7.0 Distribution System Water Quality

This chapter describes the results of water quality monitoring for nitrification and compliance assessments for Stage 2 DBPR and LCR. A detailed analysis of distribution system water quality as it pertains to nitrification monitoring and control was conducted based on distribution system water quality data provided by LWS. LWS collects samples for distribution system water quality analysis from nearly 160 monitoring sites located throughout the distribution system. Approximately 120 of the sample locations are for compliance with the Total Coliform Rule (TCR), and another 25 sample locations are for general distribution system water quality monitoring for operational purposes. Additionally, LWS collects samples from a minimum of 50 sites for Lead and Copper Rule (LCR) compliance monitoring and 7 sites for Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) compliance monitoring.

This chapter also provides a summary of distribution system water quality modeling to characterize relationships between water age and degradation of chlorine residual. As part of the distribution system evaluation, alternatives such as implementation of chloramine booster stations and installation of PRVs, were modeled to identify viable solutions for distribution system water quality improvements. Pilot and full-scale testing procedures to evaluate the effectiveness of recommended distribution system water quality improvements are also included herein.

7.1 Disinfection Byproducts

As noted in Chapter 5, LWS must maintain compliance with all regulated disinfection byproducts (DBPs) summarized in Table 7-1. Stage 1 Disinfectant and Disinfection Byproduct Rule (Stage 1 DBPR) defined maximum contaminant limits (MCLs) for total trihalomethanes (TTHM), the five regulated haloacetic acids (HAA5), chlorite and bromate. Subsequently, the Stage 2 DBPR revised compliance with the MCLs for TTHMs and HAA5s to be based on a locational running annual average (LRAA) of individual DBP monitoring sites, whereas compliance with chlorite and bromate MCLs is based on the running annual average (RAA) at the point of entry (POE).

Table 7-1 Maximum Contaminant Levels for Disinfection Byproducts

Disinfection Byproducts	MCL (mg/L)
Total trihalomethanes (TTHM)	0.080
Haloacetic acids (HAA5)	0.060
Chlorite	1.0
Bromate	0.010

7.1.1 Bromate

Since the East Plant includes ozonation, bromate monitoring is required at the South Pump Station POE. As specified under Stage 1 DBPR, the MCL for bromate is 10 µg/L and compliance is monitored based on the RAA of monthly measurements or quarterly measurements for systems on reduced monitoring. Reduced monitoring can be obtained if the raw water bromide RAA is less than 0.05 mg/L or if the bromate RAA is less than 2.5 µg/L at the POE. LWS has been on reduced quarterly monitoring for bromate since the third quarter of Year 2013 based on their ability to maintain a bromate RAA of less than 2.5 µg/L at the POE.

Figure 7-1 provides the individual bromate measurements and associated RAA from November 2014 to August 2018. As demonstrated by the figure, the bromate RAA has consistently been less than or equal to 2.5 µg/L with all individual measurements less than 4 µg/L.

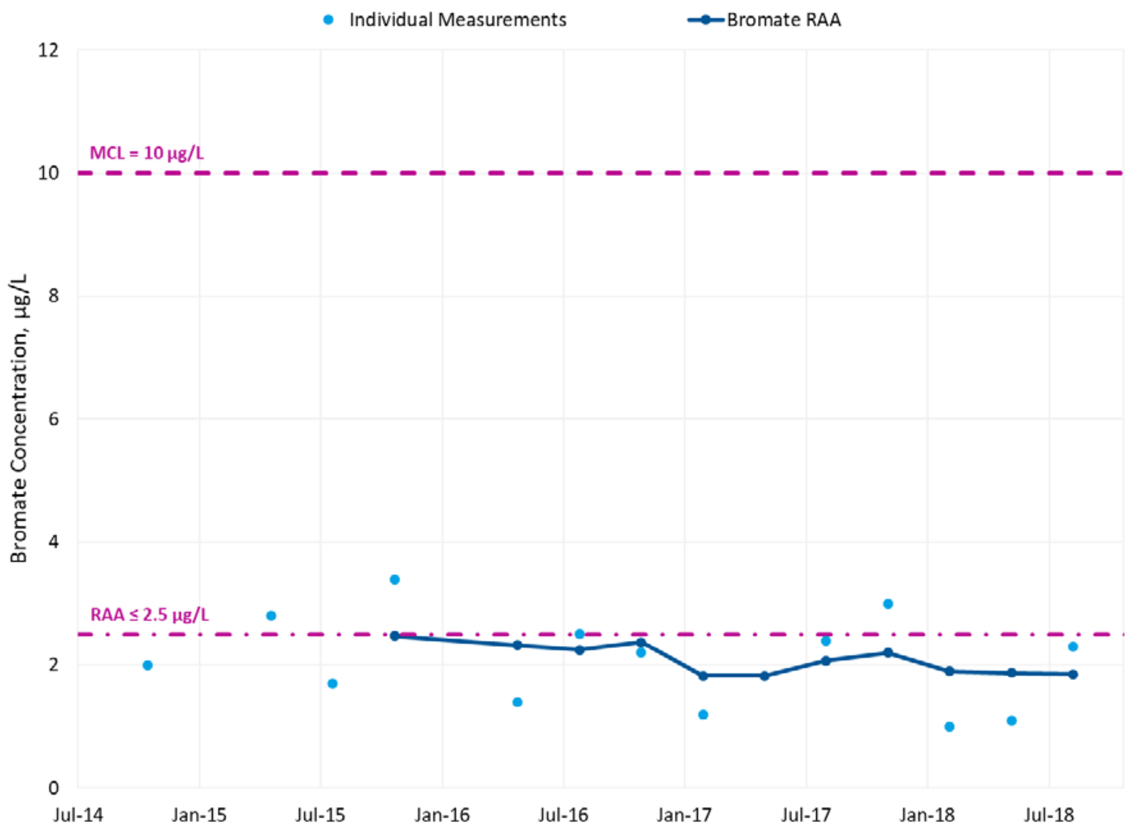

Figure 7-1 Bromate Concentration and RAA at the East Plant Point of Entry from November 2014 to August 2018

7.1.2 TTHMs and HAA5s

Based on the population served, routine monitoring normally consists of quarterly sampling from 12 monitoring sites. However, LWS is on reduced monitoring since TTHMs and HAA5s have been maintained at less than 50 percent of the MCL. Therefore, compliance with the MCL is based on the LRAA of quarterly measurements at the monitoring sites identified as 12-2H, 4-3J, and 7-4J for TTHMs and 11-5B, 9-8B and 9-9D for HAA5s. While separate sites are used for compliance monitoring of TTHMs and HAA5s, LWS collects information on both parameters at each location. Figure 7-2 and Figure 7-3 provide the LRAA from October 2015 to October 2018 for TTHMs and HAA5s, respectively, at all monitoring sites. As demonstrated in Figure 7-2, the LRAA for TTHMs has consistently been less than 40 µg/L (50 percent of the MCL). Similarly, the LRAA for HAA5s has been maintained at less than 20 µg/L (33 percent of the MCL).

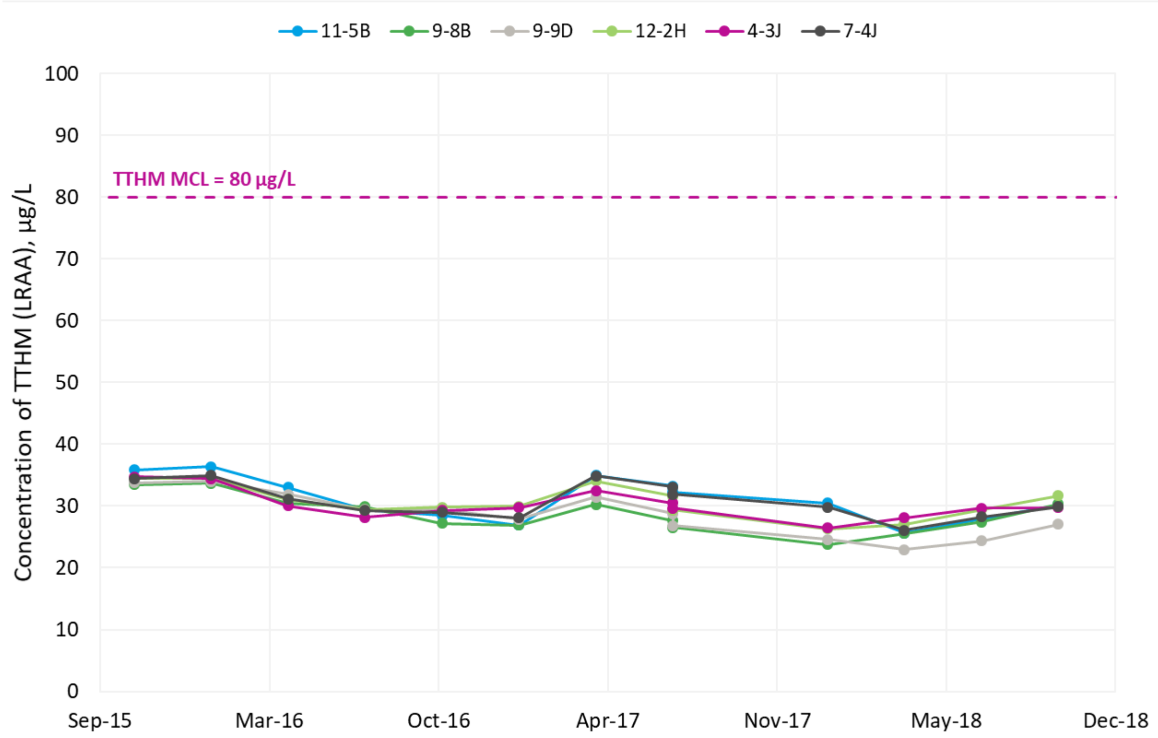

Figure 7-2 **TTHM Locational Running Annual Average from 2015 to 2018**

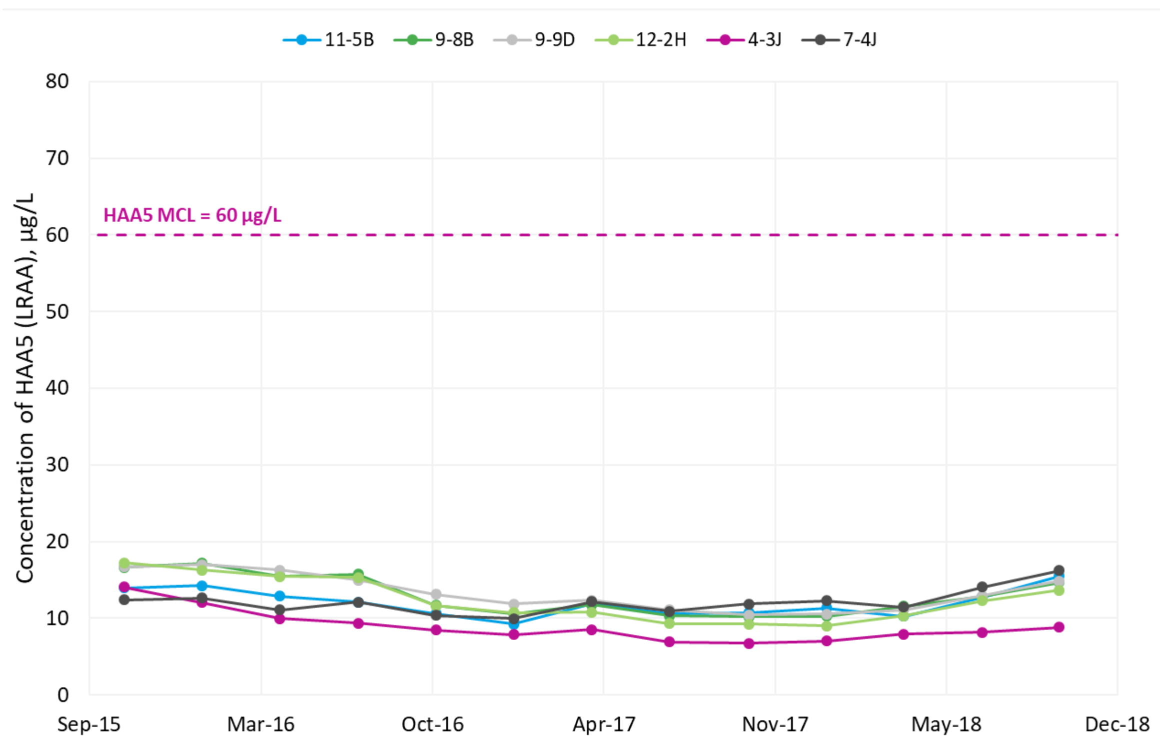

Figure 7-3 **HAA5 Locational Running Annual Average from 2015 to 2018**

7.2 Lead and Copper

7.2.1 LCR Monitoring and Compliance

LWS is currently on reduced monitoring for lead and copper, which requires LWS to monitor for LCR compliance data every three years. LWS's historical LCR compliance monitoring results for lead are shown in Figure 7-4, where the minimum value, 90th percentile compliance value and maximum value are indicated for each monitoring event. The minimum values of lead detected for each LCR monitoring event have been below detection levels and are shown as zero on Figure 7-4. The 90th percentile lead levels have always been below the lead action level of 15 µg/L, which explains how LWS is on reduced monitoring. The maximum detected lead levels have historically been less than the lead action level since 1998, but in 2016 there was a lead level measured at 403 µg/L. Due to the elevated lead level measured during the 2016 sampling event a closer evaluation was conducted for the three most recent sampling events (i.e., 2013, 2016 and 2019).

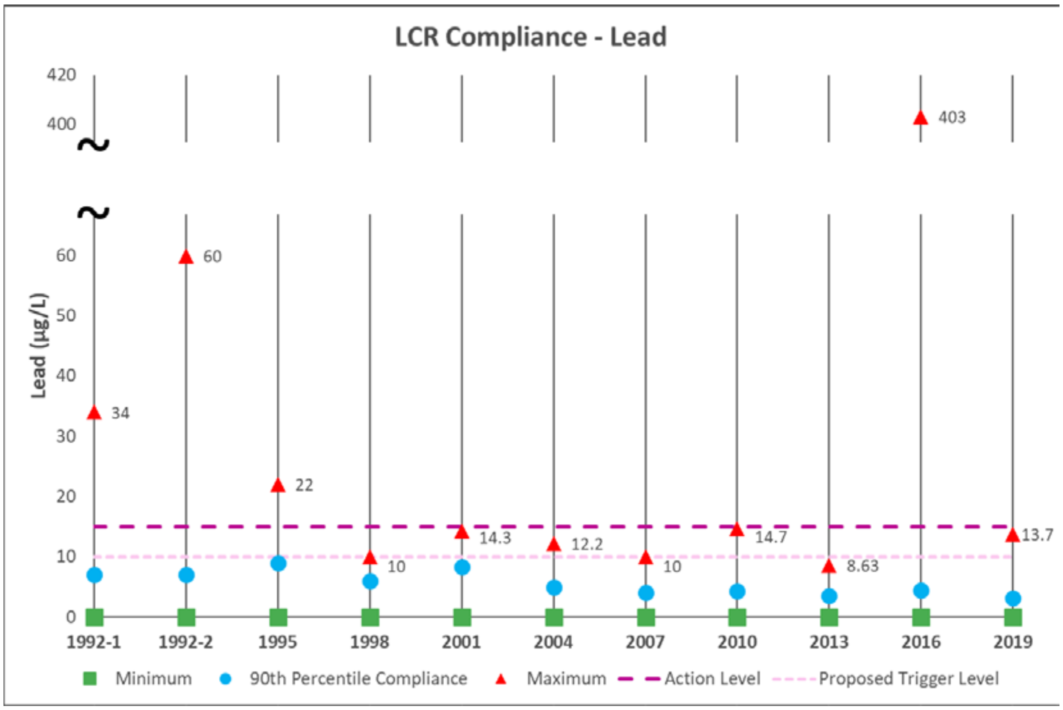

Figure 7-4 Historical LCR Compliance Monitoring for Lead

As noted in Chapter 5, the action levels for lead (15 µg/L Pb) and copper (1,300 µg/L Cu) are based on the 90th percentile ranking of the sample result data set for any particular sampling event. The three most recent lead and copper compliance results are shown in Figure 7-5 and Figure 7-6 respectively. The 90th percentile results for lead and copper have been below the action levels for each of the sampling events in 2013, 2016 and 2019.

During the 2016 sampling event, 2 of the 57 samples had lead concentrations greater than the lead action level, with results of 60.6 µg/L Pb and 403 µg/L Pb. Both locations with elevated lead levels were resampled by LWS and the results were 0.73 µg/L Pb and 55.5 µg/L Pb, respectively. The one location that still showed elevated lead levels was resampled by DHHS and the lead result was 20.2 µg/L Pb. The location with repeat levels of elevated lead during 2016 sampling was a house built in

1903 that has a lead service line, but its LCR result from 2013 only showed 3.5 μg/L Pb and in 2019 the lead result was 5.09 μg/L Pb.

Of the 57 samples analyzed during the 2016 sampling event, 32 were from houses served by lead service lines, and only one of these 32 samples had lead concentrations greater than 7 μg/L Pb. The 2019 LCR results at this location returned to low levels indicating that the spike in lead was a short-term occurrence at one location.

The 90th percentile for both lead and copper increased slightly during the Year 2016 sampling event when compared to the Year 2013 sampling event, but then the results decreased slightly during the Year 2019 sampling event. In terms of compliance with the lead and copper action levels, LWS is still well below the regulatory limits.

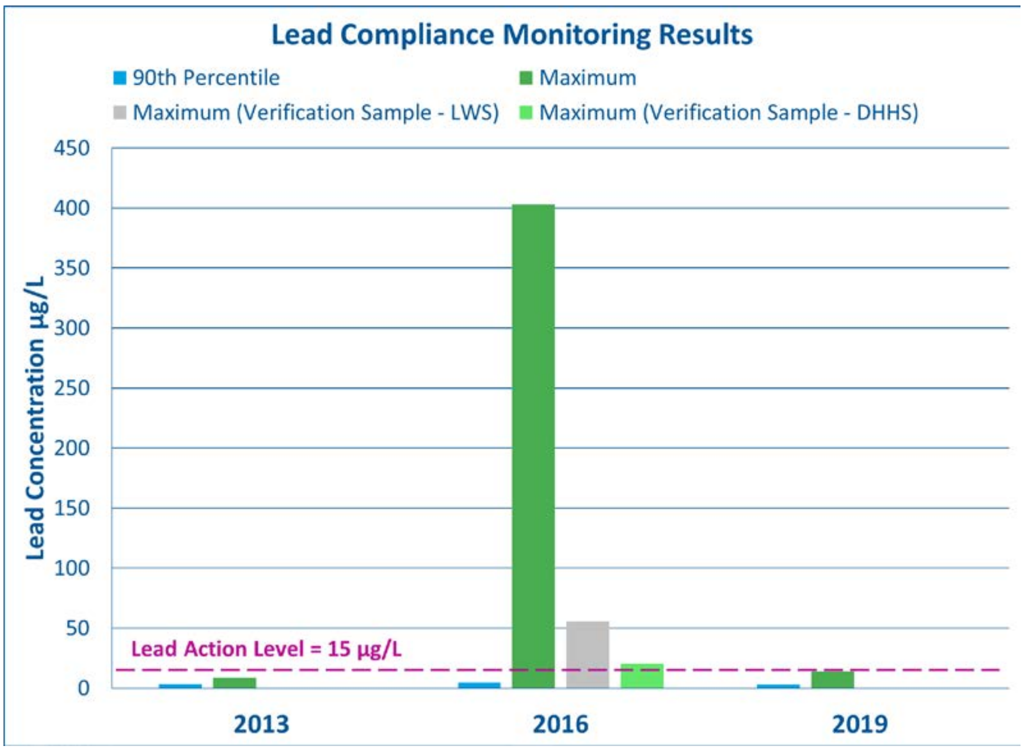

Figure 7-5 Lead LCR Compliance Data for 2013, 2016 and 2019

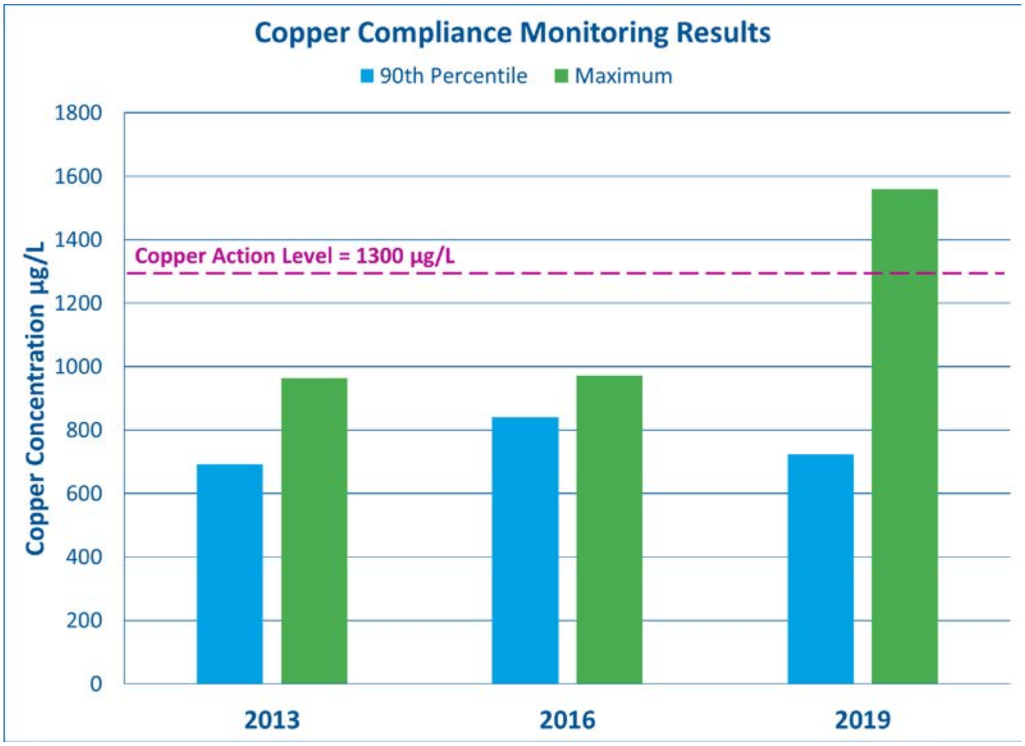

Figure 7-6 Copper LCR Compliance Data for 2013, 2016, and 2019

7.2.2 Lead Service Line Replacement Strategy

When treated drinking water enters the Lincoln distribution system, lead is not detectable. However, the presence of materials containing lead in the private service lines and premise plumbing present the opportunity for leaching of lead. There are two alternatives to limit the potential for lead to leach into drinking water: 1) remove sources of lead and 2) optimize water chemistry and corrosion control treatment to limit the solubility of lead. LWS's compliance monitoring for the Lead and Copper Rule (LCR) indicates that the system is optimized to limit the aggressiveness of the finished water toward pipe materials, as both lead and copper levels are well below respective action levels. However, there are still samples with detectable levels of lead and thus removing lead materials will benefit the finished water quality at customers' taps.

7.2.3 Identifying Lead Service Lines

Most lead pipes were installed prior to 1950. Removing lead materials such as lead service lines (LSLs) or lead goosenecks (pigtails, swings) is a difficult undertaking, as records identifying these materials are rare and difficult to locate. Typically, utilities begin the process of identifying lead pipes by reviewing the following:

- Tap cards from the initial service connection that might include the pipe material or date to confirm if lead was used at that time.
- Historic maintenance records that could explain if a repair was made to a lead pipe or if the lead pipe was removed either as a standalone project or as a result of main repairs.
- Tax records to determine the date when a building or residence was constructed.
- Plumbing permits for when buildings were renovated to determine whether a service line was replaced.

- Historic plumbing codes or ordinances to identify when specific materials were allowed for service lines.
- Discussions with personnel that have worked with the utility for an extended period to learn the typical practice for noting the replacement or repair on an LSL.

It is important to note that galvanized iron pipe downstream of lead materials should be removed when lead pipes/materials are removed as the iron can act like a sponge for dislodged lead particulate. Disturbances from stopping flow, removing lead materials and re-starting the flow of water through the service line can release lead particulate from the iron pipe and create a health risk.

7.2.4 LWS LSL Identification Program

LWS reviewed available information to identify locations with LSLs, galvanized iron service lines, and service lines of unknown material that require further investigation. LWS conducted their LSL identification by searching the following datasets:

- Scanned Water & Sewer Tap Record Image Files located on LWS's Website.
- Extracted Hansen CMMS Service Line Asset Data.
- GIS feature classes for Mains and Service Lines.
- Historical Records spreadsheets in EXCEL that include records of all Water Replacement Projects since 1975.

After reviewing the records, the data was sorted to identify potential LSLs based on the following criteria:

- Date of installation (e.g. before 1950 or blank).
- Service line pipe diameter (e.g. greater than ½-inch or blank).
- Service line status (e.g. active service line, not expired, or blank).

The compilation of these records identified approximately 4,000 potential service lines for replacement based on the review completed in October 27, 2016 as shown in Figure 7-7.

LWS's records focus on the service line material from the main to the stop box. There is a potential that the portion of the service line from the stop box to the premise plumbing could be a different material. As such, LWS is now incorporating an additional field to their dataset to try and categorize the service line material for this portion of pipe. Once the inventory is completed, the next step is to develop a plan to verify the records and begin the process of removing LSLs and downstream galvanized iron pipe, where applicable. It should be noted that in Lincoln, NE, the customer owns the entire service line from the water main to the connection with interior plumbing, as indicated in Figure 7-8.

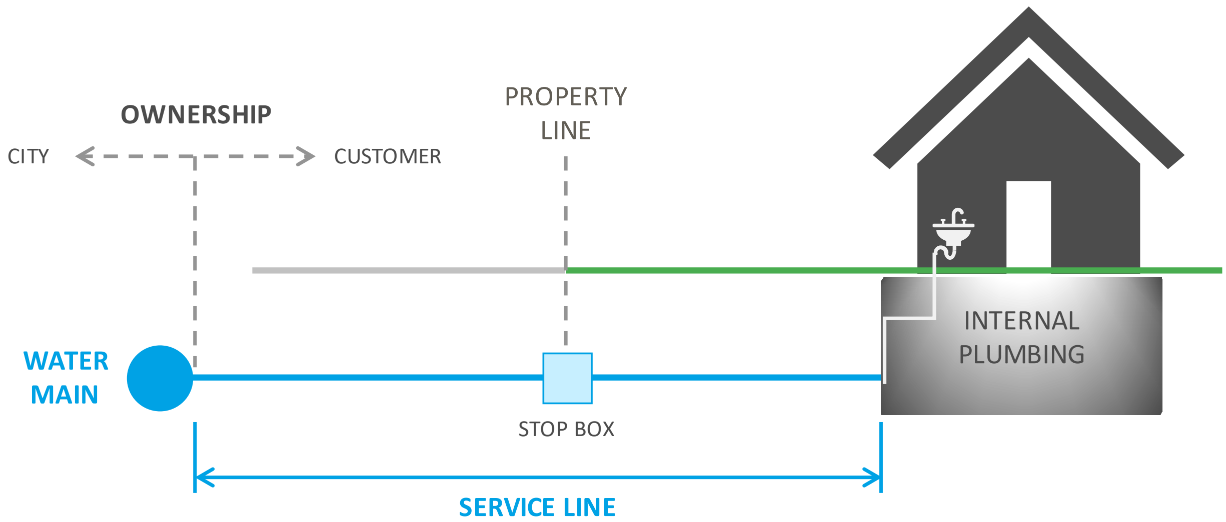

Figure 7-7 Diagram of LWS Service Line Connection to a Residence

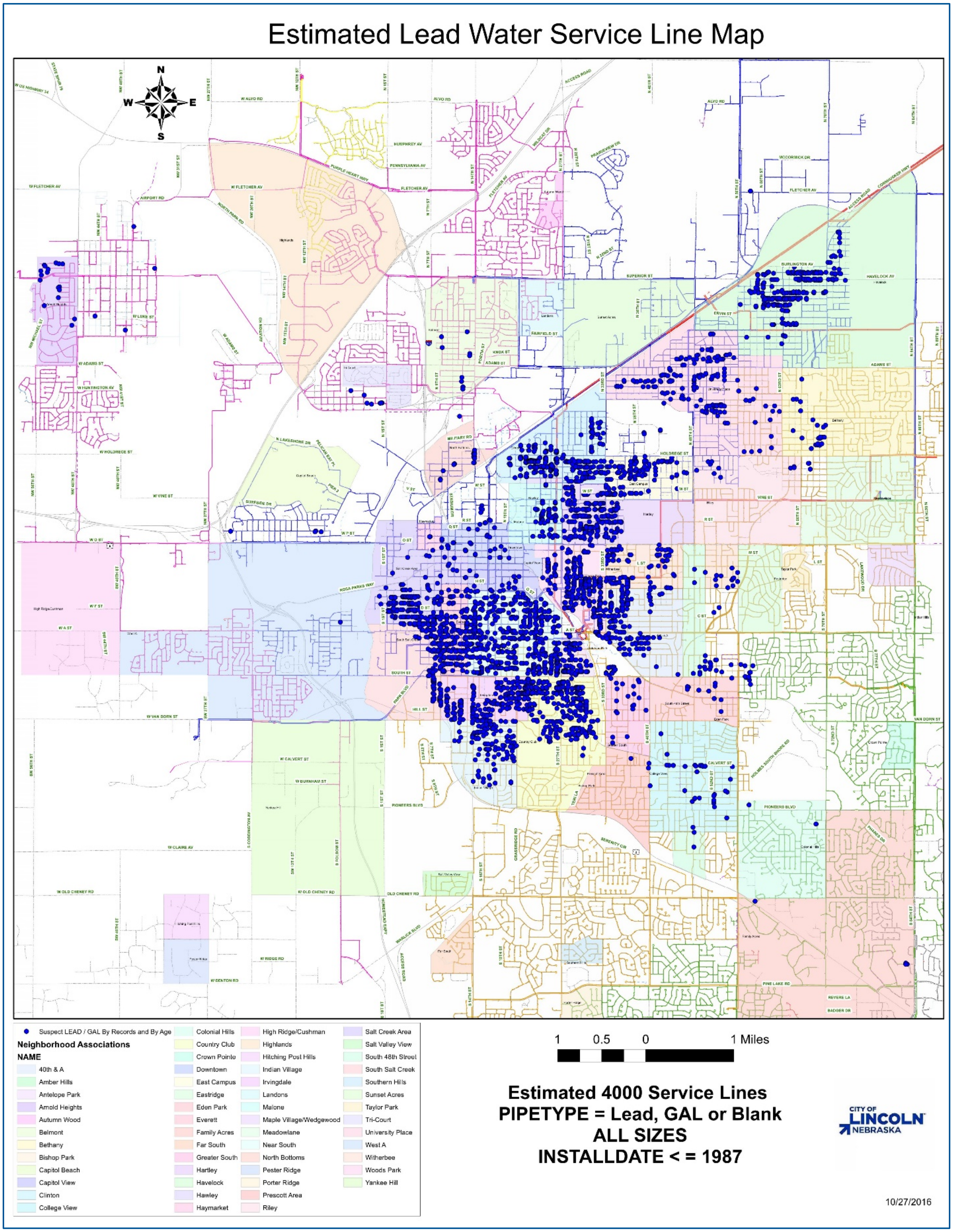

Figure 7-8 Estimated LSLs or Galvanized Iron Service Lines in Lincoln's Distribution System (10/27/2016)

7.2.5 Proposed Lead and Copper Rule Revisions

On October 10, 2019, the United States Environmental Protection Agency (USEPA) released proposed Lead and Copper Rule (LCR) Revisions that were published in the federal register on November 13, 2019. Major changes in the proposed LCR include:

- Implementation of publicly available LSL inventory.
- Proactive LSL replacement program.
- Requirement for full LSL replacement, as opposed to partial LSL replacement.
- Public outreach and educational programs.

