

Gap Analysis of the United States Geologic Survey's Streamgauge Network

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Executive Summary

While the United States Geological Survey's Streamgage Network is one of the most extensive in the world, it still contains large gaps in various regions across the United States. This report investigates where these gaps are located across the continental United States and offers a rationale for expanding the network based on projected climate change impacts, as outlined by the Fourth National Climate Assessment. Gaps were determined by the ratio of gaged area in each National Oceanic and Atmospheric Administration climate division. Climate divisions in coastal areas and the Mountain West lack gaging most dramatically, while the Midwest and Northern Great Plains are most extensively gaged. Expanded stream monitoring should be prioritized in coastal areas due to the high population concentration and extensive climate impacts. All other streamgage gaps with climate priorities should be implemented by population size and economic prosperity to minimize widespread impacts.

Gap Analysis of the United States Geologic Survey's Streamgage Network

In 2022, the United States Geologic Survey (USGS) conducted a network analysis on its streamgage system to explore the extent of its coverage across the nation. This piecemeal analysis divided the nation into two units to measure gaging capabilities: incremental gaged areas, which are the areas between two downstream gages and 12-digit hydrologic unit code areas (HUC12s), which are small, sub-basin areas of roughly 90 square kilometers. These two metrics were used to identify gaps in the network. The smaller monitored areas were then related to the 344 climate divisions across the continental United States to create a more comprehensive image of gage coverage. The study was successful and identified gaps largely along coastlines and in the Mountain West as well as some under monitored climate divisions within the nation's interior.

The USGS study provides a broad framework of what areas in the continental United States objectively require the expansion of the streamgage program based on spatial necessity. It categorizes incremental gaged areas into three main categories: maintain sites, add and maintain sites, and add sites. Maintain sites designates the area as already being adequately monitored and well-gaged, with only upkeep of existing streamgages necessary to meet gaging needs. Add sites and maintain sites as a category requires not only the upkeep of existing gages but also the expansion of the stream monitoring system in the region, implying that there are existing gages in the area. Add sites alone implies that there are not enough gages in the area to require maintenance and that increasing the gaged area is necessary. HUC12s are categorized much more simply; they are either labelled gaged or ungaged because of their small size.

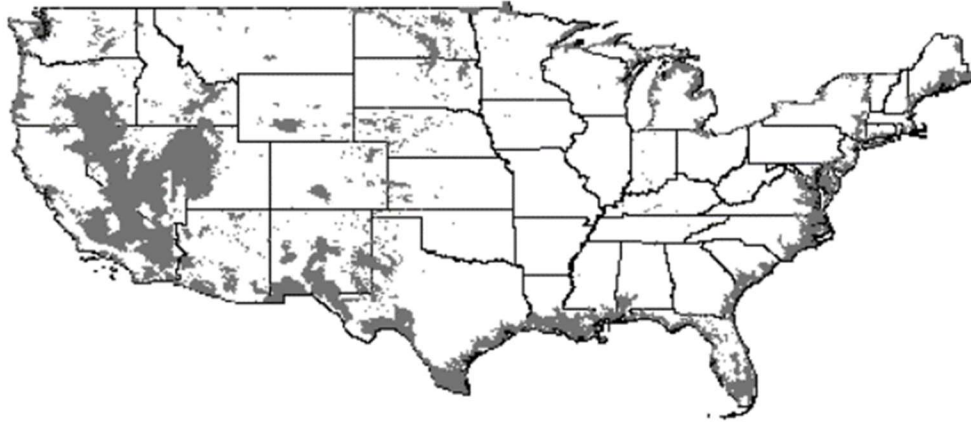


Figure 1: A map of the ungaged HUC12s across the contiguous United States. Source: Christopher Konrad.

This report uses the spatial gaps outlined within the USGS study and provides a justification for expanding the streamgaging system using the projected hydrologic changes due to climate change as outlined by National Climate Assessment. The National Climate Assessment analyzes the various impacts of climate change on regions across the United States, ranging from sea level rise to increasing wildfires. Combining these impacts with local gaps in the stream monitoring system emphasizes the importance of expanding the network and a strong justification for additional funding.

