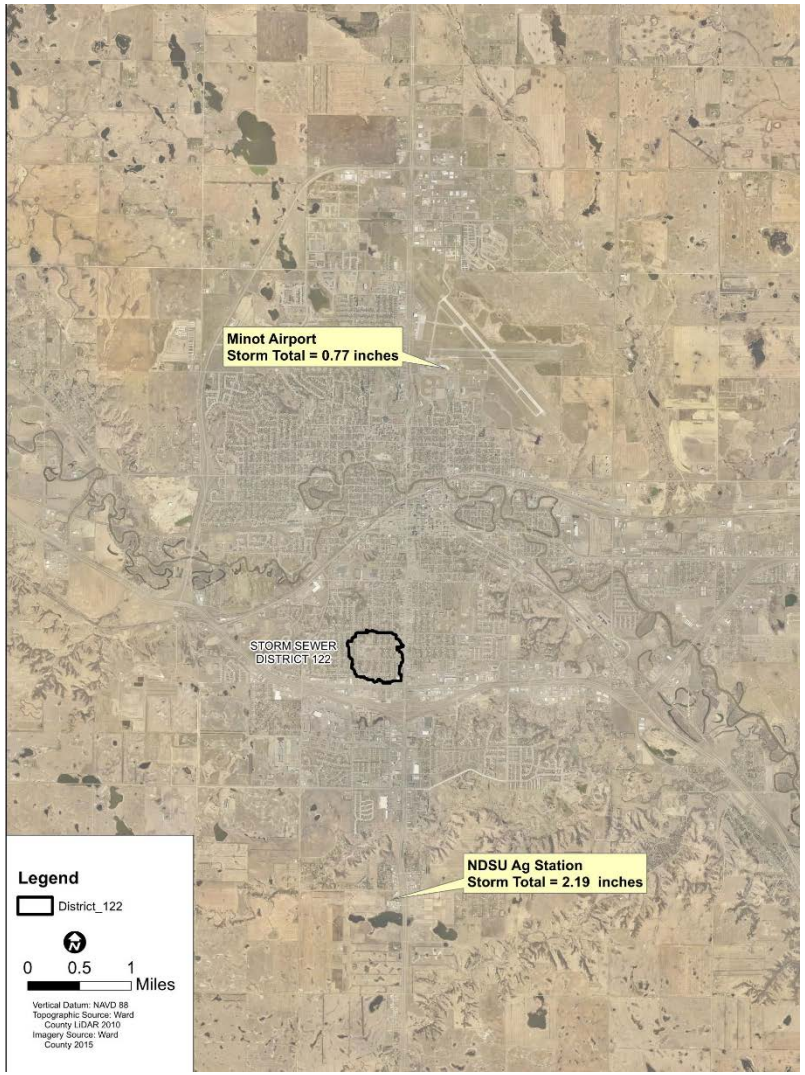
Initial Loss / continuing loss

For Academic Study

Type II

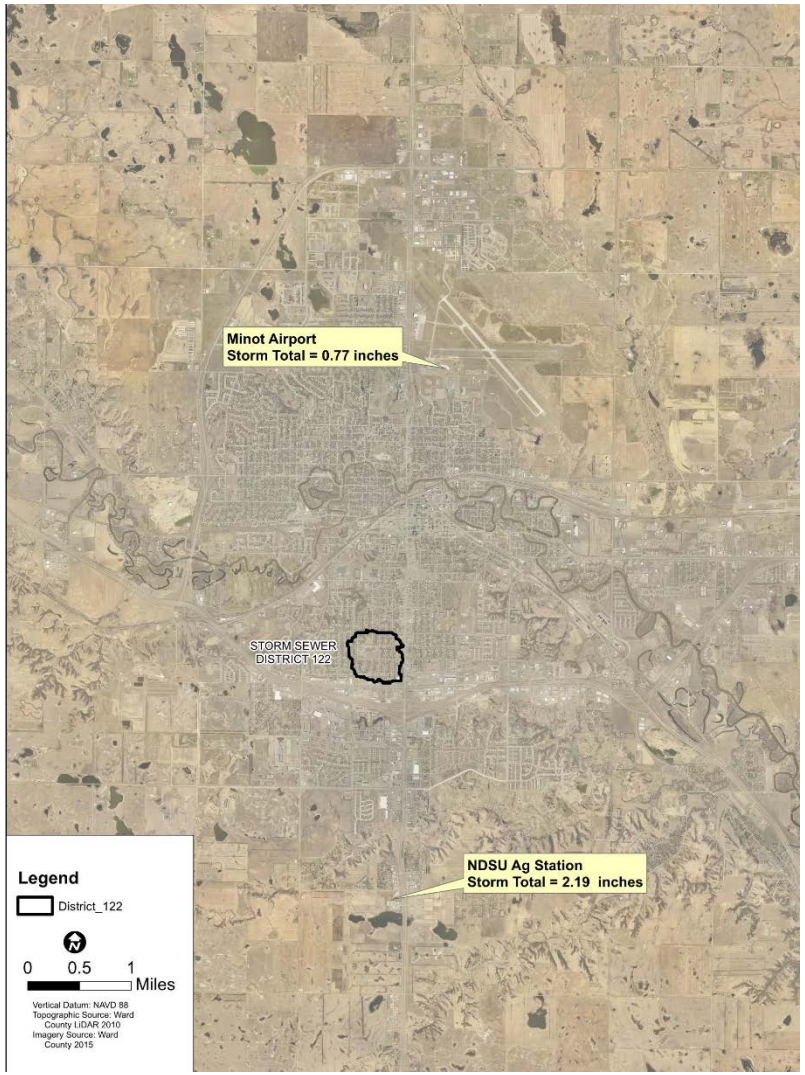
NOAA Atlas 14

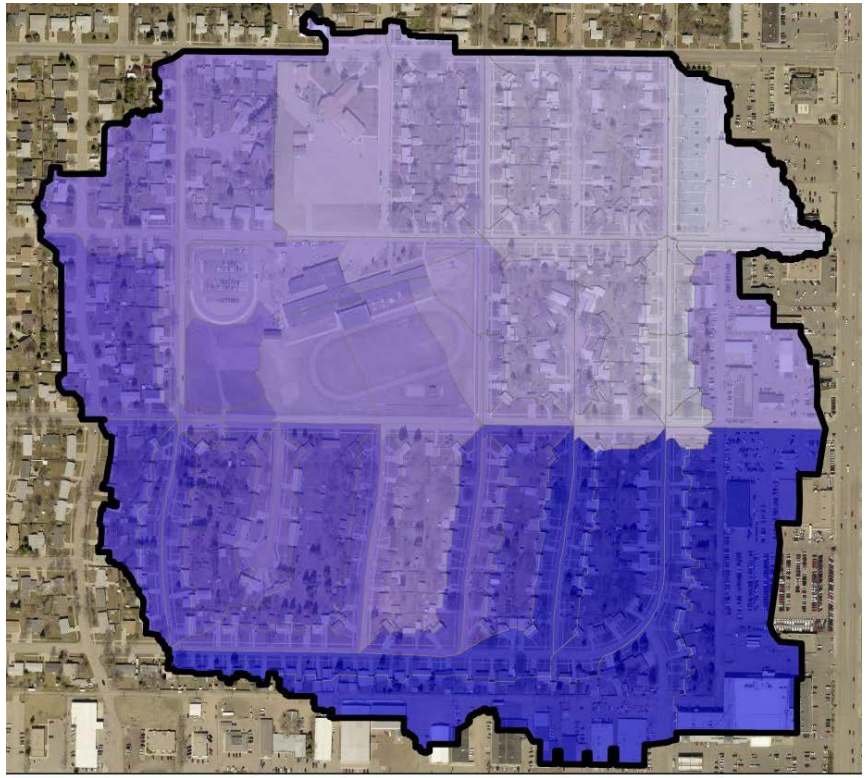
June 4, 2014 Rainfall



DATA

June 4, 2014 Rainfall





Legend

Storm total precipitation

- 1.533000 - 1.580000
- 1.580001 - 1.607000
- 1.607001 - 1.655000
- 1.655001 - 1.656000
- 1.656001 - 1.778000
- 1.778001 - 1.799000
- 1.799001 - 1.800000
- 1.800001 - 1.836000
- 1.836001 - 1.954000
- 1.954001 - 2.288000

