Paterson Street Stormwater Study

Hydraulic Analysis

Prepared for

City of Kalamazoo

May 2021

2180207

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1 INTRODUCTION

In 2017, the City of Kalamazoo was awarded a SAW grant to assist in asset management of its stormwater and wastewater systems. As part of the City's asset management program for stormwater, a hydraulic model of the storm sewer on Paterson Street was created and used to analyze pipe capacity during modeled design rainfall events (see Appendix A). City of Kalamazoo residents have reported surcharging onto the road surface on Paterson Street in the residential area between Woodward Avenue and Pitcher Street, so the model was developed to identify system bottlenecks and deficiencies, as well as evaluate alternatives for resolving system deficiencies. Figure 1 shows the modeled area, including storm pipe diameter, and flow direction.

The purpose of the Paterson Street storm sewer capacity analysis is to identify pipes which may be undersized for conveying flows during rainfall events - especially restrictions that result in reported surcharging on Paterson Street. Storm sewers are typically designed to maintain the hydraulic gradient within the crown of the pipe during a 10-year, 24-hour rain event. Table 1 provides the design storm rainfall depths for the City of Kalamazoo from NOAA Atlas 14 precipitation estimates.

Table 1. NOAA Atlas 14 Design Storm Events

Design Storm	1-Year	2-Year	5-Year	10-Year	25-Year	100-Year
24-Hour Rainfall (in)	2.29	2.59	3.14	3.67	4.51	6.04

2 EXISTING SYSTEM

The existing Paterson Street stormwater system is shown in Figure 1. The Paterson Street system flows to four outfalls: one north of Dunkley Street between Park Street and Church Street, one north of Dunkley Street east of Pitcher Street at the Wastewater Treatment Plant, and two south of Paterson Street at the Kalamazoo River. The portion of the Paterson Street sewer with the surcharging complaints between Woodward Avenue and Burdick Street is 36-inch pipe which flows into the 42-inch sewer on Burdick Street, Clay Street, and Pitcher Street and discharges to the 54-inch sewer on Dunkley Street before flowing east to the Kalamazoo River.

Figures 2 through 6 show model results for pipe capacity and surface surcharging for the following 24-hour storm events, respectively: 1 inch, 1-year, 2-year, 5-year (3.14 inches), and 10-year (3.68 inches). Pipes in red are undersized and restrict flow during the peak runoff of the storm event. Catch basins and manholes that are highlighted in yellow experience some duration of surface surcharging during the storm event.

Model results for the existing system indicate that portions of the existing sewer are undersized and cause surface surcharging on Paterson Street, even during more frequent rain events including the 1-year storm (2.29 inches in 24 hours), and the 2-year storm (2.59 inches in 24-hours). Significant system improvements are needed to meet a recommended 10-year design storm standard.

2.1 Undersized Pipes

An investigation was done to determine possible explanations to why many pipes in the study area are undersized.

The majority of the storm sewer in the Paterson Street study area was installed prior to 1930, which is well before the 10-year design storm standard was implemented. Storm events were less intense 100 years ago, which accounts for the current undersizing and lack of capacity.

To get a historical perspective of land use, Sanborn Maps of the study area in 1908 and 1921 were reviewed. It was determined that after the main storm system was installed, development in the watershed has caused significant increase in discharge rates. An example of this is shown in Appendix B.

The lack of natural grade in the area landscape also contributes to current surcharge conditions. The10-foot contours shown on Figure 1 demonstrate the flat terrain. Most stormwater pipes were laid at or below currently recommended minimum grades.

2.2 System Condition and Maintenance

While pipe capacity restrictions have a significant impact on where surcharging occurs in a stormwater system, the physical condition of the stormwater system can also impact the frequency and severity of sewer surcharging. Blocked, partially-blocked, or undersized catch basin inlets or pipes can cause surcharging and reduce system capacity. For the purposes of identifying system bottlenecks, the storm sewer system is assumed to be free from blockages or other maintenance issues. This assumption enables the identification of hydraulic capacity restrictions due to inverts and pipe sizes.

It is important to note that a pole mounted video camera was used to investigate the manhole at the flow split on Paterson Street and Woodward Avenue. The video revealed a flow blockage a few inches high in the north pipe flowing to Woodward Avenue. Master Plan maps indicate a proposed 'dam' in the east pipe that flows to Paterson Street, but the video did not show a 'dam.' Based on the video, the first few inches of stormwater runoff flows out of the manhole through the east pipe on Paterson Street. Since the flow blockage in the north pipe on Woodward Avenue does not look permanent and could be removed by cleaning, the flow blockage was not included in the hydraulic model. The Woodward Avenue and Paterson Street intersection is modeled as a flow split, with stormwater flowing out of the manhole both to the north along Woodward Avenue and to the east along Paterson Street. The inverts at the flow split were measured to increase the model accuracy at this location. Given reports of surcharging on Paterson Street, removing the flow blockage on Woodward Avenue could help reduce some of the surface surcharging; however, model results indicate that pipe capacity restrictions downstream of Paterson Street also contribute to the observed surcharging.

2.3 System Deficiencies and Bottlenecks

Even during the 1-inch simulated rain event, the sewer on Pitcher Street between Prouty Street and Dunkley and on Paterson Street between Church Street and Burdick Street is nearing its full flow capacity. During a 10-year design storm rain event, almost the entire length of sewer between the residential area on Paterson Street and the outfall on Dunkley Street at the Wastewater Treatment Plant is restricting flow. Undersized storm sewer on streets contributing to the Paterson Street storm sewer are also identified on the capacity maps.

2.3.1 12-inch Storm Sewer

As seen on Figure 1, there are many streets within the study area that have 12-inch storm sewer collecting stormwater from an entire block. These 12-inch sewers are sufficient for the 1-inch storm event but restrict flow for the 1-year and larger storm events. As these streets are reconstructed, the storm sewer should be upsized to reduce the risk of surcharging.

2.3.2 Dunkley Street from Pitcher Street east to the Outfall

The existing 54-inch sewer on Dunkley Street from Pitcher Street east to the outfall is undersized for all design storms. The sewer on Dunkley Street receives flow from both Pitcher Street and East Dunkley Street. The sewer on East Dunkley Street west of Pitcher Street is also 54-inches and the sewer on Pitcher Street is 42-inches. The existing sewer would need to be upsized pipe to adequately convey flow within the pipe for the 10-year design storm event and reduce the risk of upstream surcharging.

2.3.3 Pitcher Street from Paterson Street to Dunkley Street

Model simulations on Pitcher Street from Paterson Street to Dunkley Street show pipe nearing full capacity during the 1-inch storm event but no pipe surcharging. During the 1-year storm event, the surcharged pipes cause surface surcharging up to 60 minutes in upstream pipes on Clay Street and Paterson Street. The existing 42-inch pipe needs to be upsized to meet the stormwater design standard for the 10-year storm.

2.3.4 Clay Street from Burdick Street to Pitcher Street

Model simulations on Clay Street from Burdick Street to Pitcher Street show pipe and surface surcharging that exceeds one hour during a 1-year storm event. The existing 42-inch pipe needs to be upsized to meet the stormwater design standard for the 10-year storm.

2.3.5 Burdick Street from Paterson Street to Clay Street

Burdick Street from Paterson Street to Clay Street shows surface surcharging lasting up to 60 minutes during the 5-year storm event. Upsizing the existing 42-inch pipe north of Paterson Street will alleviate surcharging and meets the stormwater design standard for the 10-year storm.

2.3.6 Paterson Street from Staples Avenue to Burdick Street

Model Simulations indicate that the sewer on Paterson Street from Staples Avenue to Burdick Street is over the 85% recommended capacity during the 1-year storm event with surface surcharging between Cobb Avenue and Church Street. The sewer needs to be upsized to adequately convey flow during the 10-year design storm event.

3 CONCLUSION

Based on model analysis, system improvements are presented below to meet the recommended 10-year design storm standard. Five improvement alternatives were built into the model. Alternatives include increasing pipe diameter until no surface surcharge is seen, redirecting stormwater, and using lift stations to move the water to the Kalamazoo River.

3.1 Existing Restrictions Impacting Paterson Street

The hydraulic model indicates that the undersized sewer on Paterson Street is causing surcharging above the surface of the road for all design storm events 1-year and larger. While upsizing the sewer on Paterson Street will help reduce the duration of surcharging, it will also worsen surface surcharging downstream on Burdick Street, Clay Street, Pitcher Street, and Dunkley Street. Therefore, the alternative recommended improvements provided in this report address the future pipe size needs of all sewer within the service area. To reduce surcharging on Paterson Street in the short-term, the recommended improvements for Paterson Street and for the sewer directly downstream of Paterson Street will need to be implemented first.

3.2 Alternative 1: Increase Pipe Diameter from Paterson Street to Existing Outlet

The first alternative is increasing pipe diameters from Paterson Street to the outlet on East Dunkley Street. Pipe diameters and model results for the 10-year storm event are shown in Figure 7 and Figure 8. In order to remove surcharging above the road on Paterson Street and contain stormwater within the pipe during the 10-year design storm event, the following pipe sizes will be required:

- Paterson Street
    - 54-inch pipe from Staples Avenue to Cobb Avenue
    - 60-inch pipe or equivalent from Cobb Avenue to Westnedge Avenue
    - 66-inch pipe or equivalent from Westnedge Avenue to Church Street
    - 72-inch pipe or equivalent from Church Street to Burdick Street
- Burdick Street, 72-inch pipe or equivalent from Paterson to Clay
- Clay Street

- 72-inch pipe or equivalent from Burdick Street to Pitcher Street
- The sewer between Clay Street and Pitcher Street is currently installed underneath a building and should be rerouted

- Pitcher Street, 84-inch and 96-inch pipe or equivalent from Clay Street to Dunkley Street
- East Dunkley Street, 96-inch pipe from Edwards Street east to the outlet

There is likely not enough pipe cover available for a circular 60-inch or larger pipe on Paterson Street, a circular 72-inch pipe on Burdick Street, a circular 72-inch pipe on Clay Street, or a circular 84-inch or larger on Pitcher Street. Appendix C provides supporting figures for the feasibility of Alternative 1.

3.3 Alternative 2: Redirect Paterson Street East to Paterson Outlet

The second alternative includes a proposed pipe on Paterson Street from Burdick Street to Pitcher Street which would redirect the flow to continue along Paterson Street to the existing outlet at the Kalamazoo River. Pipe diameters and model results for the Paterson Street storm sewer redirect are shown in Figure 9 and Figure 10a. Figure 10b illustrates the model results with replacement of the Paterson Street sewer only. By upsizing the Paterson Street sewer first, surcharging is eliminated on Paterson Street and surcharging is reduced throughout the system.

- Paterson Street
  - 66-inch proposed pipe from Burdick Street to Pitcher Street was built into the model to redirect the flow east to the existing 38-inch by 60-inch elliptical pipe on Paterson Street. The existing outlets for both the elliptical pipe and the parallel 36-inch pipe on Paterson Street east of Walbridge Street are located on Paterson Street near the Kalamazoo River.
  - The downstream elliptical pipe would need to be upsized to a 78-inch pipe to adequately convey the flow from Paterson Street
  - 72-inch pipe or equivalent is required from Burdick Street to Church Street
  - 66-inch or equivalent is required from Church Street to Westnedge Avenue
  - 60-inch pipe is required from Westnedge Avenue to Cobb Avenue
  - 54-inch pipe is required from Cobb Avenue to Staples Avenue

There is likely not enough pipe cover available for a circular 60-inch or larger pipe on Paterson Street. Appendix C provides supporting figures for the feasibility of Alternative 2.

3.4 Alternative 3: Lift Station at Paterson Street and Cobb Avenue

The feasibility of a stormwater lift station at Paterson Street and Cobb Avenue was investigated using the hydraulic model. Figure 11 shows the future pipe diameter requirements on Paterson Street and downstream of Paterson Street for this alternative and a 10-year design storm event. To reduce the need for pipe upsizing on Pitcher Street and Dunkley Street, a 48-inch sewer on Paterson Street between Burdick Street and the existing sewer at Porter Street is recommended for this alternative. The sewer on Paterson between Staples Avenue and Cobb Avenue would need to be upsized to 54-inch pipe, and the sewer on Paterson Street between Westnedge Avenue and the Paterson Street outlet would need to be upsized as shown on Figure 11. The peak hour flow at the lift station for the 10-year storm would be approximately 20,200 gpm (45 cfs). Figure 12 provides the pipe capacity results for the 10-year storm with the proposed lift station at Paterson Street and Cobb Avenue and future pipe diameters in place.

3.5 Alternative 4: Lift Station at Paterson Street and Burdick Street

A stormwater lift station at Paterson Street and Burdick Street was also modeled to reduce the need for pipe upsizing between the Dunkley Street outfall and the intersection of Paterson and Burdick. Figure 13 shows the future pipe diameter requirements on Paterson Street for a 10-year design storm event. The sewer on Paterson between Staples Avenue and Burdick Street would need to be upsized as shown on Figure 13. The peak hour flow at the lift station for the 10-year storm would be approximately 59,700 gpm (133 cfs). Figure 14 provides the pipe capacity results for the 10-year storm with the proposed lift station at Paterson Street and Burdick Street and future pipe diameters in place.

3.6 Alternative 5: Staples, Elizabeth, Edwards, and Paterson Redirects

The fifth alternative attempts to minimize construction in Paterson Street right-of-way to avoid utility conflicts. Pipe diameters and model results for this alternative are shown in Figure 15 and Figure 16a. Figure 16b illustrates the model results with replacement of pipes only affecting the main drainage route.