The process applied in this gap analysis followed a procedure of analyzing the current state of the region's streamgaging, where additional gages should be added, and the importance of reaching these goals. The current state was evaluated by analyzing which climate divisions in each region and state required expanding gaging capacity. Some qualitative observations were included about trends in ungaged locations, such as the urban versus rural areas in a division or unique trends in that division. These discussions were almost purely based on the USGS' network analysis and can be confirmed by viewing their in-depth maps. The maps attached

below served as the basis for determining which climate divisions were deemed in need of expanded gaging.

Climate Divisions by Area Percentage Ungaged

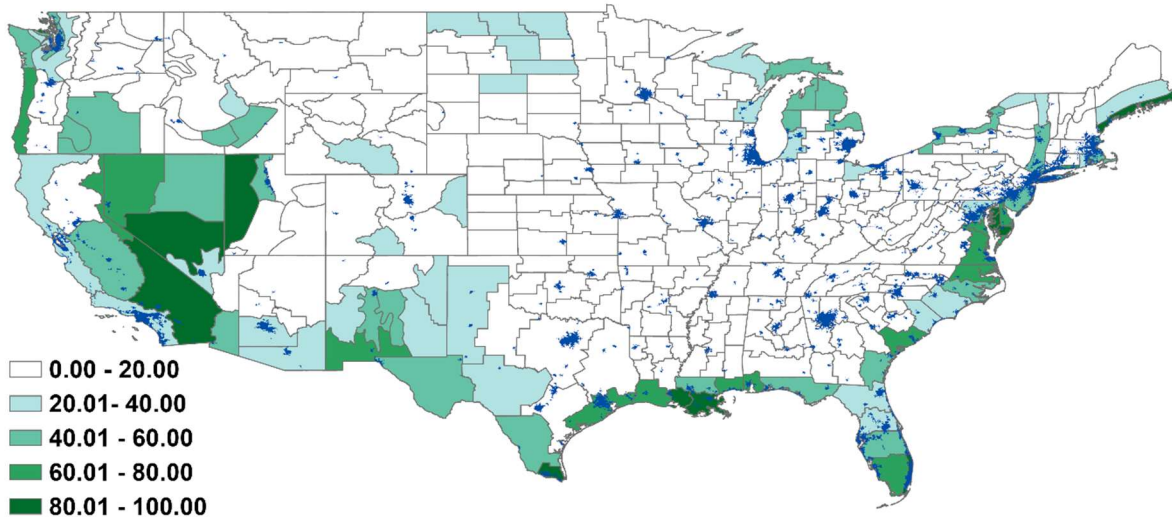


Figure 3: A map representing the percent area ungaged in each climate division across the United States. The blue markings overlay the population clusters across the United States. Source: Kaitlyn Engel