The proposed LCR revisions include a requirement for public water systems (PWSs) to develop a publicly available LSL inventory. LWS had already begun this process prior to the release of proposed regulations and is well positioned to meet or exceed any proposed timelines established for LSL inventory development and replacement plans. The proposed LCR revisions detailed a proactive full LSL replacement program, regardless of whether the AL has been exceeded. The proposed LCR revisions also require utilities to focus on public education and engage with customers on LSL replacement plans. A distinction was made between full and partial LSL replacements, as research has shown that a partial replacement can increase the release of lead due to the disturbance of particulate lead during partial replacement activities. Full lead service line replacement includes replacing any lead pipe or downstream galvanized iron pipe between the water main and the connection to the interior plumbing of a residence or building as shown in Figure 7-7.

One uncertainty surrounding the requirement for full LSL replacement is the cost of replacement for customer-owned service lines. Subsequent sections describe funding strategies available for LSL replacement and case studies of funding options that other PWSs have utilized.

7.2.6 Funding for LSL Replacements

The State of Michigan revised its LCR in 2018, which requires PWSs to locate and remove LSLs, including the portion owned by the homeowner at the PWS's cost. The USEPA's proposed LCR revisions do not require that the PWS pay for the replacement of the LSL portion owned by the homeowner. Since the LSLs in Lincoln, NE are completely owned by the customer, LWS will have to determine if the cost of the full LSL replacement is paid by the customer, subsidized by LWS or fully paid by LWS. These funding considerations are important and there are several federally available funding programs to assist PWSs with LSL replacement programs.

The following funding options are available for LSL replacement projects:

- USEPA's Drinking Water State Revolving Fund (DWSRF) – the DWSRF has provided $1.126 billion for infrastructure improvement projects including LSL replacements in the 2019 fiscal year.
- Clean Water State Revolving Fund (CWSRF) – states have the option of transferring funds from their CWSRF to their DWSRF to address lead-related projects through October 4, 2020. The State of Nebraska might have available funding sources, which could be transferred to DWSRF for LSL replacement projects.
- Community Development Block Grant (CDBG) – the US Department of Housing and Urban Development developed the CDBG to provide communities with resources to address a wide range of projects including LSL replacement programs.

- USEPA's Water Infrastructure Improvements for the Nation (WIIN) Act – this act provides federal funding to address LSL replacement projects.
- Water Infrastructure Finance and Innovation Act (WIFIA) – utilities can pursue a low interest rate federal loan through the WIFIA program administered by the USEPA. WIFIA loans provide funding for water infrastructure related projects and improvements.

With the proposed LCR revisions focusing on identifying the sources of lead and removing them from the distribution system, it is anticipated that more federally-available funds will be allocated for LSL replacement projects when the final rule is promulgated. It is anticipated that the final LCR revisions will be published in 2020 and that the rule will allow PWSs to develop their distribution system material inventories and LSL replacement programs over a three-year period. All these steps are expected to take a few years to implement, which would provide Federal and State governments the opportunity to set aside more funding to assist with LSL replacement projects.

7.2.7 Examples of LSL Replacement Programs

Some PWSs have proactively started to replace LSLs and pay or provide financing options for the replacement on the homeowner's side to ensure that all parts of the community receive the highest quality water regardless of economic status. Below are a few examples of approaches that PWSs have taken to address LSL replacement programs and funding options for customers:

- Milwaukee Water Works began a program in 2017 to remove LSLs and they developed a special financing option to help the homeowner's pay for their portion of the LSL over 10 years.
- Philadelphia Water created a Homeowner's Emergency Loan Program (HELP) to provide customers a zero-interest loan to be paid back over a 60-month period.
- The City of Madison Wisconsin chose to replace LSLs rather than change chemical treatment that would have dramatically increased capital and operating costs, and now the City is reimbursing customers a portion of what they paid to replace their portion of the LSLs.
- The Boston Water and Sewer Commission created an incentive program to offer its customers a credit of up to $2,000 to allow the utility to replace the full LSL at one time, and the customer can finance the remainder of the cost interest free over 48 months.

7.2.8 LSL Replacement Plan Development

The development of an LSL replacement plan with the appropriate prioritization is key to limiting disturbances to the infrastructure, minimizing inconveniences for the community and maximizing the funds available.

Replacing an LSL involves coordination between the utility, the homeowner, potentially the current tenant if the residence is a rental property, and the contractor who will be replacing the LSL. When designing an LSL replacement plan LWS should coordinate with the department of transportation and City officials to overlap activities so that when a road is being repaired or replaced that any lead service lines can be replaced while already under construction to limit the disturbances to pipes, roads, and homeowner's property. Prioritization of LSL replacements should be based on a combination of both the health risk for vulnerable populations and the cost-effectiveness of replacement.

If there are no main replacement projects or street improvement projects scheduled in areas with LSLs, then prioritization should be given to areas with vulnerable populations such as the following:

- Registered childcare facilities or areas with high populations of children.
- Areas with longer water age or lower disinfectant residuals.
- Older areas with a higher likelihood of premise plumbing containing lead pipe, copper pipe with lead solder, galvanized pipe, or older brass fittings and fixtures with higher levels of lead.
- LCR monitoring locations with elevated levels of lead (i.e., “find-and-fix” description in the proposed LCR).

The proposed LCR describes that a PWS would be required to replace the water system-owned portion of the LSL within 45 days if the homeowner chooses to replace their portion of the LSL. It would be beneficial for the customer to have the entire LSL replaced at one time to avoid a partial LSL replacement. LWS could develop a list of customers that would like to pay to replace their portion of the LSL and coordinate with contractors to limit the effort and have the entire LSL replaced at one time. The LSL replacement program should take into consideration that lower income households may not have financial ability to take part in full LSL replacement. The program needs to account for all considerations and design a plan that will help the funds to go the furthest by combining LSL replacements with other infrastructure improvement projects while also focusing on areas with vulnerable populations.

7.2.9 LSL Replacement Activities

Prior to conducting an LSL replacement, the contractors must be trained to understand the importance of delicately removing lead or galvanized piping to avoid pipe scale disturbance that could dislodge metal particulate. The contractors should also be provided with door hangers or flyers with information about lead risks and the LSL replacement program with contact numbers so that the contractors are not acting as the spokesperson for LWS if the homeowners have questions, comments, or complaints.

After an LSL is replaced, there are additional steps to ensure that a customer’s water quality is not compromised (LSLR Collaborative, 2019). These steps involve whole house flushing. LWS will need to determine if the contractors replacing the LSLs will be responsible for this task or if there will be a separate crew dedicated to whole house flushing. Whole house flushing is critical to remove particulate that enters a customer’s home after the new service line is installed and the water service is turned back on. The flushing process involves removing aerators from faucets throughout the house to allow the particulate to pass though the lines. A water heater, water softener, or filtration device (either for the entire house or at specific faucets) should be bypassed during the flush so that metal particulate does not collect in these devices.

The flushing begins by fully opening the hose bib (typically on the outside of the house or in the basement at the point of connection) and allowing water to flow continuously throughout the flush. Then the faucets throughout the house are opened one by one starting on the lowest level (i.e., basement if available) and then moving up a level until all the faucets with a drain are open. This flushing involves turning on faucets in laundry rooms, bathtubs, showers, sinks, etc. Once all the faucets are open, they are left on for 30 minutes to allow any released particulate to find its way out of the premise plumbing. The faucets are closed in the opposite order that they were turned on, meaning that the top floor faucets are turned off first. Additional water quality sampling should be collected to quantify the concentration of metals. If lead levels are elevated, then additional flushing might be necessary along with follow up monitoring. Filters and extra filter cartridges should be supplied when elevated levels of lead are detected after the removal of an LSL and could be used as a standard practice with three months of replacement filters for all LSL replacements.

7.3 Nitrification Water Quality Monitoring

7.3.1 TCR Monitoring Sites

The TCR monitoring sites are a set of approximately 120 locations, which are sampled every two to four weeks for the following water quality parameters:

- Total chlorine residual.
- Monochloramine residual.
- Free ammonia.
- Total coliform and e-coli.
- Nitrite.

7.3.2 Distribution Monitoring Sites

The distribution monitoring sites include 25 locations, which are sampled once a month for the following water quality parameters:

- pH and temperature.
- Total chlorine residual.
- Nitrite.
- Nitrate.
- Total coliform and e-coli.
- Heterotrophic plate counts.
- Conductivity / total dissolved solids.
- Fluoride.
- Turbidity.
- TOC.
- Iron and manganese.
- Hardness and alkalinity
- Metals analysis (ICP-MS)
- Phosphate

In February 2019, LWS added alkalinity and hardness to the water quality monitoring conducted at the distribution monitoring sites. In September 2019, additional monitoring of free and total ammonia was incorporated at the distribution monitoring sites.

7.3.3 Distribution Water Quality Monitoring Map

Figure 7-9 provides a map of all the distribution system water quality monitoring sites. All of the water quality monitoring sites are designated with alphanumeric codes, where the TCR monitoring sites lead with a number (e.g. 7-6E), and the distribution monitoring sites lead with a letter (e.g. D7). Additional monitoring is conducted at the pump stations, which are labeled according to location (e.g. Belmont).

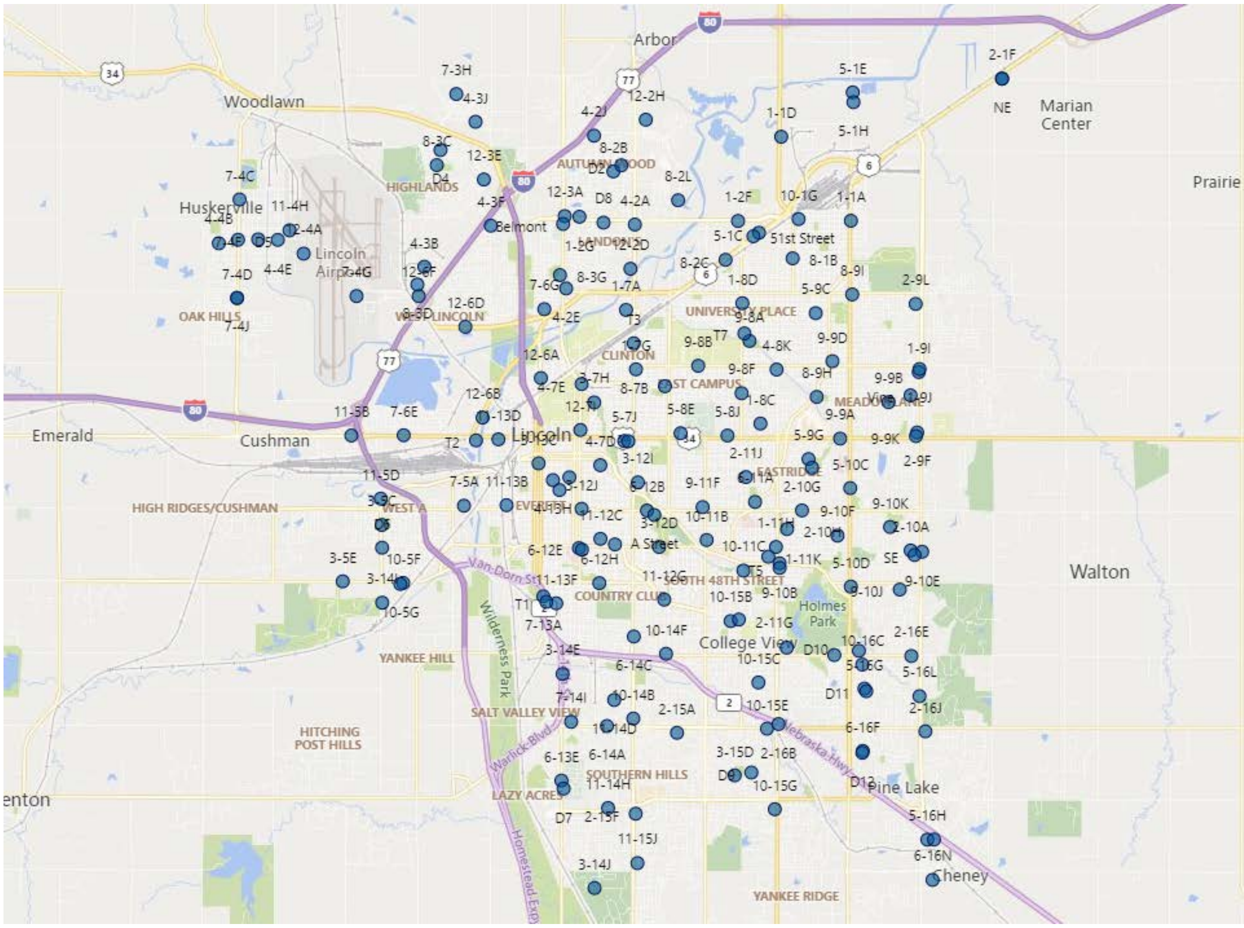

Figure 7-9 Map of Distribution System Water Quality Monitoring Sites

7.4 Nitrification Overview

Nitrification in the distribution system is typically caused by two bacteria groups: ammonia oxidizing bacteria (AOBs) and nitrite oxidizing bacteria (NOBs). AOBs consist of *Nitrosomonas* bacteria, which utilize ammonia (NH_3) as a substrate, converting the NH_3 to nitrite (NO_2). As the total chlorine residual decays, free ammonia becomes available to microorganisms in the distribution system allowing for this process to occur. Similarly, NOBs consist of *Nitrospina* and *Nitrobacter*, which utilize nitrite as a substrate to produce nitrate (NO_3). The rate of nitrification can slow down if either substrate or product concentration becomes too high or too low.

American Water Works Research Foundation (AwwaRF) Report No. 900669 – Nitrification Occurrence and Control in Chloraminated Water Systems identifies significant levels of nitrification as occurring when an increase in nitrite concentration of 50 µg/L or greater is observed. However, initial signs of nitrification may be observed earlier due to loss of total chlorine residual and smaller incremental changes in nitrite (i.e. increase in nitrite of 20 µg/L).

Other conditions, such as temperature, pH and disinfectant residual, can impact the extent to which nitrification may occur. Nitrification is more prevalent when water temperature ranges from 25°C to 30°C but can occur at temperatures as low as 15°C. Additionally, total chlorine residuals of less than 1.5 mg/L can support the growth of nitrifying bacteria, so maintaining a chlorine residual in the range of 2.5 mg/L or higher is generally recommended for controlling nitrification. Additionally, most bacteria groups are sensitive to high or low pH conditions. Previous studies have observed that high pH conditions generally deter biological growth.

Nitrification is typically characterized by:

- Reduction in total chlorine residual
- Decrease in free/total ammonia
- Increase in nitrite and/or nitrate
- Increase in HPCs

Indicators of nitrification may also include reduction in alkalinity, dissolved oxygen and pH.

7.5 Nitrification Occurrence

Distribution system water quality data collected from 2014 through 2018 demonstrates a consistent pattern of chlorine residual decay with corresponding increases in nitrite concentration occurring between August and December of each year. This timeframe overlaps with relatively warm water temperatures of 20°C to 25°C in water supplied by horizontal collector wells and 18°C to 23°C in water supplied by the vertical wells. With water demands dropping in late summer/early fall, the increased water age in the distribution system and elevated water temperatures provide an environment conducive for bacterial regrowth and nitrification. As climate change continues to impact ambient air temperatures, it can be expected that over time, the water temperature will rise as well, likely at a slower rate and lag relative to the rise in ambient air temperature creating more challenging conditions for nitrification control.

Figure 7-11 shows the total chlorine residual in the East and West WTP finished water, Belmont Pump Station, D2 and D5 monitoring sites located within the Belmont Service Level from January 2015 to January 2019. The figure demonstrates a trend of chlorine residual decay between the months of August and December, which is highlighted by the gray bands. Figure 7-10 identifies the D2, D5 and Belmont monitoring sites on a map for context.

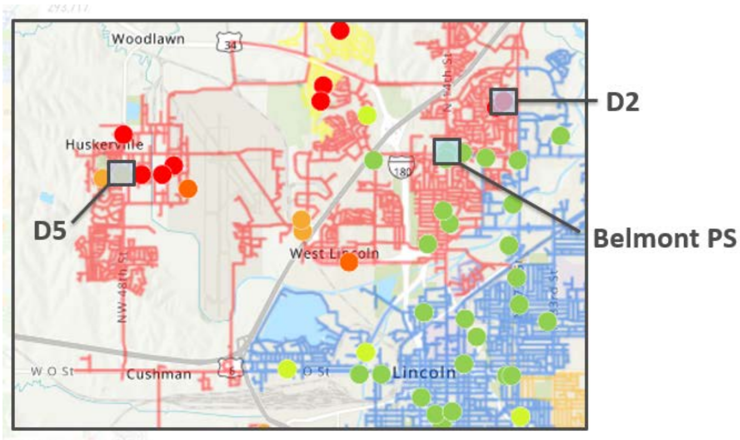

Figure 7-10 Locations of D2, D5 and Belmont Water Quality Monitoring Sites

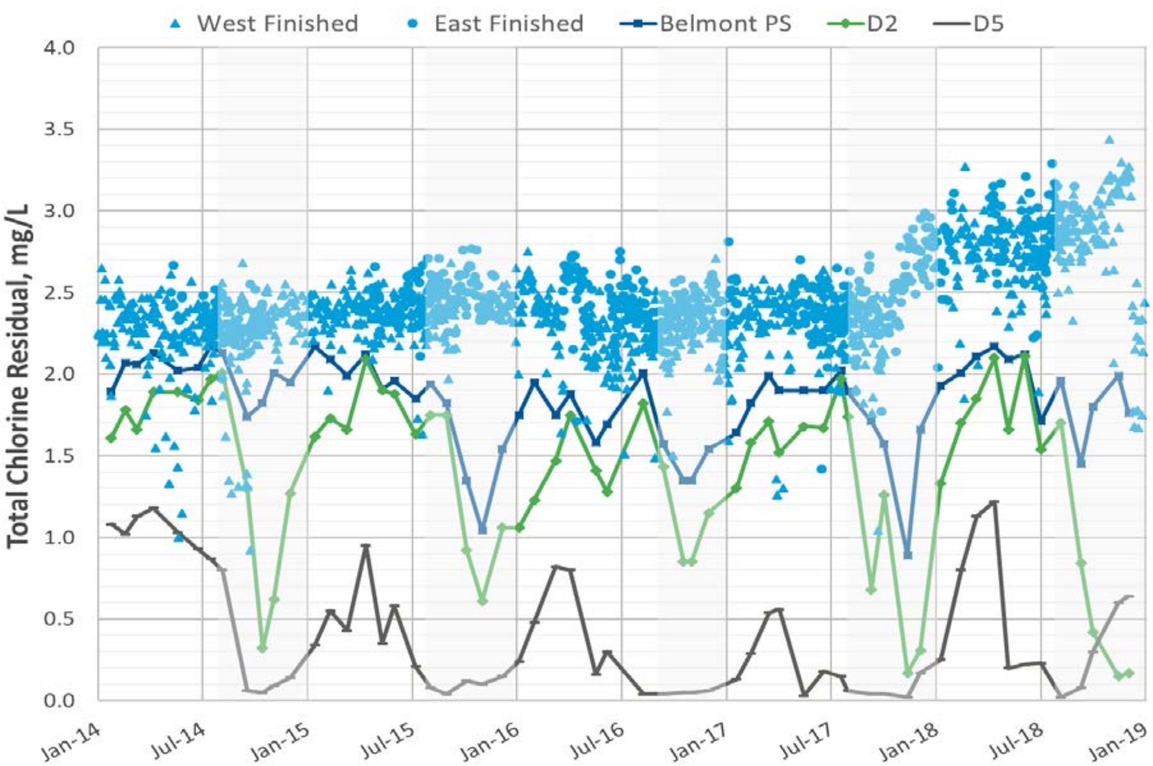

Figure 7-11 Total Chlorine Residual at Distribution System Monitoring Sites in the Belmont Service Level from January 2014 to January 2019

Figure 7-12 shows the resulting increase in nitrite concentration at the same monitoring sites, as excess ammonia from chloramine residual decay is converted into nitrite by AOBs. While major spikes in nitrite concentration typically occur between September and January, increases in the nitrite concentration exceed 50 µg/L at the D2 monitoring site nearly year-round.

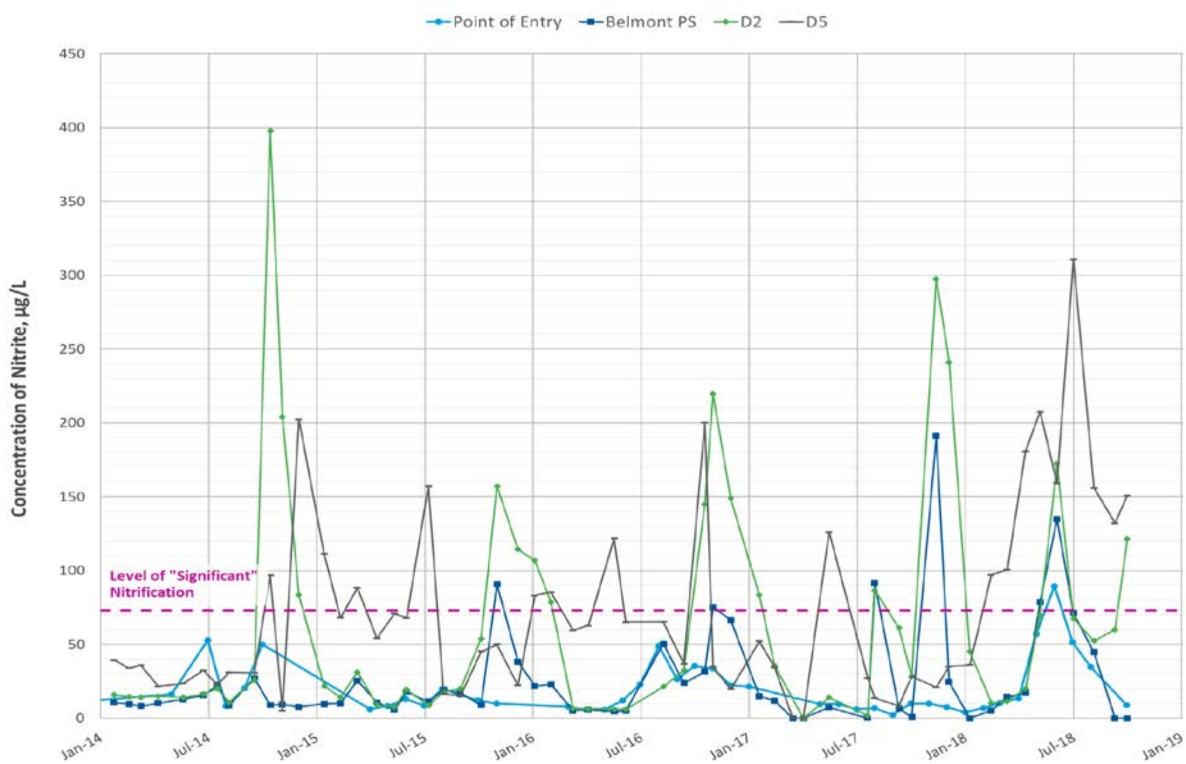

Figure 7-12 Nitrite Concentration at Distribution System Monitoring Sites in the Belmont Service Level from January 2014 to January 2019

The impacts of nitrification have historically been more significant in areas with high water age, such as Air Park, Northwest, Cheney, and Pioneers. Figure 7-13 and Figure 7-14 provide heat maps of the average monthly chlorine residuals monitored throughout the distribution system from April to November of 2016 and 2017, respectively.

From 2014 to 2017, the total chlorine residual leaving the WTP was maintained at approximately 2.5 mg/L as Cl_2. However, the chlorine residual tends to degrade as water moves south and west across the distribution system. From February to July, the total chlorine residual in most of the Low and High Service Levels remained above 1.5 mg/L as Cl_2. However, during the peak nitrification season between September and December, chlorine residuals dropped to less than 0.25 mg/L as Cl_2 in 20 percent of the distribution system monitoring sites in 2016 and 26 percent of the distribution system monitoring sites in 2017. Nitrification was at its peak in November 2017, with chlorine residuals of less than 0.25 mg/L as Cl_2 in as much as 36.7 percent of the distribution system monitoring sites.

As noted previously, it is desirable to maintain chlorine residuals greater than 2.5 mg/L as Cl_2 since values less than 1.5 mg/L can support the growth of nitrifying bacteria. Between the months of September and December 2017, the total chlorine residual was greater 1.5 mg/L as Cl_2 in only 18 percent of the distribution system monitoring sites.

While the impacts of nitrification are more significant between the months of September and December, the Belmont, Northwest, and Cheney Service Levels experience significant degradation of chlorine residual year-round due to the long water age and relatively low demands. Specifically, in Air Park, Industrial Zone and the immediately surrounding areas, the total chlorine residual is typically below 0.5 mg/L as Cl_2 year-round, and during the nitrification season the chlorine residual is less than 0.25 mg/L as Cl_2.

Figure 7-15 and Figure 7-16 provide heat maps of the average monthly total chlorine between the peak nitrification seasons from September to December in 2016 and 2017, respectively. Figure 7-17 and Figure 7-18 provide heat maps for nitrite and HPCs over the same timeframe in 2017.