- Redirect flow from Staples toward Elizabeth Street with a 54-inch pipe from Staples to Woodward, east on Elizabeth Street and Norway Street to Rose Street.
- Rose Street, 54-inch pipe from Norway Street to Paterson Street
- Paterson Street
    - 66-inch pipe from Rose Street to Edwards Street
    - 66-inch pipe overflow from Edwards Street to the 38-inch by 60-inch elliptical pipe
- Edwards Street
    - 66-inch pipe from Paterson Street to Clay Street
    - 72-inch pipe from Clay Street to Dunkley Street
- Dunkley Street
    - 72-inch pipe from Edwards Street to Pitcher Street
    - 84-inch pipe from Pitcher Street to the outfall

3.7 Recommendation

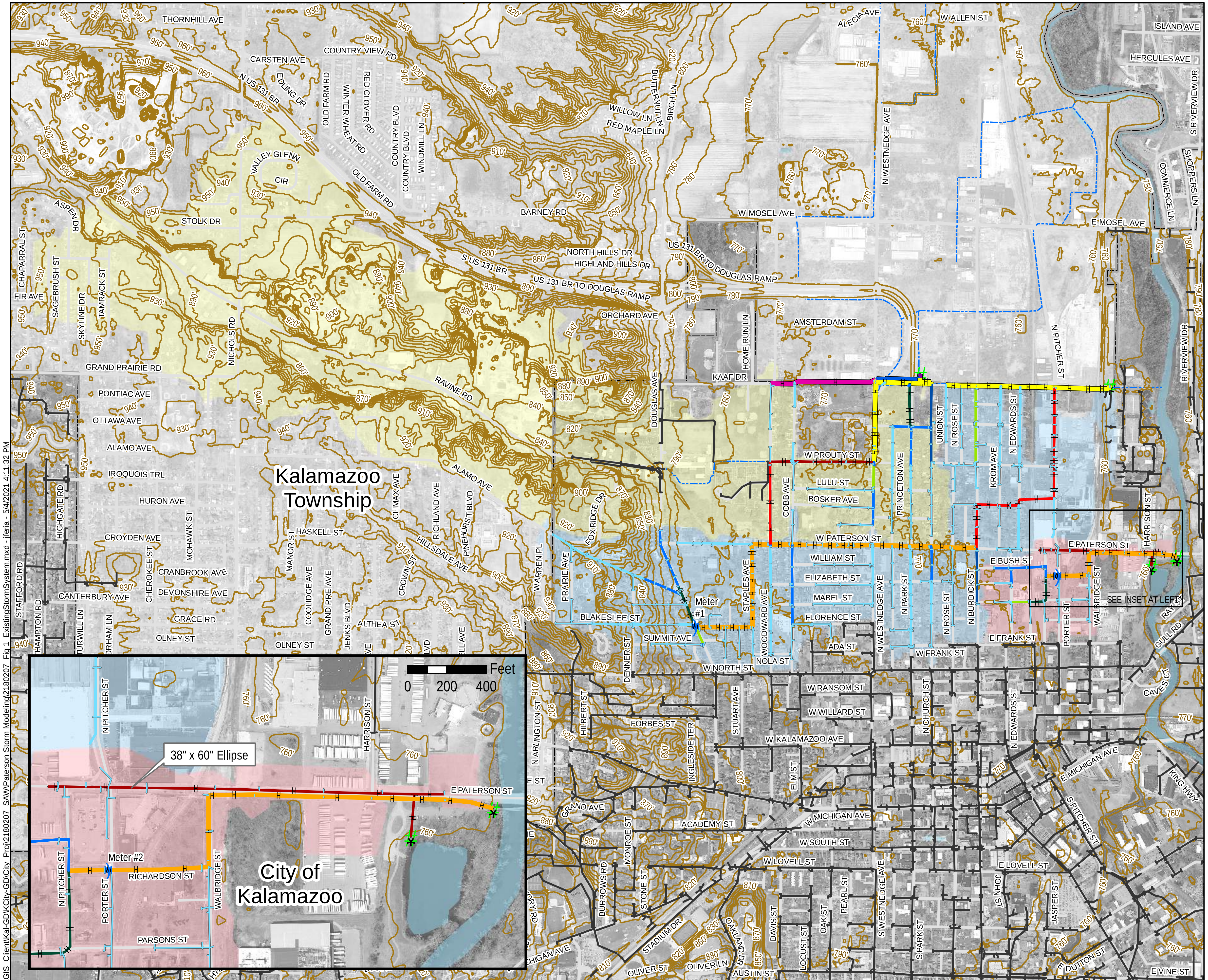
Both improvement Alternatives 1 and 2 require large pipe sizes to meet the recommended 10-year design storm standard based on the model results. Pipe size requirements for Alternative 1 are likely not feasible because there is less pipe cover depth available along the Pitcher Street route. Alternative 2 would require less pipe replacement, but the pipe sizes on Paterson are still very large and fitting this into the Paterson right-of-way with other existing utilities may still not be feasible.

Given the cost and long-term operation and maintenance of lift stations and the only slight reduction in Paterson pipe upsized needed, pumping the stormwater in Alternatives 3 and 4 do not appear to be the best options.

Alternative 5 avoids construction in Paterson Street west of Rose Street, addresses the redirection of storm sewer under the building on Pitcher Street, and reduces surcharge in many pipes in the Paterson study area. Therefore, reconstruction of the “Main Drainage Route” shown in

Alternative 5 is the recommended first step to reduce surcharge in the study area. If surcharge is concerning in other streets in the study area, a short-term solution may be to upsize small portions of pipe to relieve surcharge conditions (such as Prouty Street west of Westnedge Avenue). Stormwater master planning for the study area should take into account all future upsize recommendations shown on Figure 15.

Figures



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CITY OF KALAMAZOO
KALAMAZOO COUNTY, MI

PATERSON STREET STORMWATER SYSTEM

FIGURE 1

Prein&Newhof
2180207

LEGEND

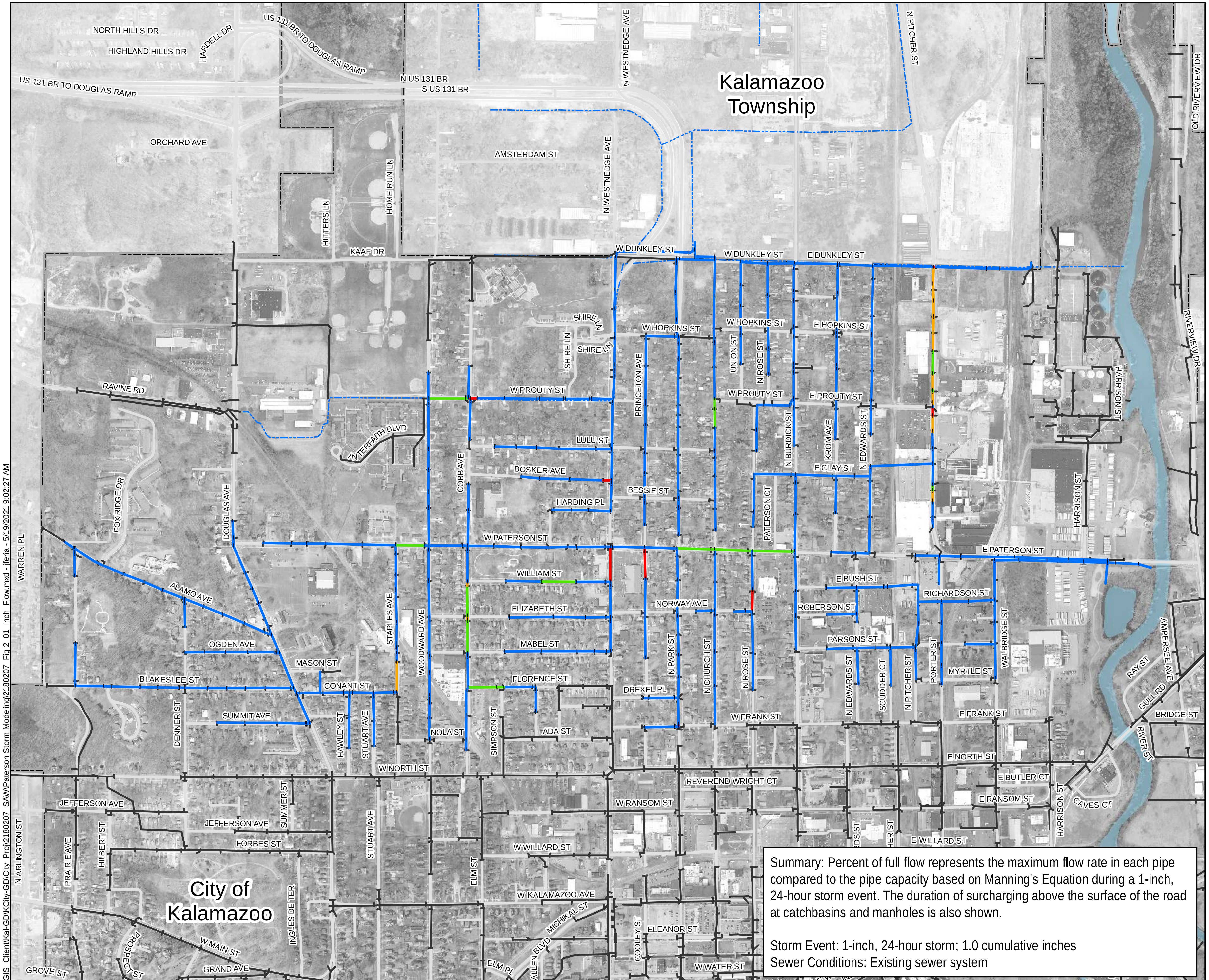
Storm Sewer Diameter

- 12" or Less
- 15"
- 18"
- 21"
- 24"
- 30"
- 36"
- 42"
- 48"
- 54"
- 72"
- 96"
- 108"
- Storm Sewer (Not Modeled)
- Drain
- 10' Contour

Drainage Areas

- Dunkley North
- Dunkley East
- Paterson East
- Outfall

Feet
0 1,000 2,000



CITY OF KALAMAZOO

KALAMAZOO COUNTY, MI

PERCENT OF FULL FLOW: 1-INCH STORM

FIGURE 2

Prein&Newhof

2180207

LEGEND

Surface Surcharge Duration

- No Surcharging
- < 15 min
- 15 - 30 min
- 30 - 60 min
- > 1 hour

Pipe Capacity (% of Full Flow)

- < 70% Full Flow
- 70% - 85% Full Flow
- 85% - 100% Full Flow
- > 100% Full Flow
- Storm Sewer (Not Modeled)
- Drain

Feet

1,000 500 0 1,000

Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 1-inch, 24-hour storm event. The duration of surcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 1-inch, 24-hour storm; 1.0 cumulative inches

Sewer Conditions: Existing sewer system

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PERCENT OF FULL FLOW: 1-YEAR STORM

FIGURE 3

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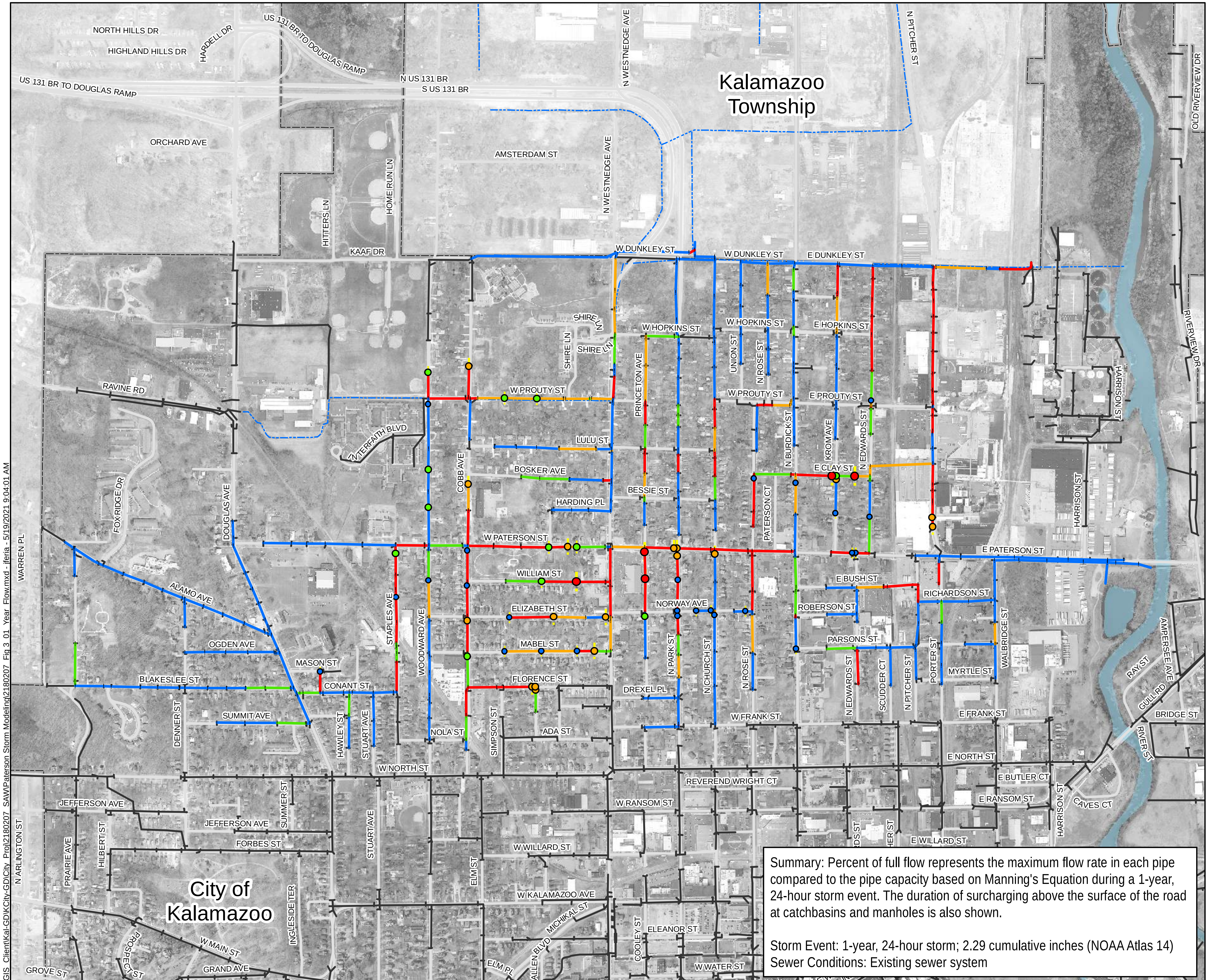

L E G E N D

Surface Surcharge Duration

- No Surcharging
- < 15 min
- 15 - 30 min
- 30 - 60 min
- > 1 hour

Pipe Capacity (% of Full Flow)

- < 70% Full Flow
- 70% - 85% Full Flow
- 85% - 100% Full Flow
- > 100% Full Flow
- Storm Sewer (Not Modeled)
- Drain

1,000 500 0 1,000 Feet

Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 1-year, 24-hour storm event. The duration of surcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 1-year, 24-hour storm; 2.29 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Existing sewer system

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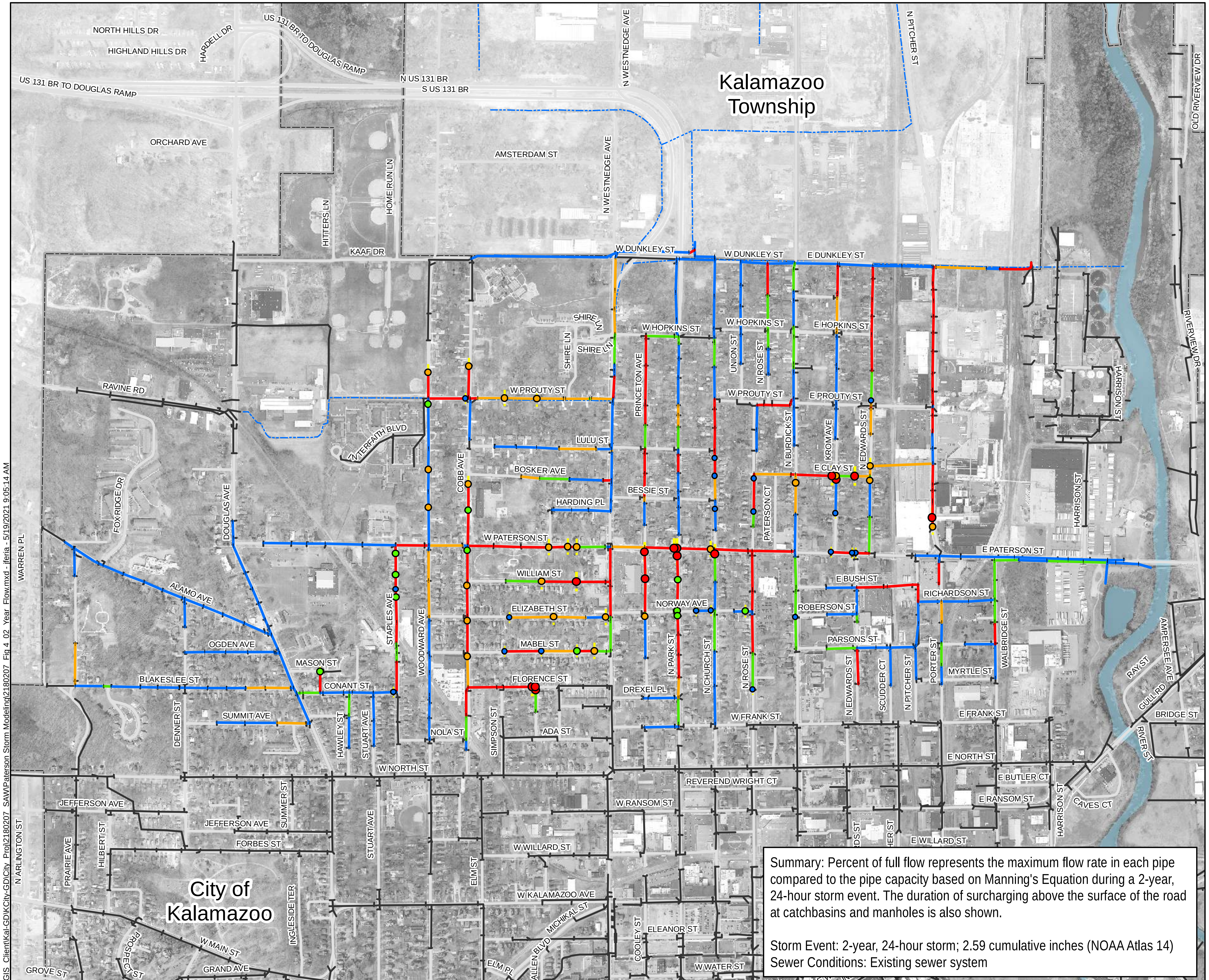

Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 2-year, 24-hour storm event. The duration of surcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 2-year, 24-hour storm; 2.59 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Existing sewer system

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PERCENT OF FULL FLOW: 2-YEAR STORM

FIGURE 4

Prein&Newhof

2180207

LEGEND

Surface Surcharge Duration

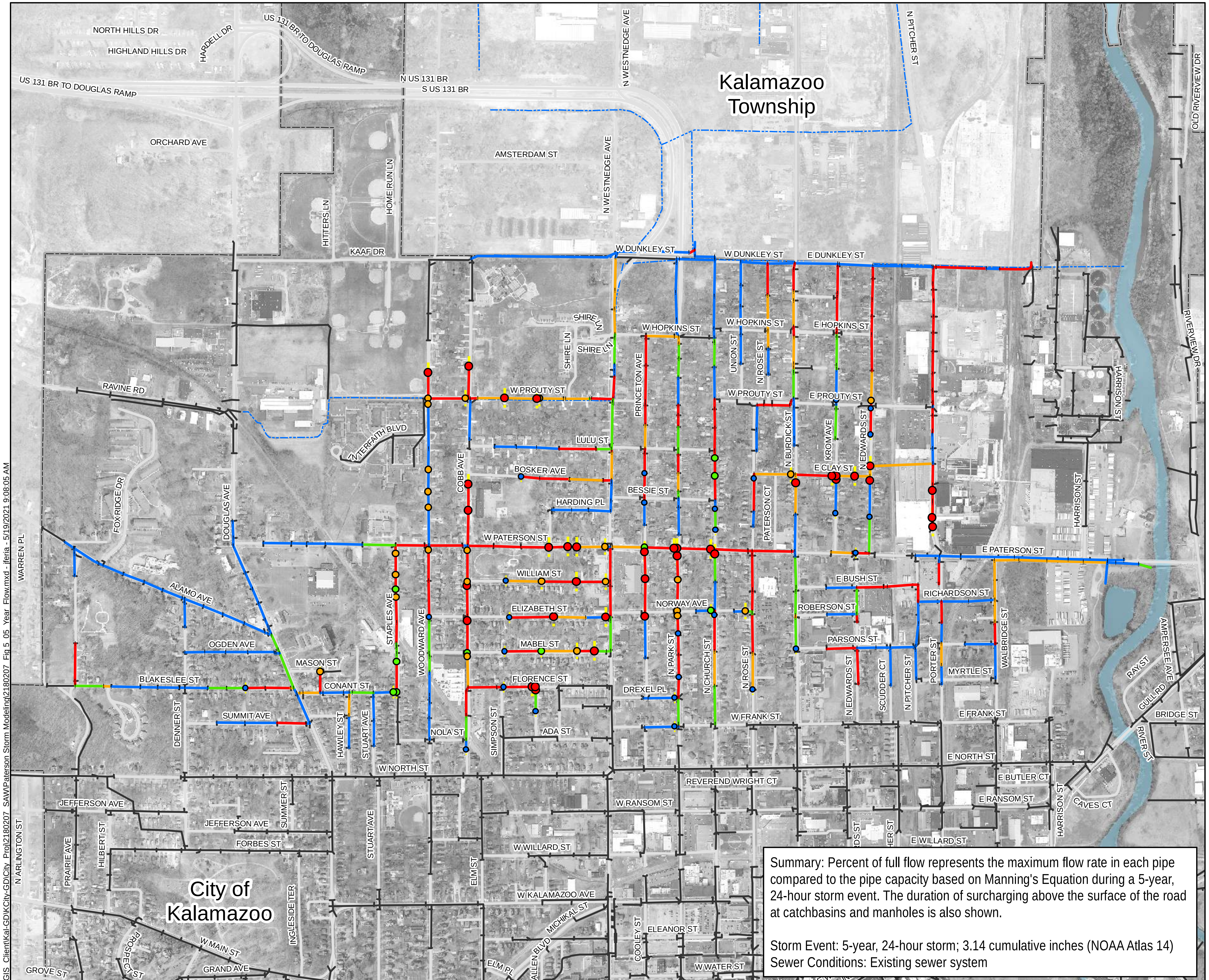
- No Surcharging
- < 15 min
- 15 - 30 min
- 30 - 60 min
- > 1 hour

Pipe Capacity (% of Full Flow)

- < 70% Full Flow
- 70% - 85% Full Flow
- 85% - 100% Full Flow
- > 100% Full Flow
- Storm Sewer (Not Modeled)
- Drain

Feet

1,000 500 0 1,000



Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 5-year, 24-hour storm event. The duration of surcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 5-year, 24-hour storm; 3.14 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Existing sewer system

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PERCENT OF FULL FLOW: 5-YEAR STORM

FIGURE 5

Prein&Newhof

2180207

LEGEND

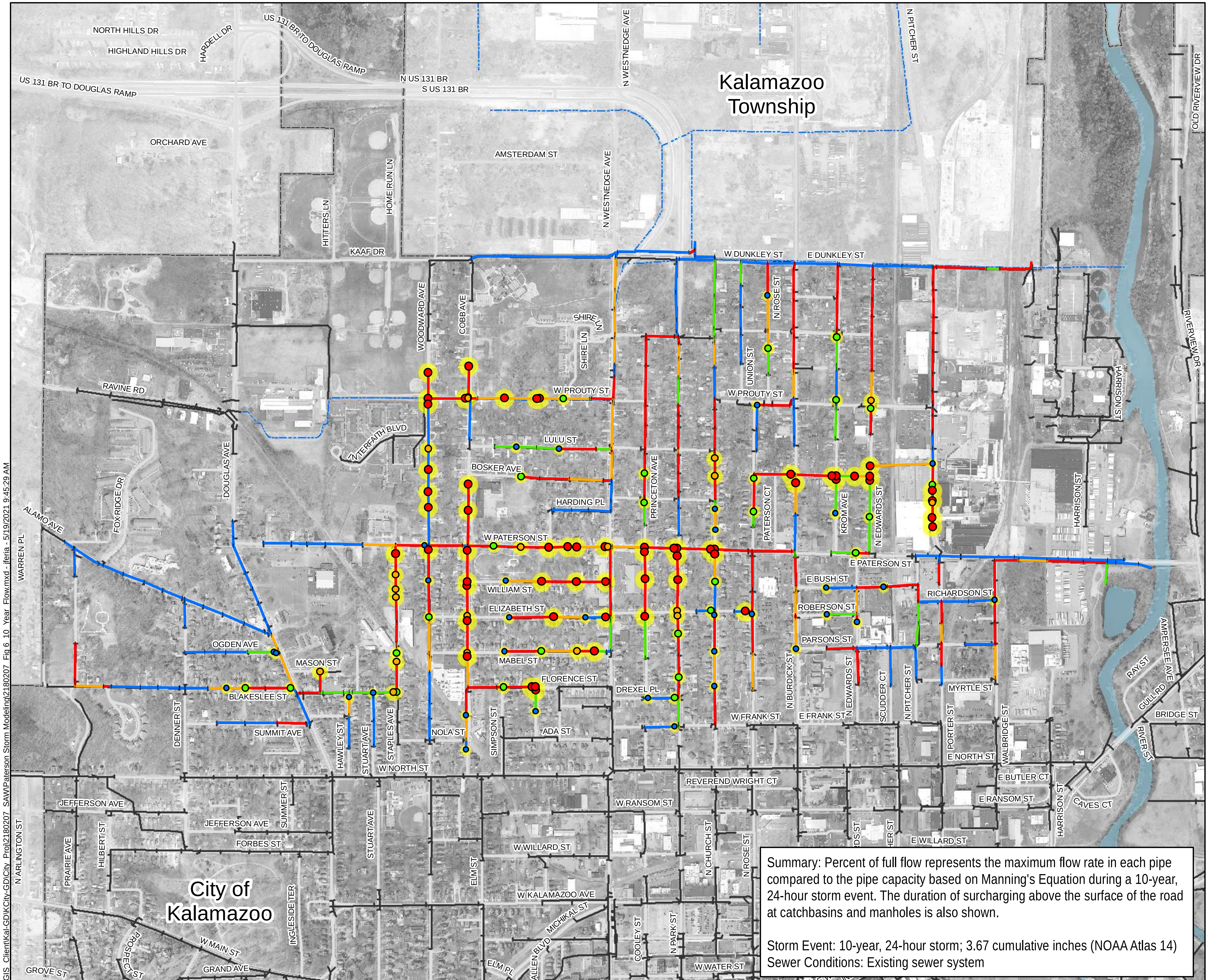
Surface Surcharge Duration

- No Surcharging
- < 15 min
- 15 - 30 min
- 30 - 60 min
- > 1 hour

Pipe Capacity (% of Full Flow)

- < 70% Full Flow
- 70% - 85% Full Flow
- 85% - 100% Full Flow
- > 100% Full Flow
- Storm Sewer (Not Modeled)
- Drain

1,000 500 0 1,000 Feet



Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 10-year, 24-hour storm event. The duration of surcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 10-year, 24-hour storm; 3.67 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Existing sewer system

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PERCENT OF FULL FLOW: 10-YEAR STORM

FIGURE 6

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LEGEND

Surface Surcharge Duration

- No Surcharging
- < 15 min
- 15 - 30 min
- 30 - 60 min
- > 1 hour

Pipe Capacity (% of Full Flow)

- < 70% Full Flow
- 70% - 85% Full Flow
- 85% - 100% Full Flow
- > 100% Full Flow
- Storm Sewer (Not Modeled)
- Drain

Feet
1,000 500 0 1,000

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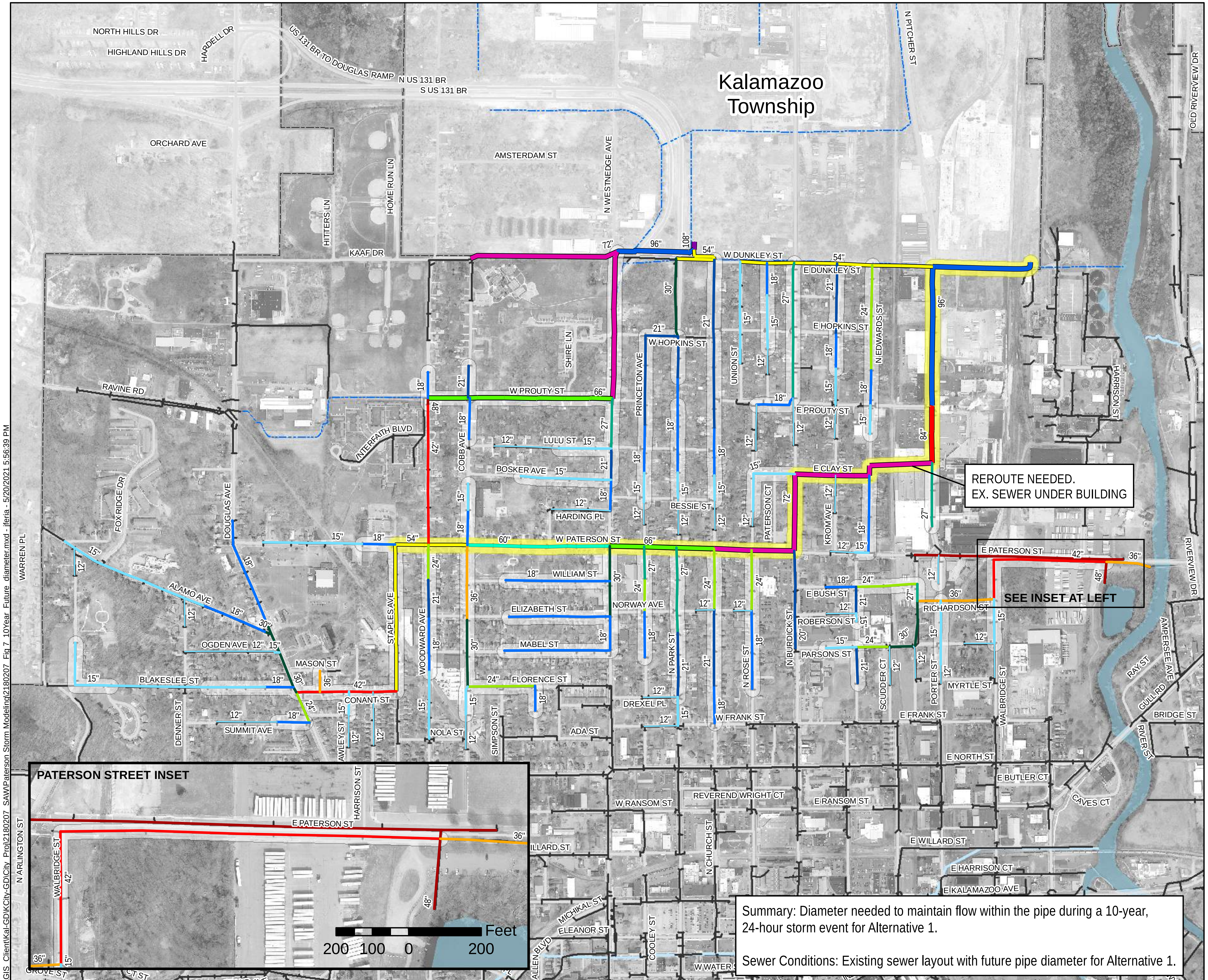

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FUTURE PIPE DIAMETER (ALTERNATIVE 1)