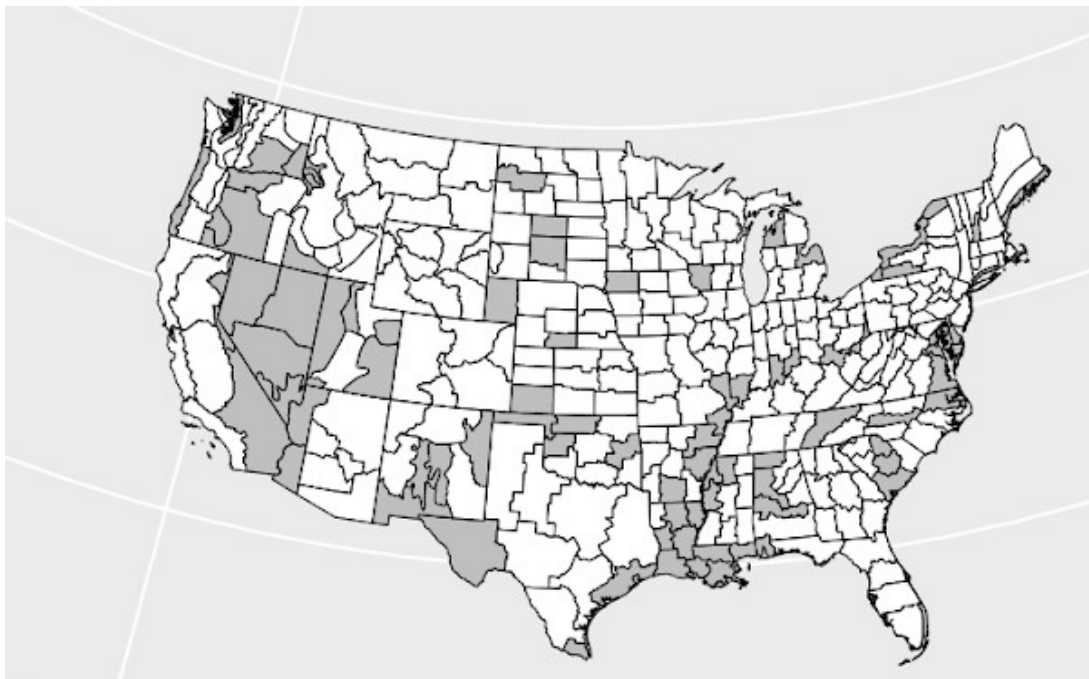


Figure 2: A map representing climate divisions that need additional gaging, shown in dark gray. To need expanded gaging, each division must be at least 50 percent ungaged and each incremental gaged area must be at least 90 percent located within the climate division. Source: Christopher Konrad

Following the analysis of ungaged climate divisions, the rationale for expanded monitoring in the region is discussed using National Climate Assessment. The justifications emphasize the threats of climate change events and future challenges of water managers, as well as the impacts on communities within the region. These results can be updated as the new National Climate Assessment is released in late 2023 to incorporate the latest climate impacts and to better equip readers with the advocacy tools to expand streamgaging in their region.

Northeast

The Northeast Region of the National Climate Assessment includes Maine, Vermont, New Hampshire, Massachusetts, New York, Connecticut, New Jersey, Pennsylvania, Rhode Island, Maryland, Delaware, and West Virginia.

Current Regional Status of the Streamgage Network

- The interior of the region is well-gaged. Existing gage infrastructure only requires maintenance to represent the region. The exception to this is Vermont, where much of the state remains ungaged.
- Along Lake Ontario and the eastern portion of Lake Erie, streamgaging needs to be expanded.
- Landlocked, urban areas are well-gaged. Most of the streams need maintenance on their gaging.
- Conversely, coastal streams along the Atlantic seaboard are largely ungaged. This includes the various large urban areas such as New York, Providence, and Boston. This gap spans the entire coastline, from Maine to Maryland.

Locations for Gaging Expansion

State	Current Status	Specific Climate Division Improvements
Maine	Northern and central Maine is relatively well-gaged; however, the coastline divisions lack adequate gaging.	<ul style="list-style-type: none"> • Division 1703, which represents the state's coastline, is deemed the highest priority in terms of gaging. Over 80 percent of this climate division's streams are ungaged. • Division 1702, though somewhat better represented through gaging, is still insufficiently monitored, and remains a streamgaging priority. This division represents the southern central portion of the state, where there are some mountains.