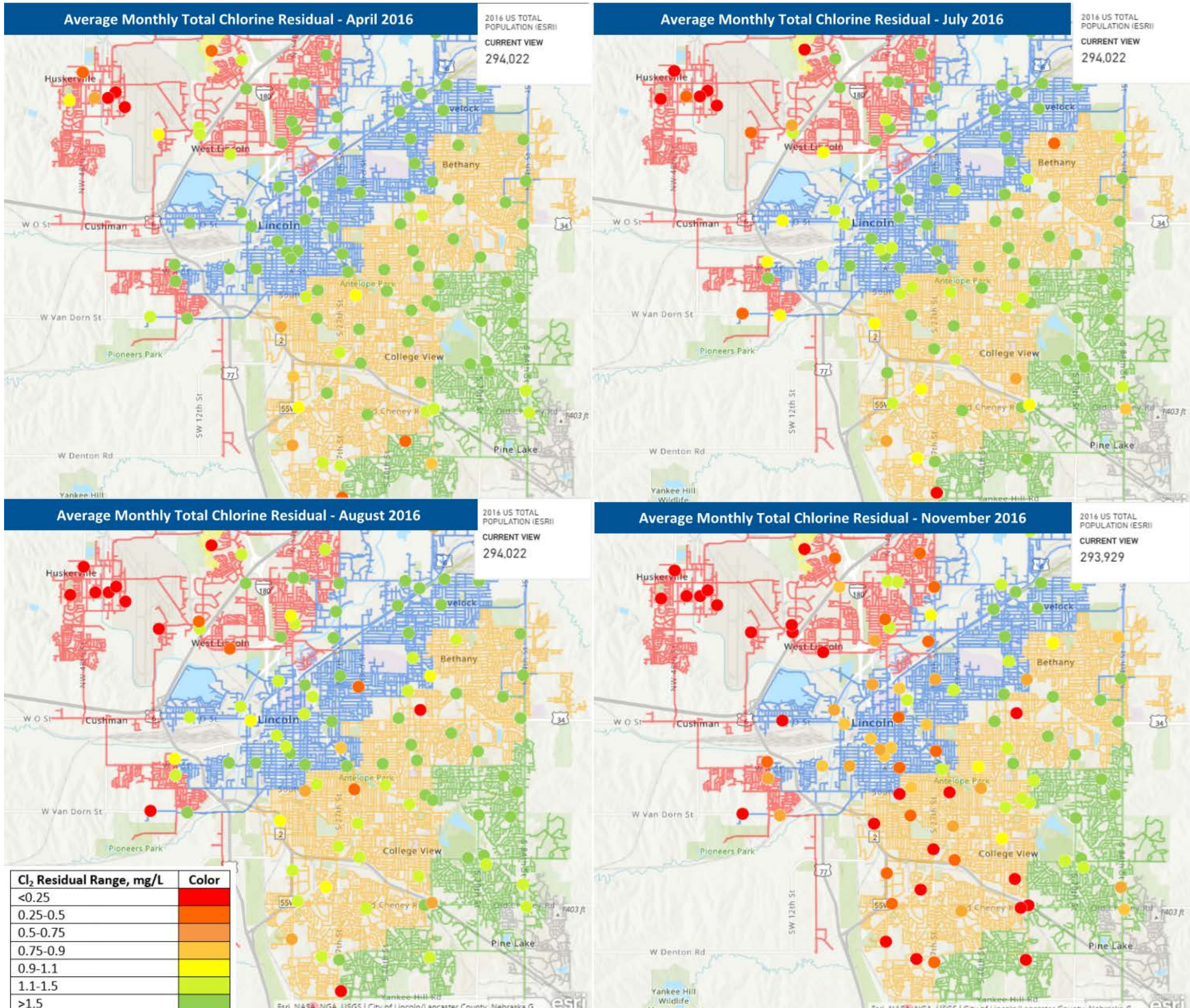

Figure 7-13 Total Chlorine Residual Heat Map from April to November 2016

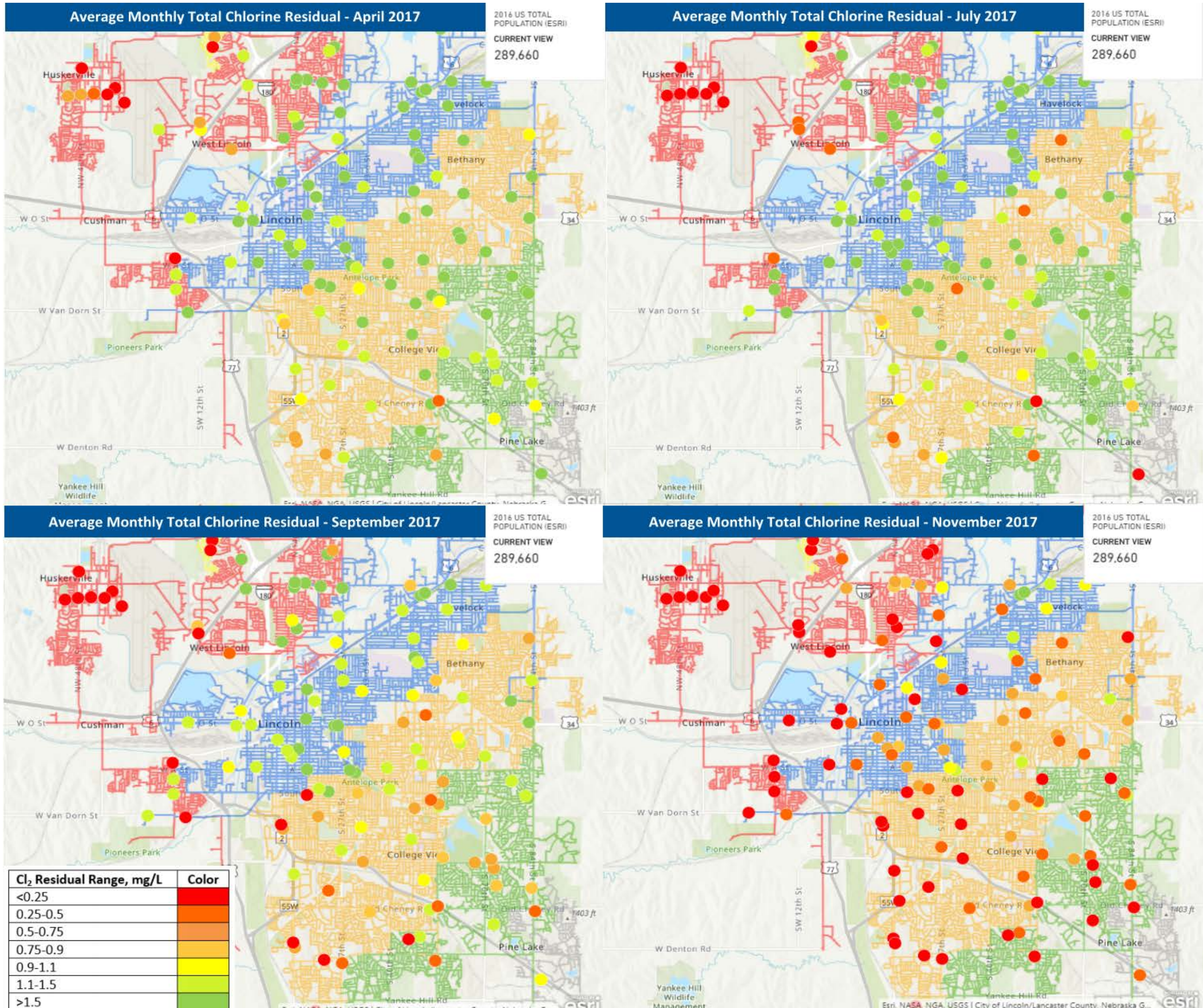

Figure 7-14 **Total Chlorine Residual Heat Map from April to November 2017**

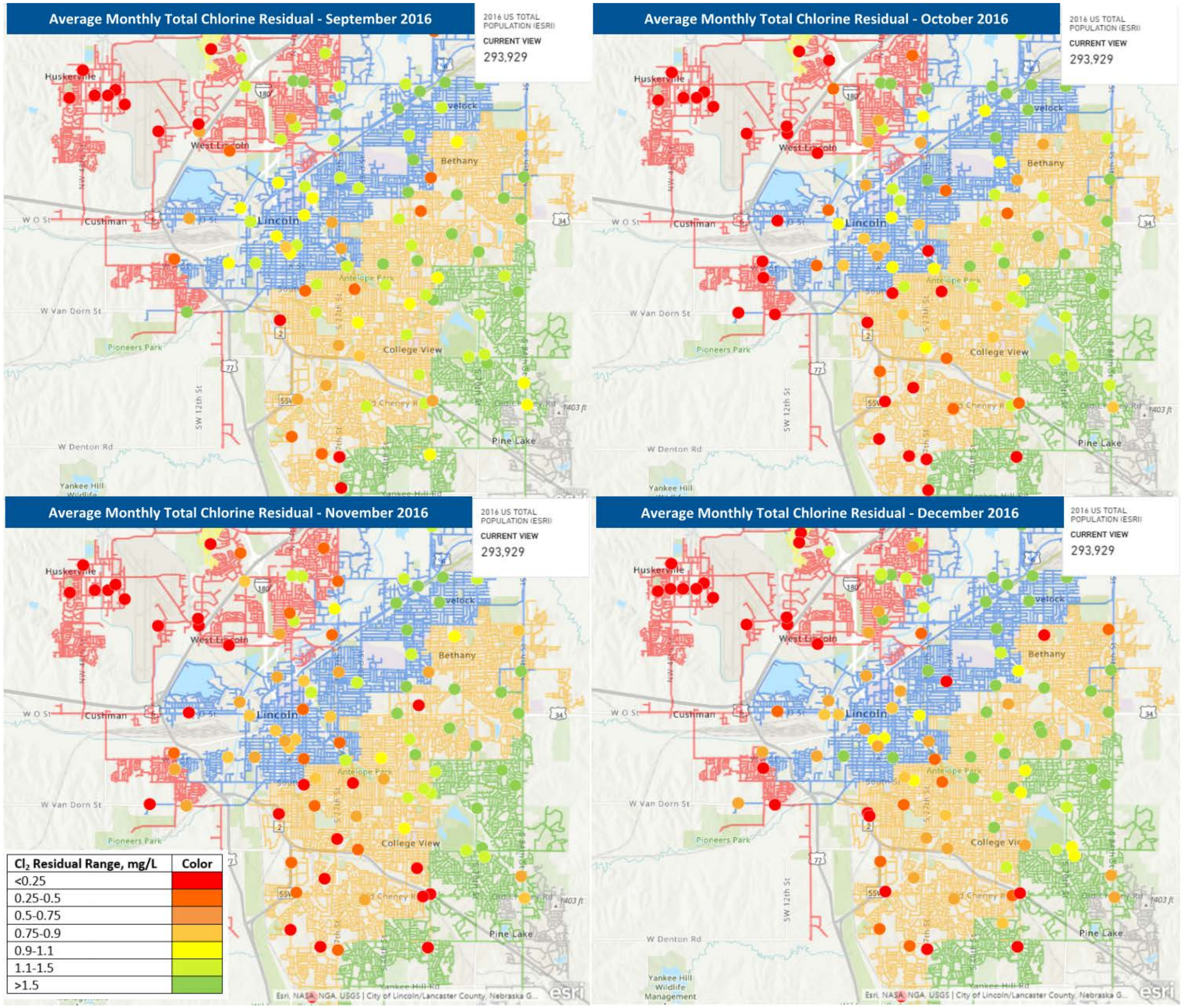

Figure 7-15 **Total Chlorine Residual Heat Map During Peak Nitrification Season from September to December 2016**

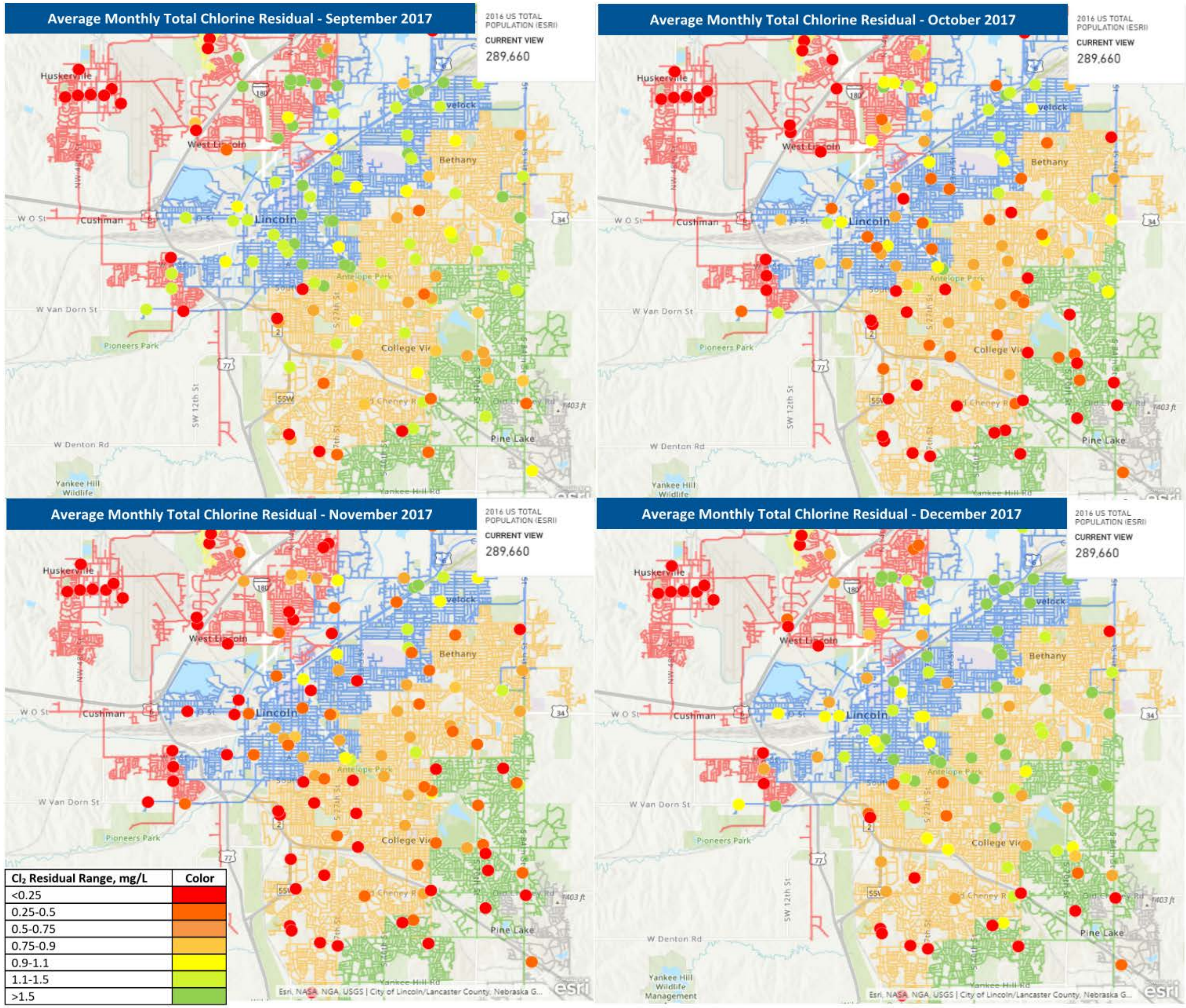

Figure 7-16 Total Chlorine Residual Heat Map During Peak Nitrification Season from September to December 2017

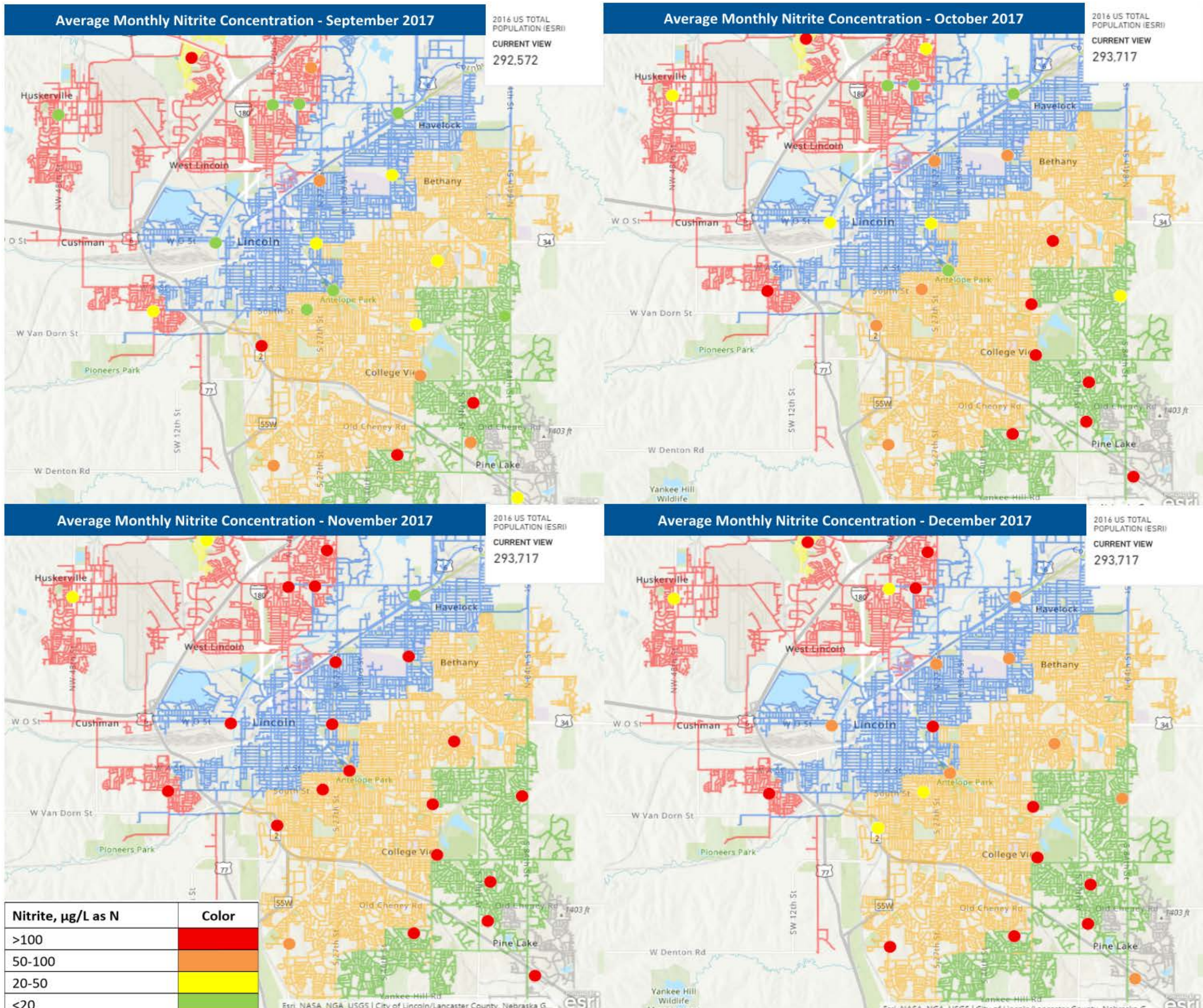

Figure 7-17 **Heat Map Illustrating the Change in Nitrite Concentration Throughout the Distribution System During Peak Nitrification Season from September to December 2017**

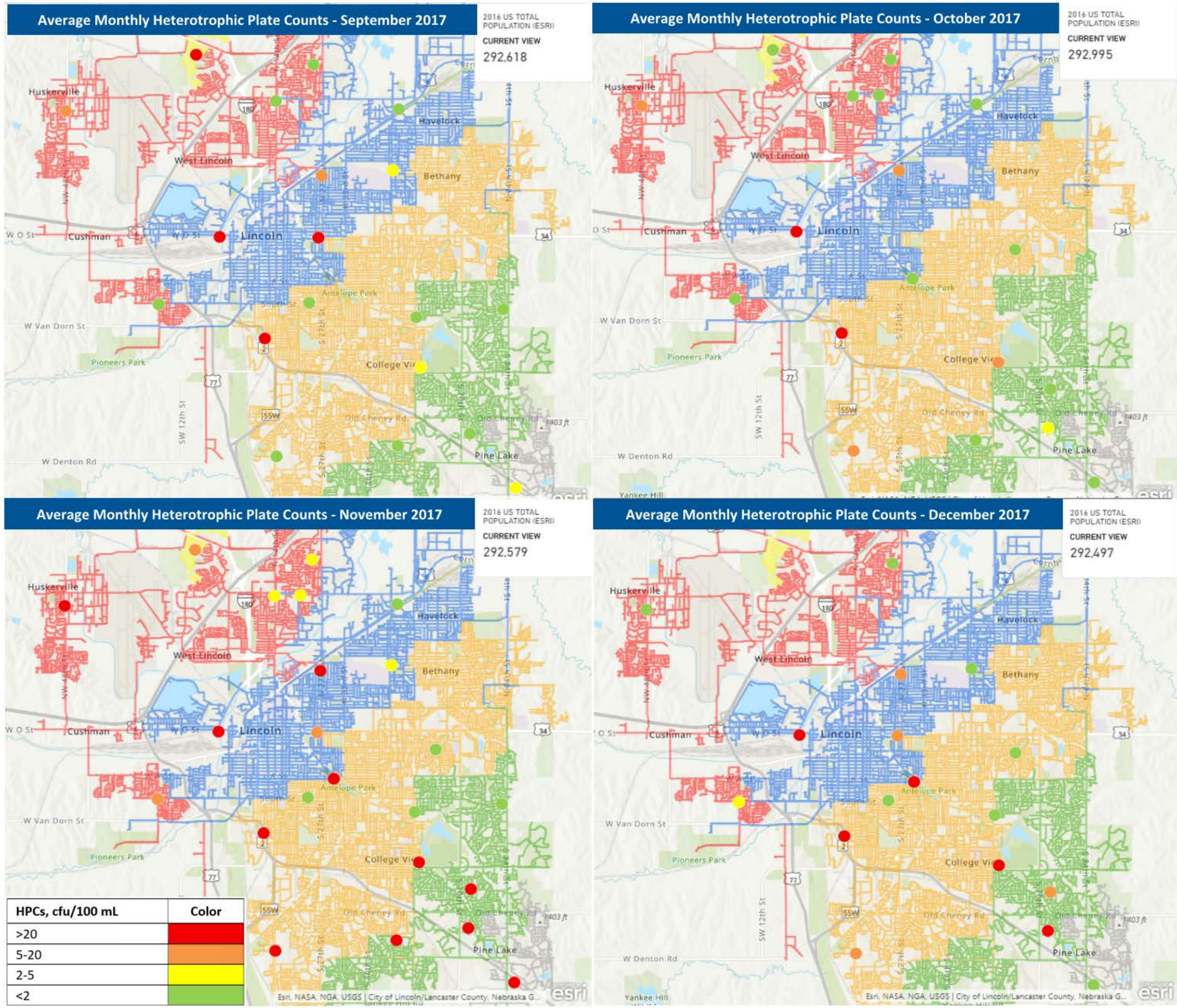

Figure 7-18 **Heat Map Illustrating the Change in Heterotrophic Plate Counts Throughout the Distribution System During Peak Nitrification Season from September to December 2017**

7.5.1 Nitrification Management (2018 to present)

In Year 2018, LWS implemented operational changes to control nitrification through management of delivered water quality and water age. Winter operations that contributed to nitrification control included the following measures:

- Increase total chlorine residual beginning in December 2017.
- Take East Plant out of service in the month of September (reduced water temperature, TOC and AOC).
- Isolate reservoirs (Vine Street, Air Park) for maintenance activities (reduced water age).
- Deep cycling of above ground storage reservoirs (improved turnover and reduces potential for stagnant water).
- Reduce operating volumes in below ground storage reservoirs (reduced water age).

These operational changes considerably improved the widespread impacts of nitrification that were observed in Year 2017. Figure 7-19 provides a heat map of the total chlorine residual measurements during the normal peak nitrification season (September to December). As a result of the measures taken by LWS, the City had significantly better control of total chlorine residual throughout the distribution system. During the peak nitrification season, chlorine residuals were less than 0.25 mg/L as Cl_2 in 14.5 percent of the distribution system monitoring sites, and the total chlorine residual exceeded 1.5 mg/L as Cl_2 in nearly 50 percent of the distribution system monitoring sites. Both of these parameters indicate major improvements to nitrification control relative to previous years.

While these operational changes have resulted in considerable improvements to distribution system water quality, taking the East Plant out of service is not a viable long-term strategy for nitrification control. Further investigation should be conducted to determine the direct impacts of taking the East Plant out of service and evaluate whether treatment modifications are required to continue utilizing the East Plant during peak nitrification seasons. Treatment modifications could include increased chloramine residual, biological filtration and/or application of sodium chlorite.

Distribution water quality improvements are shown in Figure 7-20, which summarizes the average monthly concentration of nitrite at monitoring sites throughout the distribution system from August to December 2018 (note that data in the month of November was not available). Particularly, in the months of October and December there is a notable reduction in the concentration of nitrite from Year 2017 to 2018, indicating that the nitrification control measures taken by LWS were effective.

However, while chlorine residual management and nitrification control improved significantly in the Low and High Service Levels, the areas surrounding Air Park, Northwest, Cheney, and southern parts of Southeast still had difficulty maintaining chlorine residuals greater than 0.5 mg/L between the months of October and December. Therefore, recommendations for distribution system water quality improvement will focus on these areas.

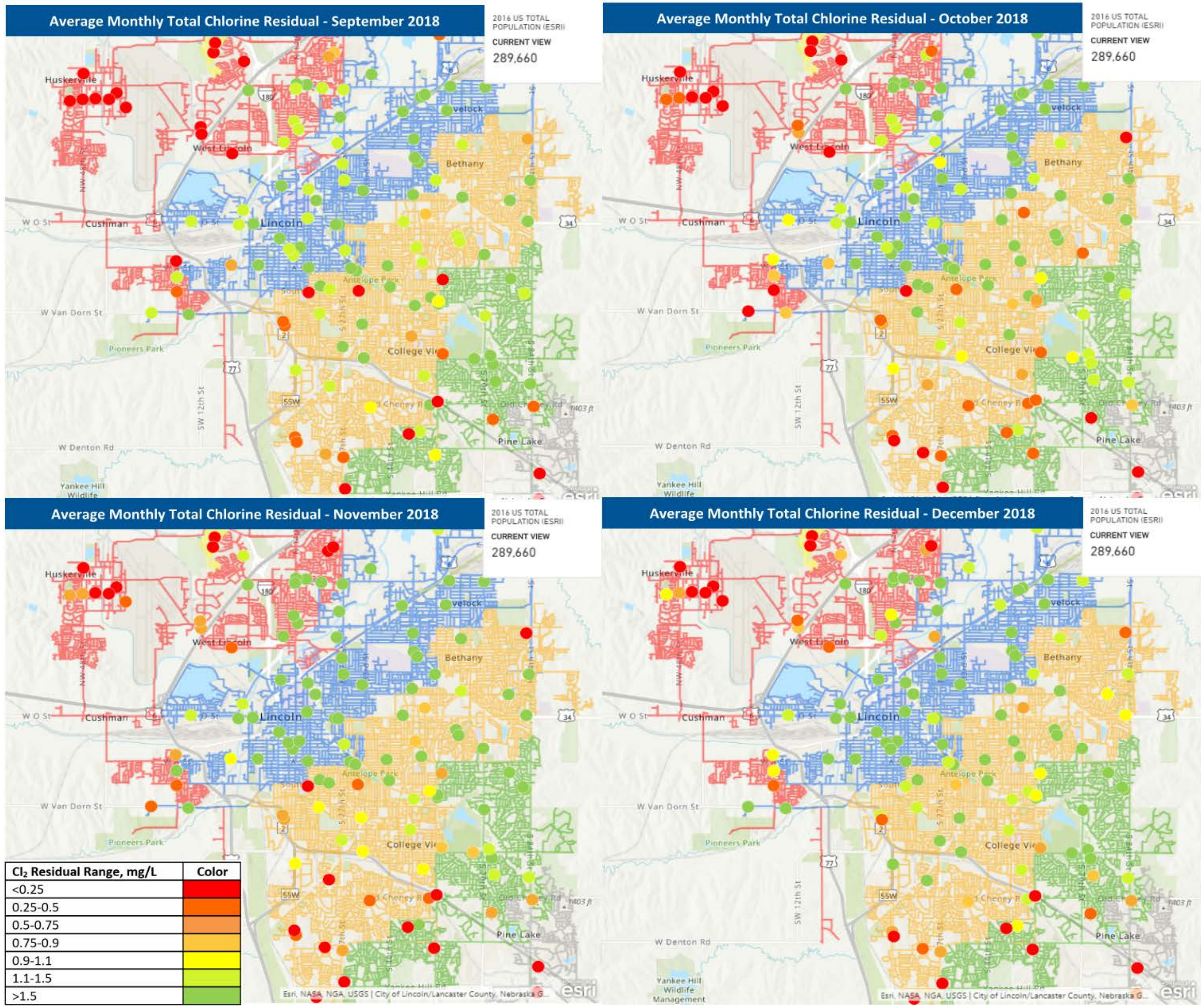

Figure 7-19 **Total Chlorine Residual Heat Map During Peak Nitrification Season from September to December 2018, demonstrating effectiveness of nitrification control measures**

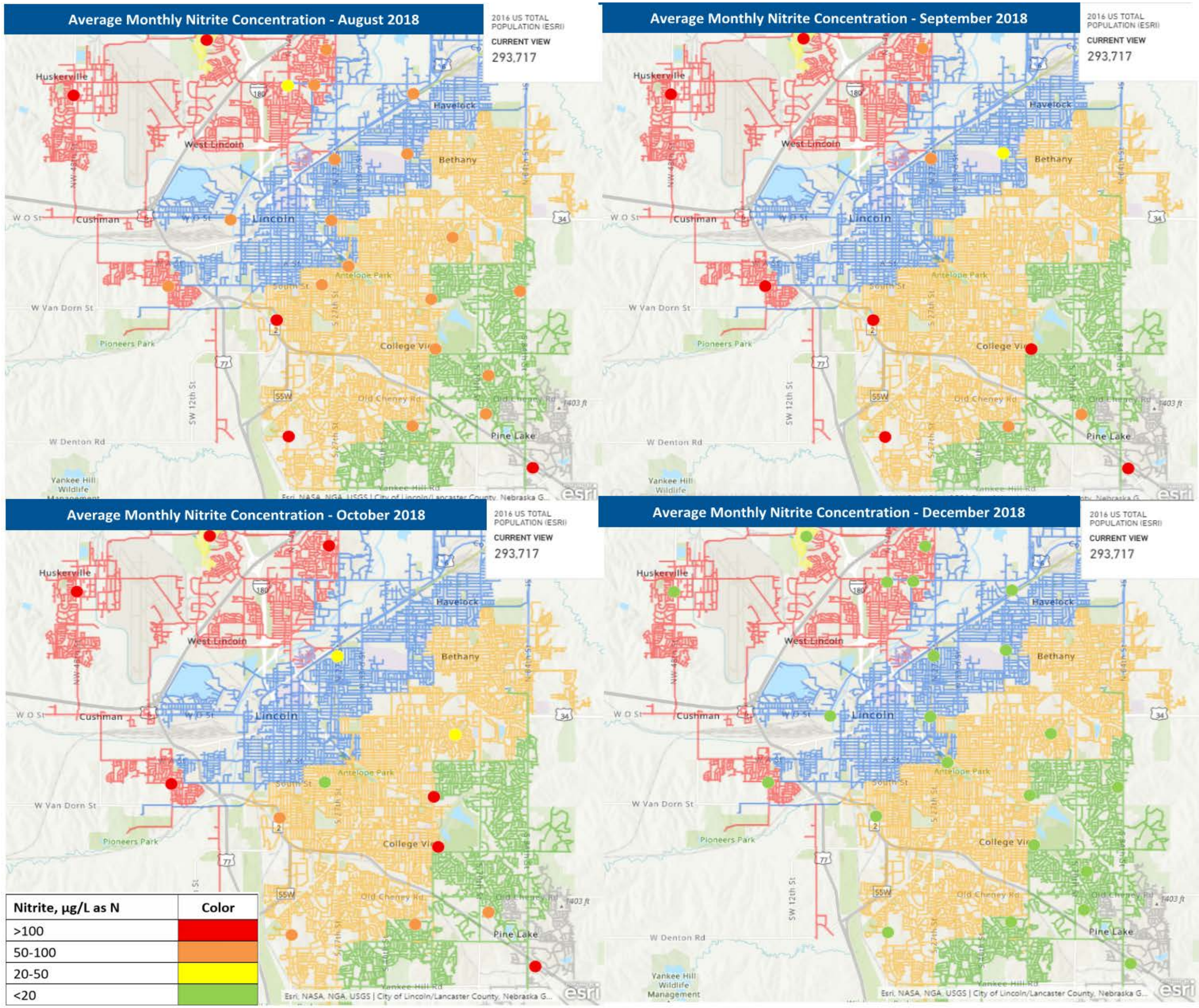

Figure 7-20 Heat Map Illustrating the Change in Nitrite Concentration Throughout the Distribution System from August to December 2018

7.6 Impacts of Distribution System Pipe Materials

Studies have shown that the type of pipe materials used in the distribution system have varying degrees of impact on the degradation of water quality. AWWARF Report No. 90950 – Influence of Distribution System Infrastructure on Bacterial Regrowth focuses on the relationship between pipe materials and biofilm development. This report confirmed previous research and field studies, which found that iron-based pipe materials - such as cast iron and ductile iron - have a higher probability of biofilm development and tend to form denser biofilm than cement, epoxy, or polyvinyl chloride (PVC) piping. Of all the materials evaluated in this study, PVC consistently had lower rates of biofilm development, resulting in lower HPCs in the biofilm and water passing through the piping.