FIGURE 7

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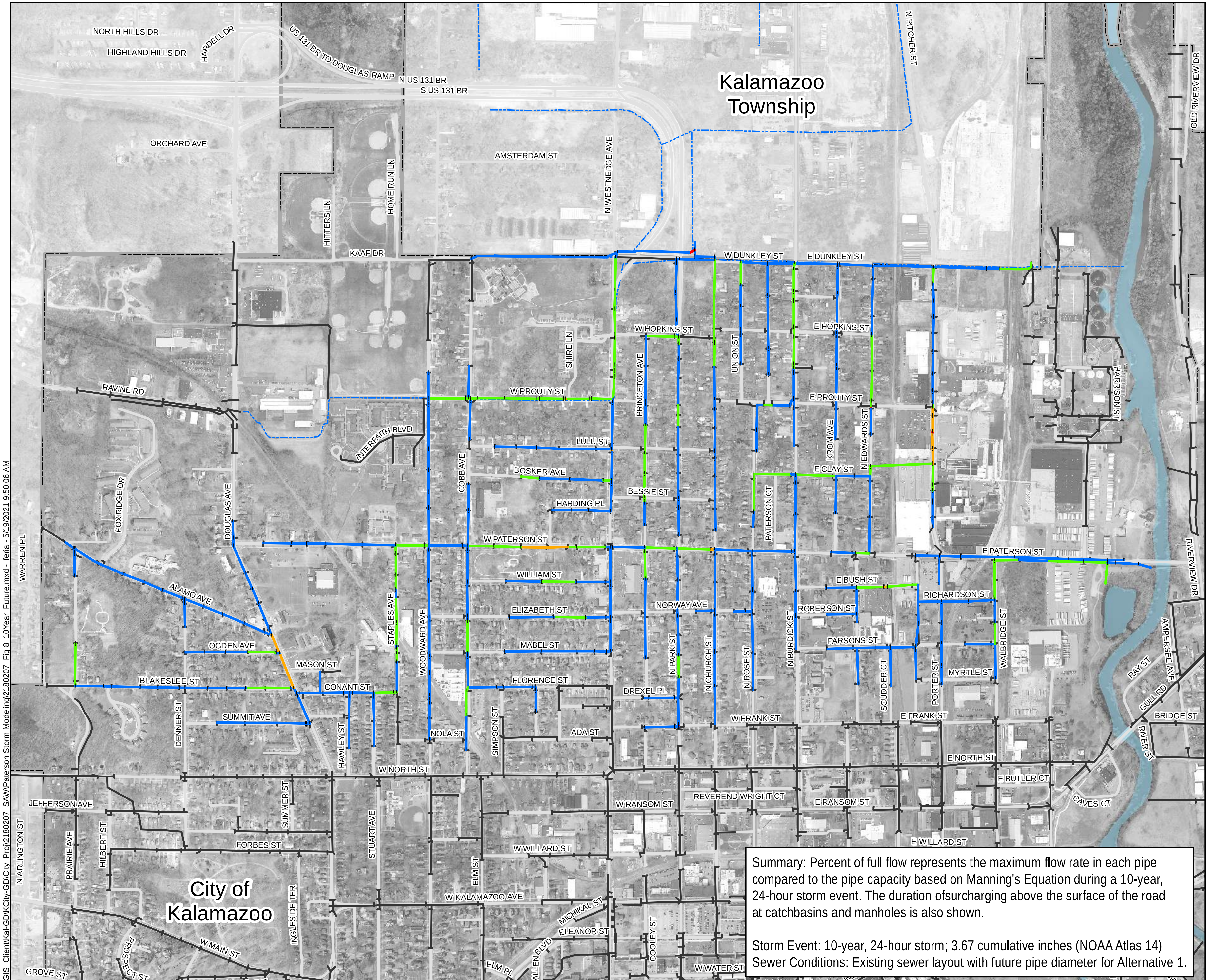
LEGEND

Future Diameter

- 12" or Less
- 15"
- 18"
- 21"
- 24"
- 27"
- 30"
- 36"
- 42"
- 48"
- 54"
- 60"
- 66"
- 72"
- 84"
- 96"
- 108"
- Paterson Drainage Route
- Future Upsize Recommended
- Drain

Feet

1,000 500 0 1,000



Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 10-year, 24-hour storm event. The duration ofsurcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 10-year, 24-hour storm; 3.67 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Existing sewer layout with future pipe diameter for Alternative 1.

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KALAMAZOO COUNTY, MI

PERCENT OF FULL FLOW: 10-YEAR STORM (ALTERNATIVE 1 FUTURE PIPE DIAMETER)

FIGURE 8

Prein&Newhof

2180207

LEGEND

Surface Surcharge Duration

No Surcharging

Pipe Capacity (% of Full Flow)

< 70% Full

70% - 85% Full

85% - 100% Full

> 100% Full

Storm Sewer (Not Modeled)

Drain

1,000 500 0 1,000 Feet

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KALAMAZOO COUNTY, MI

REDIRECT PIPE DIAMETER (ALTERNATIVE 2)

FIGURE 9

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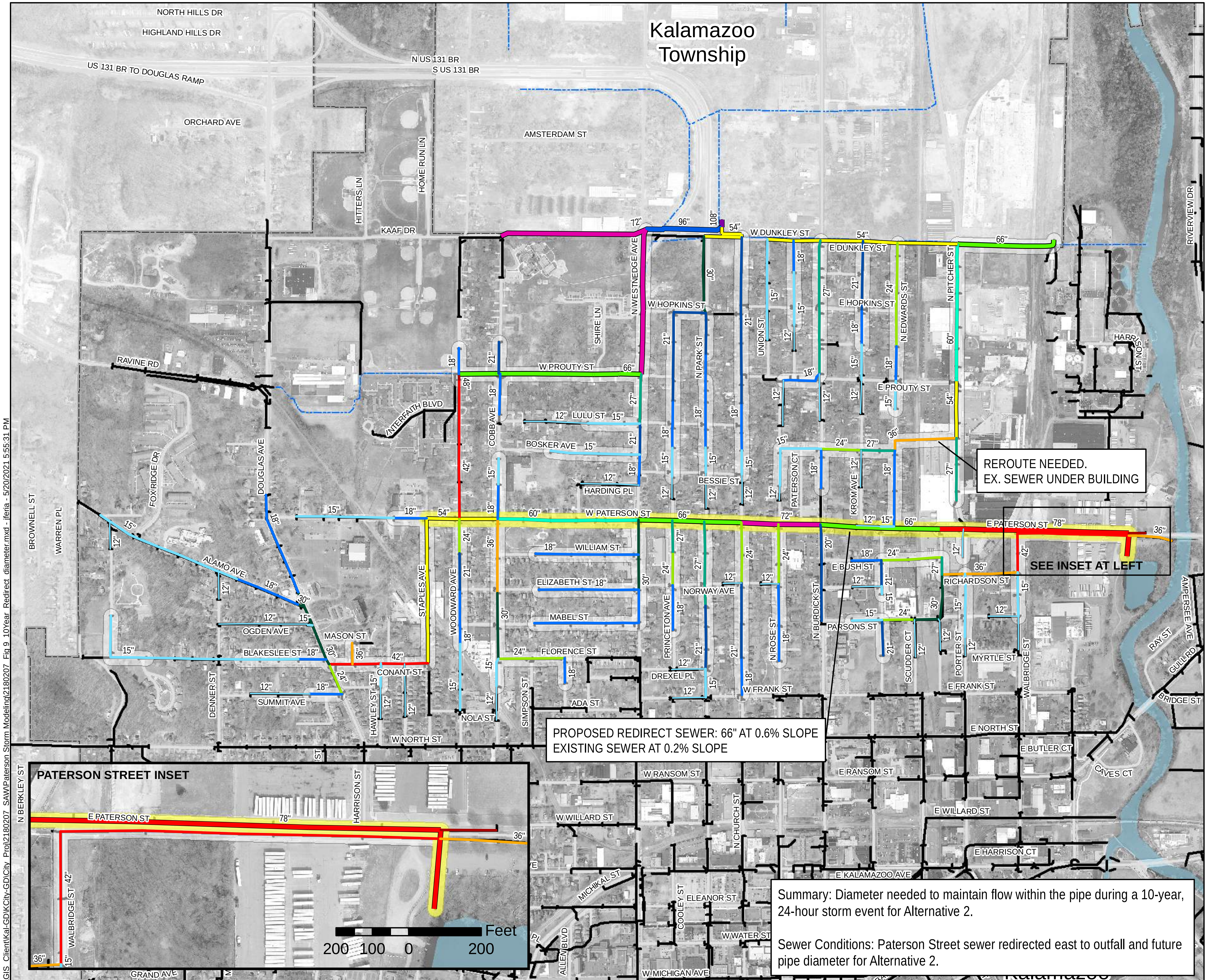

Summary: Diameter needed to maintain flow within the pipe during a 10-year, 24-hour storm event for Alternative 2.

Sewer Conditions: Paterson Street sewer redirected east to outfall and future pipe diameter for Alternative 2.

LEGEND

Future Diameter

- 12" or Less
- 15"
- 18"
- 21"
- 24"
- 27"
- 30"
- 36"
- 42"
- 48"
- 54"
- 60"
- 66"
- 72"
- 84"
- 96"
- 108"
- Paterson Drainage Route
- Future Upsize Recommended
- Existing Gravity Sewer
- Drain

Feet
1,000 500 0 1,000

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PERCENT OF FULL FLOW: 10-YEAR STORM (ALTERNATIVE 2 REDIRECT EAST TO OUTLET)

FIGURE 10A

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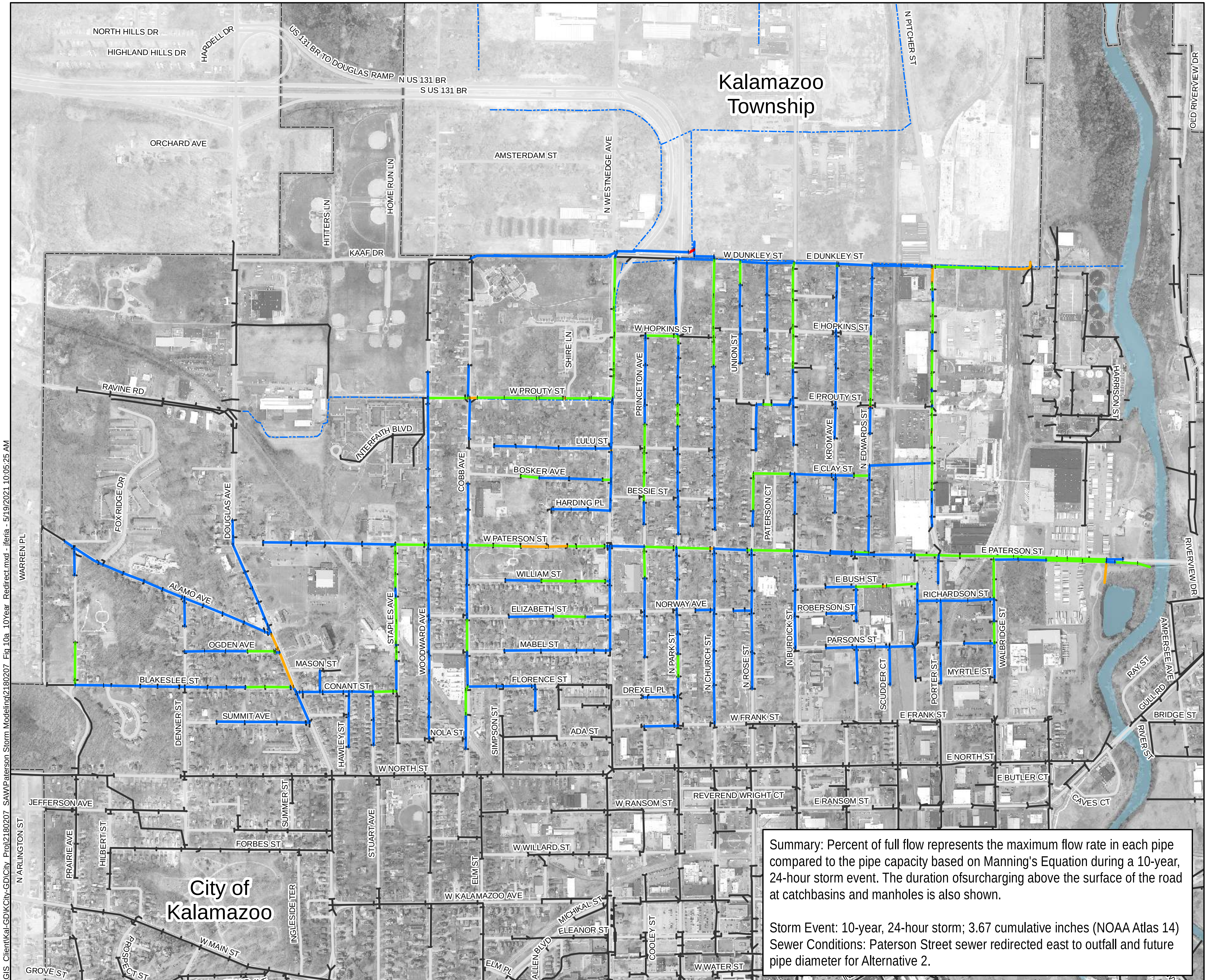

Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 10-year, 24-hour storm event. The duration ofsurcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 10-year, 24-hour storm; 3.67 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Paterson Street sewer redirected east to outfall and future pipe diameter for Alternative 2.

LEGEND

Surface Surcharge Duration

- No Surcharging

Pipe Capacity (% of Full Flow)

- < 70% Full
- 70% - 85% Full
- 85% - 99% Full
- > 100% Full
- Storm Sewer (Not Modeled)
- Drain

Feet
1,000 500 0 1,000

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PERCENT OF FULL FLOW: 10-YEAR STORM (ALTERNATIVE 2 REDIRECT EAST TO OUTLET - PATERSON STREET IMPROVEMENTS ONLY)

FIGURE 10B

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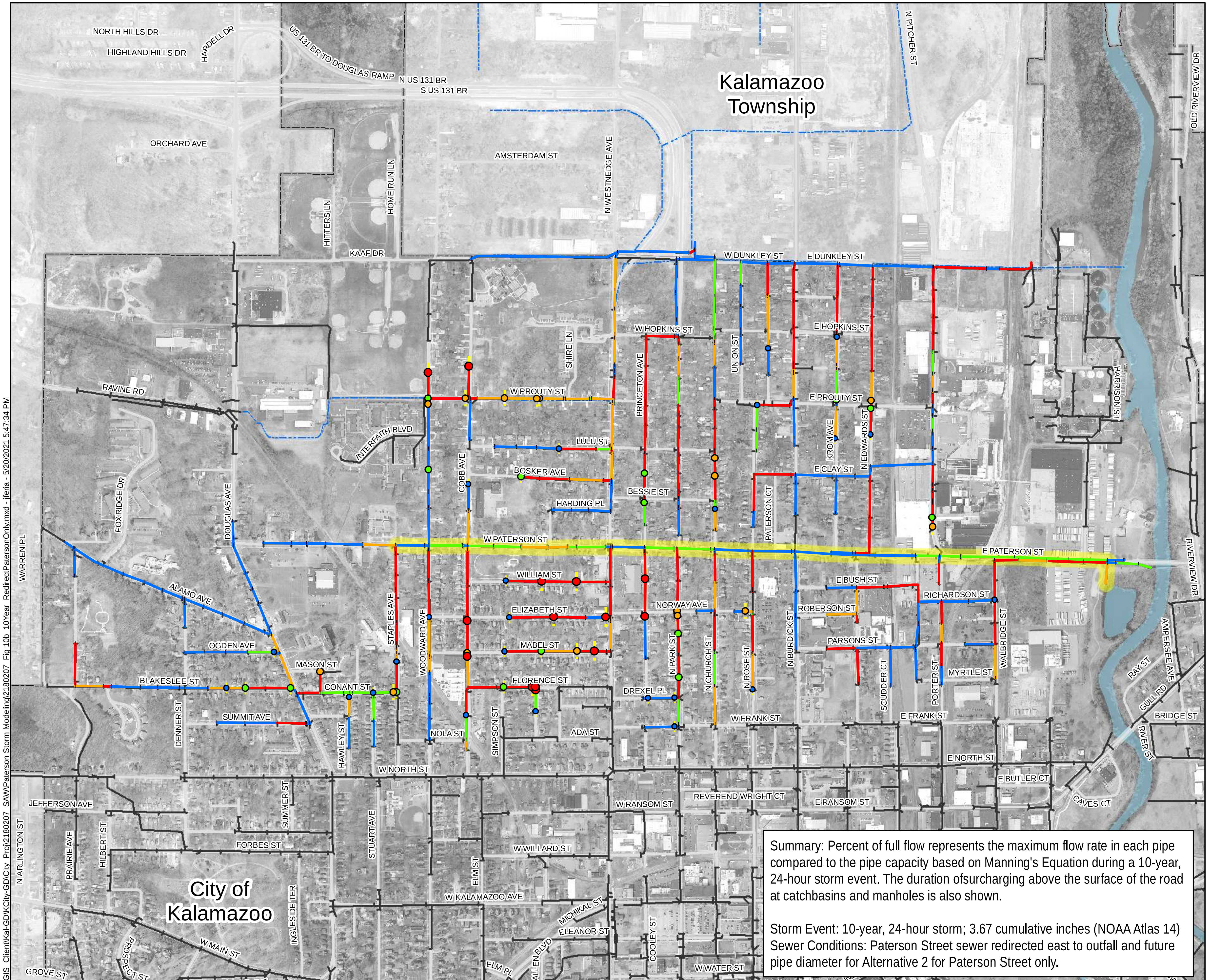

Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 10-year, 24-hour storm event. The duration ofsurcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 10-year, 24-hour storm; 3.67 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Paterson Street sewer redirected east to outfall and future pipe diameter for Alternative 2 for Paterson Street only.