State	Current Status	Specific Climate Division Improvements
Vermont	Vermont lacks adequate gaging in much of the state.	<ul style="list-style-type: none"> • Division 1701, representing northern Maine, is well-gaged and only needs adequate maintenance of existing gages. • Divisions 4701 and 4703, in the eastern portion of the state, are both in need of expanding gaging, though gaging here may more difficult due to the mountainous terrain. • Division 4702 in the west is well-gaged and requires maintenance of existing gages.
New Hampshire	New Hampshire is well-gaged in the northern portion, but lacks gaging in the south.	<ul style="list-style-type: none"> • Division 2702 in southern New Hampshire requires more gaging. The coastal streams flowing to the short coastline and the mountainous area along the Vermont border are mostly ungaged and require additional monitoring. • The Northern Division, 2701, requires maintenance of existing gages.
Massachusetts	Massachusetts is well-gaged along the state's interior, but the coast is relatively unmonitored.	<ul style="list-style-type: none"> • Central and western Massachusetts, represented by climate divisions 1901 and 1902, are well-gaged and require adequate upkeep of existing streamgages. • Division 1403, encompassing coastal Massachusetts, lacks gaging on coastal streams. This includes the city of Boston.
New York	New York's eastern interior only requires maintenance, while the western and southern perimeter need additional gaging.	<ul style="list-style-type: none"> • Climate Divisions 3001, 3005, 3007, 3008 and 3009 all require expansion of current monitoring capabilities. These regions include most of New York's mountains and borders with the Great Lakes. Both topographical features add difficulty to streamgaging. • Climate Division 3004, which encapsulates the entirety of the New York coast, also requires additional gaging. This area also includes New York City. • The Climate Divisions in the interior of the state (3002, 3003, 3006, and 3010) are adequately gaged, only requiring the maintenance of current gages.
Connecticut	Like other states in the region, Connecticut has adequate gaging throughout its interior, but lacks	<ul style="list-style-type: none"> • Climate Divisions 0601 and 0602 are well-gaged and represent the central portion of the state. • Climate Division 0603 represents the state's coastline, which lacks adequate gaging and requires additional monitoring sites.

State	Current Status	Specific Climate Division Improvements
	gaging along the Atlantic Coast.	
New Jersey	New Jersey's streams are sufficiently gaged towards the center of the state; along the coasts, the state lacks streamgage infrastructure.	<ul style="list-style-type: none"> • Climate Division 2801, representing the interior of New Jersey, has adequate gaging and only needs maintenance for the streamgages in the area. • Climate Divisions 2802 and 2803, both of which border the Atlantic coast, require the expansions of the streamgage system to adequately represent their stream setting.
Pennsylvania	All ten of Pennsylvania's diverse climate divisions have adequate streamgaging and only require maintenance of existing locations.	
Rhode Island	Rhode Island almost completely borders the Atlantic Coast, and lacks adequate gaging in the state's one Climate Division, 3701.	
Maryland and Washington DC	Maryland and Washington DC lack adequate gaging throughout.	<ul style="list-style-type: none"> • In the western portion Maryland, Climate Division 1808 has adequate gaging. • Climate Divisions 1806 and 1807 in the state's interior lack adequate gaging. These regions fall in Maryland's portion of the Appalachian Mountains, making it difficult to locate appropriate sites for streamgaging. • Along the coast, Climate Divisions 1801, 1802, 1803, 1804, and 1805 all lack adequate stream monitoring.
Delaware	Delaware lacks adequate gaging throughout both of the state's climate divisions. They both border the Atlantic Coast, adding difficulty to gaging.	
West Virginia	West Virginia has adequate gaging throughout all six of the state's Climate Divisions.	

Climate Justification for Expanded Gaging

For the Northeast, expanded streamgaging will be an invaluable tool to monitor the impacts of climate change. One of the most noticeable impacts here will be the pervasiveness of coastal flooding. As warmer temperatures lead to higher sea levels, the Atlantic coast will likely have increased flooding during and after storm events, affecting millions along the coast. The areas most susceptible to coastal flooding along the Atlantic coast are the least monitored and densely populated. Expanded streamgaging can allow for the study of coastal rivers' impacts on flooding to help the region cope. New York City experienced extensive flooding during

Hurricane Sandy, isolating communities from vital resources. As hurricanes are projected to increase and move further North, more major cities in the Northeast will face similar scenarios, impacting large populations. Increased streamgaging along coastal streams will allow for a greater understanding of how to mitigate and cope with these conditions.

Increased streamgaging also helps monitor shifting precipitation patterns with regards to drought. In such times, streamgaging can monitor low flow patterns to gauge drought severity. In this region, droughts are likely to increase in duration and frequency, impacting local agriculture. Expanded gaging capabilities would track these shifts and allow water managers to plan policy more effectively for dry periods. Beyond droughts, the Northeast is projected to have less frequent, more intense precipitation events, especially in the late winter and early spring. Annual snowfall is also projected to decline with the increasingly warmer winters, leading to a higher proportion of rain. This shifts the timing of maximum streamflow to earlier in the year and is expected to increase inland flooding, particularly in the valleys where communities tend to be concentrated. Urban streams are particularly susceptible to flooding due to the lack of soil infiltration, impacting large populations throughout the region. Additional streamgage data will allow for more effective water management in the region at times of both high and low flow.