The LWS distribution pipe materials include lined and unlined cast iron pipe, ductile iron pipe, prestressed concrete cylinder pipe (PCCP), and PVC pipe. Figure 7-21 provides a map of the overall distribution system infrastructure, categorized by year of installation (left) and pipe material (right). Color designations were assigned to each pipe material and installation timeframe based on its propensity for degradation of water quality. The maps demonstrate that there is a high proportion of cast iron pipe in the High Service Level, as well as in the areas surrounding Air Park within the Belmont Service Level. These parts of the distribution system may be subject to higher rates of biofilm development, which may result in faster degradation of chlorine residual and elevated levels of HPCs. To evaluate the relative impacts of pipe material on biofilm development, sampling could be performed to compare HPCs in biofilm and sample water for areas with different pipe materials located in the same Service Level. Recommendations for this field study are provided in Chapter 8.

Much of the cast iron pipe in the distribution system appears to have been installed in the early to mid-1900's. With LWS's ongoing distribution infrastructure repair and rehabilitation program, many of these aging pipes are in the process of being replaced or relined. Given the influence of pipe material on water quality, it is recommended that LWS continue with their existing repair and rehabilitation program, prioritizing the replacement of cast iron pipes with alternative materials (PVC or ductile iron) and lining/relining cast iron pipes as needed.

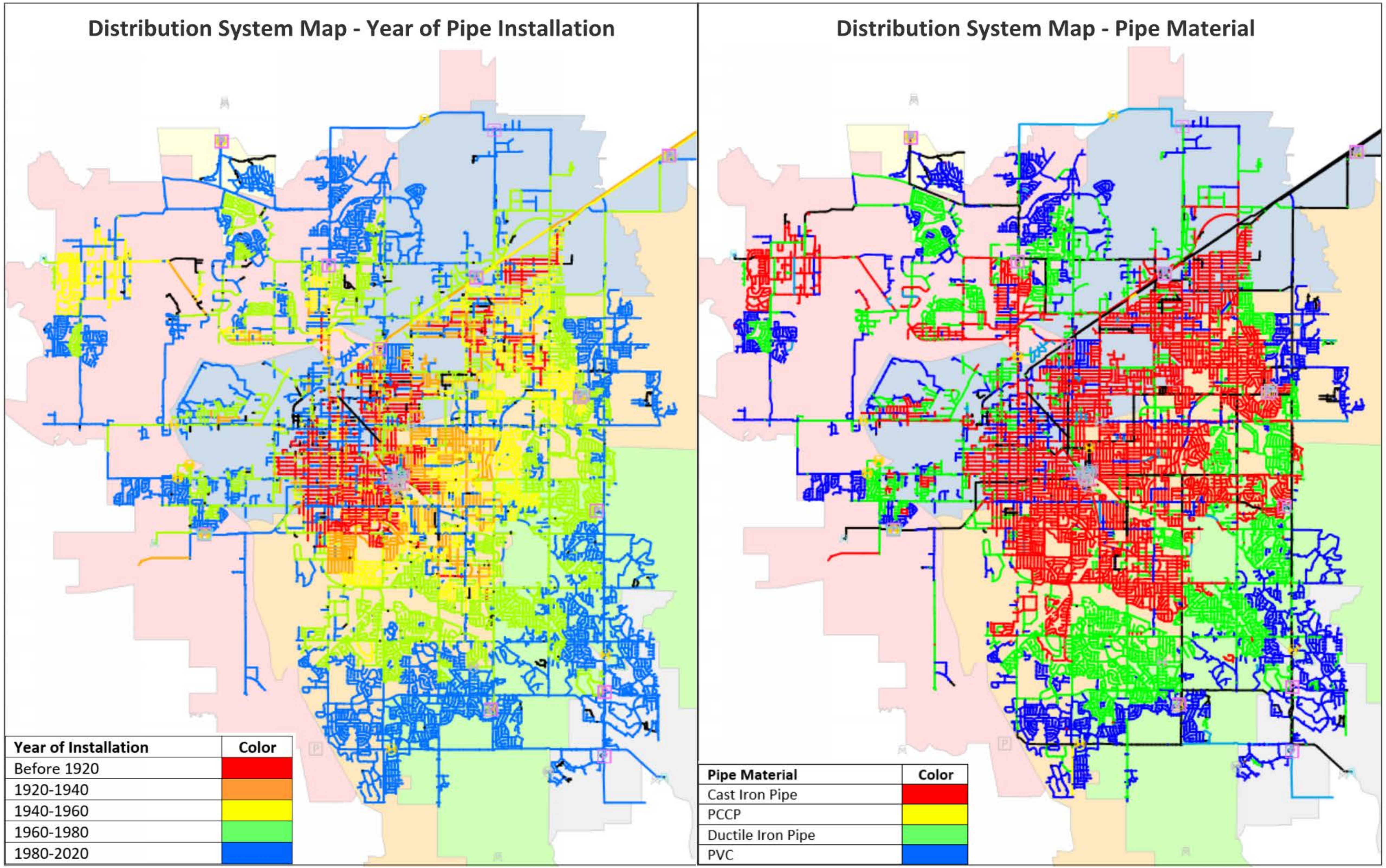

Figure 7-21 Map Identifying Distribution System Infrastructure by Year of Installation and Pipe Material

7.7 Distribution System Water Age Modeling

Distribution system water age modeling was performed with the goal of determining empirical relationships between water age and water quality characteristics. Water age modeling is often used in the industry as a surrogate for constituent modeling to evaluate degradation of water quality as water moves through the distribution system. True constituent modeling, for whichever parameters are desired, is possible in the InfoWater software but requires a high-confidence, high level-of-effort, water quality constituent calibration to develop model parameters for decay/formation potentials, bulk decay coefficients in all storage facilities and of the source water and pipe-wall decay coefficients for all model pipes. Because of the large level of effort required to perform a constituent-calibrated model for water quality analysis, water age modeling evaluations are often used as a surrogate. However, water age modeling alone should not be used to form definite conclusions about water quality without first comparing and establishing relationships to the observed data.

Two base year water age modeling scenarios were developed for Year 2020, based on average day demands and winter operations. This condition represents the system characteristics and demands during the months of October and November, as operations generally shift from Summer Operations to Winter Operations.

7.7.1 Winter Operations

A list of current operations used in the off-peak times of the year, implemented at the beginning of October, were provided by LWS. These operations are followed for energy management and to promote good water quality and include standard operating procedures for pump stations and the cycling of storage facilities, both floating and below-ground. They include the following:

- East Plant taken off-line.
- Airpark (or NW 12th Street) Reservoir isolated from the system.
- Northeast Reservoir placed in series operation.
- Vine St North reservoir isolated from system.
- Increased chlorine residuals leaving treatment plant(s) to 3.4-3.8 mg/L range
- Deep cycling of above ground storage reservoirs.
- Reduced operating volume of below ground storage reservoirs.
- Suspended operations of Southeast Pump Station and only a single pump at Vine Street East should be used to fill Yankee Hill.

During this time-frame, HPP 11 or HPP 12 will be used to pump water directly into the Low Duty system down the 54-inch or 60-inch transmission main. Expected rates will be from a minimum of 12 mgd to 20 mgd. At the higher end of this range a potable water pump can be turned off for additional energy savings as the 54-inch discharge main pressure will be sufficient for plant service water needs.

Using either HPP 1, HPP 2, or HPP 3, water will be pumped down the 48-inch transmission main to Northeast Reservoir (approximately 9 mgd) and the 36-inch transmission main (approximately 4 mgd) to 51st Street Reservoir. It should be ensured that the 36-inch main pressure remains at 30 psi or higher during low flow, winter conditions to reduce cavitation issues on HPP 1, HPP 2, or HPP 3.

Water from the 48-inch main will only enter the East Cell of NE reservoir via NE yard valve No. 30. Valve No. 32 or No. 33 will be used to regulate water coming into the station and Transfer Pump 1 will be used accordingly to move water out of NE. Valves No. 4 and No. 5 on the West Cell of Northeast Reservoir will remain closed. These Northeast valve combinations allow "series" operation of the reservoir which will provide adequate turnover and flow through them. A one pump rule at Northeast will still be in effect with the added condition that only Transfer Pump No. 1 is to be used during these winter pumping operations. No other low duty pumps are to be used unless an emergency exists. Pumps Nos. 2 - 6 will be put into local control during winter operations.

New operating levels and ranges for below ground storage reservoirs that do not provide floating storage were also provided, shown in Table 7-2. The goal is to cycle the levels in these reservoirs from the low alarm to the high alarm to promote turnover unless weather related issues, system facilities out-of-service, or other maintenance related activities dictate the need to fill these reservoirs back to their original high levels.

Table 7-2 Summer/Winter Operations, Ground Storage Alarm Levels

	Summer Operations Alarms				Winter Operations Alarms			
Reservoir	Lo-Lo	Lo	Hi	Hi-Hi	Lo-Lo	Lo	Hi	Hi-Hi
Northeast Reservoir	11	12	15.5	16	5	6	9	10
51st Street Reservoir	9.8	10	13	13.5	4	4.5	7	8
"A" Street Reservoirs 8 and 9	4	6.5	13	13.5	4	4.5	7	8
"A" Street Reservoir 6	6	7	12	13	4	4.5	7	8

Guidelines for floating storage reservoir refill initiation levels are noted as the following:

- Pioneers – 44 feet.
- Yankee Hill – 60 feet.
- Southeast – 47 feet.
- Airpark – 73 feet.
- NW 12th – 54 feet.
- S. 56th Street – 50 feet.
- Cheney – 22 feet.

Winter pump rules for pumping stations are noted as the following:

- Northeast - One pump only, No. 1 Transfer Pump. All low Duty pumps out-of-service.
- 51 St. - One pump only, either one Low Duty or one Booster pump.
- "A" St. Main Complex - One pump only, either one Low Service or one High Service pump.
- "A" St. Satellite No. 9 and No. 10 - Zero pump rule. Pump No. 9 or No. 10 are not to be operated.
- Belmont - One pump only, either Pump No. 1 or No. 2. Pump No. 3 or No. 4 are not to be operated.
- Cheney - One pump Rule. Pumps No. 4 or No. 5 are not to be operated.
- Yankee Hill - One pump Rule.
- Southeast - One pump only, either pump No. 1 or No. 2. Pumps No. 3 or No. 4 are not to be operated.
- Vine St. Main Complex - One pump rule.
- Vine St. East Complex - One pump rule.

7.7.2 Water Age Modeling Scenario No. 1

Using the Winter Operations detailed in the previous section, a 28-day water age modeling scenario was developed to assess water age. For the Water Age scenario No. 1, the Airpark Reservoir was placed out-of-service and all other controls were modeled as described in the Winter Operations section. The results were captured in a dashboard to allow for the ability of rapid filtering by Service Level and display of more than one scenario on-screen for comparison purposes. Figure 7-23 through Figure 7-28 on the following pages show the results by Service Level of the Water Age Scenario No. 1. These figures show the average water age (blended over time) that occurred within the evaluation on the left side of the figure, and the maximum water age (the highest-age plug of water during any time during the scenario) on the right. The maximum water age is experienced when storage is being drawn down in times of equalization. At the bottom of each map figure is a pie-chart which shows a relative percentage of how many model junctions fall within each category. A general legend for all map colors and how they are related to water age is provided below in Figure 7-22 since some of the figures on the following pages do not have junctions within all categories. A quick visual way to determine the overall average age of water within an area is to eyeball where the “50-percent line” would be from the pie-charts. Doing this with the sample on Figure 7-22 shows that the “50-percent” line occurs almost between the 2 to 4 days and 4 to 6 days category, or that the average age would be just over 4 days.

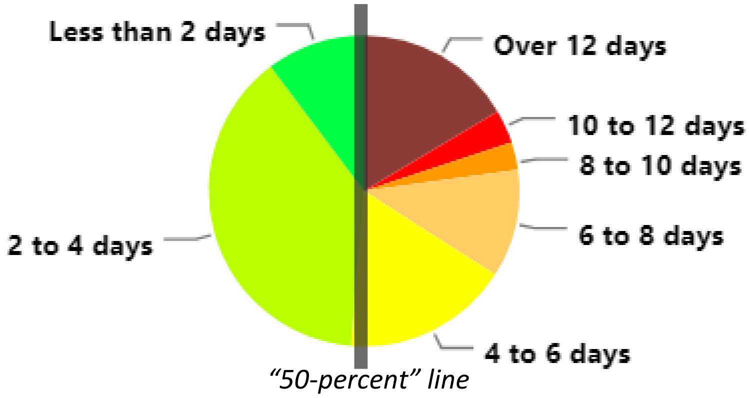

Figure 7-22 Category Legend for Figure 7-23 through Figure 7-28

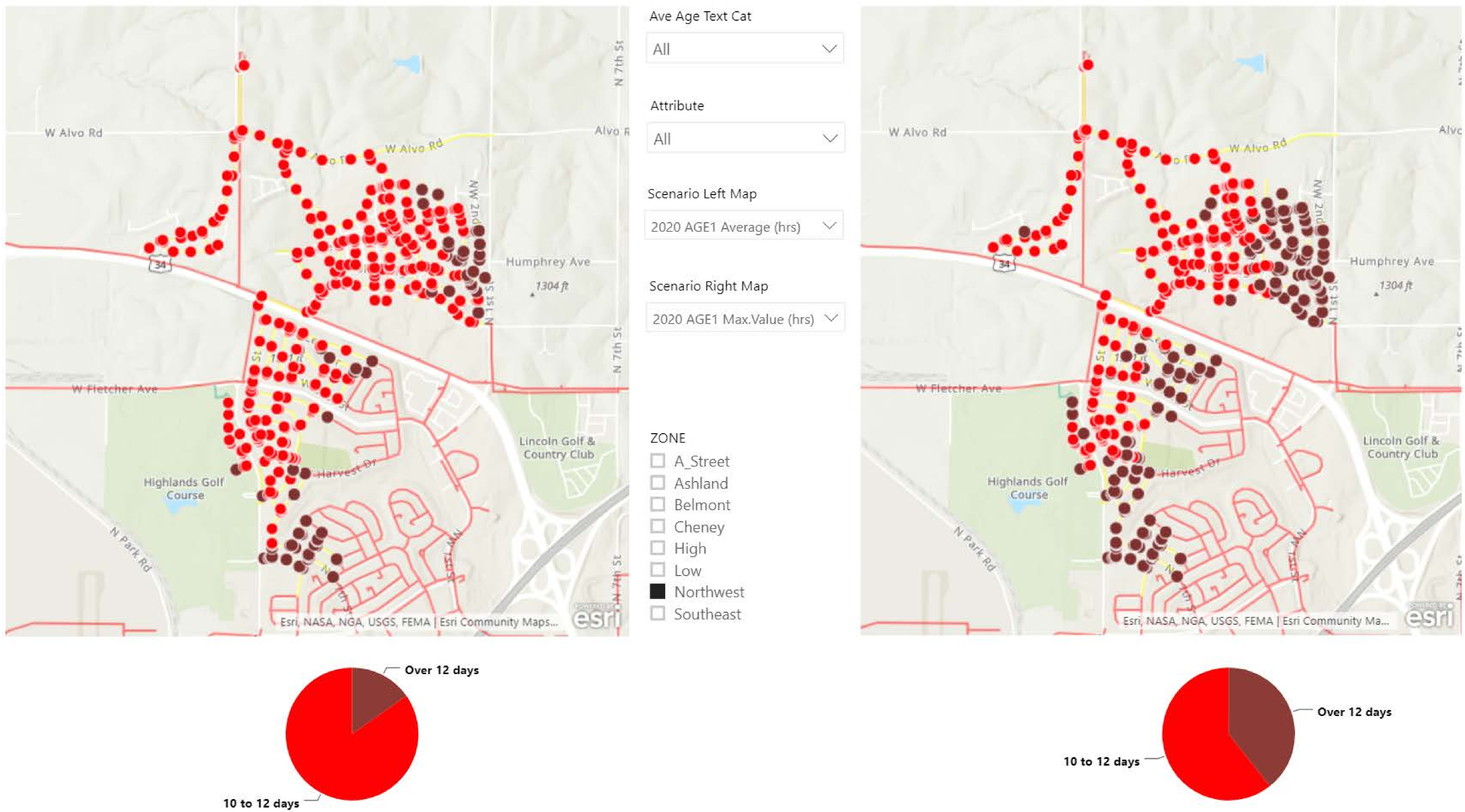

Figure 7-23 Northwest SL Water Age Scenario 1 (Average-Left, Maximum-Right)

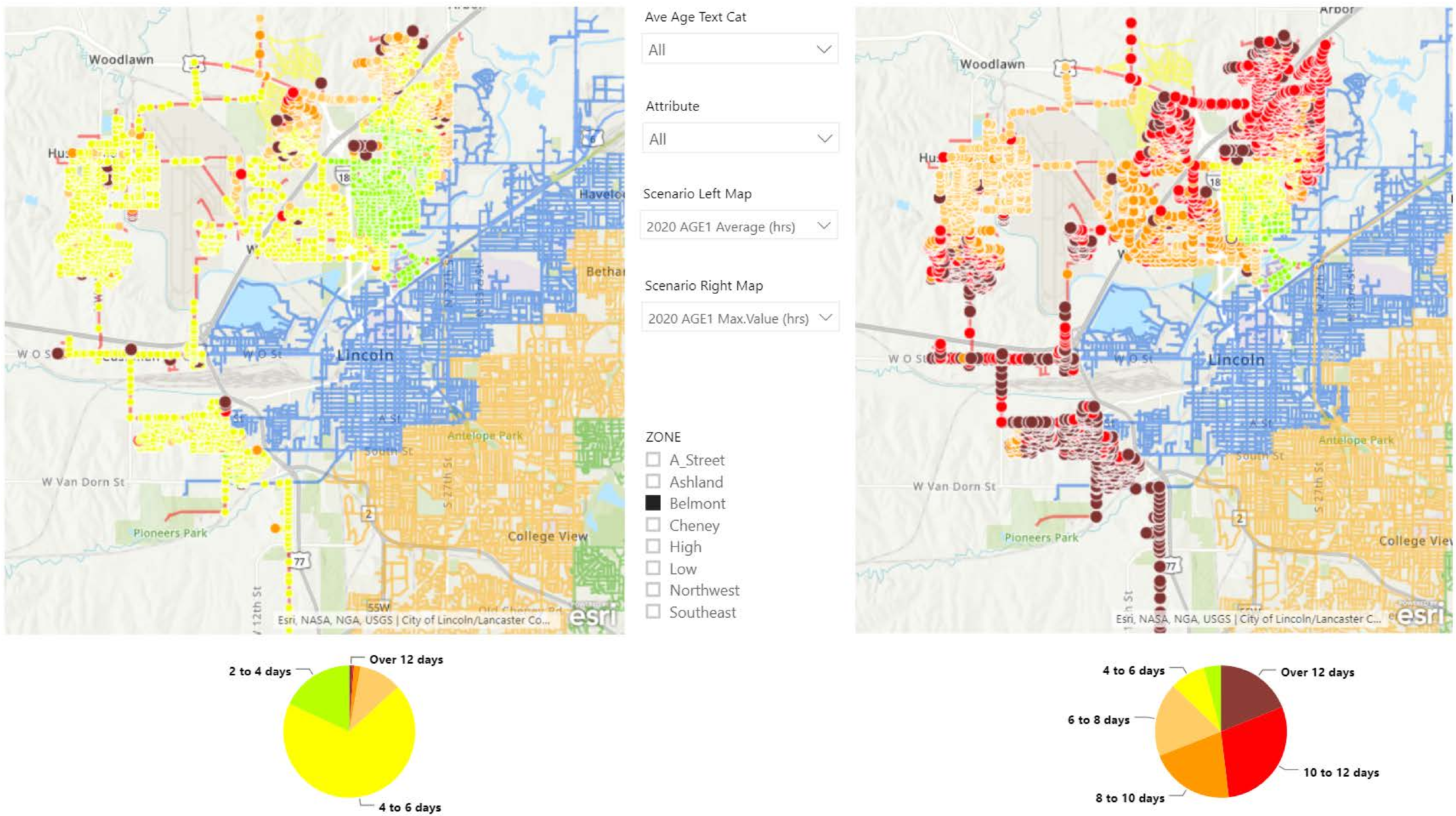

Figure 7-24 Belmont SL Water Age Scenario 1 (Average-Left, Maximum-Right)

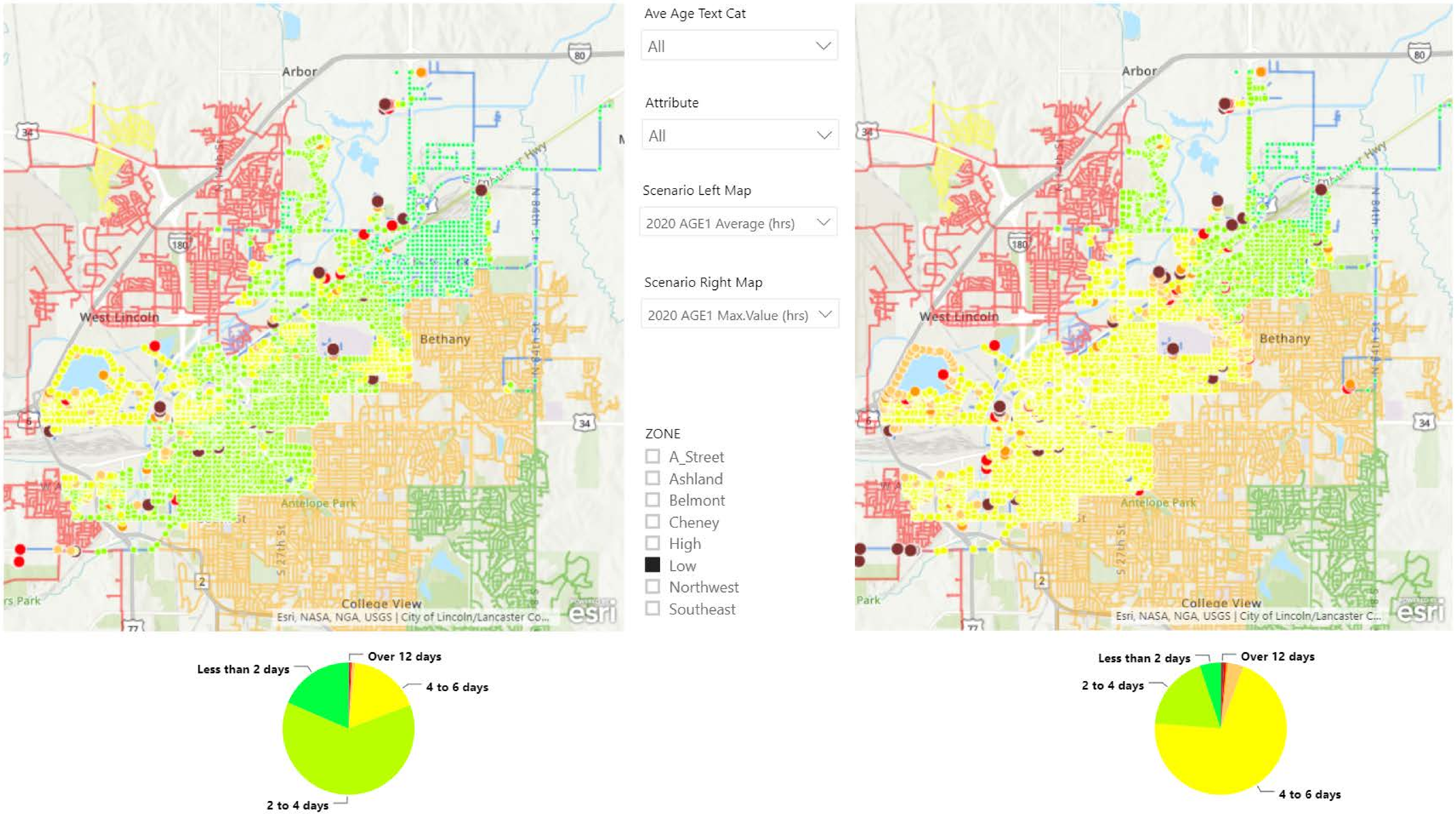

Figure 7-25 **Low SL Water Age Scenario 1 (Average-Left, Maximum-Right)**

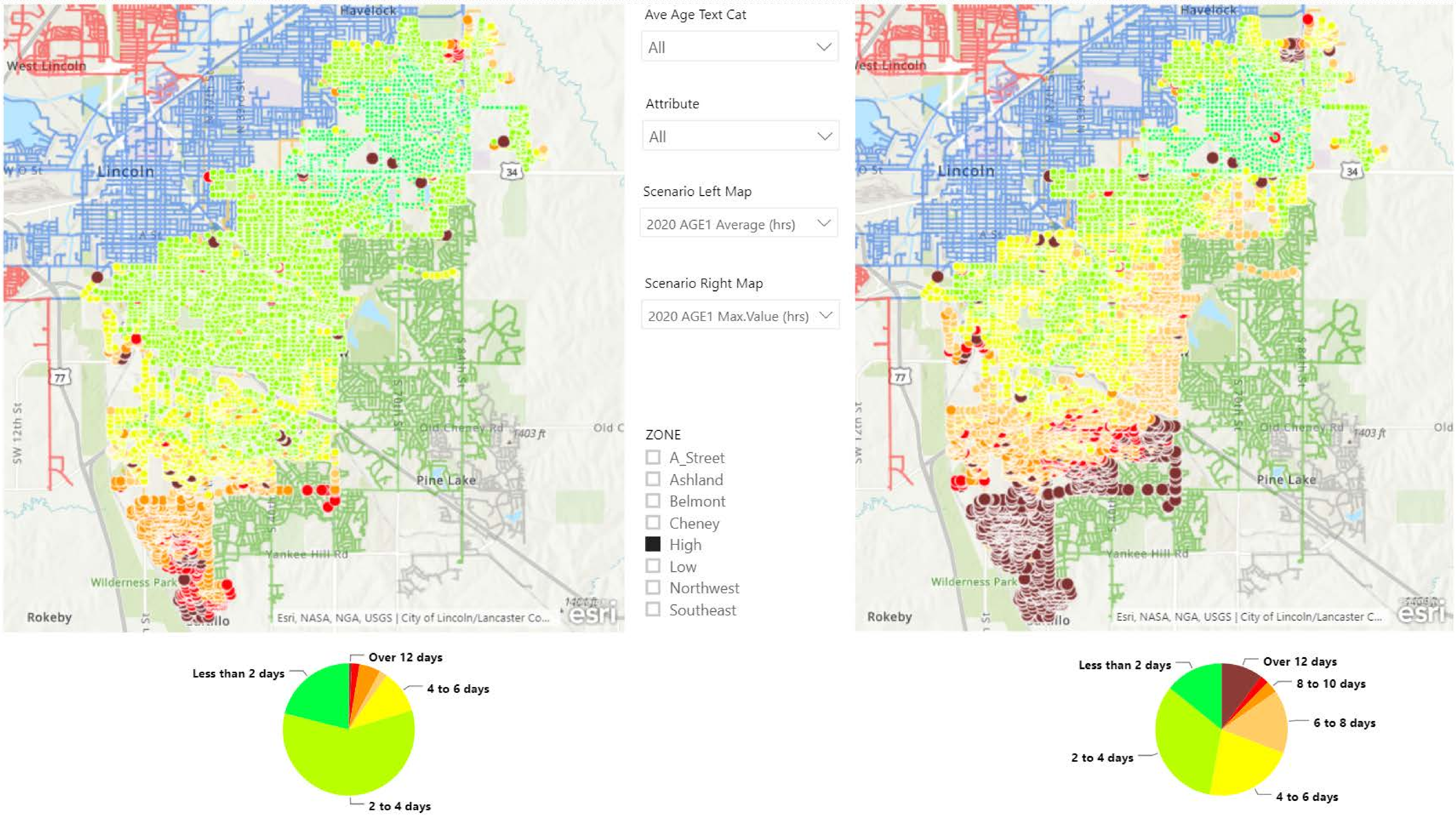

Figure 7-26 High SL Water Age Scenario 1 (Average-Left, Maximum-Right)