LEGEND

Surface Surcharge Duration

- No Surcharging
- < 15 Min
- 15 - 30 Min
- 30 - 60 Min
- > 60 Min

Pipe Capacity (% of Full Flow)

- < 70% Full
- 70% - 85% Full
- 85% - 99% Full
- > 100% Full
- Storm Sewer (Not Modeled)
- Drain
- Paterson Drainage Route

1,000 500 0 1,000 Feet

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CITY OF KALAMAZOO
KALAMAZOO COUNTY, MI

LIFT STATION AT PATERSON & COBB (ALTERNATIVE 3)

FIGURE 11

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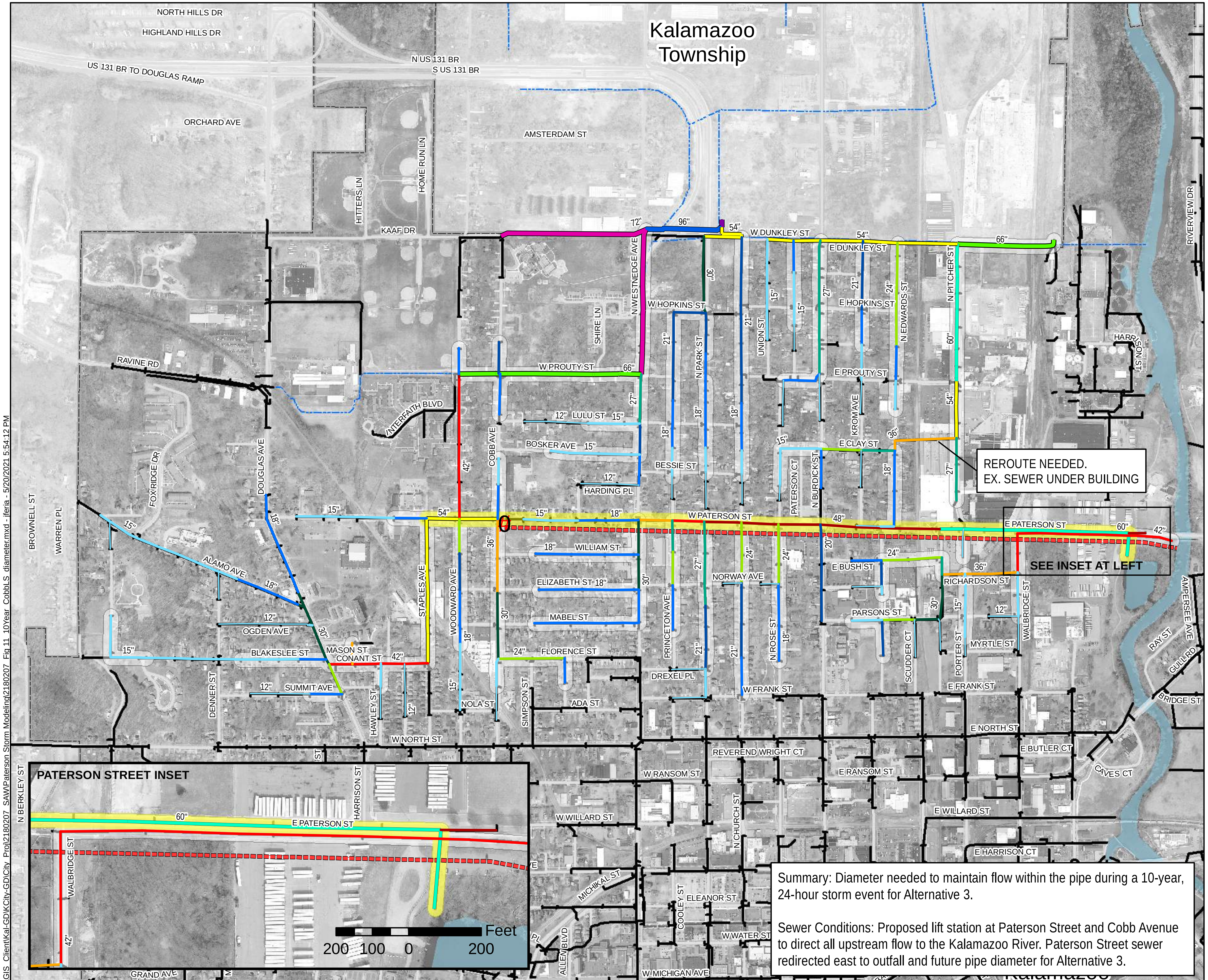
2180207



LEGEND

- Proposed Stormwater Lift Station
- Proposed Force Main

Future Diameter

- 12" or Less
- 15"
- 18"
- 21"
- 24"
- 27"
- 30"
- 36"
- 42"
- 48"
- 54"
- 60"
- 66"
- 72"
- 96"
- 108"
- Main Paterson Drainage Route
- Future Upsize Recommended
- Existing Gravity Sewer
- Drain

Feet
1,000 500 0 1,000

CITY OF KALAMAZOO

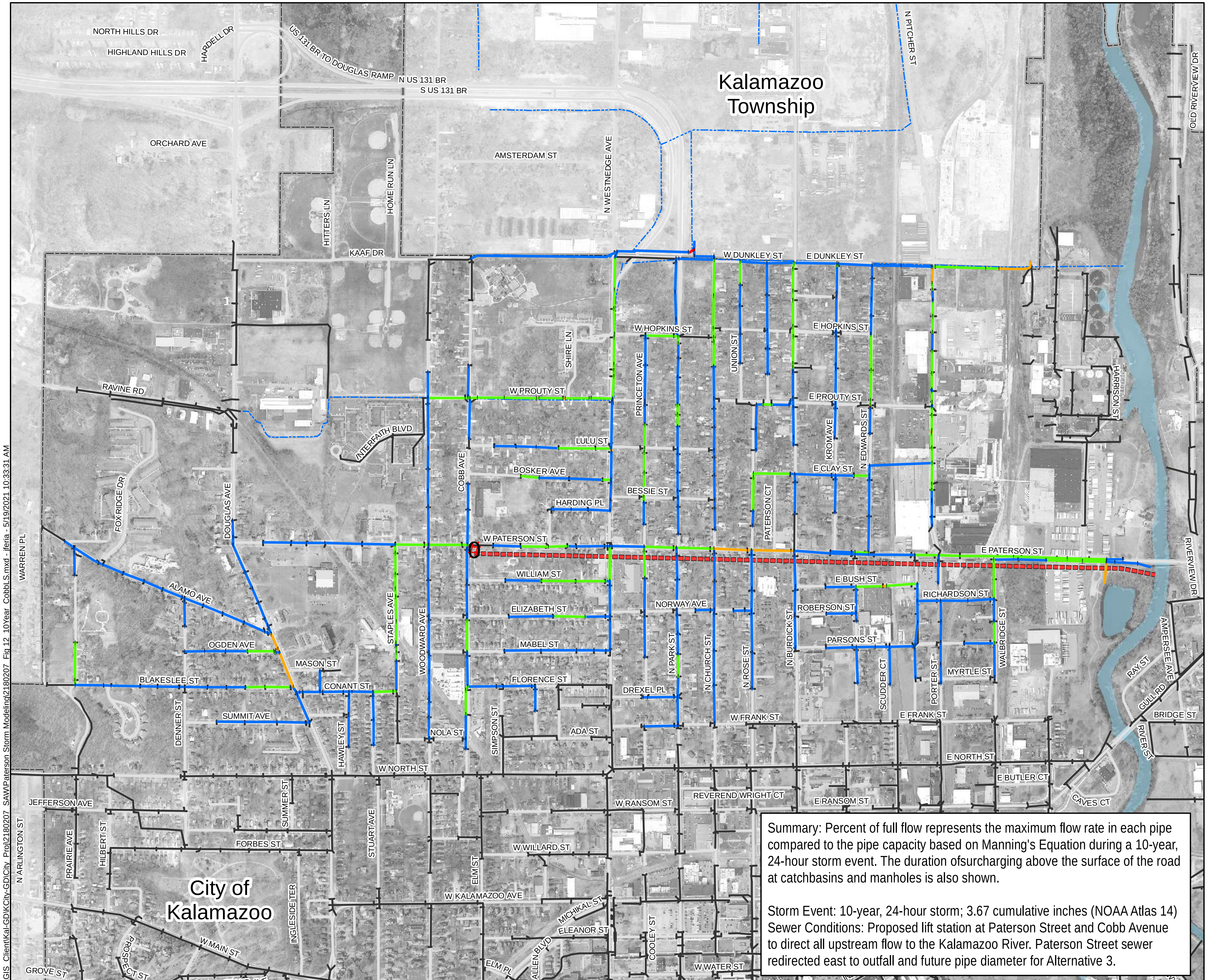
KALAMAZOO COUNTY, MI

PERCENT OF FULL FLOW: 10-YEAR STORM (ALTERNATIVE 3 LIFT STATION AT COBB)

FIGURE 12

Prein&Newhof

2180207



LEGEND

- Proposed Stormwater Lift Station
- Proposed Force Main

Surface Surcharge Duration

- No Surcharging

Pipe Capacity (% of Full Flow)

- < 70% Full
- 70% - 85% Full
- 85% - 99% Full
- > 100% Full
- Storm Sewer (Not Modeled)
- Drain

Feet

1,000 500 0 1,000

Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 10-year, 24-hour storm event. The duration ofsurcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 10-year, 24-hour storm; 3.67 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Proposed lift station at Paterson Street and Cobb Avenue to direct all upstream flow to the Kalamazoo River. Paterson Street sewer redirected east to outfall and future pipe diameter for Alternative 3.

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CITY OF KALAMAZOO
KALAMAZOO COUNTY, MI

LIFT STATION AT PATERSON & BURDICK (ALTERNATIVE 4)

FIGURE 13

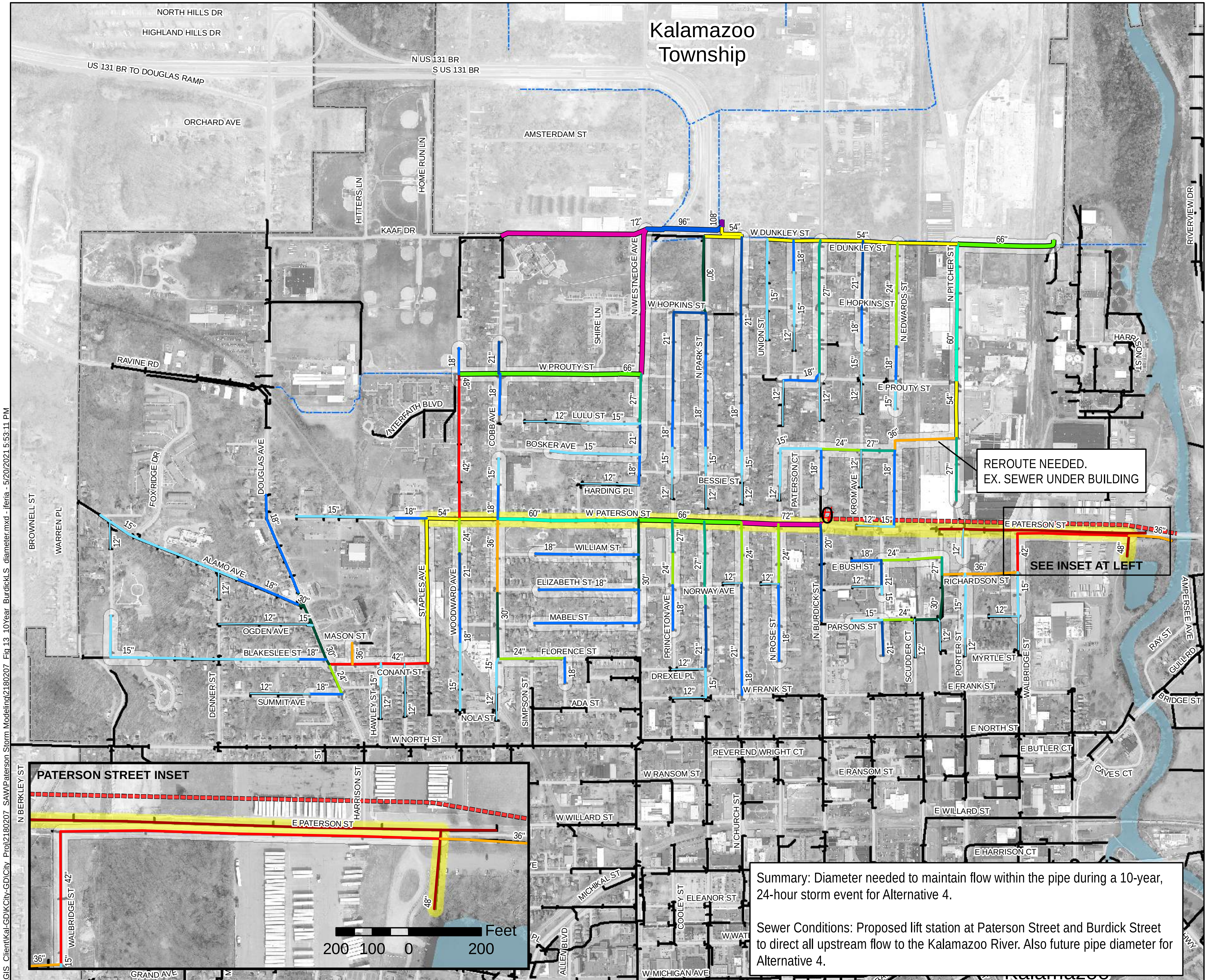
Prein&Newhof

2180207

LEGEND

- Proposed Stormwater Lift Station
- Proposed Force Main
- Future Diameter
  - 12" or Less
  - 15"
  - 18"
  - 21"
  - 24"
  - 27"
  - 30"
  - 36"
  - 42"
  - 48"
  - 54"
  - 60"
  - 66"
  - 72"
  - 96"
  - 108"
- Paterson Drainage Route
- Future Upsize Recommended
- Existing Gravity Sewer
- Drain

Feet: 1,000 500 0 1,000



Summary: Diameter needed to maintain flow within the pipe during a 10-year, 24-hour storm event for Alternative 4.