Southeast

The states in the Southeast Region of the National Climate Assessment are Virginia, Kentucky, Arkansas, Tennessee, North Carolina, South Carolina, Georgia, Mississippi, Alabama, Louisiana, and Florida.

Current Regional Status of the Streamgage Network

- The Atlantic and Gulf Coasts are almost completely ungaged. The most prominent ungaged coastlines are in Florida and Louisiana, with the majority of their climate divisions almost completely ungaged.
- Urban areas away from coastlines, such as Nashville and Atlanta are more adequately gaged than the surrounding rural areas.
- The climate divisions along the Mississippi River need additional gages.

Locations for Gage Expansion

State	Current Status	Specific Climate Division Improvements
Virginia	Virginia's interior is well-gaged but lacks monitoring along the Atlantic coast.	<ul style="list-style-type: none"> • Climate divisions 4401 and 4404 along the Atlantic Coast lack sufficient gaging. These divisions include major urban centers such as Richmond and suburbs of Washington DC. • The western and central climate divisions, making up the more mountainous portions of the state, are well-gaged and only require maintenance.
Kentucky	While eastern and central Kentucky's climate divisions are well-gaged, the northwestern portion of the state lacks adequate gage coverage.	<ul style="list-style-type: none"> • Climate Division 1501 and the northern portion of 1502, representing the northern and central regions of the state, are most in need of additional gages. These divisions include urban areas such as Louisville. • The climate divisions in eastern portion of the state are well-gaged and only require maintenance.
Arkansas	Arkansas lacks gaging in the southern and eastern portions of the state, particularly in	<ul style="list-style-type: none"> • Climate Divisions 0303 and 0306 (northeast and east central divisions) need expanded monitoring capabilities. These

State	Current Status	Specific Climate Division Improvements
	<p>climate divisions bordering the Mississippi River. The western portion of the state appears to be well-gaged despite having more topographic variety.</p>	<p>regions border the Mississippi River, which could explain the lack of gaging.</p> <ul style="list-style-type: none"> • Climate division 0308 in the south-central portion of the state lacks gaging. This region includes the Yazoo-Mississippi Delta, where the two rivers converge. • The central and western climate divisions are well- gaged and only require maintenance of existing streamgages.
Tennessee	<p>The western portion of Tennessee is well-monitored; however, the eastern climate division that borders North Carolina lacks adequate gaging.</p>	<ul style="list-style-type: none"> • Climate division 4001 is under-monitored. This division predominantly represents the Appalachian Mountains, making it more difficult to gage. • Large urban areas (excluding Nashville) are also lacking gaging. Chattanooga, Memphis, and Knoxville all require additional gaging measures. • The western climate divisions are well-monitored apart from the Mississippi-Yazoo Delta.
North Carolina	<p>North Carolina lacks appropriate gaging along its coastline and along the state's central piedmont while the interior of the state is more adequately gaged.</p>	<ul style="list-style-type: none"> • The entirety of the state's coastal plains (climate divisions 3106, 3107, and 3108) lack adequate gaging. • The central piedmont (primarily climate division 3104 with portions of 3105 and 3106) also is insufficiently gaged. These regions include some of the state's largest cities, such as Charlotte, Raleigh, and Durham, making it even more of a monitoring priority. • The border areas and western portion of the state are well-monitored and only require maintenance of existing gages.
South Carolina	<p>South Carolina requires expanded gaging statewide. The coastline and central corridor are especially in need of additional monitoring.</p>	<ul style="list-style-type: none"> • The climate divisions along the Atlantic Coast (3804 and 3807) are in strong need of gaging, with roughly half of each division ungaged. These divisions include large urban areas such as Charleston. • Climate divisions 3803 and 3806 in South Carolina's interior also lacks significant gaging. Within these divisions are other include large urban areas, such as Columbia and Sumter.