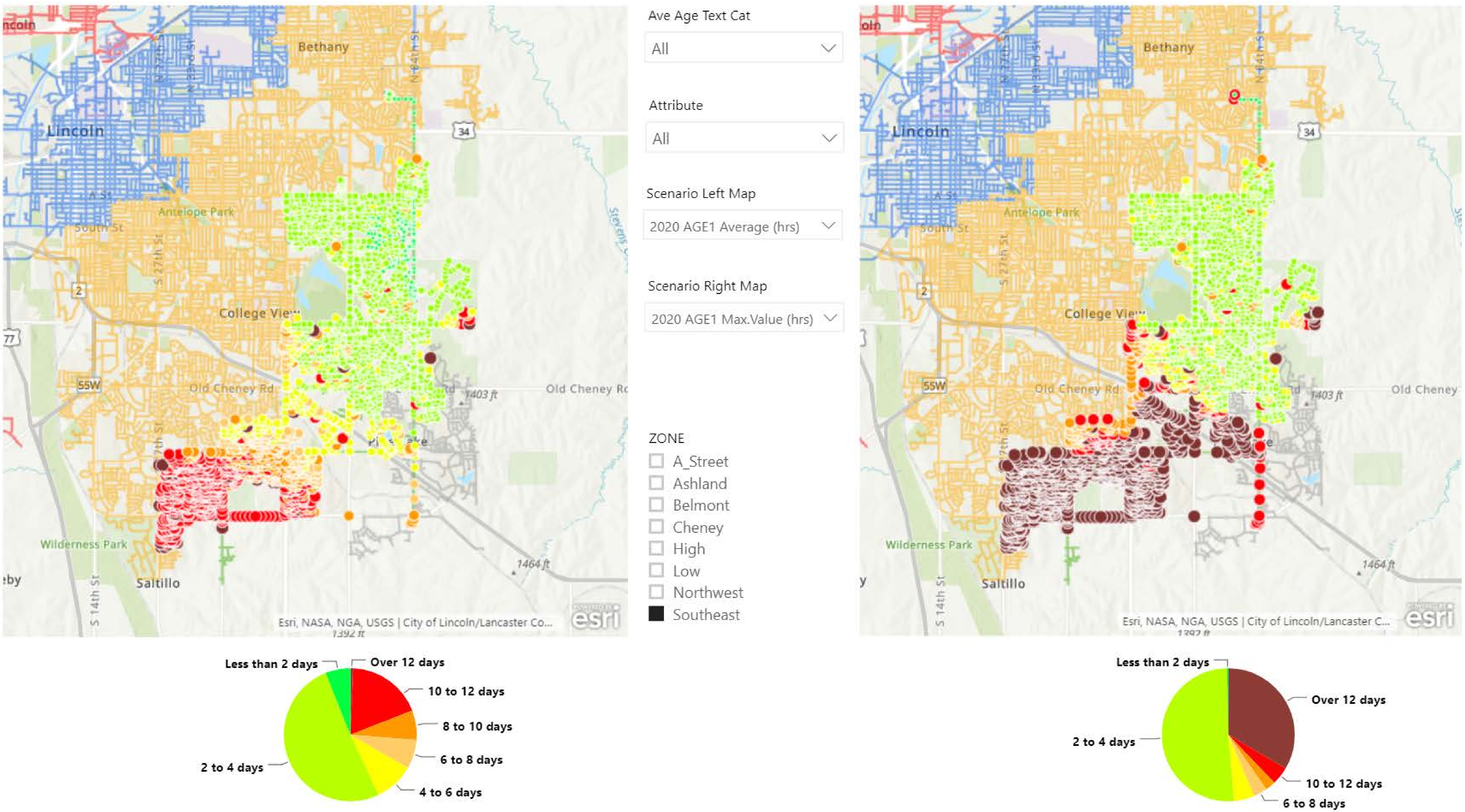

Figure 7-27 Southeast SL Water Age Scenario 1 (Average-Left, Maximum-Right)

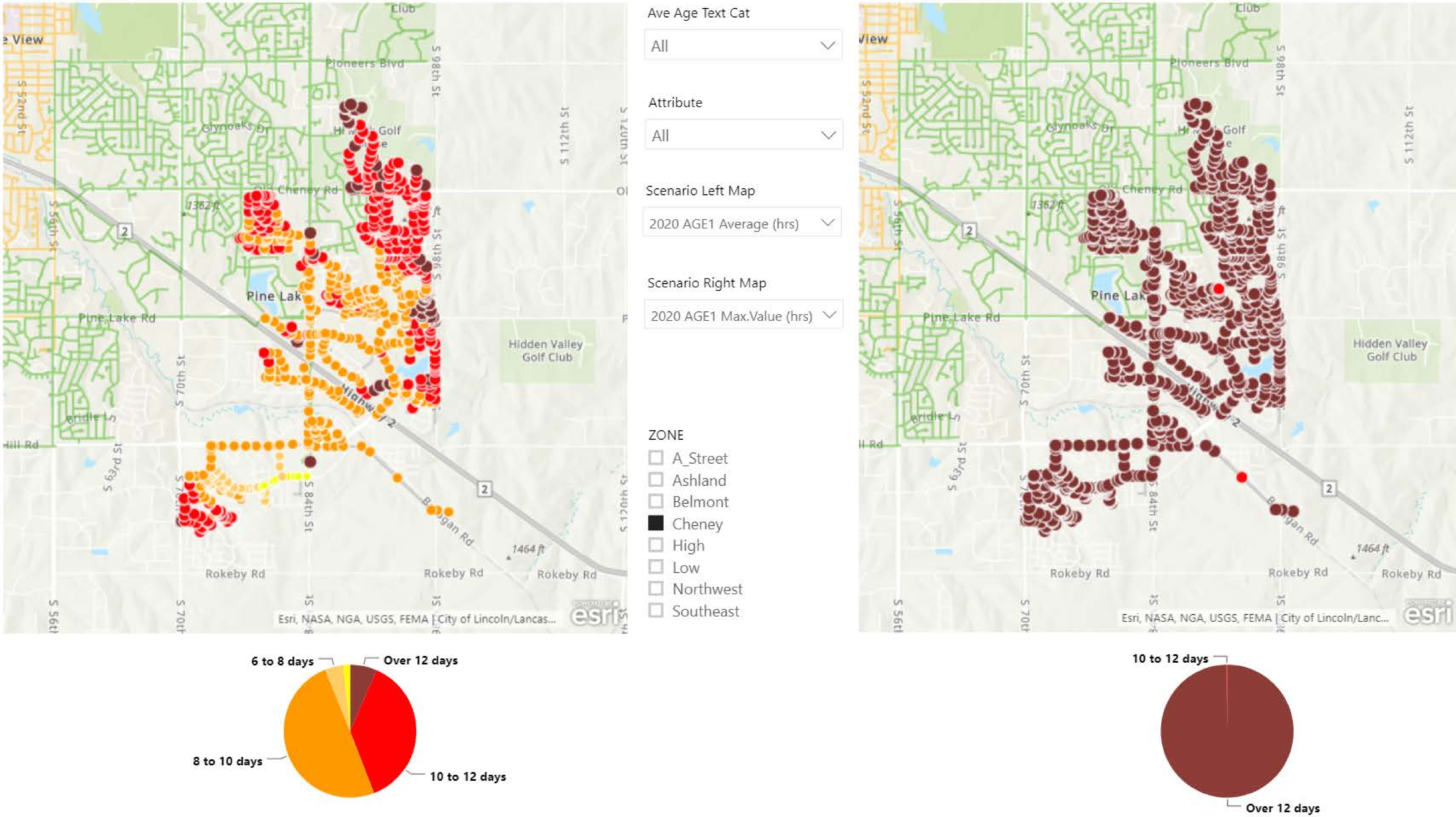

Figure 7-28 Cheney SL Water Age Scenario 1 (Average-Left, Maximum-Right)

7.7.3 Water Age Modeling Scenario No. 2

A second water age scenario was developed, identical to the first scenario with the exception that the NW 12th Reservoir was taken out of service instead of Airpark. This only impacted the water age results in the Belmont and Northwest Service Levels, and ages in other Service Levels did not change so these need not be shown in additional figures. To compare the difference between placing Airpark vs. NW 12th out-of-service during Winter Operations, Figure 7-29 (average age) and Figure 7-30 (maximum age) are provided on the following pages. The left side figures show the water age results from Scenario 1 (Airpark out of service, "o.o.s") and the right-side results show the water age results with Scenario 2 (NW 12th out of service).

It is interesting to note that the water ages in the Belmont and Northwest Service Level are higher on average when the Airpark reservoir is taken out-of-service (left-side figures) compared to the scenario where NW12th is taken out-of-service (right-side figures). This is due to the fact that NW12th has a larger volume and adds more residence time to the water within the Belmont and Northwest Service Levels. However, the water age alone does not tell the complete story because the travel path of water needs to be considered. The water age might be higher in the Northwest Service Level with Airpark Reservoir out-of-service, but much of the water feeding the Northeast Service Level flows through newer pipes and fewer cast iron pipes. To illustrate this example, a source trace was performed for both of the base water age scenarios to show the relative blending zones between the Belmont Pumping Station water and the Pioneers Pumping Station water based on which reservoir is taken out-of-service. This is shown in Figure 7-30 with the 50/50 approximate blending zone line drawn in blue over the top of the figures. While the age may be lower with the Airpark Reservoir out-of-service vs. the NW 12th out-of-service, most of the water that is pumped into the Northwest Service Level has its source from the Pioneers Pumping Station and its flow path has gone through the Airpark area, where many older Cast Iron Pipes reside. Conversely, water age may be lower with the Airpark Reservoir out-of-service, but the water pumped into the Northwest SL is roughly a 50/50 blend of water between Belmont and Pioneers Pumping Stations. This means, on average, less of the water being pumped into the Northwest Service Level, when the Airpark Reservoir is out-of-service, has its source from the Pioneers Pumping Station which must flow through the higher-age Cast Iron Pipes in the Airpark area. This provides an example of why conclusions about system water quality should not be drawn based on water age alone, especially when considering constituents that are significantly impacted by the pipe-wall interactions such as Chlorine.

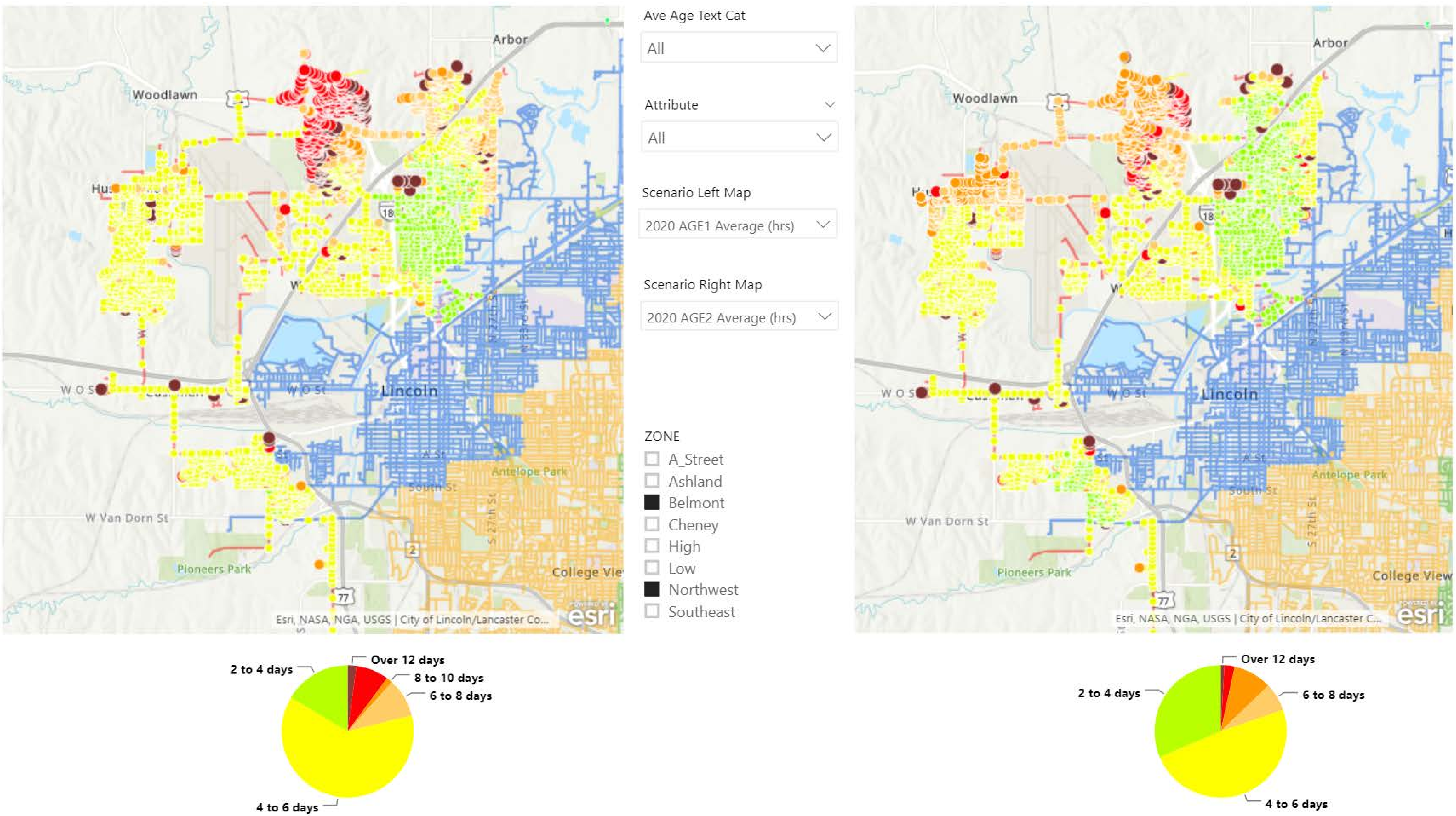

Figure 7-29 Belmont/Northwest Average Water Age (Airpark o.o.s Left, NW 12th o.os Right)

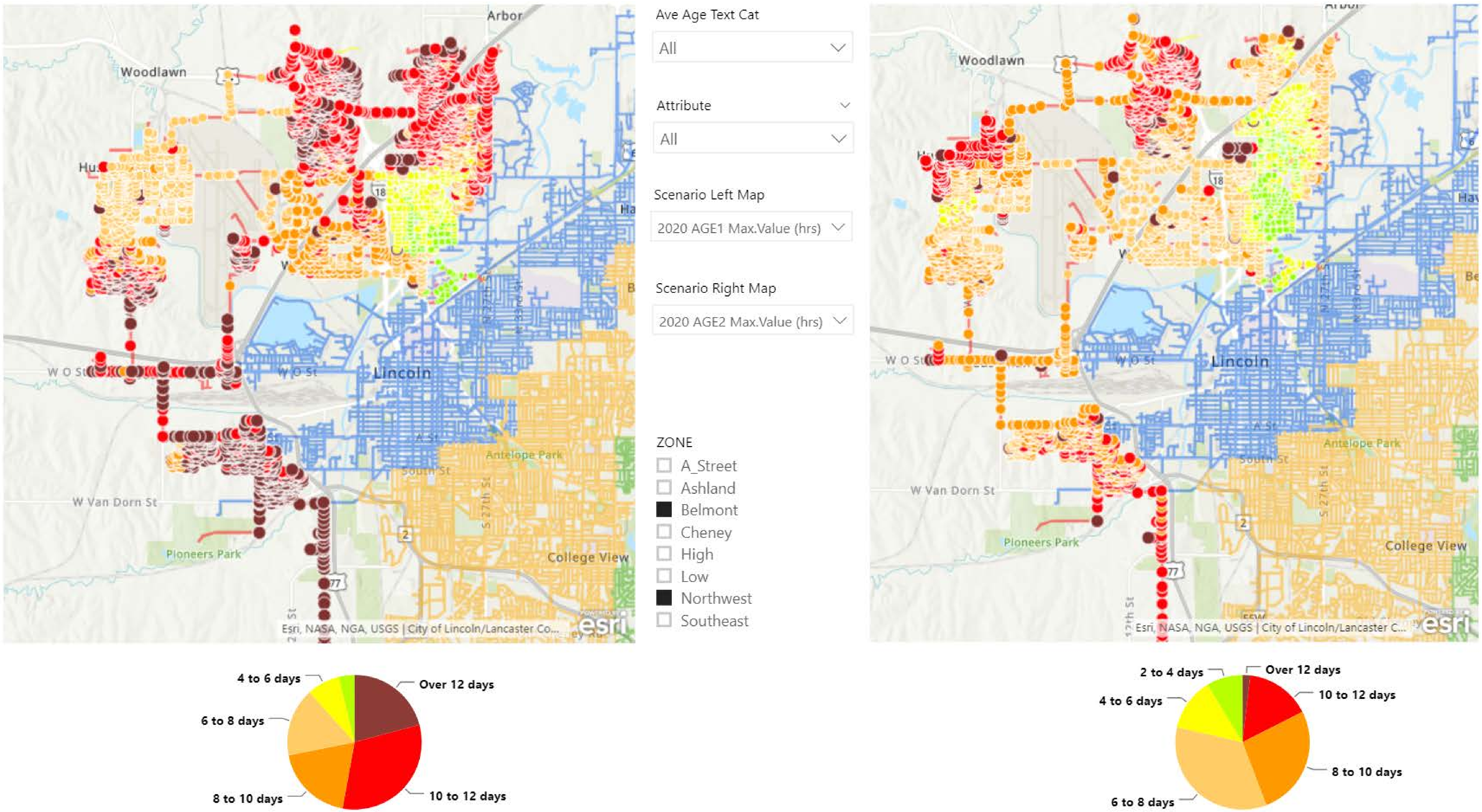

Figure 7-30 Belmont/Northwest Maximum Water Age (Airpark o.o.s Left, NW 12th o.os Right)

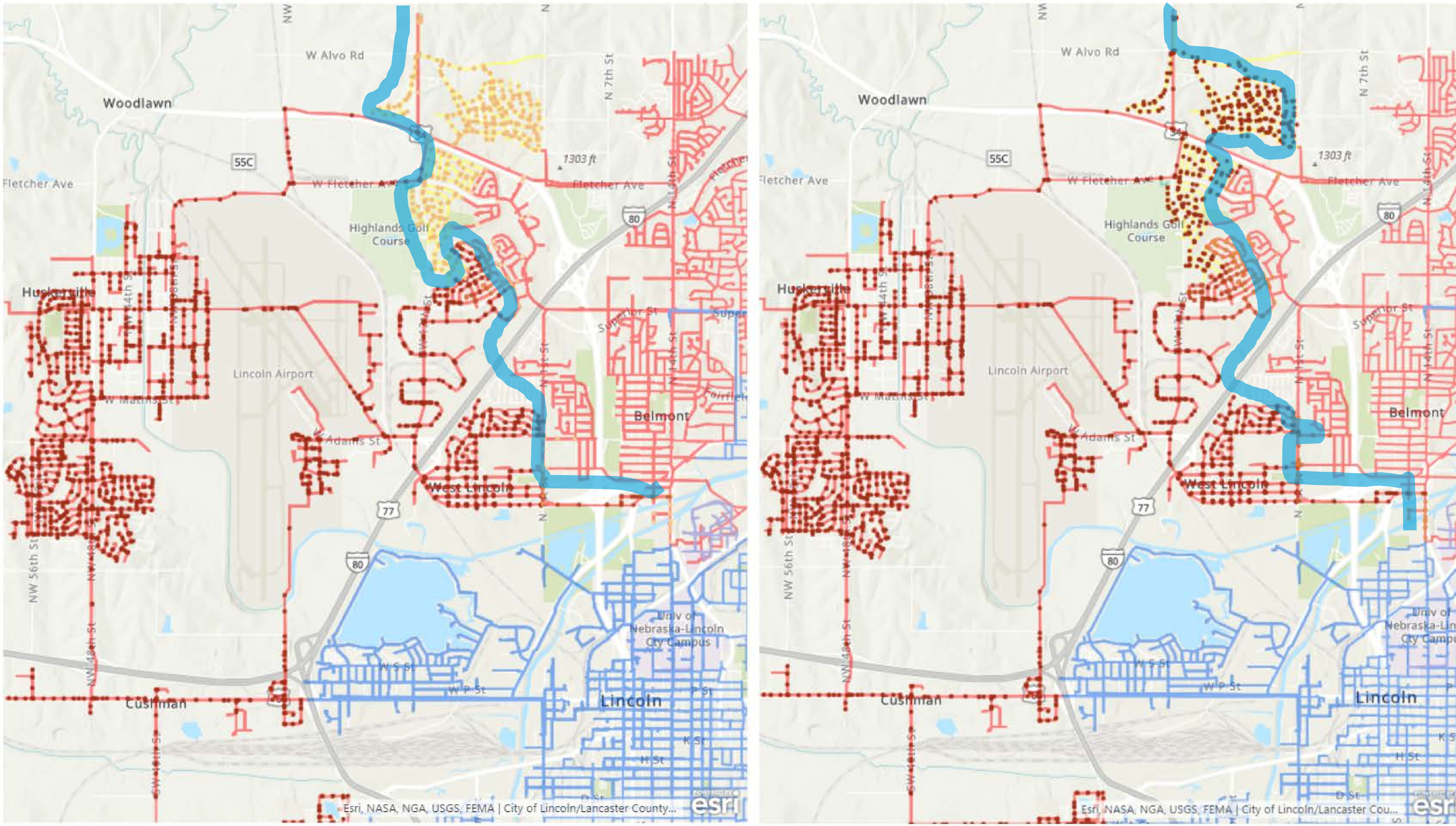

Figure 7-31 **Pioneers PS Influenced Area (Airpark o.o.s Left, NW 12th o.o.s Right)**

7.7.4 Modeled Water Age Relationship with Observed Water Quality

Further analysis was conducted to assess the relationship between the modeled water age and the observed water quality. The modeled water age results from Scenario No. 1, which simulates October operating conditions, were compared with the monitored water quality data for chlorine residual, nitrite, and nitrates from October 2018. This is the closest comparison that can be made because the scenario was developed based as closely as possible on the actual operating controls that occurred in October 2018. The process for developing a relationship involved assigning the monitoring locations to the closest model junction and pipe. This was done to determine if there was an observable difference in the water quality trends as they relate to the pipe material, relative pipe age, and the Service Level in which the monitoring is being conducted.

Scatter plots were developed in the dashboard to review observable patterns based on each of the parameters described above (pipe material, age, and service level). Scatter plots demonstrating water quality vs. water age for the entire distribution system are shown in Figure 7-32 with a map for reference on the left. Each scatter plot uses the same x, y relationship between modeled water age and chlorine residual. The details in each scatter plot highlight different distribution infrastructure parameters with material (top-right), decade category (middle-right) and Service Level (bottom-right).

The overall relationship between modeled water age and chlorine residual on the scatter-plots are representative of an empirical, or observed, chlorine decay curve. While there is some variability in the scatter plots, the scatter plots demonstrate the expected relationship between water age and chlorine residual, with residual declining as water age increases. Figure 7-33 through Figure 7-36 shows these relationships with the data isolated for individual service levels. Scatter plots demonstrating the relationship between modeled water age and nitrate and nitrite concentrations across the entire distribution system are provided Figure 7-37 and Figure 7-38, respectively. Because there is much less data available for these constituents, only an overall figure is provided. As expected, the scatter plots demonstrate increasing nitrite and nitrate concentrations with increasing water age. From a review of these figures, the following observations can be made:

- The scatter plots demonstrate that chlorine residual decay occurs most rapidly in the High Service Level.
- The next most rapid decay of chlorine residual was observed in the Belmont Service Level.
- The Low Service Level has a more moderate decay of chlorine residual. Distance from supply entry into the Low Service Level to the end user (travel path) is much shorter in this Service Level than in High or Belmont Service Levels.
- The Southeast and Cheney Service Levels have the least variability of all the scatter plots and show a much more gradual rate of chlorine decay.
- Decay relationships between pipe decade category and/or pipe material do not show any observable trends that can be separated out. One of the reasons for this is that the characteristics at the sampling site do not necessarily consider upstream piping that the water has already traveled through to get to the monitoring location. For example, a monitoring location may be served through new PVC pipe, but the water would have traveled through mostly older cast iron pipes before arriving at the monitoring location.

In order to illustrate how the relationships between the empirical, or observed, decay trends may be related to pipe materials and age, four additional figures were developed to show the relative percentages for each Service Level of pipe material by volume (Figure 7-39), pipe material by length (Figure 7-40), pipe age by volume (Figure 7-41), and pipe age by length (Figure 7-42). The larger relative amounts of cast iron pipe, by percentage of total volume/length, within the High and Belmont Service Levels supports that the more rapid decline of residual is likely occurring because of higher biological activity from denser biofilm. Although the same interactions are occurring in the Low Service Level, which also has a high percentage of cast iron pipe, there is less contact time through these pipes because the distance between the supply entering the Service Level to the end-user is much shorter. For the High Service Level, there is much longer travel distance for water to arrive at the southern portions and a higher probability that water has traveled through numerous sections of pipes with a cast iron material before it reaches the customer's tap.