Sewer Conditions: Proposed lift station at Paterson Street and Burdick Street to direct all upstream flow to the Kalamazoo River. Also future pipe diameter for Alternative 4.

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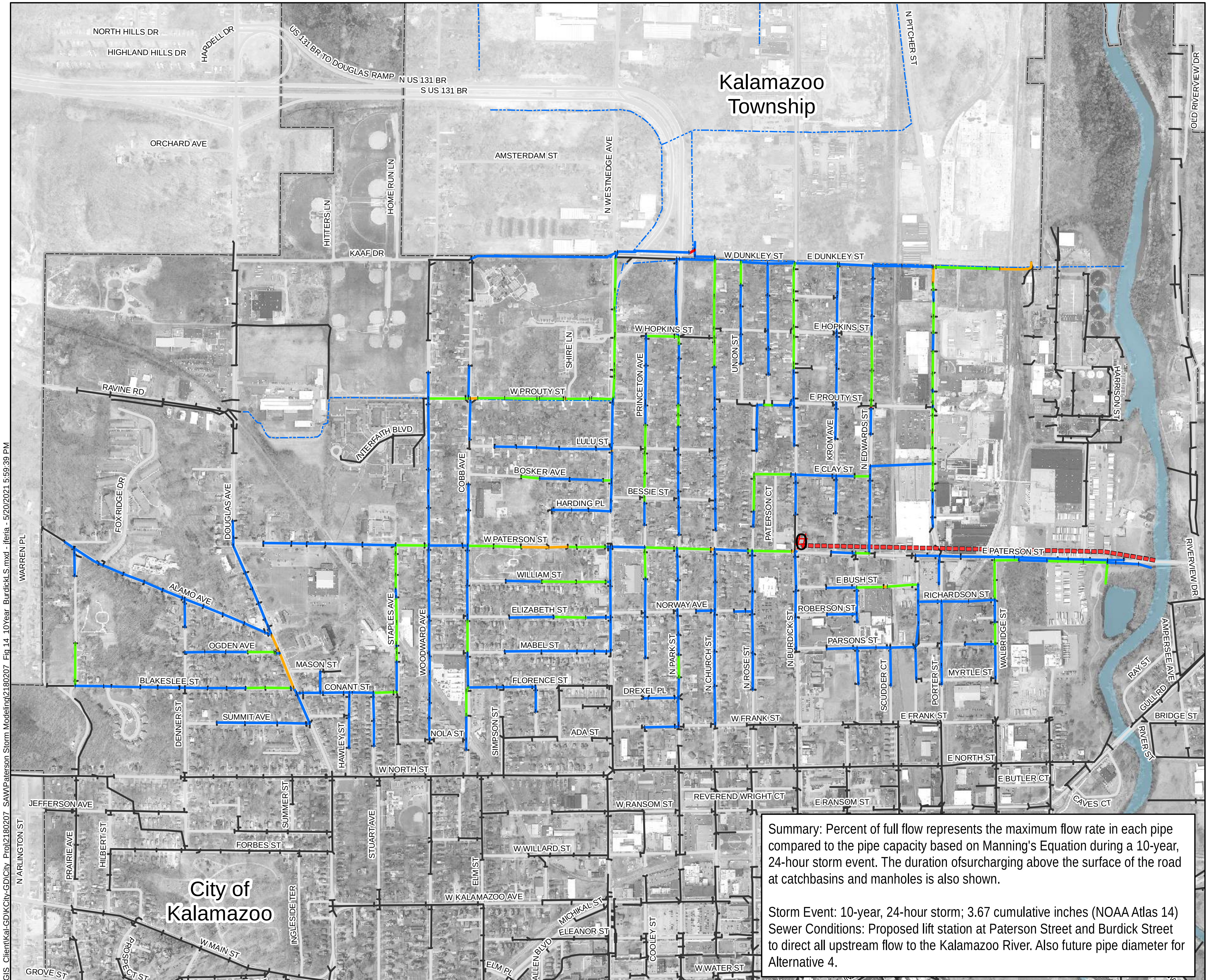

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KALAMAZOO COUNTY, MI

PERCENT OF FULL FLOW: 10-YEAR STORM (ALTERNATIVE 4 LIFT STATION AT BURDICK)

FIGURE 14

Prein&Newhof

2180207

LEGEND

- Proposed Stormwater Lift Station
- Proposed Force Main

Surface Surcharge Duration

- No Surcharging

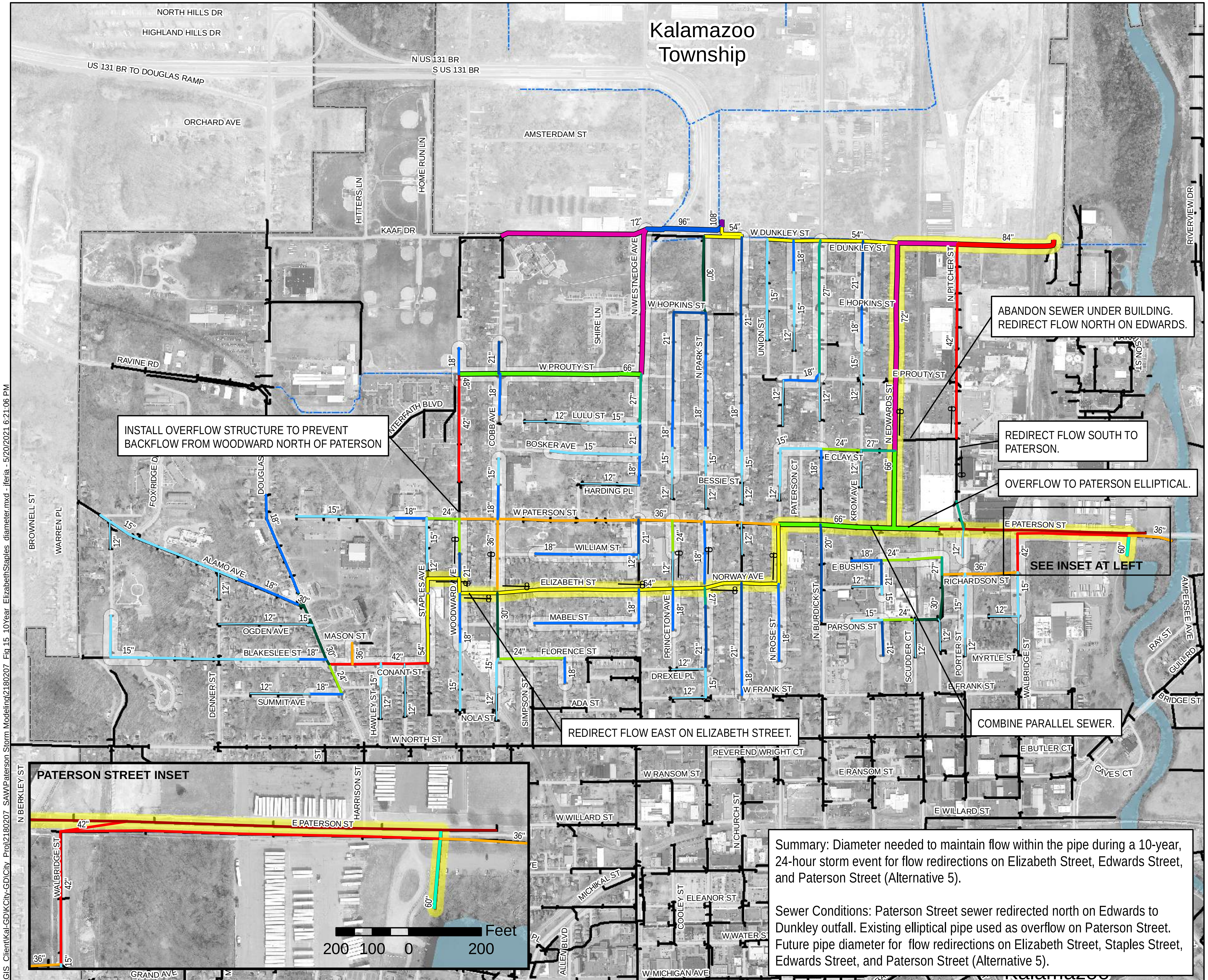
Pipe Capacity (% of Full Flow)

- < 70% Full
- 70% - 85% Full
- 85% - 99% Full
- > 100% Full
- Storm Sewer (Not Modeled)
- Drain

Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 10-year, 24-hour storm event. The duration ofsurcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 10-year, 24-hour storm; 3.67 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Proposed lift station at Paterson Street and Burdick Street to direct all upstream flow to the Kalamazoo River. Also future pipe diameter for Alternative 4.

Feet
1,000 500 0 1,000



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CITY OF KALAMAZOO
KALAMAZOO COUNTY, MI

STAPLES, ELIZABETH, EDWARDS, & PATERSON REDIRECTS (ALTERNATIVE 5)

FIGURE 15

Prein&Newhof

2180207

LEGEND

Future Diameter

- 12" or Less
- 15"
- 18"
- 21"
- 24"
- 27"
- 30"
- 36"
- 42"
- 48" (Also 38" x 60" Ellipse)
- 54"
- 60"
- 66"
- 72"
- 84"
- 96"
- 108"
- Main Drainage Route
- Future Upsize Recommended
- Existing Gravity Sewer
- Drain

Feet
1,000 500 0 1,000

Summary: Diameter needed to maintain flow within the pipe during a 10-year, 24-hour storm event for flow redirections on Elizabeth Street, Edwards Street, and Paterson Street (Alternative 5).

Sewer Conditions: Paterson Street sewer redirected north on Edwards to Dunkley outfall. Existing elliptical pipe used as overflow on Paterson Street. Future pipe diameter for flow redirections on Elizabeth Street, Staples Street, Edwards Street, and Paterson Street (Alternative 5).

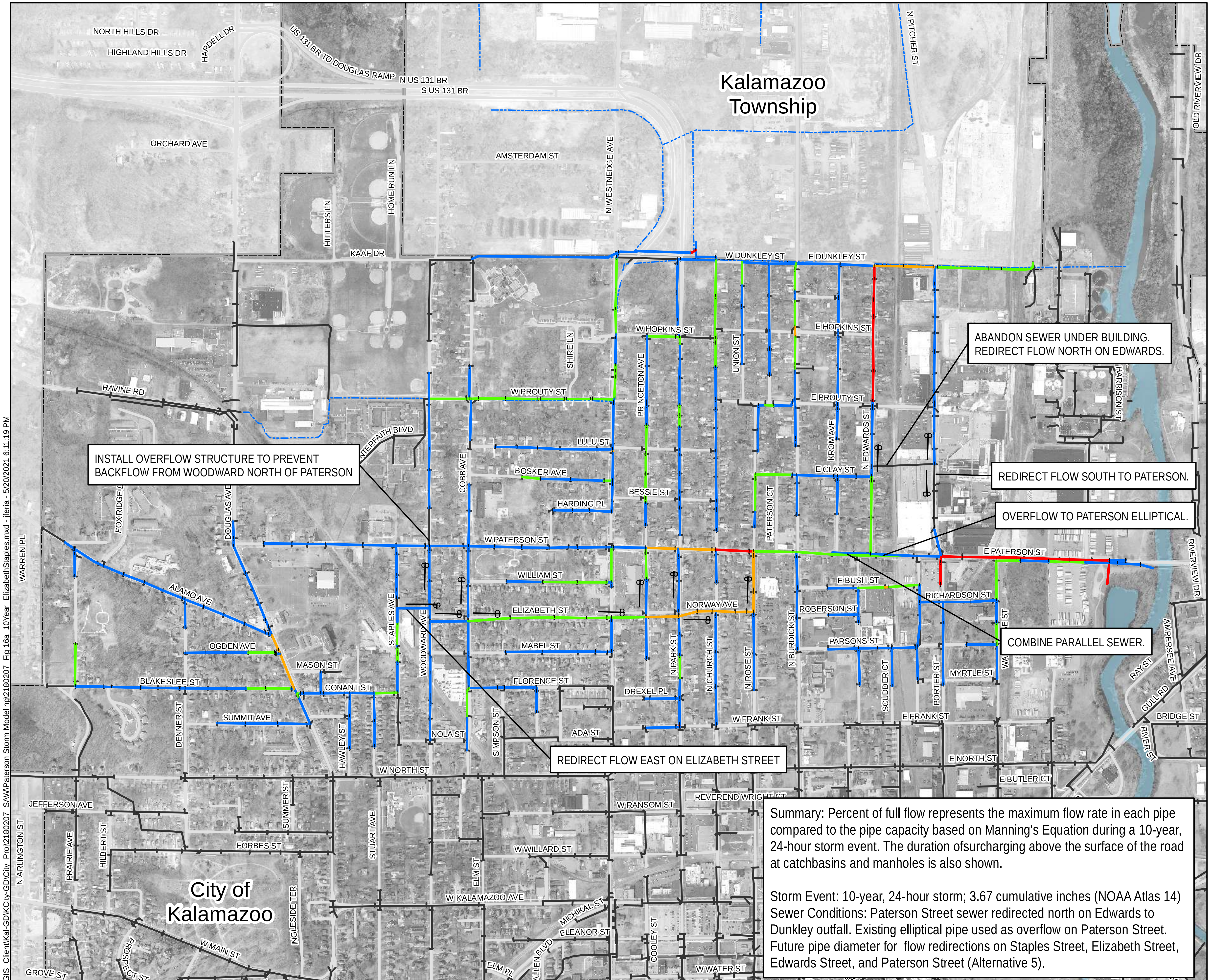
CITY OF KALAMAZOO
KALAMAZOO COUNTY, MI

PERCENT OF FULL FLOW: 10-YEAR STORM STAPLES, ELIZABETH, EDWARDS, & PATERSON REDIRECTS (ALTERNATIVE 5)

FIGURE 16A

Prein&Newhof

2180207



LEGEND

Surface Surcharge Duration

- No Surcharging

Pipe Capacity (% of Full Flow)

- < 70% Full
- 70% - 85% Full
- 85% - 99% Full
- > 100% Full
- Storm Sewer (Not Modeled)
- Drain