State	Current Status	Specific Climate Division Improvements
Georgia	Georgia is largely well-monitored throughout the state; however, again, areas bordering the Atlantic Coast lack adequate gaging.	<ul style="list-style-type: none"> • The borders of the state have adequate stream monitoring. • Climate division 0909 in the southeastern portion of the state, is largely under-monitored. This region also includes the city of Savannah, which is located along Georgia's Atlantic Coast. • The interior of the state is well-gaged and requires adequate maintenance of existing gages.
Mississippi	While the center of the state is well-gaged, Mississippi lacks monitoring along the Mississippi River Delta and the Gulf Coast.	<ul style="list-style-type: none"> • Along the Gulf Coast, climate division 2210 lacks monitoring. This area includes some of Mississippi's largest towns, including Gulfport and Biloxi. • The Mississippi-Yazoo River Delta also lacks adequate streamgaging. This impacts climate divisions 2201, 2202, and 2204 most severely. The areas along the Mississippi River also lacks monitoring and requires additional streamgages. • Central Mississippi has an adequate stream monitoring system, especially surrounding urban areas.
Alabama	Alabama lacks adequate gaging in the northwest, along its coast, and in some portions of its interior.	<ul style="list-style-type: none"> • The Gulf Coast climate division (0108) lacks streamgages and faces the difficulties of monitoring coastal streams. This region has the urban area of Mobile. • In the lowlands of northern Alabama, the Climate Divisions (0101 ,0103, and 0106) require additional gages. This includes large urban areas such as Birmingham, Tuscaloosa, and Huntsville. • The northeastern portion of the state is well-monitored and only requires gage maintenance, despite being in the foothills of the Appalachians.
Louisiana	Louisiana lacks gaging overall, especially along the its southern coastline.	<ul style="list-style-type: none"> • Climate divisions 1606, 1607, 1608, and 1609 encompass Louisiana's Gulf Coast and are almost completely ungaged. New Orleans and Baton Rouge, two of the state's largest cities, are in these divisions. • Climate divisions 1603 and 1605 make up portions of the Mississippi River Delta and lack sufficient stream monitoring.

State	Current Status	Specific Climate Division Improvements
		<ul style="list-style-type: none"> The northwestern corner of the state, in climate division 1601, is the only adequately gaged area within the state.
Florida	Florida also lacks adequate gaging throughout its entirety, largely due to its extensive coastlines.	

Climate Justifications for Expanded Gaging

The Southeast faces a wide array of climate change impacts due to the geographical diversity of the region, making stream monitoring an essential and universal tool to mitigate them. The most likely and extreme impact that the region faces is extensive coastal flooding. Bordering the Atlantic Ocean to the east and the Gulf of Mexico to the south, its extensive coastline is especially susceptible to inundation as a result of rising sea level. Nuisance flooding along the coasts is projected to increase, impacting over forty percent of the national population and a strong majority in the Southeast. The effects of rising sea levels will be especially prominent in areas of subsidence across the region, namely the majority of Louisiana and portions of Alabama. Expanded streamgaging would allow for coastal streams (which are likely tidal) to be continuously monitored for flood impacts to better inform communities of risks.

In addition to rising sea levels as a source of coastal flooding, hurricane frequency in the Southeast is predicted to increase as a symptom of rising temperatures. The extreme rain and storm surge that would inundate coastal communities will likely be exacerbated by the higher sea level, creating more dire conditions on a broader scale. One clear example of this was the devastation that followed Hurricane Irma in 2017. The storm made landfall with the continental United States in Florida, but storm surges were felt across the Atlantic Seaboard, including record flooding in Charleston, South Carolina. Increased streamgaging could measure the

impacts of hurricanes on coastal streams and the resultant flooding. This would help water managers create new resiliency strategies to minimize the effects of future storms.