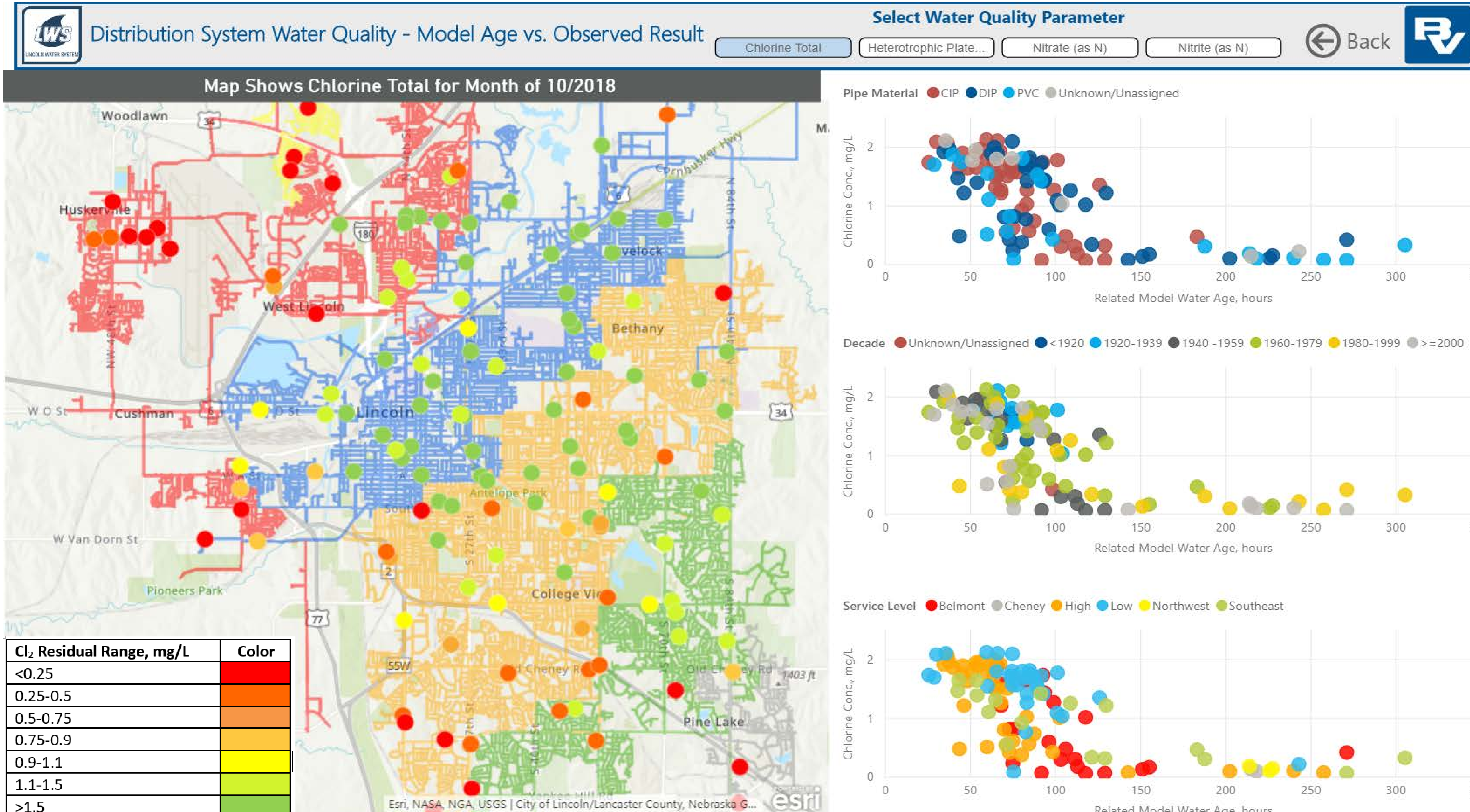

Figure 7-32 **Overall System Modeled Water Age vs. Observed Chlorine Residual**

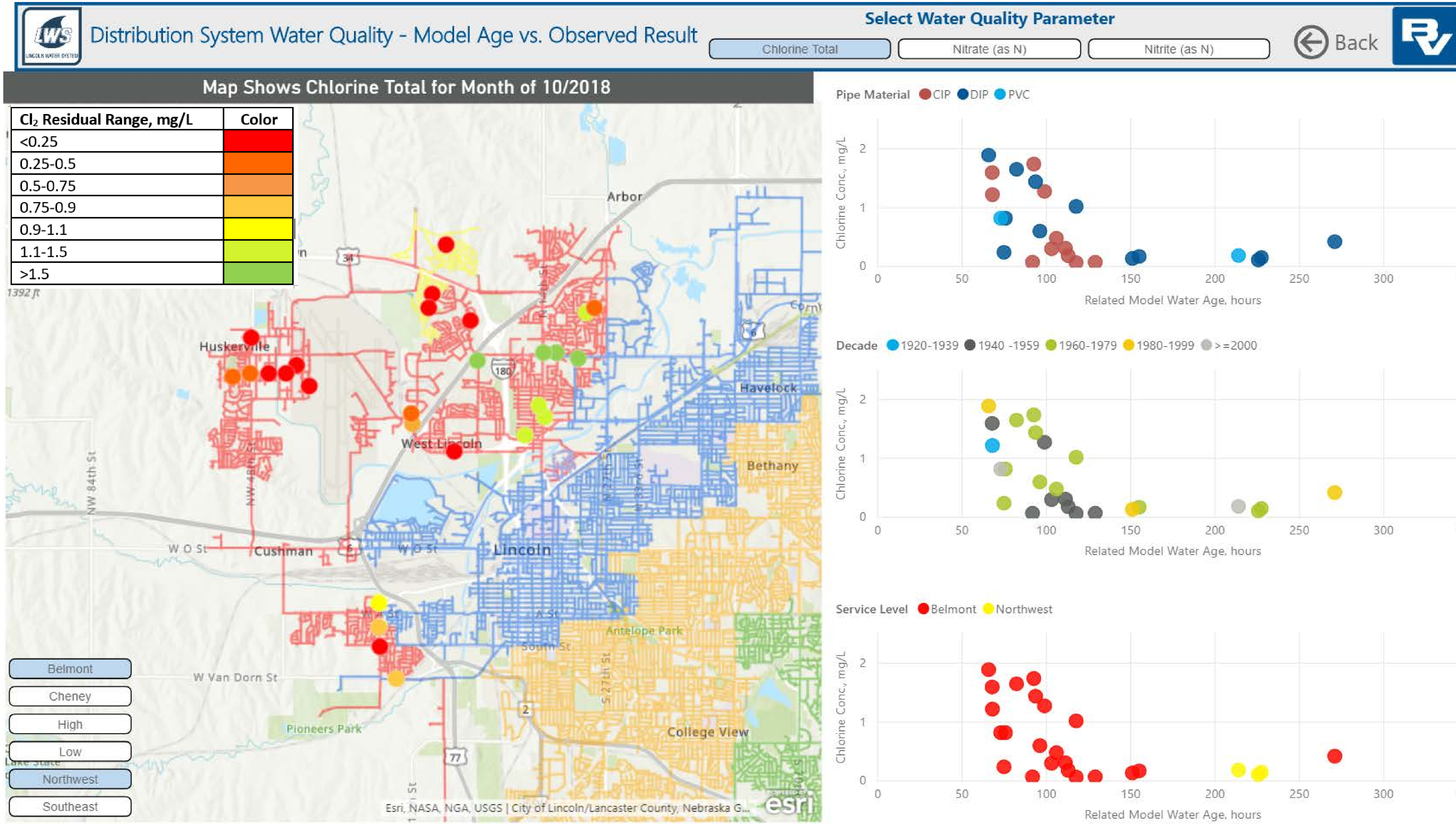

Figure 7-33 **Northwest/Belmont SL Modeled Water Age vs. Observed Chlorine Residual**

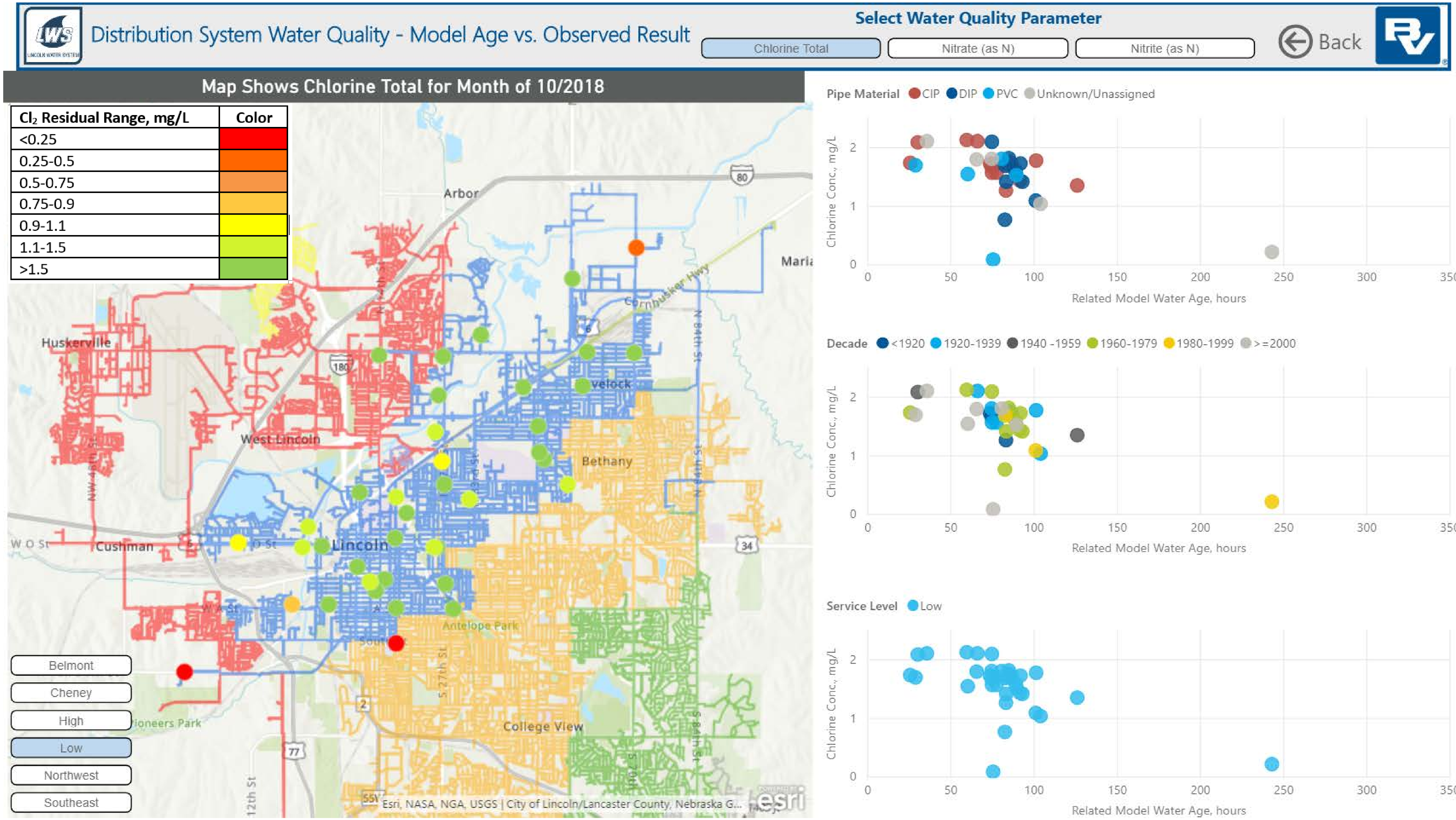

Figure 7-34 **Low SL Modeled Water Age vs. Observed Chlorine Residual**

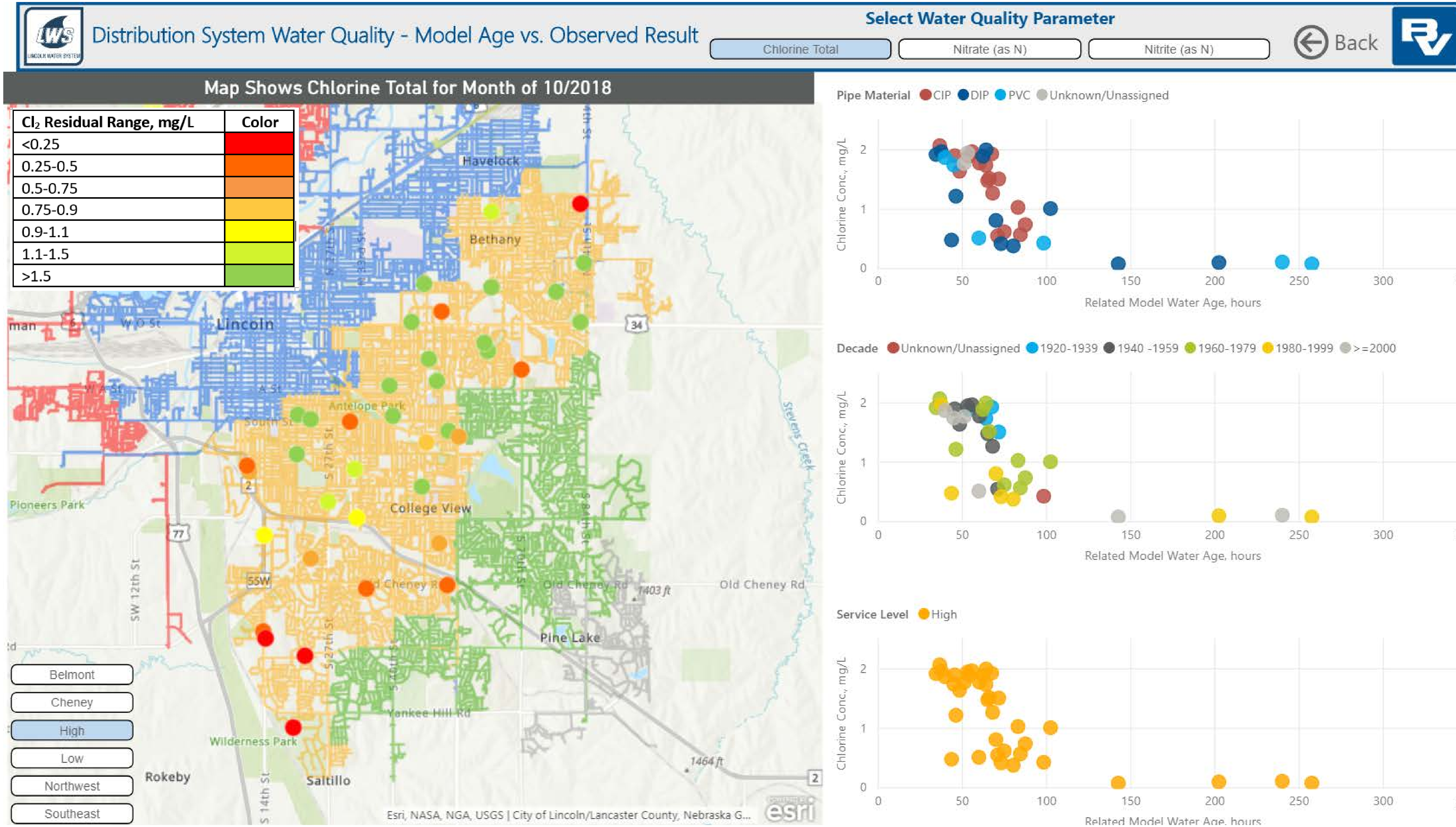

Figure 7-35 **High SL Modeled Water Age vs. Observed Chlorine Residual**

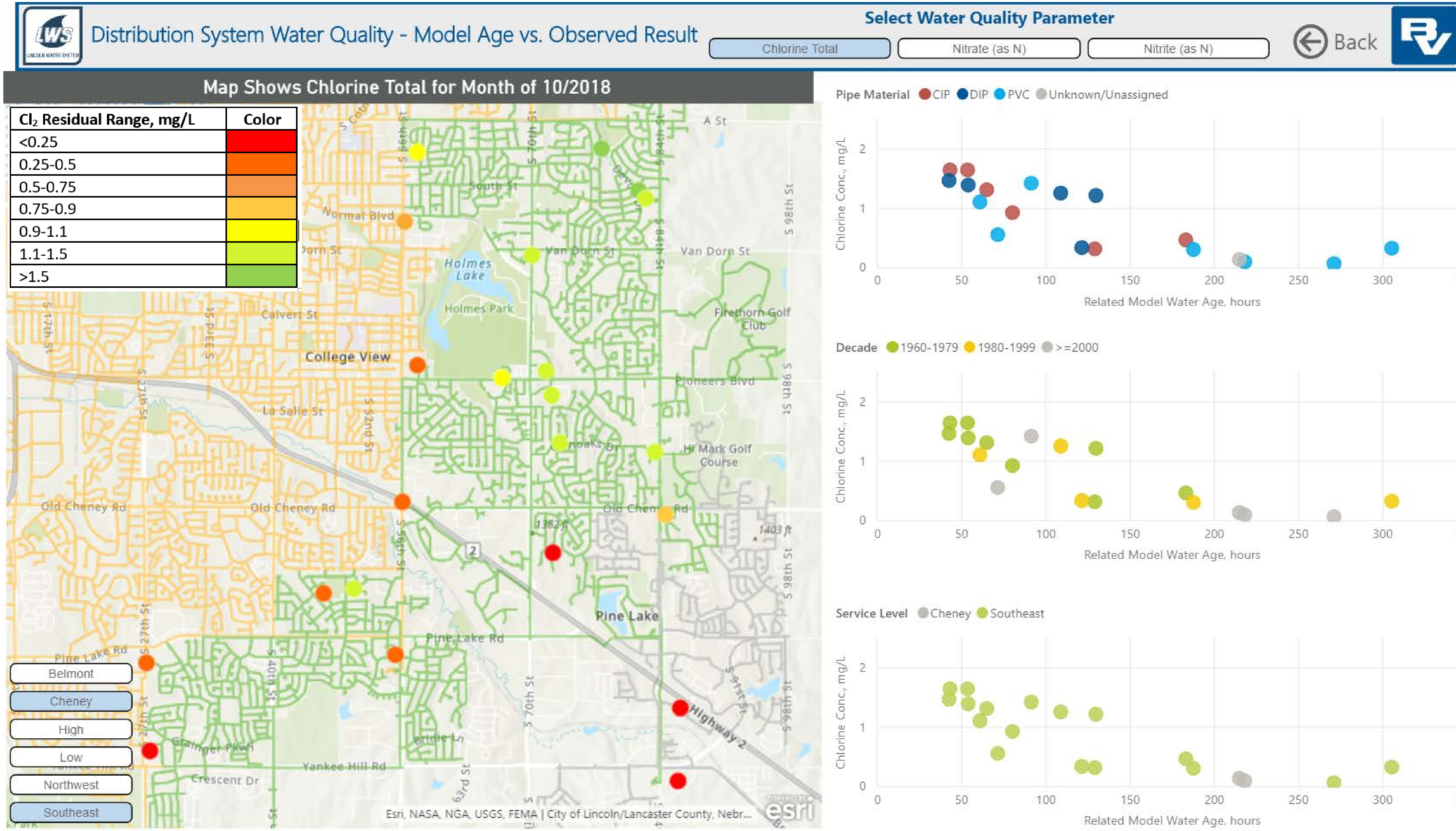

Figure 7-36 **Southeast/Cheney SL Modeled Water Age vs. Observed Chlorine Residual**

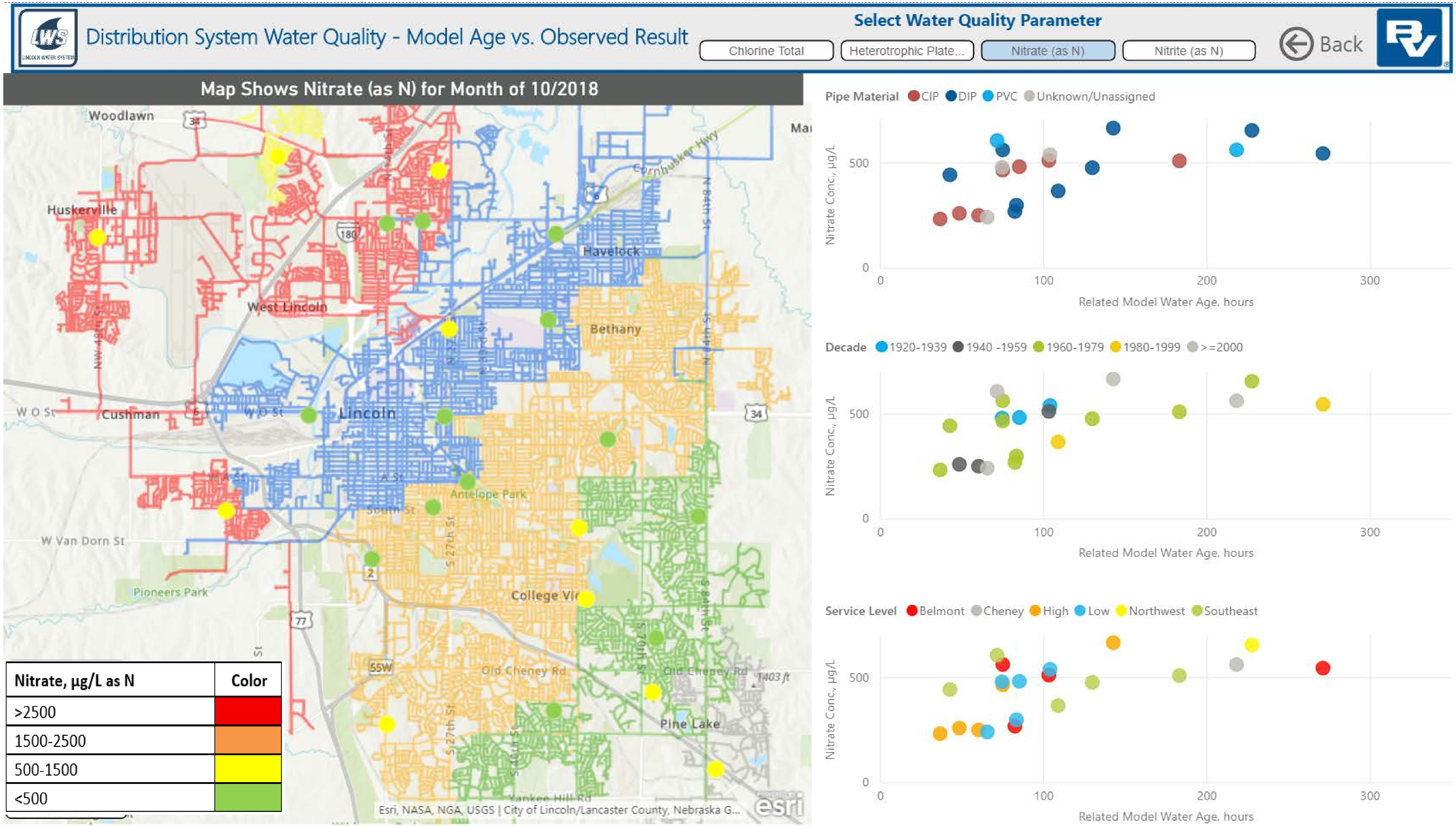

Figure 7-37 **Overall System Modeled Water Age vs. Observed Nitrate Concentration**