1,000 500 0 1,000 Feet

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CITY OF KALAMAZOO

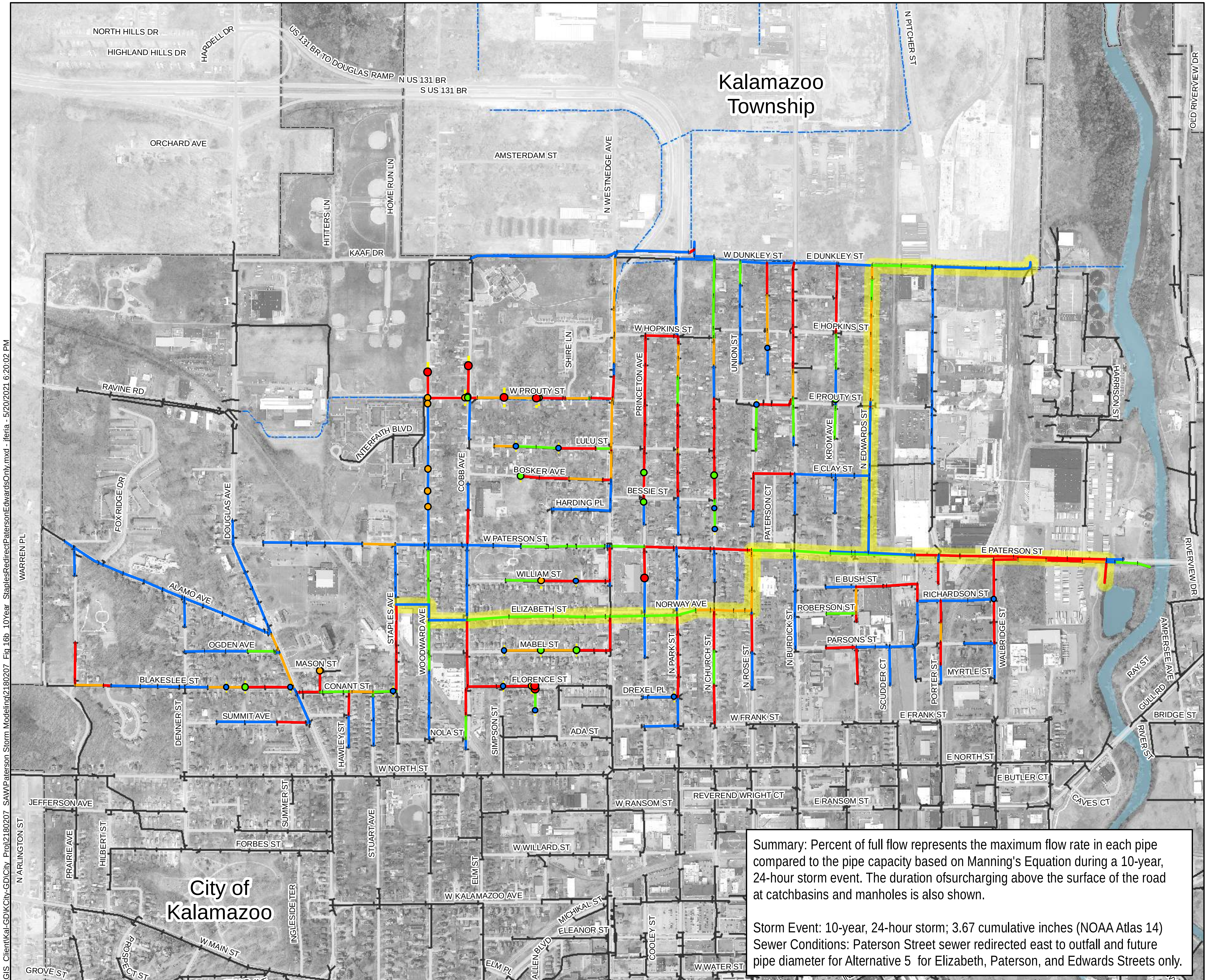
KALAMAZOO COUNTY, MI

PERCENT OF FULL FLOW: 10-YEAR STORM (ALTERNATIVE 5 - ELIZABETH, PATERSON, EDWARDS IMPROVEMENTS ONLY)

FIGURE 16B

Prein&Newhof

2180207



Summary: Percent of full flow represents the maximum flow rate in each pipe compared to the pipe capacity based on Manning's Equation during a 10-year, 24-hour storm event. The duration ofsurcharging above the surface of the road at catchbasins and manholes is also shown.

Storm Event: 10-year, 24-hour storm; 3.67 cumulative inches (NOAA Atlas 14)
Sewer Conditions: Paterson Street sewer redirected east to outfall and future pipe diameter for Alternative 5 for Elizabeth, Paterson, and Edwards Streets only.

LEGEND

Surface Surcharge Duration

- No Surcharging
- < 15 Min
- 15 - 30 Min
- 30 - 60 Min
- > 60 Min

Pipe Capacity (% of Full Flow)

- < 70% Full
- 70% - 85% Full
- 85% - 99% Full
- > 100% Full
- Storm Sewer (Not Modeled)
- Drain
- Main Drainage Route

Feet: 1,000 500 0 1,000

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Appendix A – Meter Summary

1 FLOW METERING

To verify that modeled flows closely match actual flows in the stormwater system, two flow meters were installed in the Paterson Street catchment area (Figure 1).

1.1 Meter Locations

Meter 1 was placed in the 30-inch sewer on Douglas Avenue between Conant and Blakeslee Streets and Meter 2 was placed in the 36-inch sewer at the intersection of Porter Street and Richardson Street. The meters were installed on October 20, 2020 and were removed on November 5, 2020. ISCO Model 2150 Area Velocity flow meters were used for this study. Depth and flow measurements were logged every five minutes, 24 hours per day, throughout the period the meter was in the sewer. The flow rate (number of gallons per minute) was calculated from these measurements, resulting in a profile of the flow over time. The data storage component of the flow meter is typically secured near the top of the manhole. Since the data storage component is susceptible to damage if submerged in water for long periods of time, meter locations with minimal risk of surface surcharging were selected.

1.2 Rainfall Events

Precipitation data from storm events was retrieved from the Kalamazoo Nature Center Enviro-weather station located in the City of Kalamazoo and Wunderground Station KMIKALAM117 located in Kalamazoo Township near Mt. Olivet Road and Riverview Drive. Both weather stations recorded similar rainfall totals. The Wunderground station was used for model calibration, because it is located closer to the study area. The largest rainfall during the metering period produced 2.42 inches of rain in 67 hours. This storm event was used for model calibration.

1.3 Metering Results

Figures A-1 and A-2 in Appendix A display the level, velocity, flow rate, and rainfall data for Meters 1 and 2. These figures display the response at the meters during each storm event. Table 2 provides a summary of the field data for the storm event and calibration results.

Table 2. Meter Data and Calibration Summary

Storm Event Flow Conditions Storm Event: 10/21/2020 to 10/23/2020 Rainfall: 2.42 inches Peak Hour Intensity: 0.46 inches/hour Duration: 67 hours								
	Field Data				Model Data			
	Maximum Rate, gpm			Total Storm Event Volume, mgal	Maximum Rate, gpm			Total Storm Event Volume, mgal
Meters	Peak 1 10/22 at 4 am	Peak 2 10/22 at 8 am	Peak 3 10/22 at 10 am		Peak 1 10/22 at 4 am	Peak 2 10/22 at 8 am	Peak 3 10/22 at 10 am	
Meter 1	2,671	2,072	1,503	0.543	2,841	2,917	2,346	0.540
Meter 2	1,865	1,860	1,710	0.397	1,788	1,736	1,258	0.397

1.4 Model Calibration

For this study, there were two meters used to assist in calibrating the storm sewer model. Using the two meters, model parameters were adjusted to match metered data to model output. These adjustments were applied to nearby, unmetered areas with similar characteristics. Figure A-3 provides an example of model calibration at Meter 1.

2 HYDRAULIC MODEL

The storm sewer in the study area was modeled using InfoSWMM®, which is a hydrologic and hydraulic modeling software program with an interface in ArcGIS. The core analysis tool is the Storm Water Management Model (SWMM), originally developed for the United States Environmental Protection Agency and later refined with commercial software improvements and extensions. The Dynamic Wave routing method was used to simulate water movement through the system while the Hazen-Williams Equation was used for the force main energy losses.

The following assumptions were used to create and analyze the hydraulic model.

1. Pipe inverts were estimated using the maps from the City of Kalamazoo's Master Storm Drainage Plan (1976). Elevations were adjusted from NGVD 29 to NAVD 88.

2. Where no upstream invert data was available, the pipe was assumed to be constructed at minimum slope per the Recommended Standards for Wastewater Facilities (2014).