In the inland portion of the region, flooding and drought remain the major threats. Excessive precipitation events are expected to be more frequent and intense, leading to flood events. The impacts of these events are especially prominent along the Mississippi River and its tributaries, creating enormous economic losses in both agriculture and shipping. Despite these extreme precipitation events, the rising temperatures throughout the region will likely leave it susceptible to drought. This would not only hurt the natural ecosystems, including the mangroves that combat flood conditions, but also negatively impact the economic activity in the region. Enhanced streamgaging in the Southeast would broadly allow water managers to combat the impacts of climate change to support its citizens.

Midwest

The states in the Midwest Region of the National Climate Assessment are Ohio, Indiana, Illinois, Missouri, Iowa, Minnesota, Wisconsin, and Michigan.

Current Regional Status of the Streamgage Network

- Overall, the Midwest region is relatively well-gaged; the key exceptions seem to be centered around the lakes and navigable rivers in the region. This could be due to the extensive agriculture in the region requiring more monitoring.
- Particularly, the length of the Ohio River is poorly gaged, extending from Ohio to Missouri. The southern portions of these states are largely ungaged.
- Areas surrounding the Great Lakes are also largely ungaged. Almost the entirety of these states' coastlines lacks monitoring.
- In the West, portions of the Mississippi and Missouri rivers lack adequate gaging. These areas are concentrated mainly in Wisconsin and Iowa.

Locations for Gage Expansion

State	Current Status	Specific Climate Division Improvements
Ohio	While Ohio is largely well-gaged, the southern portion of the state lacks monitoring.	<ul style="list-style-type: none"> • Climate division 3309 along the Ohio River does not have adequate streamgaging and requires additional sites.
Indiana	Indiana is well-monitored in the northern portion of the state, but lacks gaging along its southern border.	<ul style="list-style-type: none"> • Climate divisions 1208 and 1209 require additional streamgaging along the Ohio River. These divisions border major urban areas such as Evansville and Louisville, Kentucky. • Along its border with Lake Michigan, climate division 1201 lacks stream monitoring. • The rest of the climate divisions in the state only require additional maintenance opposed to expanded streamgaging.
Illinois	Like other states that border the Ohio River, Illinois'	<ul style="list-style-type: none"> • Climate divisions 1108 and 1109 in southern Illinois are particularly under

State	Current Status	Specific Climate Division Improvements
	climate divisions along it lack appropriate gaging, while the rest of the state is largely well-gaged.	<p>monitored compared to other portions of the state. These populate the Ohio River Valley as well as its confluence with the Mississippi River, leaving it largely unmonitored.</p> <ul style="list-style-type: none"> • Unlike other states that border the Great Lakes, Illinois maintains gaging along its short border with Lake Michigan. • Streamgaging is well implemented throughout Illinois' interior and only requires consistent maintenance.
Missouri	Missouri maintains adequate gaging throughout the state, but lacks gaging along the Mississippi River in the southeast.	<ul style="list-style-type: none"> • Along the state's eastern border, the Mississippi River, climate divisions 2303, 2305, and 2306 lack stream monitoring. • The entire city of St. Louis, located along the Mississippi in climate division 2302, lacks adequate gaging. • The entirety of the climate division 2306 lacks monitoring. This area is Missouri's "bootheel" and borders other unmonitored areas in northern Arkansas. • The rest of the state is well-gaged and only requires additional maintenance.
Iowa	With its borders defined by the two largest rivers in the United States, expanded gaging capabilities along Iowa's northern climate divisions are critical.	<ul style="list-style-type: none"> • Climate division 1303, located along the Mississippi River in eastern Iowa, requires additional gaging capacity. This division includes urban areas with higher population concentrations such as Dubuque. • Bordering the Missouri River in the West, climate division 1301 lacks streamgaging throughout. Sioux City, a densely-populated urban area, lies predominantly ungaged within this climate division. • Beyond these divisions, the majority of the state is well-monitored and only requires gage maintenance.
Minnesota	Minnesota's climate divisions are well-monitored and only require maintenance of existing streamgages.	
Wisconsin	Wisconsin's interior is largely well-gaged, with the only notable exceptions being along Lake Michigan and in its southwest corner.	<ul style="list-style-type: none"> • Climate division 4706, which represents a large portion of the state's coastline, is almost completely unmonitored. The coast includes urban areas such as Green Bay and Sheboygan.