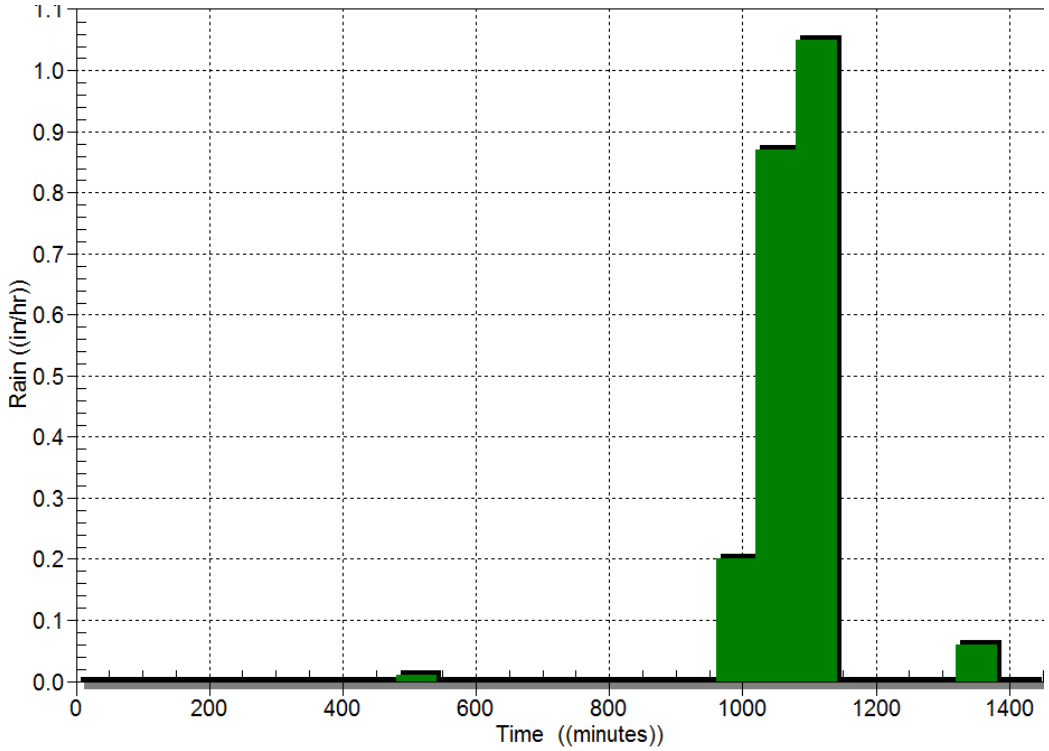
NEXRAD DATA

The Problem with Parameters

NDSU Ag Station

Storm Total = 2.2-inches (>10-year, 3 hr storm)