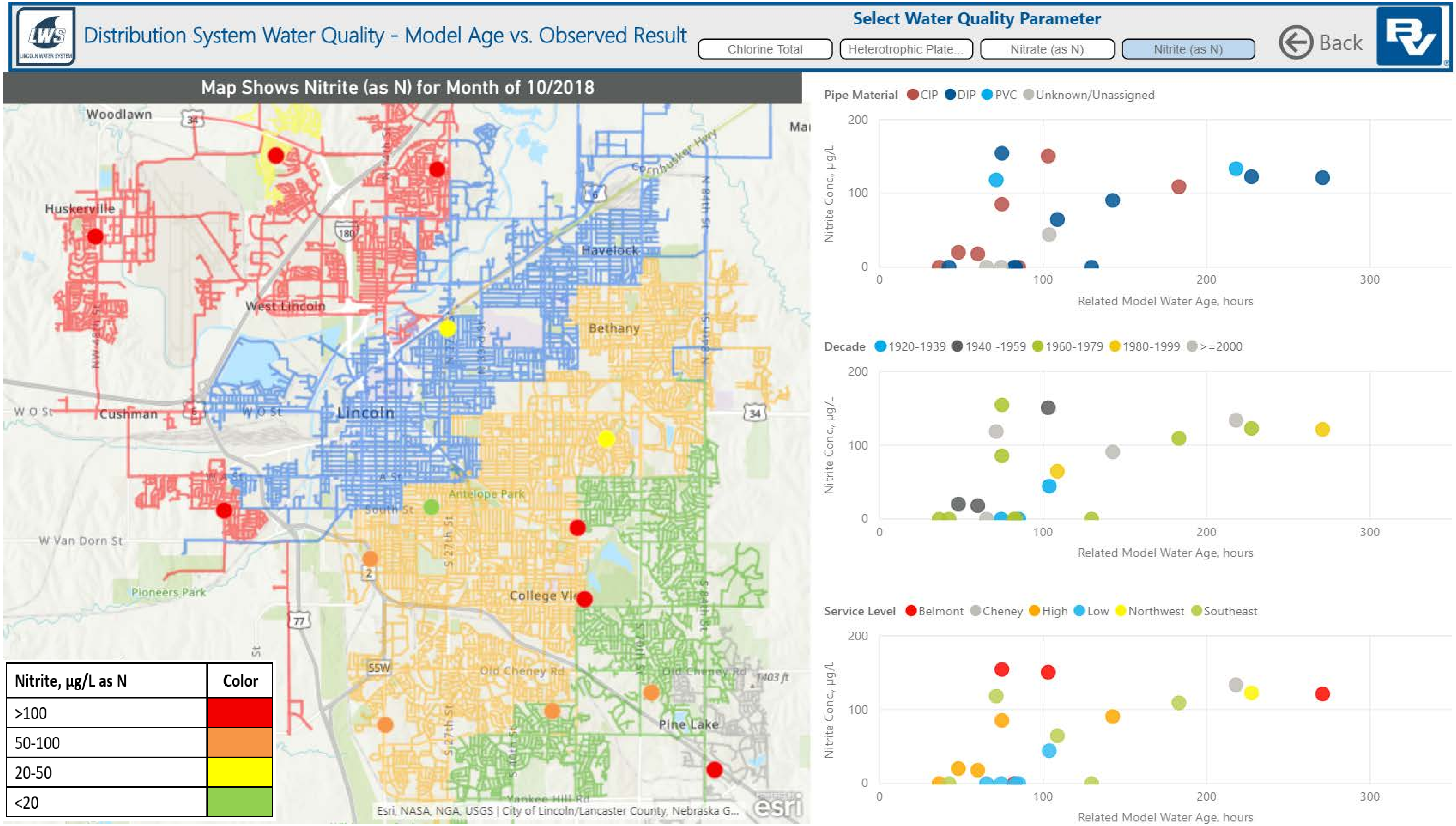

Figure 7-38 **Overall System Modeled Water Age vs. Nitrite Concentration**

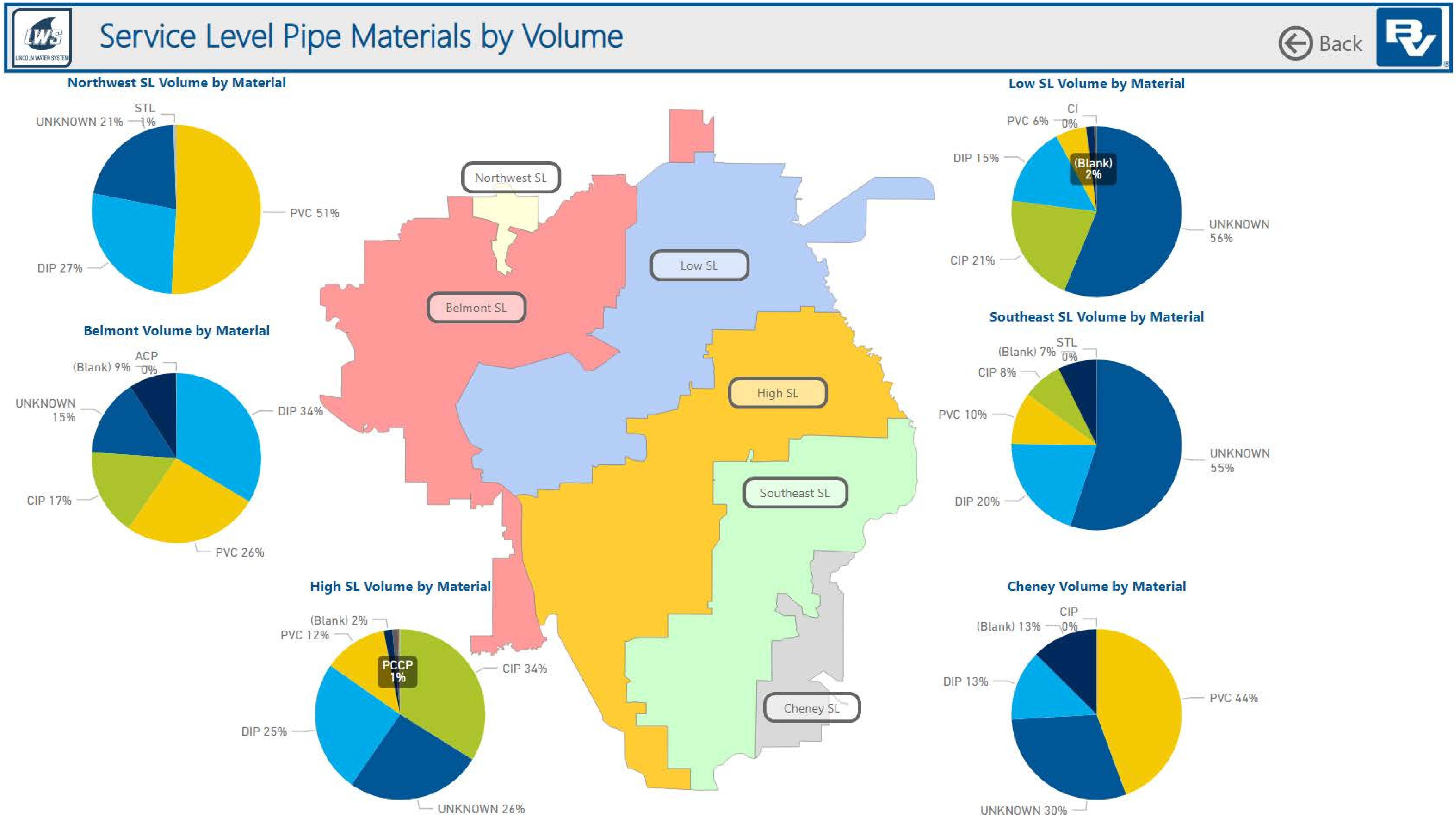

Figure 7-39 Service Level Pipe Material by Volume

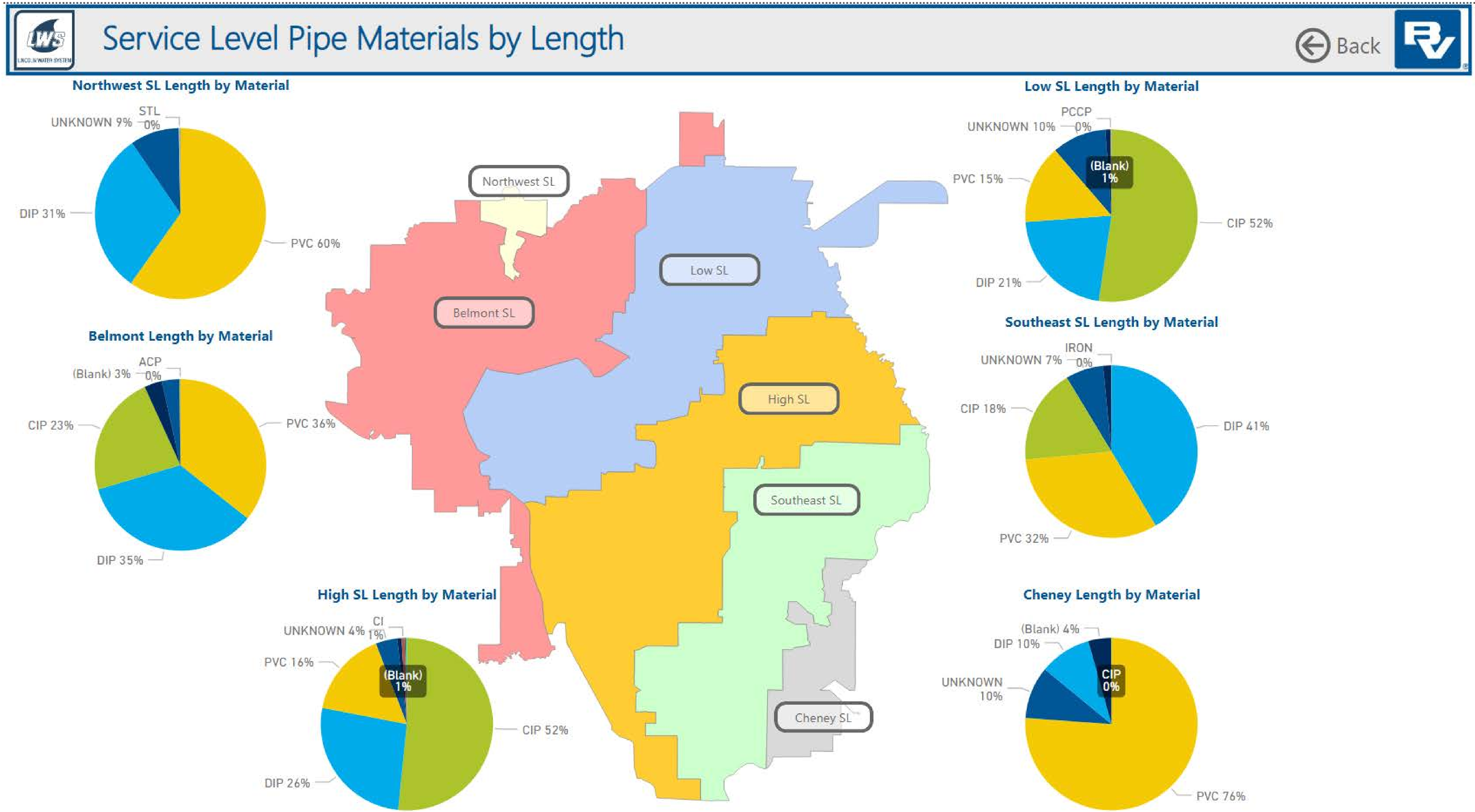

Figure 7-40 Service Level Pipe Material by Length

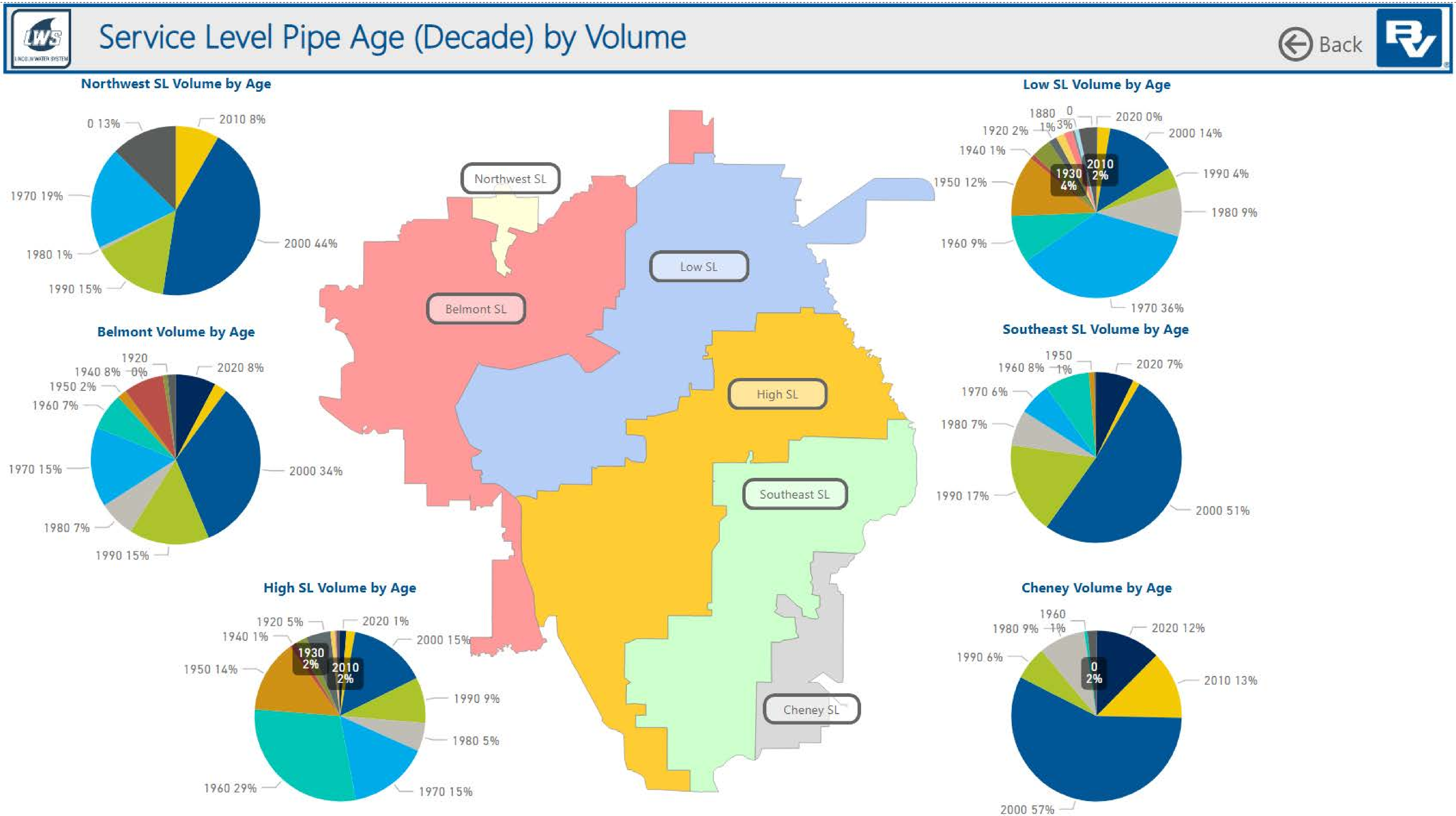

Figure 7-41 Service Level Pipe Age (Decade) by Volume

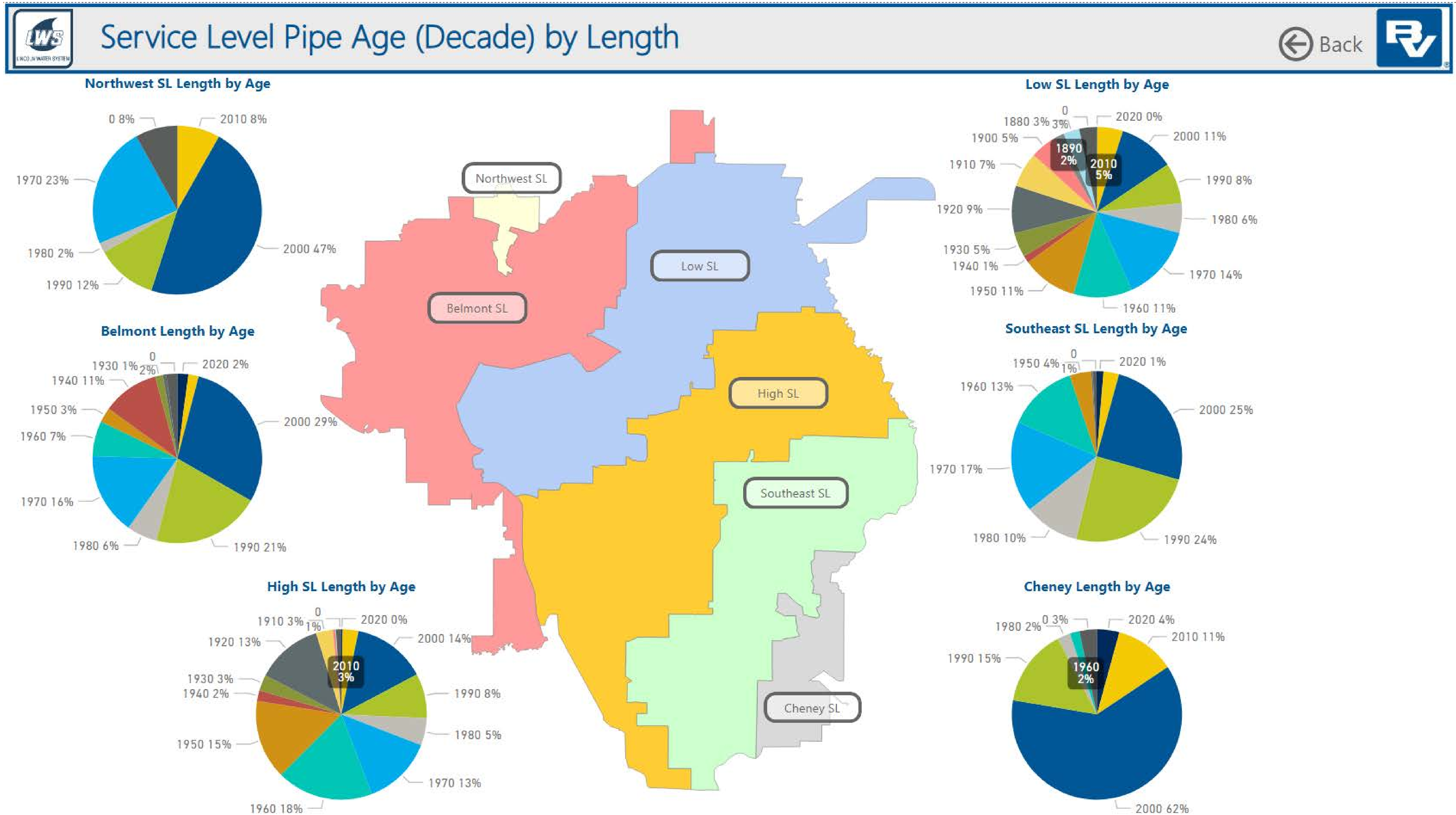

Figure 7-42 **Service Level Pipe Age (Decade) by Length**

7.1.3 Yankee Hill "Influence Zone"

One final modeling scenario was performed using the controls and operations of the Age Scenario No. 1 to determine the area impacted by the Yankee Hill Reservoir. Source trace analysis is used to identify the percentage of water that comes from a given source (e.g. reservoir or pump station). A source trace using the Yankee Hill Reservoir as a "source" was performed and the model results were captured in the dashboard. Figure 7-43 compares the areas that are source influenced by Yankee Hill (e.g. water which feeds the area has passed through the reservoir) on the left compared with the water age modeling results on the right. The highest ages in the southwest portion of the Southeast Service Level can be attributed almost exclusively to the fact that a blended 80-percent of the water has passed through the Yankee Hill Reservoir and then comes across to this area through the new main along Yankee Hill Drive. An alternative way to think about this blending area is that 8 times out of 10, when a customer opens their tap, they would be receiving water that has resided in or passed through the reservoir.

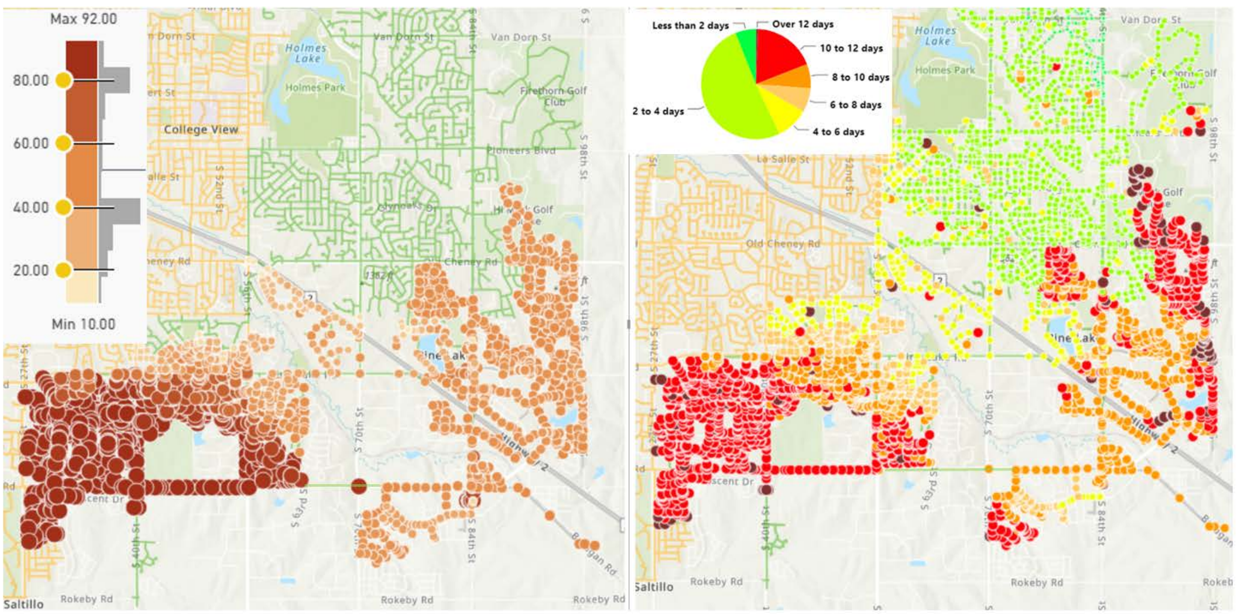

Figure 7-43 Yankee Hill Source Influence vs. Southeast/Cheney Water Age

7.8 Distribution System Water Quality Improvement Alternatives

7.8.1 Water Quality Modeling Alternatives

Additional water age modeling was performed to evaluate the impact that auto-flushers may have in reducing water age and consequently improving water quality. Generally, it takes a large volume of water flushed before major improvements in water quality can be observed. To provide an example of this, in 2018 Black & Veatch worked on an auto-flushing optimization project with a confidential utility in the southeast part of the country. As part of this project, extensive field testing and sampling was performed with the utility's current auto-flushing program. This utility maintains over 30 auto-flushers in a system a little larger than the Belmont Service Level. The utility desired to understand the impact on water quality from operating this many auto-flushers and to quantify the benefits relative to the expense of increased operational costs. Water quality sampling was performed at 50 different locations at, near, and distant from the existing auto-flushers for a week when the auto-flushers had been turned off for the prior three-weeks and for a week when the auto-flushers had been operating for the prior three-weeks. Chlorine residuals leaving the plant were maintained at a constant value through these periods to provide as much consistency with the sampling data as possible and utility operations for pumping and the use of storage were also maintained consistent during the non-flushing and flushing sampling periods. The weather and temperature, fortunately, were relatively consistent through both periods.

The results of the program demonstrated that in the sampling areas where auto-flushers were located, there was an improvement in water quality. However, the water quality benefits were not as significant as originally anticipated. Additionally, locations further away from the auto-flushers (a few blocks over or somewhere else in the system between the supply and the auto-flusher locations) experienced a range of marginal to almost negligible difference in water quality. As a result of this project, the utility decided to reduce the number of existing auto-flushers rather than to continue installing more auto-flushers. The utility was able to identify and prioritize auto-flushing locations that had the highest positive impact on water quality.

This example was provided not to discourage the installation of auto-flushers or to argue against them but to provide a cautionary example of implementing auto-flushers as a global solution to water quality. Locations should be carefully developed when installing auto-flushers, as should the dates/times/rates of the auto-flushing. The *2014 Master Plan* identified some key locations that auto-flushers could be placed to improve water quality and in review of these locations they appear to be well-placed. The modeling age modeling with flushing which will be shown on the following pages, also supports these locations. With the addition of auto-flushers, it should be recognized that their zone of influence could be more localized and will not resolve most water quality concerns in a Service Level, unless the flushing-to-demand ratios are very high. One additional consideration when using auto-flushing equipment that senses chlorine residual and responds in kind, is that flushing could occur very frequently if left on auto-control at some locations because chlorine residuals may be consistently below the desired threshold during the more water quality challenging times of the year. Caution should be taken when setting up auto-flushing controls to avoid over-flushing and having too large of an impact on the cost of operations.

To quantify the benefits to water quality vs. the volume of water flushed, four locations were selected in the model to simulate auto-flushers and to review the water age results. A conservatively large flushing volume was used at these locations and they were simulated as an every-day flush at a rate of 150 gpm for a two-hour period in the early morning. This relates to a conservatively large daily volume of 18,000 gallons per auto-flusher. They were simulated to come on at the time when reservoirs began to fill so that it could be ensured that fresh water coming from the points of supply entry was being pulled through the system instead of pulling water from storage and creating a sloshing effect. The locations where these auto-flushers were simulated are the following:

- Cheney Service Level - Dempster Drive & Countryview Road
- Northwest Service Level - Isaac Drive & NW 10th Street
- Southeast Service Level – Whispering Wind Boulevard and S. 29th Street
- Belmont Service Level - Folsom Street & W. Denton Road

The results of the third water age scenario with high auto-flushing volumes at the four locations noted above were compared against the base water age scenario to illustrate the difference. These are shown in Figure 7-44 through Figure 7-51 by Service Level for both the average water age and for the maximum water age. There were insignificant differences in water age in the Low Service Level and the High Service Level where auto-flushers were not simulated, so these are not shown. These figures indicate that the selected locations for the auto-flushers will have a positive impact on water age, though it could be less than modeled depending on the selected volumes being flushed. The smaller Service Levels of Cheney and Northwest show the most impact and it is more globally seen than in the larger Service Levels of Belmont and Southeast, where the improvements are more localized. In general, flushing at these rates could improve water age by a day or two.

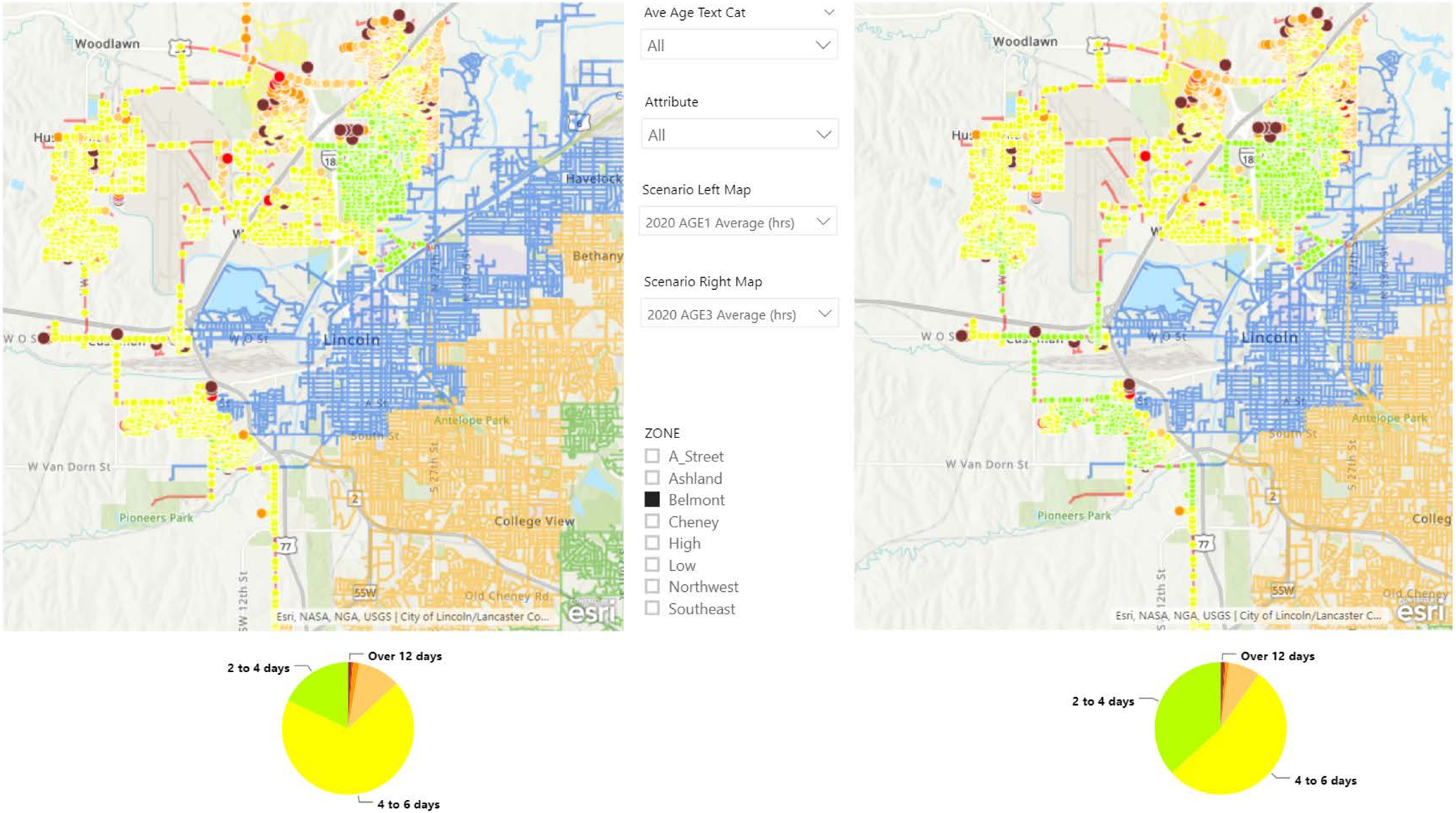

Figure 7-44 Average Water Age Comparison with Flushing – Belmont Service Level

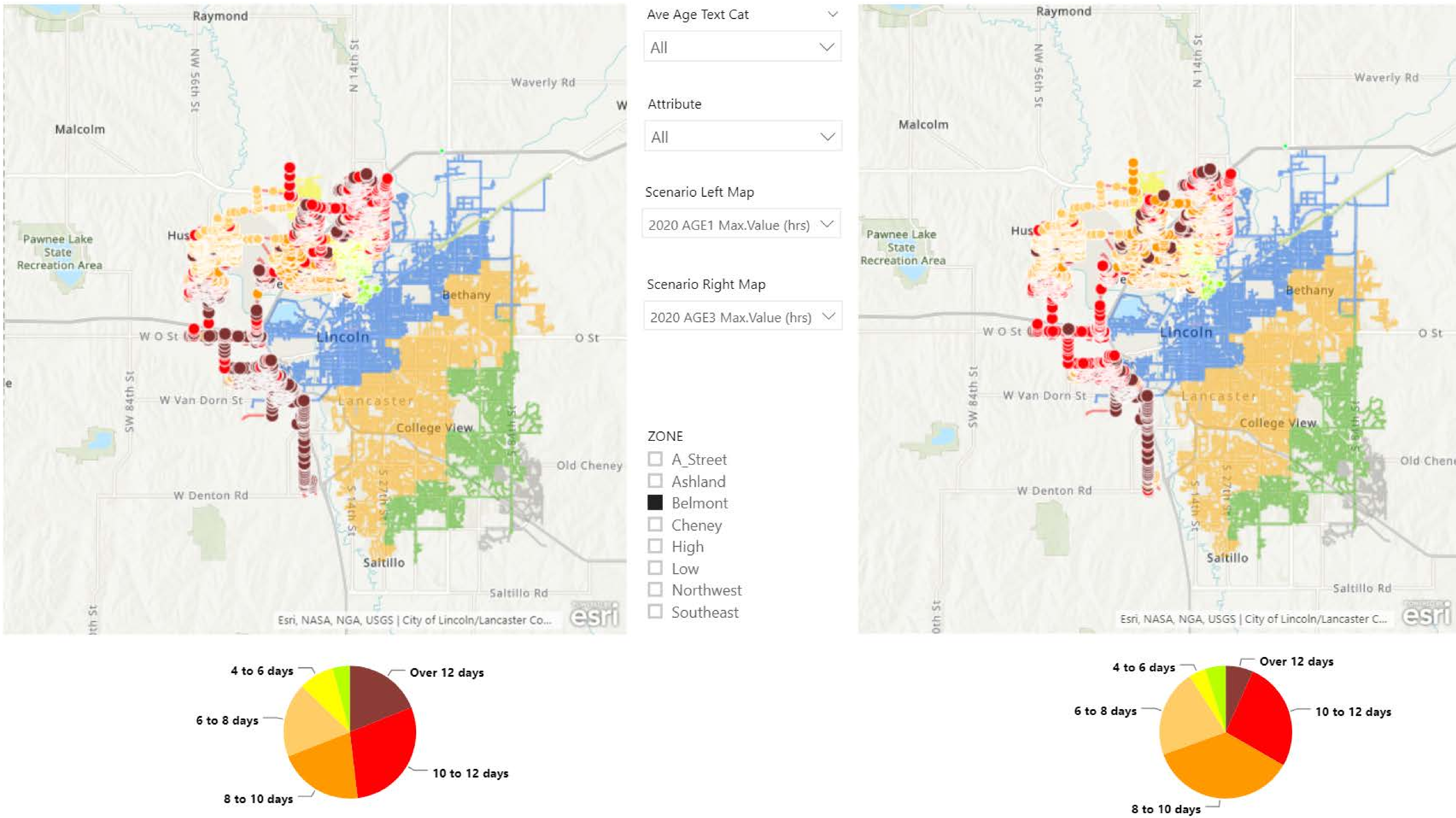

Figure 7-45 Maximum Water Age Comparison with Flushing – Belmont Service Level

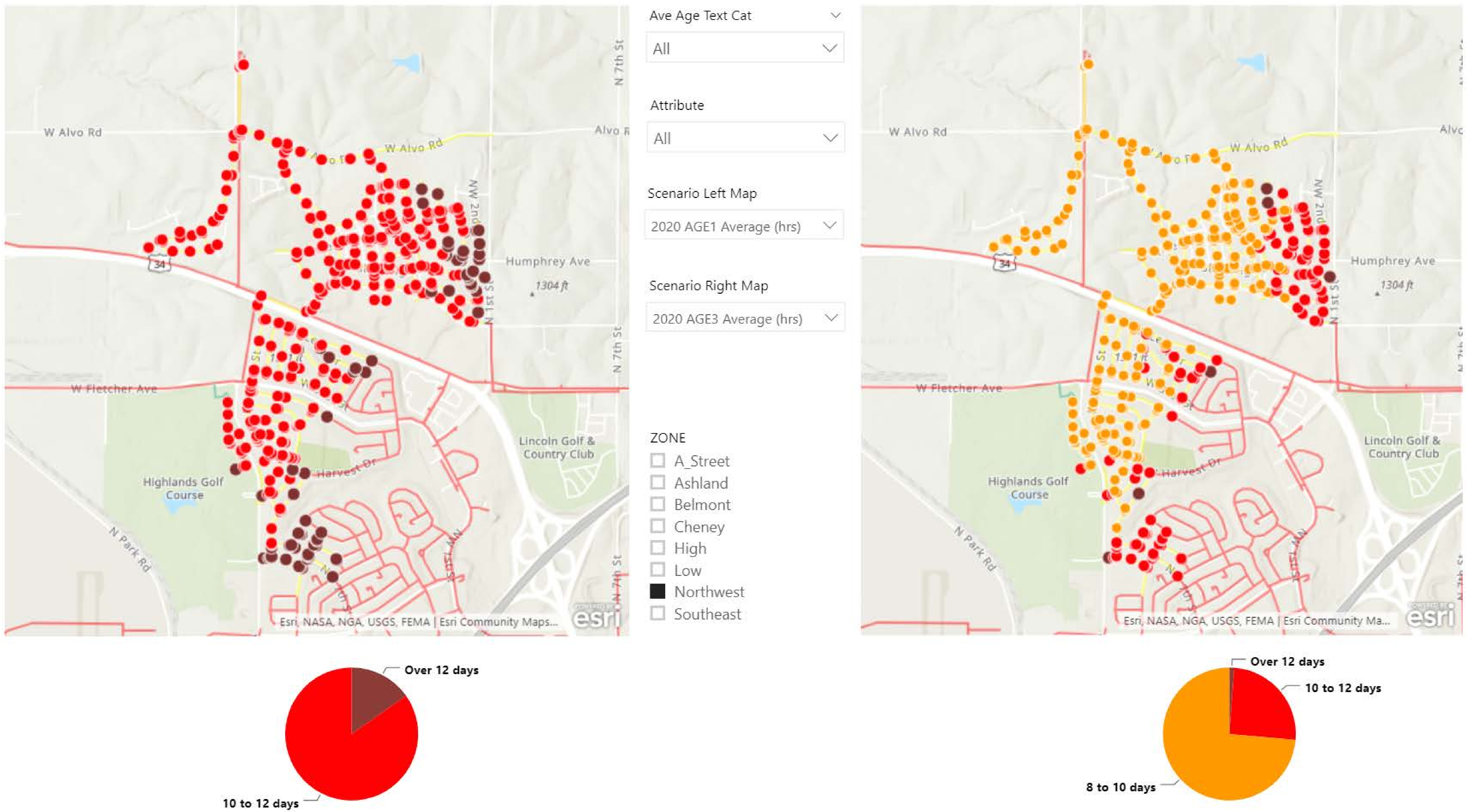

Figure 7-46 **Average Water Age Comparison with Flushing – Northwest Service Level**