Figure A-1: Meter Location #1 Rainfall and Meter Data Comparison

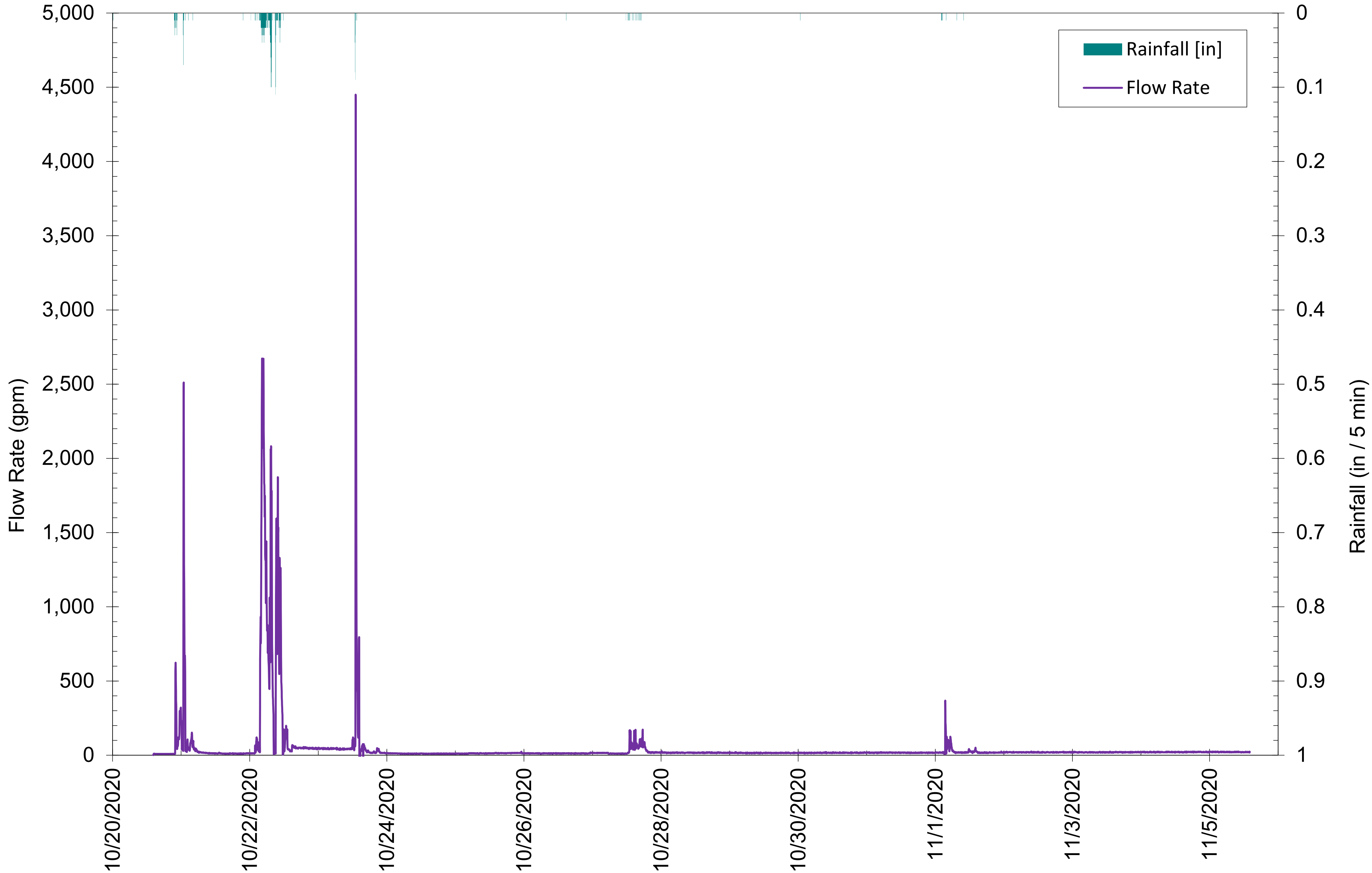


Figure A-2: Meter Location #2 Rainfall and Meter Data Comparison

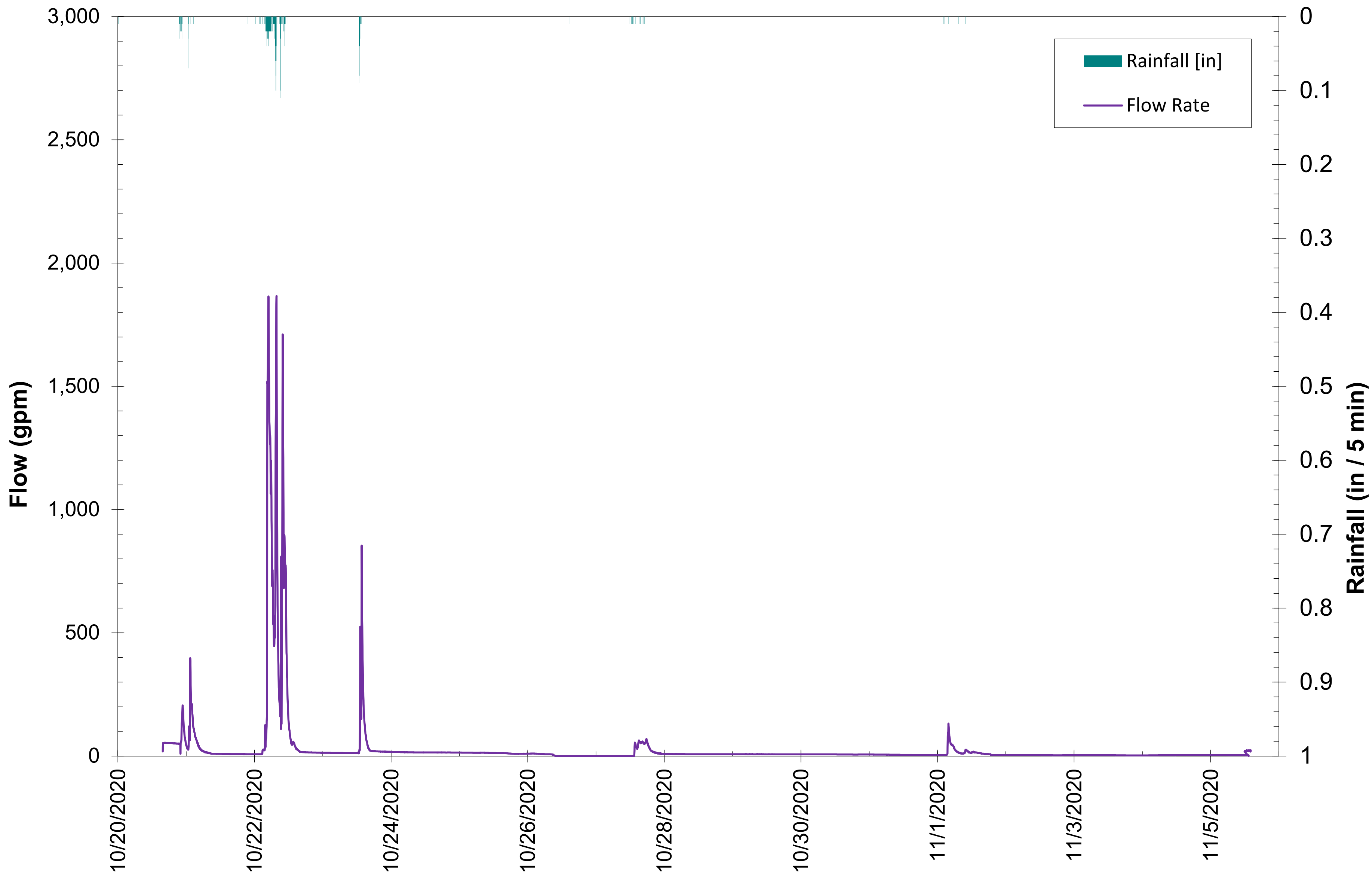
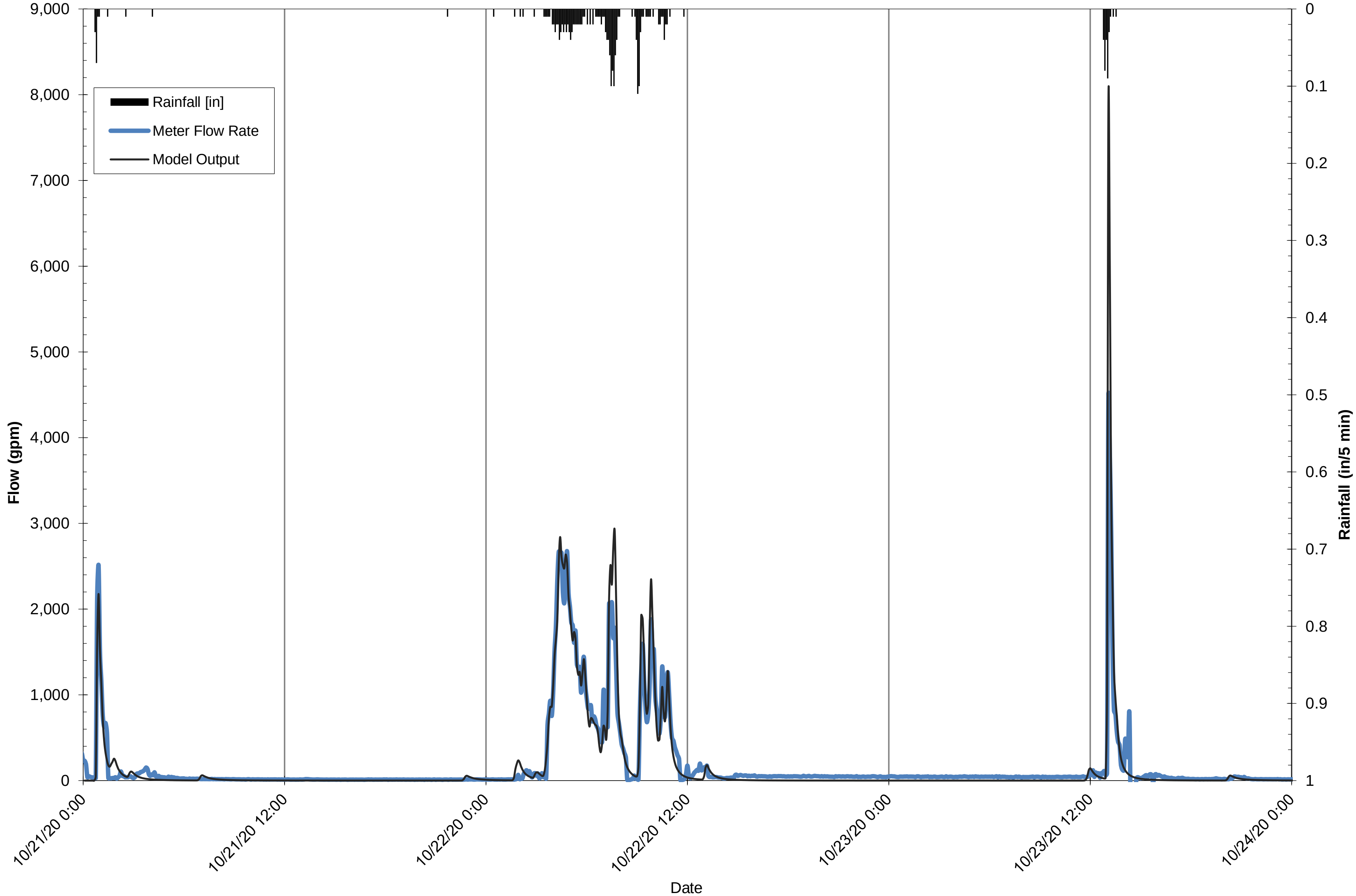
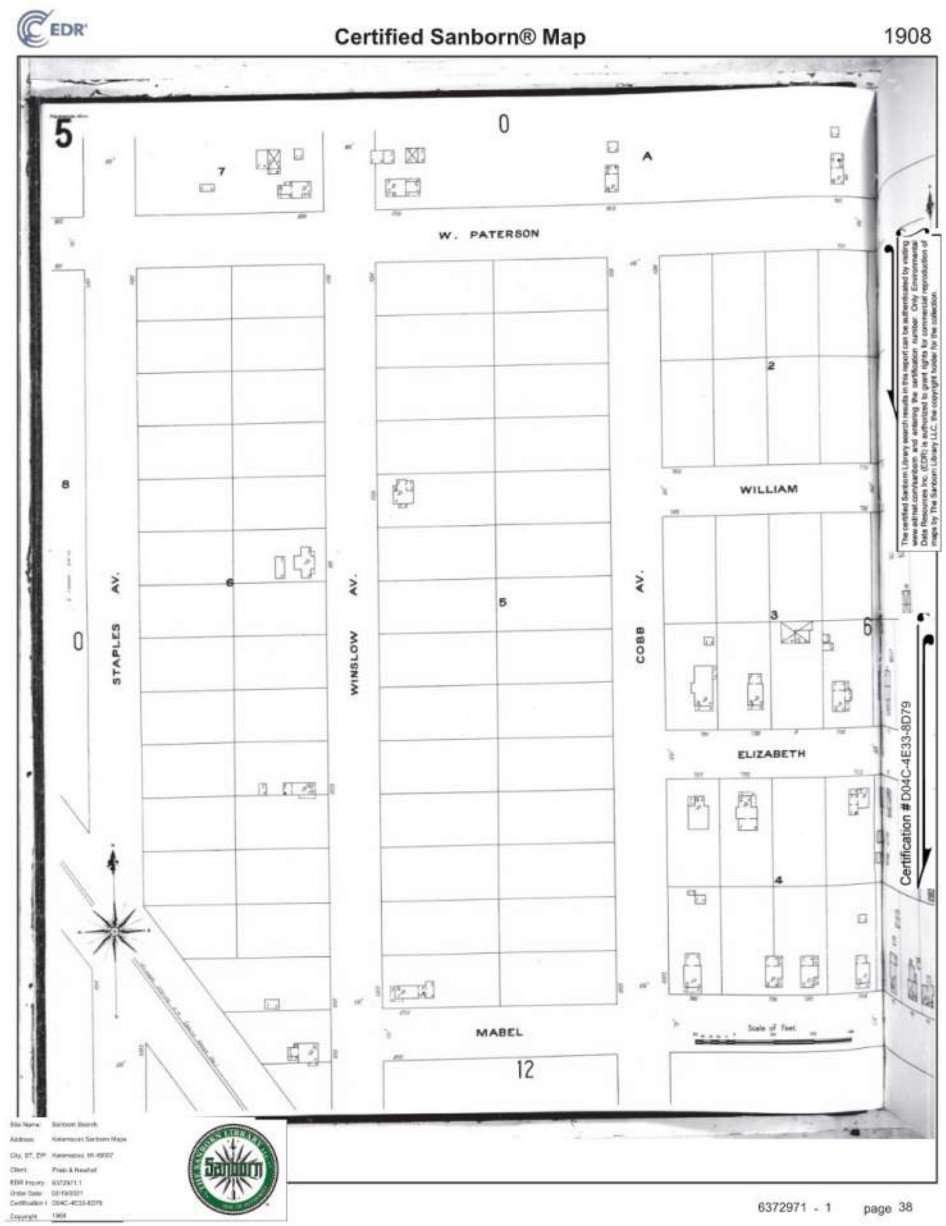


Figure A-3: Example Calibration Graph (Meter 1)



Appendix B – Sanborn Maps

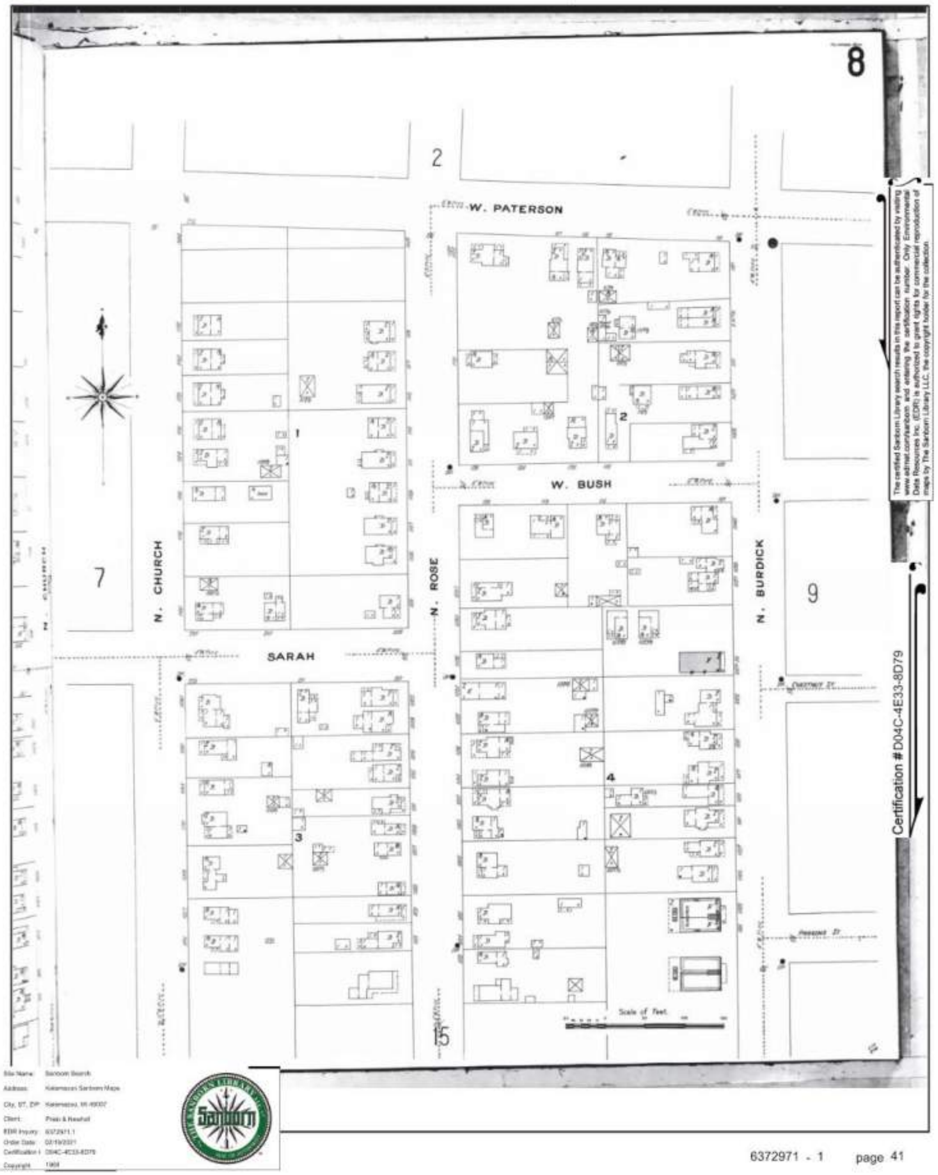
Figure B-1 **Historical Development Comparison**



2021

Certified Sanborn® Map

1908

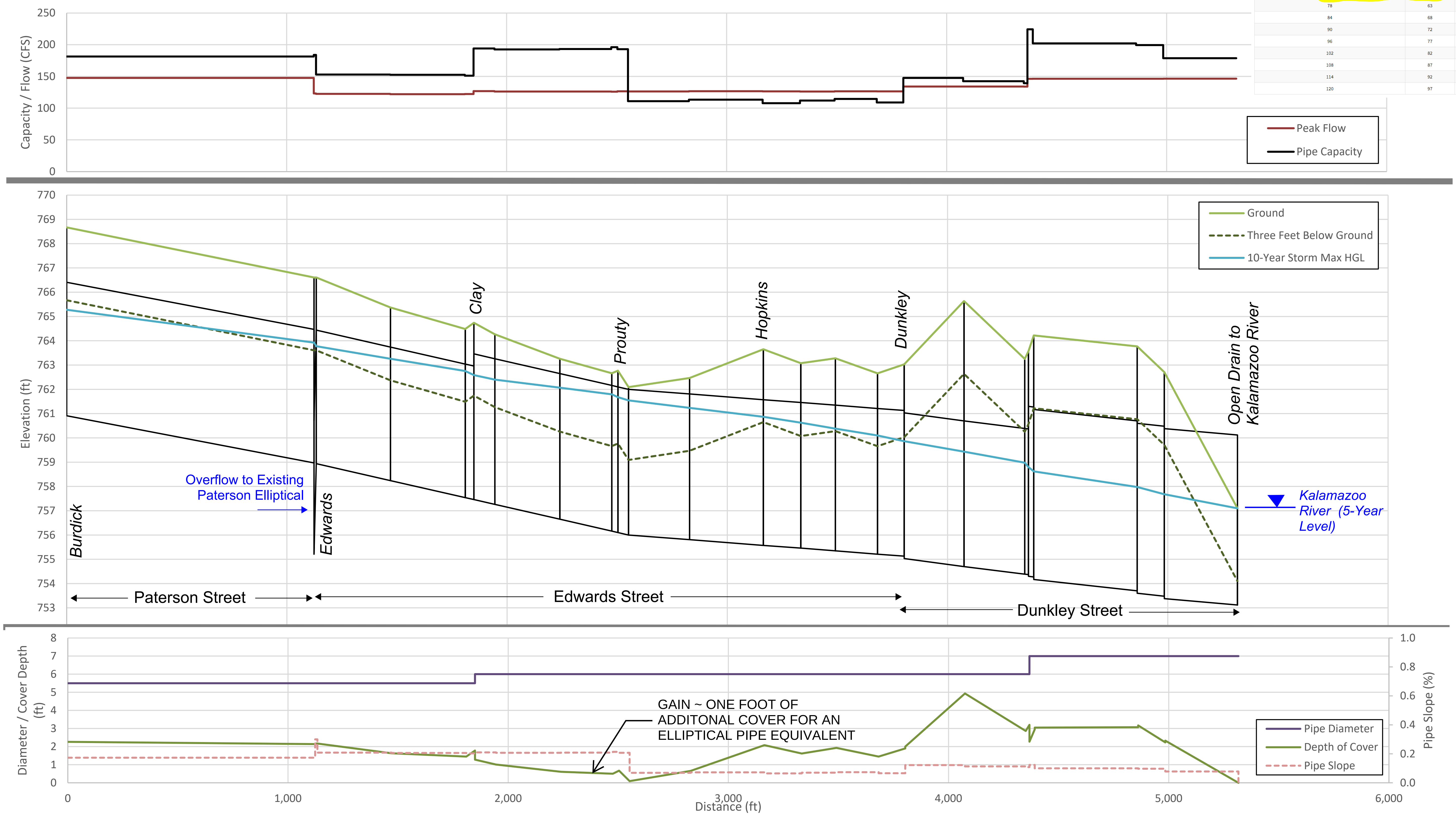


2021

Appendix C – Alternative Feasibility Documentation

Profile 1: Paterson Redirect North to Dunkley Outfall (Alternative 1)

Round Equivalent	Rise	Span
15	12	18
18	14	23
24	19	30
30	24	38
36	29	45
42	34	53
48	38	60
54	43	68
60	48	76
66	53	83
72	58	91
78	63	98
84	68	106
90	72	113
96	77	121
102	82	128
108	87	136
114	92	143
120	97	151



Profile 2: Paterson to Elliptical to Paterson Outfall (Alternative 2)