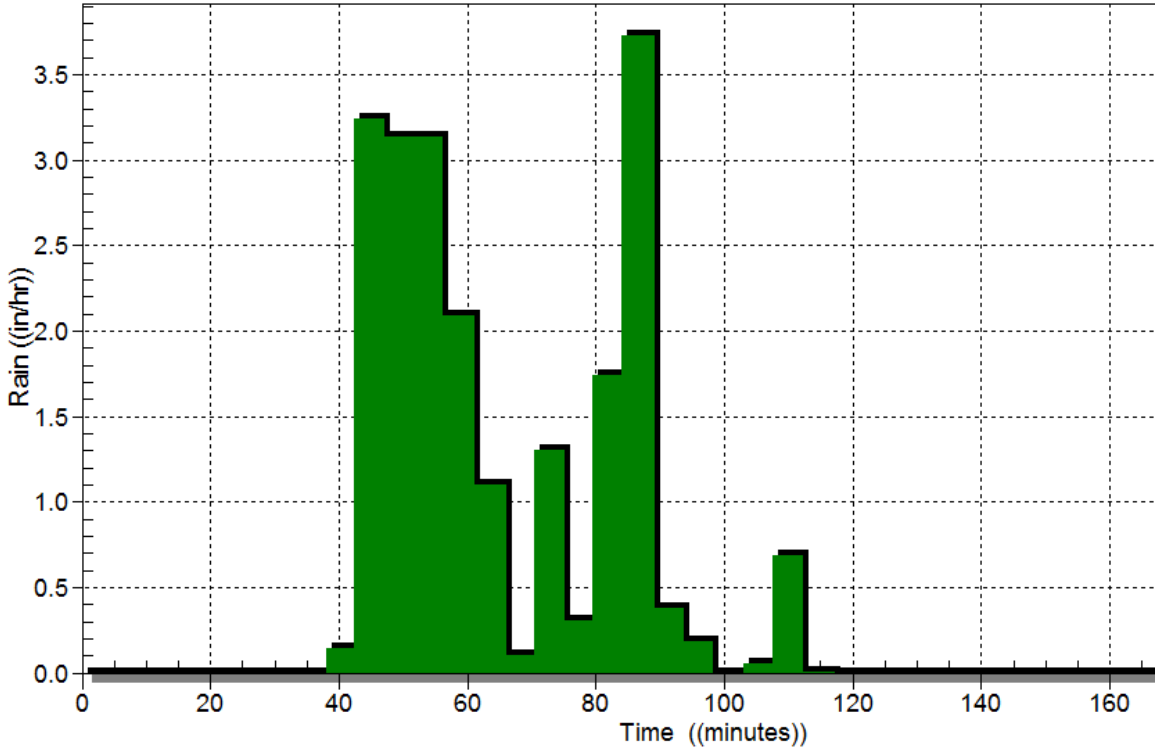
Peak Intensity = 1.05-in/hr (>2 year intensity)



NEXRAD

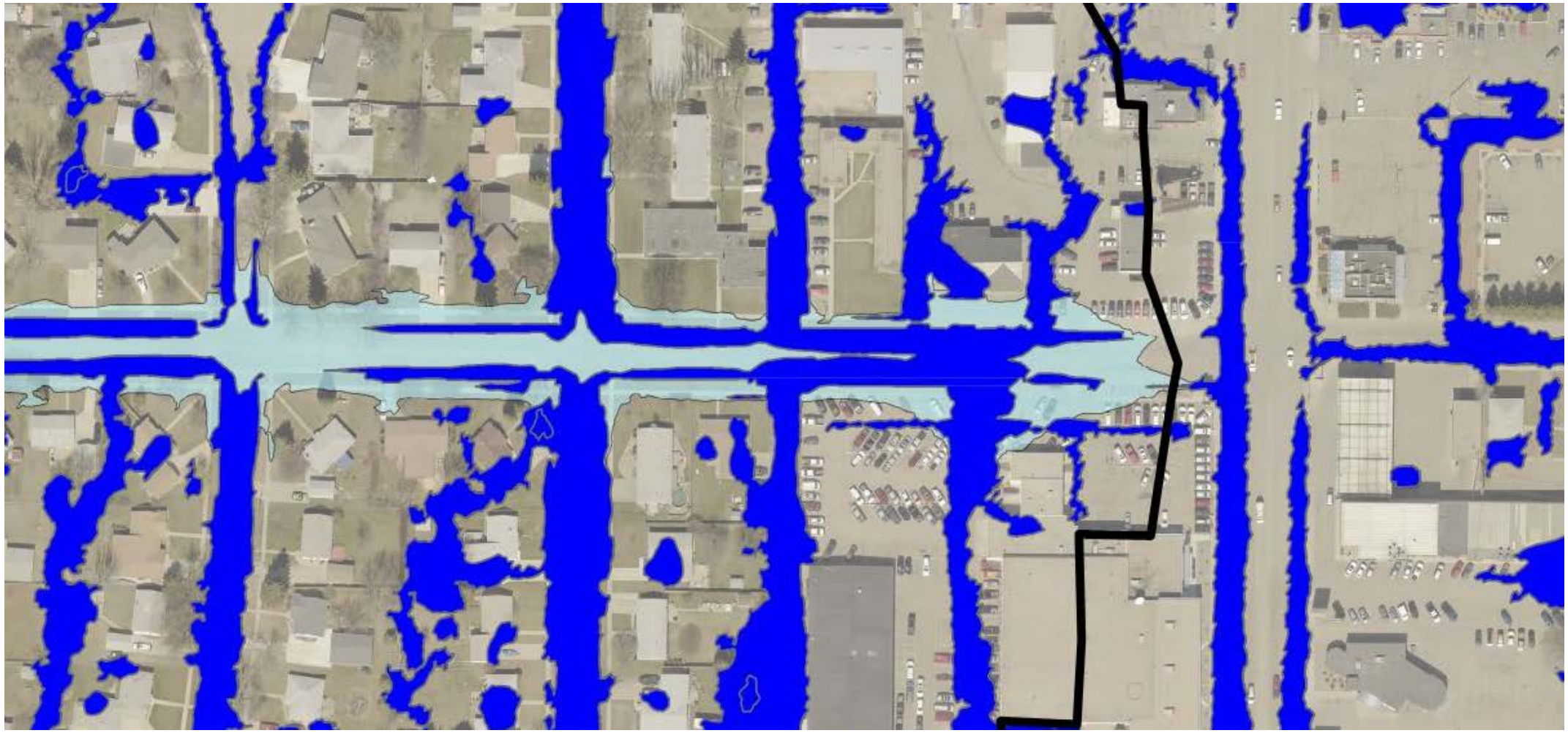
Storm Total = 1.8-inches (>10-year, 1-hr storm)