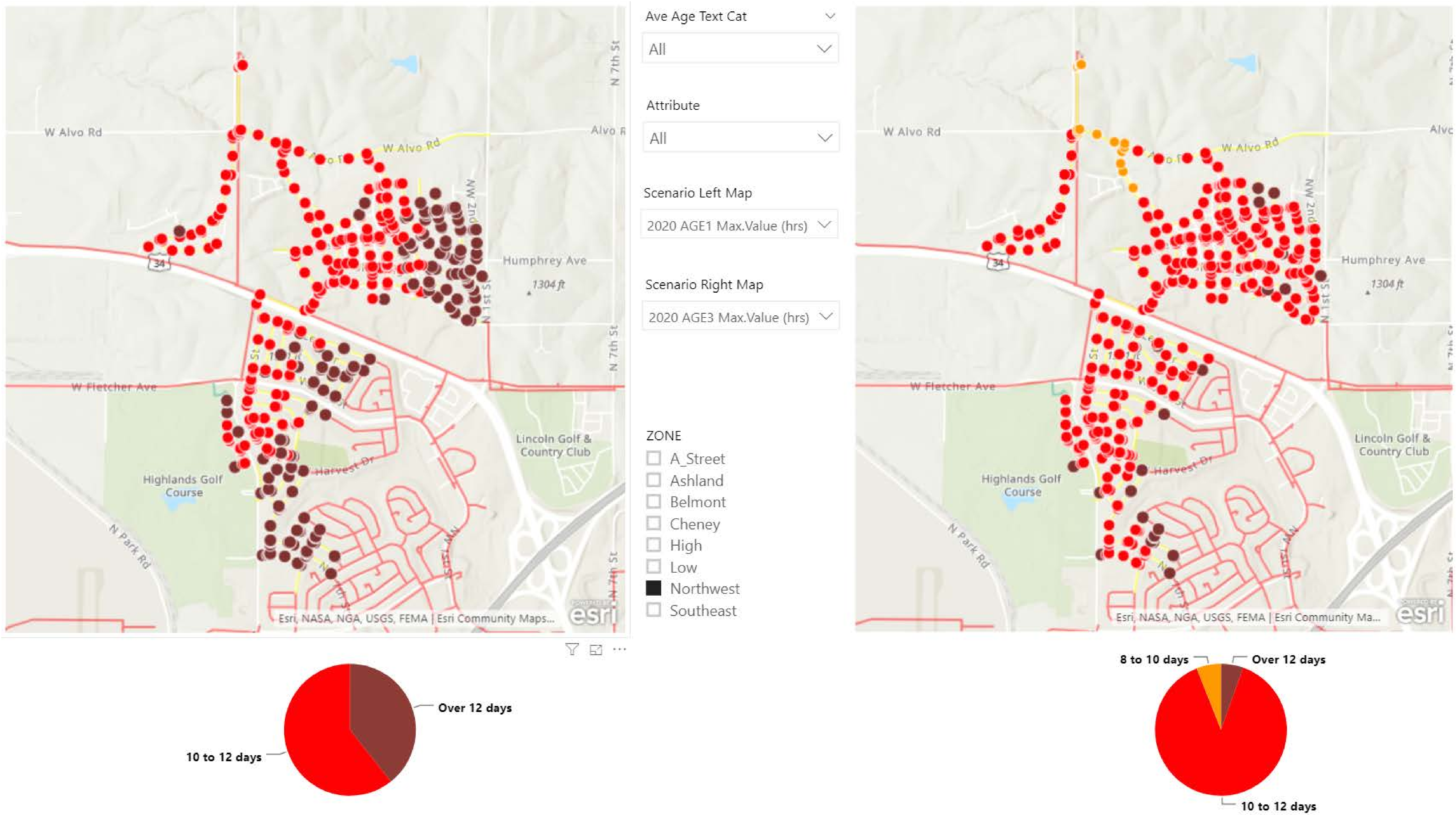

Figure 7-47 Maximum Water Age Comparison with Flushing – Northwest Service Level

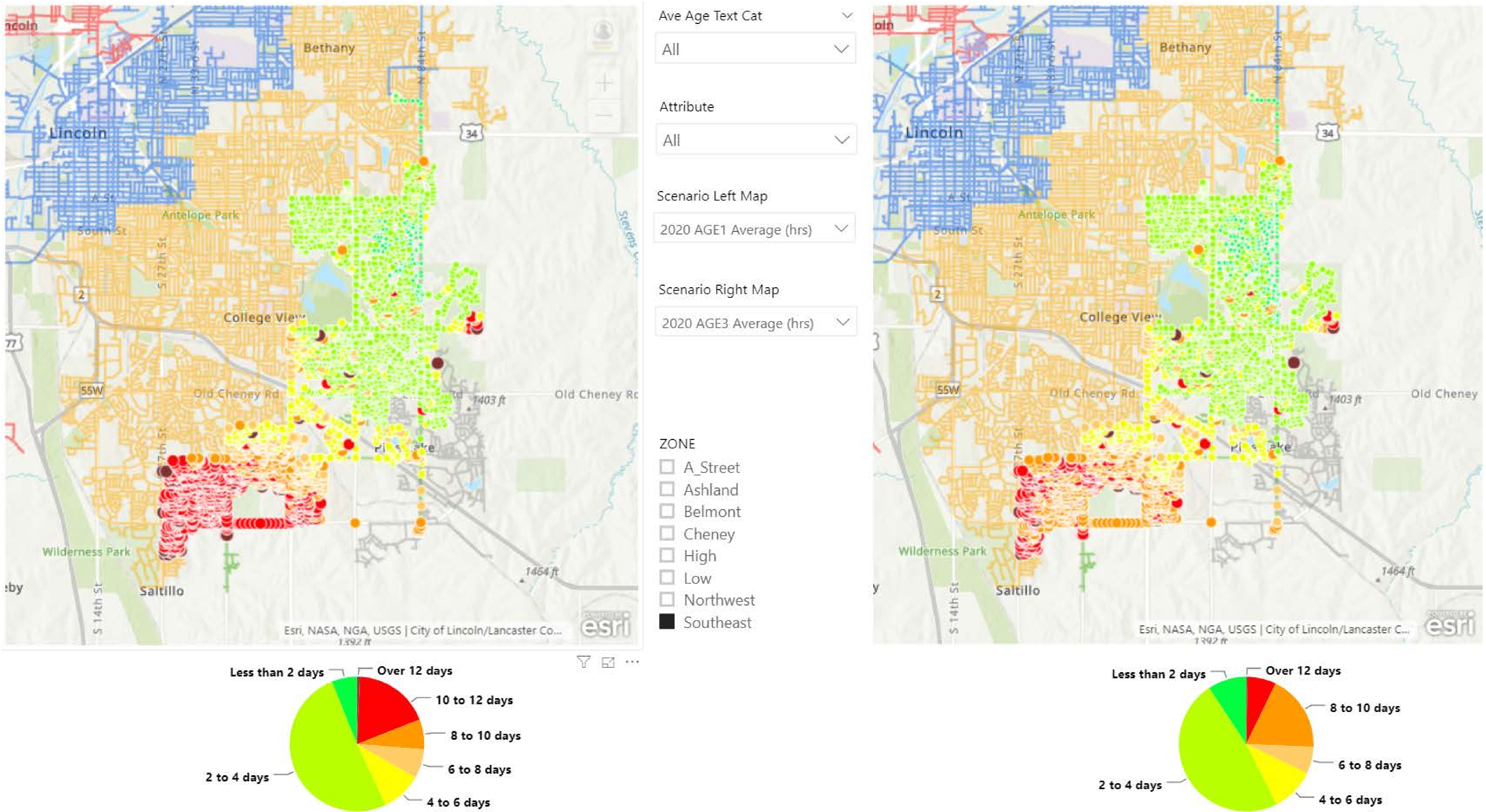

Figure 7-48 Average Water Age Comparison with Flushing – Southeast Service Level

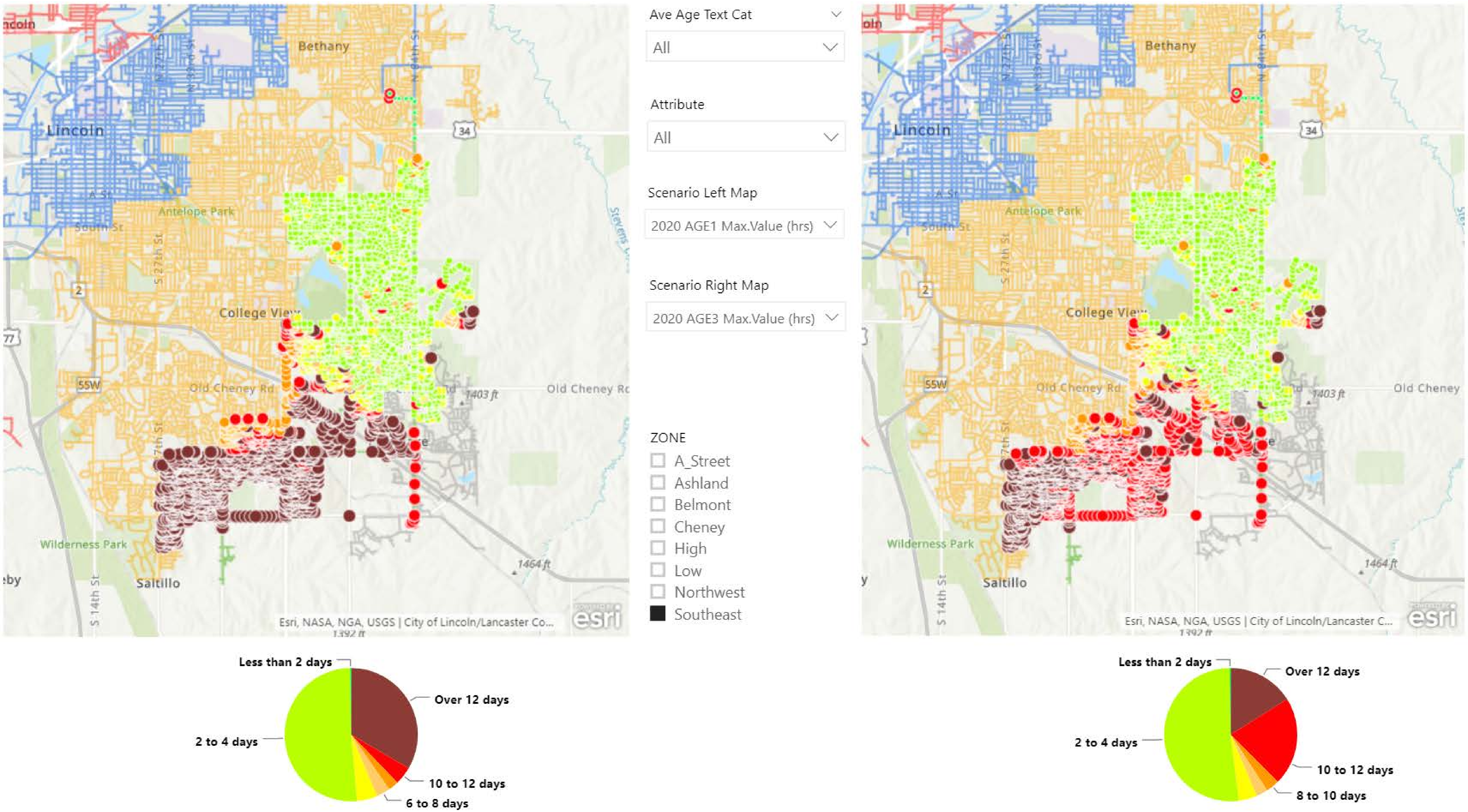

Figure 7-49 Maximum Water Age Comparison with Flushing – Southeast Service Level

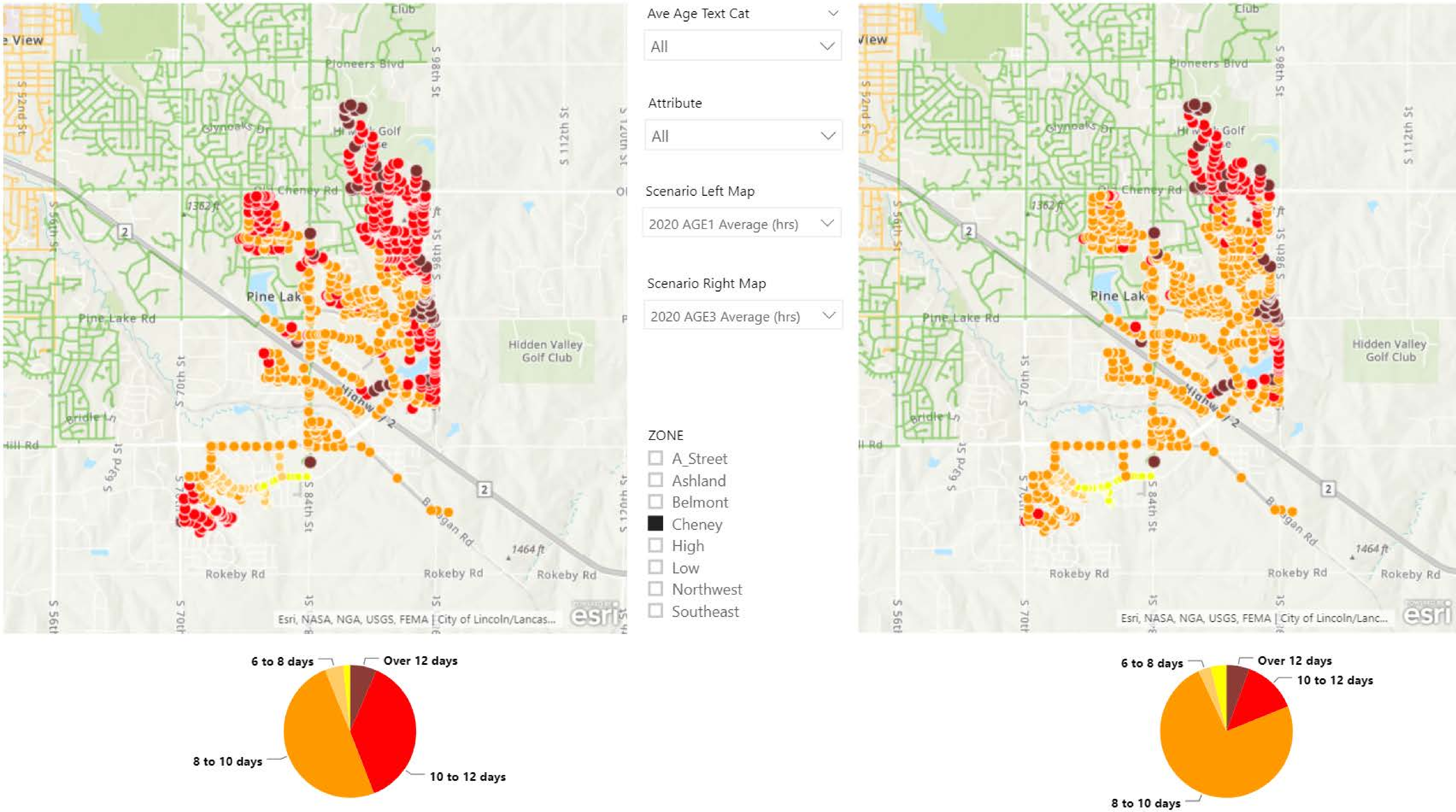

Figure 7-50 Average Water Age Comparison with Flushing – Cheney Service Level

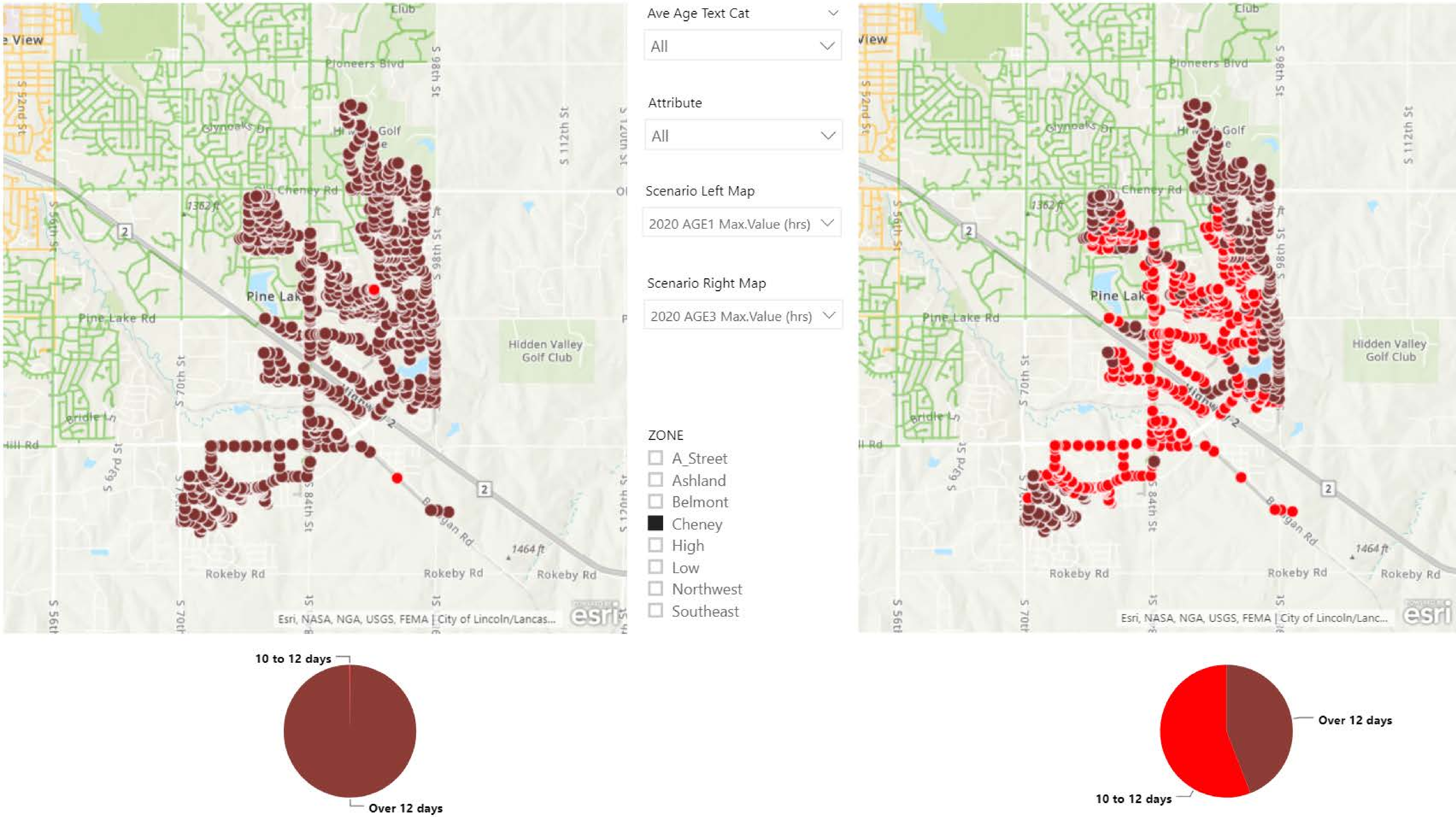

Figure 7-51 Maximum Water Age Comparison with Flushing – Cheney Service Level

7.8.2 Other Distribution Water Quality Improvement Alternatives

This section describes potential alternatives to further improve distribution system water quality, with emphasis on improving water quality in the areas surrounding the Northwest Service Level, Air Park, Cheney (southeast Lincoln), and southern parts of Southeast and High Service Levels. These areas generally encompass the southern and western areas of the distribution system, which are furthest from where water enters the distribution system on the northeast corner and historically have had difficulty with chlorine residual degradation.

7.8.2.1 Chloramine Booster Systems

Chloramine booster systems are being implemented throughout the United States to address degradation of disinfectant residual by increasing the chloramine residual in distribution system reservoirs. Chloramine booster systems are remote-operated systems that include chlorine and ammonia chemical storage and feed equipment, in-tank mechanical mixing equipment, online analyzers, and a programmable logic controller. Figure 7-52 provides a process schematic of the UGSI Monochlor® system, which is one of the equipment suppliers for chloramine booster systems.

Figure 7-52 Process Schematic of UGSI Monochlor® Chloramine Booster System

Chemicals are typically supplied in liquid form as sodium hypochlorite and liquid ammonium sulfate to minimize operational complexity and eliminate safety concerns associated with gaseous chlorine. A mechanical mixing system is installed within the reservoir to provide adequate dispersion of chemical and create a homogeneous mixture within the reservoir. Chlorine residual analyzers are then used to control the chlorine and ammonia feed rates, based on a target total chlorine residual and a chlorine-to-ammonia ratio of 5:1. Typically, a target total chlorine residual ranging from 1.5 mg/L to 2.5 mg/L is selected, and the PLC is used to control chlorine and ammonia feed rates based on breakpoint chemistry.

Given the challenges with maintaining the total chlorine residual in the far reaches of the distribution system (Belmont, Northwest, portions of Southeast and Cheney Service Levels), it is recommended that LWS implement chloramine booster systems to address residual degradation in those areas. The Yankee Hill Reservoir has been identified as the preferred location for implementation of a chloramine booster system to improve water quality in the Cheney Service Level, as well as along the southern reaches of the Southeast Service Level. To improve water quality in the Belmont and Northwest Service Levels, two locations have been proposed: Pioneers Reservoir and Northwest 12th Street Reservoir (NW12th). Water age and source trace modeling was conducted to simulate the potential improvement to water age (as an indicator of water quality) associated with implementing chloramine booster systems at the two locations. Preliminary findings from this analysis indicate that both locations provide water quality improvements with similar degrees of influence. Implementing a rechloramination system at Pioneers provides immediate water quality improvements to Air Park, whereas implementing at the NW12th location may not directly address Air Park based on the operating conditions and flow paths simulated by the model. Alternatively, the NW12th location is expected to provide water quality improvements over a broader area within Belmont and the Northwest Service Level, so additional consideration should be given to account for overall impact on water quality, ease of operations, and constructability at each location.

7.8.2.2 Biological Filtration

Biological filtration is often implemented downstream of ozonation as a means for reducing the biological organic matter (BOM) formed during ozonation. BOM is typically characterized and measured by the concentration of assimilable organic carbon (AOC) or biodegradable dissolved organic carbon (BDOC) present in a water sample. As noted in Chapter 5, the East Plant finished water has moderate to high concentrations of AOC. Between January 2001 and July 2009, the average and maximum concentration of AOC in the East Plant finished water was 154 µg/L and 350 µg/L, respectively.

Given that ozonation is utilized at the East Plant, biological filtration may present an opportunity to improve biological stability in the distribution system. Biological filtration is a process that reduces or eliminates the presence of chlorine residual upstream of filtration, allowing biological growth to occur on top of the filter media for enhanced removal of organics and inorganics. Biological filtration is often effective for decreasing biological activity in the distribution system, since the biomass that develops on the filter media utilizes biodegradable organic matter as a substrate.

A filter pilot study was conducted by Black & Veatch in Year 1995 to evaluate the performance of oxidant and polymer application for manganese removal. In the pilot study, a low chlorine residual was maintained over the filters to form a manganese oxide coating on the filters for enhanced removal of manganese. The low chlorine residual may have allowed for biological activity in deeper parts of the filter bed. Since the primary goal of this study was to evaluate the feasibility and effectiveness of manganese removal, additional pilot testing should be considered to evaluate the merits of biological filtration for removing AOC to reduce biological activity in the distribution system. Pilot testing should be conducted over a 9-month period overlapping with summer/fall months. Pilot testing should be done as a side-by-side comparison against current filter operations to evaluate the effectiveness of biological filtration on AOC removal relative to a baseline condition. The biological filtration column will require chemical feed to eliminate the chlorine residual upstream of the filter. Both columns should be monitored for water quality parameters related to biological stability and finished water quality, including AOC, TOC/DOC, turbidity, pH and alkalinity.

7.8.2.3 Sodium Chlorite

The addition of sodium chlorite at low doses has shown potential in some systems for controlling microbial regrowth in the distribution system. Chlorite is particularly effective at inactivating ammonia oxidizing bacteria, which makes it a potential alternative for nitrification control and distribution system water quality improvement. Systems that utilize sodium chlorite to control nitrification and bacterial regrowth typically feed at a dose of 0.30 mg/L, which is well below the MCL of 1.0 mg/L. Pilot testing should be conducted over a 9-month period to determine the feasibility of this treatment approach. Pilot testing usually consists of benchtop bioreactors and small-scale pipe systems with stagnation periods to simulate distribution water age. The bioreactors contain coupons, which can be extracted at various stages in the pilot study for DNA speciation to quantify the effectiveness of chlorite for reducing AOBs in biofilm. Two bioreactors would be required for this pilot study to compare the effectiveness of sodium chlorite against current operations (plant finished water).

7.8.2.4 Improvements to Tank Mixing

Poor tank mixing can lead to stratification within tanks, which can affect effluent water quality (particularly temperature and chlorine residual). Implementation of new mixing equipment in the distribution system reservoirs could potentially improve issues with chlorine residual management. Given the recent installation of tank mixing equipment in the South 56th St and Pioneers Reservoirs, it is recommended that LWS conduct a study to evaluate the effectiveness of existing tank mixing systems. The study would focus on the benefits of the existing mixing equipment and determine whether LWS should continue implementing in other tanks. The study could be conducted over a two-week period, monitoring the inlet and outlet water temperature and chlorine residual. In the first week of the study, the existing mixers would be in operation, and in the second week of the study, the mixers would be turned off. Flow rate in and out of the tank should be relatively constant over the two-week testing period in order to draw effective comparisons between the two operating conditions.

7.9 Distribution System Water Quality Summary & Recommendations

Based on a review of distribution water quality data, LWS has demonstrated effective management of DBPs and as a result, is on reduced monitoring for bromate, TTHM and HAA5. LWS has maintained a bromate RAA of less than 25 percent of the MCL since 2013. Similarly, the LRAA for TTHMs has consistently been less than 40 µg/L (50 percent of the MCL), and the LRAA for HAA5s has been maintained at less than 20 µg/L (33 percent of the MCL).

LWS is also on reduced monitoring for lead and copper, which requires LCR compliance data to be collected every three years. The 90th percentile values for lead and copper compliance monitoring in 2013, 2016 and 2019 have been below the action levels of 15 µg/L and 1300 µg/L, respectively. The proposed LCR revisions have proposed a new lead trigger level of 10 µg/L to prompt water systems to take proactive actions to reduce lead levels prior to exceeding the lead AL. Since 2004, the 90th percentile value for lead has been less than 5 µg/L, which is well below the proposed trigger level. Additionally, given the LWS's existing LSL inventory and replacement plan, LWS is well-positioned to comply with the potential requirements for implementing a publicly available LSL inventory and proactive, full LSL replacement program.

Between 2014 and 2017, LWS experienced challenges with nitrification between the months of August and December. Nitrification was characterized by rising water temperatures, loss of chlorine residual, increases in nitrite concentration, and in some locations, occurrences of HPCs. In 2018, LWS made significant improvements in distribution system water quality through various nitrification control measures, which resulted in increased chlorine residuals throughout the distribution system and reduced nitrite and nitrate concentrations. The nitrification control measures included increasing the chlorine residual at the POE, taking the East Plant out of service during peak nitrification season, and reducing water age in the distribution system by isolating and reducing operating volumes in reservoirs.

This resulted in considerable improvements to distribution system water quality in the High, Low and Southeast Service Levels. However, the areas surrounding Air Park, Northwest, Cheney, and southern parts of Southeast still had difficulty maintaining chlorine residuals greater than 0.5 mg/L at the distribution system monitoring sites. Additionally, alternative long-term solutions should be investigated, since taking the East Plant out of service limits the overall plant capacity and is not sustainable for future operations. Potential long-term solutions include:

- Chloramine booster systems within the distribution system.
- Improvements to tank mixing in distribution system reservoirs.
- Biological filtration at the East Plant.
- Sodium chlorite feed at the East and West Plant.

Given the continued challenges in Air Park, Northwest, Cheney and southern parts of Southeast Service Levels; a source trace analysis was conducted to identify optimal locations for chloramine booster systems. Source trace analysis is used to identify the percentage of water that comes from a given source, allowing for easier identification of areas that can provide a high impact on water quality. Based on the source trace analysis, it was determined that the most beneficial locations for installation of chloramine booster systems would be at Yankee Hill and Pioneers Reservoirs.

- **Yankee Hill** – Most of the water in the Cheney SL and southern parts of Southeast SL has passed through the Yankee Hill reservoir, making it an ideal location for rechloramination. It is also recommended that a PRV be installed around 84th and South Street to allow rechloraminated water to be transferred to the High SL to address pockets with low chlorine residual.
- **Pioneers** –The source trace analysis found that during winter operations, over 80 percent of the water in Air Park has been pumped through Pioneers Pumping Station. With such a high proportion of water from Pioneers being delivered to these areas, there is a meaningful opportunity to improve distribution water quality through rechloramination at Pioneers.

For the time being, it is recommended that LWS continue with their current nitrification control measures, while other in-plant treatment and distribution system management alternatives are evaluated. The following alternatives for distribution system water quality improvements are recommended for further evaluation through pilot testing. Each of the proposed treatment alternatives should be compared with the plant's current operating conditions to establish a baseline and determine the preferred approach for nitrification control.

- **Biological filtration** – This alternative considers implementation of biological filtration in the East Plant to reduce the concentration of AOC, which is increased during the ozonation process. Reducing the AOC in the finished water will improve biological stability in the distribution system, which could allow for continued use of the East Plant during peak nitrification seasons.
- **Sodium chlorite** – This alternative considers feeding 0.3 mg/L of sodium chlorite to the plant finished water. Sodium chlorite is particularly effective at inactivating ammonia oxidizing bacteria and has proven to be effective for nitrification control for other utilities in the Midwest.
- **Improvements to Tank Mixing** – This alternative considers field-testing to evaluate the performance of existing distribution system tank mixing systems to provide guidance on future implementation strategies to reduce potential for stratification.

7.10 References

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