Peak Intensity = 3.5 in/hr = 0.31 inches in 5 min (<2 year intensity)



June 4, 2014 Rainfall Event (~1.8”)

June 4, 2014 Rainfall Event (~1.8”)



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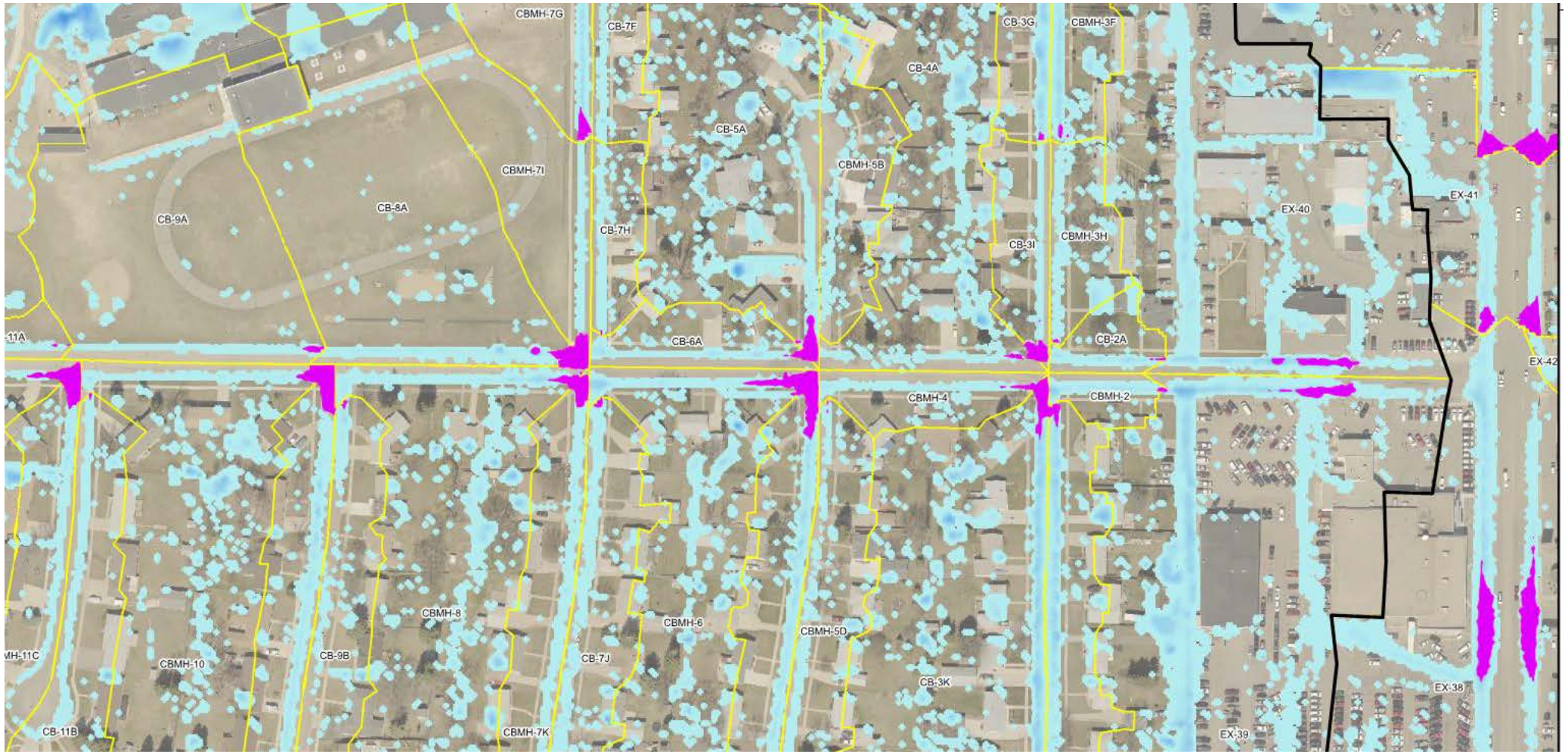
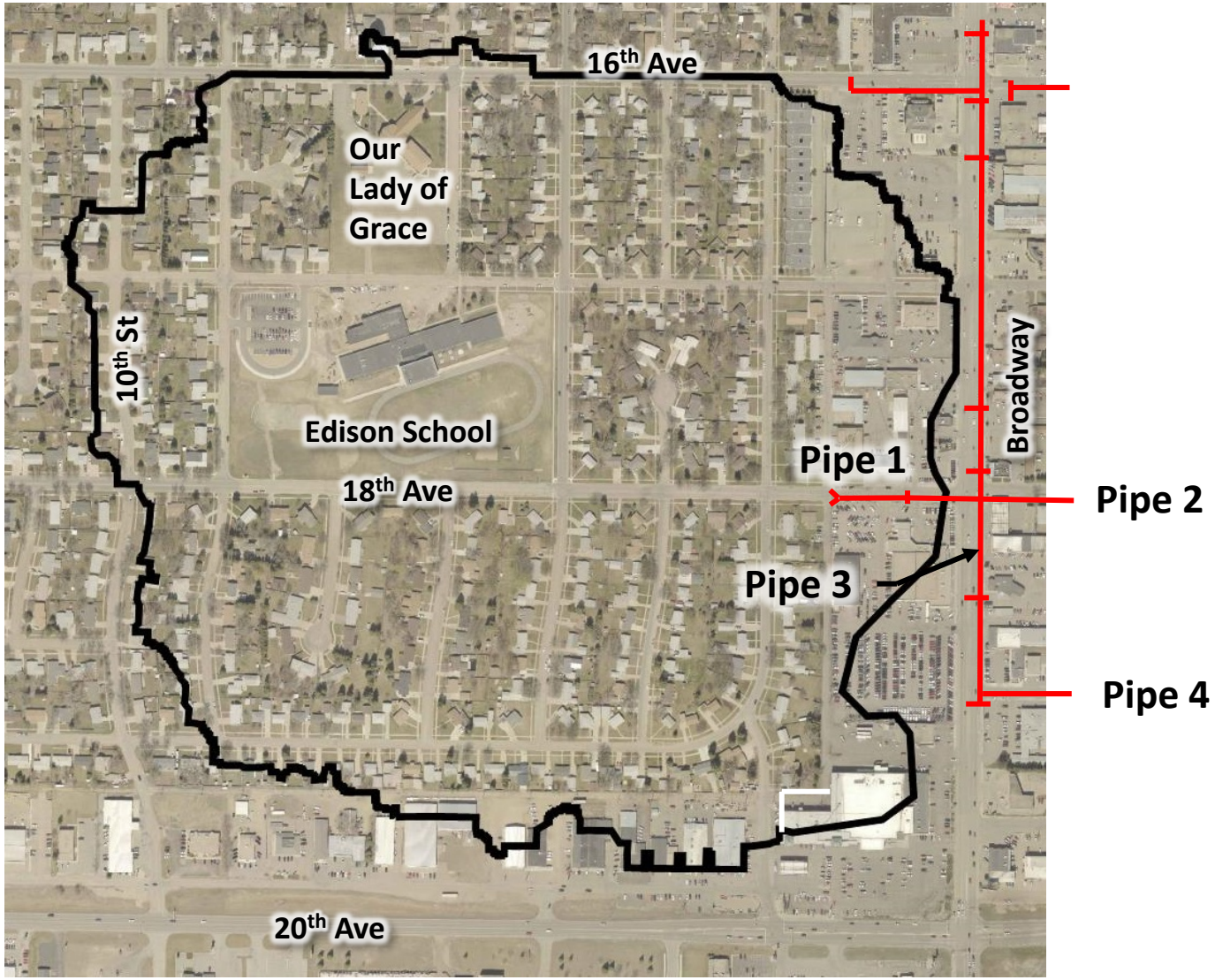
Comparison of 1-D and 2-D



Comparison of 1-D and 2-D

2-Year Storm (Type II, NOAA Atlas 14)

	1D-Model	2D-Model
Pipe 1	115 cfs	79 cfs
Pipe 2	48 cfs	38 cfs
Pipe 3	86 cfs	56 cfs
Pipe 4	93 cfs	65 cfs



Comparison of 1-D and 2-D

Depth In 18th Avenue Sag

	2-Year		5-Year	
Model	1-D	2-D	1-D	2-D
Existing	1.0 ft	0.9 ft	2.1 ft	1.9 ft
Project	0.4 ft	0.5 ft	1.3 ft	0.9 ft

Comparison of 1-D and 2-D

The Problem with Parameters

Used to SCS curve number methodology

	SCS Method			2D-Mesh		
	Curve Number	Initial Abstraction (Inch)	Total RO		Initial Loss (Inch)	Total RO
Commercial	94	0.12	1.50	Building	0.1	2.01
Street	91	0.20	1.26	Impervious	0.1	2.01
Residential	82	0.50	0.72	Pervious	1.3	0.71
School	76	0.63	.47			

Comparison of 1-D and 2-D

The Problem with Parameters

Used to SCS curve number methodology

	SCS Method	2D-Mesh
	Initial Abstraction	Initial Loss
	Rate of Water Transmission	Continuing Loss
Curve Number	86.7	92.3 (equivalent)
Rainfall (inch)	2.11	2.11
Runoff (inch)	0.97 (equivalent)	1.36 (computed)

Comparison of 1-D and 2-D

The Problem with Parameters

Used to SCS curve number methodology

Curve Number	Runoff (inches)	Area	Volume
98	1.88	1-acre	6,840 cu ft
61	0.10	1-acre	347 cu ft
79.5	0.60	2-acres	4,422 cu ft

So which is it? 2-D or not 2-D?

"I am not bound to please thee with my answer."

(The Merchant of Venice, Act 4)

- Results
- Time building models
- Required data
- Computation Time
- Puddles
- Visual outputs

- XP-SWMM or RAS 2D?

Questions?

Tom Johnson
Ackerman-Estvold
1907 17th Street SW
Minot, ND 58701
thomas.johnson@ackerman-estvold.com
701-857-9142

ACKERMAN ESTVOLD