State	Current Status	Specific Climate Division Improvements
Michigan	Michigan's climate divisions are largely ungaged along its extensive coastlines.	<ul style="list-style-type: none"> • In the southwest, climate division 4707 largely lacks gaging. This division borders the Mississippi River. • In the Upper Peninsula, climate divisions 2001 and 2002 are insufficiently gaged immediately along the coasts and require expanded monitoring capacities. • Climate divisions 2003, 2005, and 2008, bordering Lake Michigan, require expanded monitoring along the coastlines. In their interiors, they are well-monitored. • The climate divisions immediately bordering Lake Huron, divisions 2004 and 2007, lack gaging both along their coasts and in the interiors. • Urban areas throughout the state are adequately monitored, and only require maintenance of existing gages.

Climate Justifications for Expanded Gaging

With the dominance of agriculture across the Midwest, increased streamgaging will be an essential tool to monitor and mitigate fluctuations in water resources as a result of climate change. Shifting precipitation patterns are projected to be one of the most prominent changes in the region. Late winter and early spring are projected to see the most dramatic changes. As winters become increasingly warm, the overall intensity and frequency of rainfall events is expected to increase; making rain a higher proportion of the regional precipitation. With this increase in rain and its intensity, flood events across the Midwest are likely to increase, particularly in the early spring. The Mississippi River and its major tributaries, such as the Ohio and the Illinois rivers, flow through the region and are susceptible to the flooding induced by heavy rains. Coastal flooding along the Great Lakes could inundate major urban areas such as Chicago, Milwaukee, and Toledo. Flooding along the Great Lakes and rivers in the Midwest would not only have immense economic effects on its agricultural sector, but also on other

regions' economic viabilities as well. The highwater upstream could induce flooding on the lower Mississippi and damage the Southeast region, leading to enormous economic disruption. The possibility of such widespread impact emphasizes the importance of expanded streamgaging across the region, particularly along the Great Lakes and the Mississippi and Ohio rivers.

Even with increasing precipitation across the Midwest, droughts are also projected to increase as a result of rising temperatures. Higher temperatures contribute to increased evaporation levels, removing water from surface resources and transferring it into the atmosphere, which creates even warmer temperatures to further drought conditions. While flooding has a somewhat localized effect to those immediately surrounding the water, drought conditions could devastate the entire region, particularly the agricultural and timber sectors. Widespread stream monitoring through drought conditions provides water managers with the information necessary to make decisions to best serve their communities. Thus, more extensive streamgaging would allow the region to better survive the projected increase in drought conditions.

With the extreme variance in water availability, which is projected to only increase due to climate change, streamgaging can be an essential resource for water managers to plan and act under pressing conditions. Therefore, closing gaps in streamgaging across the Midwest is important to improving response to hydrologic crises.

Northern Great Plains

The five states in the Northern Great Plains are Montana, Wyoming, North Dakota, South Dakota, and Nebraska according to the National Climate Assessment.

Current Regional Status of the Streamgage Network

- Compared to other regions, the Northern Great Plains are relatively well-gaged. This is likely because the extensive irrigation in the region, requires in-depth monitoring of surface and groundwater resources.
- Wyoming and Montana both have particularly extensive gaging networks, with almost all their climate divisions having adequate streamgaging.
- In the Dakotas and Nebraska, there are more gaps in monitoring. These tend to correlate with interstate river basins such as the Missouri, Platte, and Republican rivers.
- The sufficiency of gaged area varies more with the surrounding surface water resources than it does with local population centers. If an area has a localized river running through it, it is more likely to be monitored than others regardless of population size.

Locations for Gage Expansion

State	Current Status	Specific Climate Division Improvements
Montana	Montana is adequately gaged across the state, only requiring maintenance of existing gages sites.	
North Dakota	Many of North Dakota's climate divisions lack adequate streamgaging. These divisions are clustered around the Canadian border, but also extend towards the state's interior.	<ul style="list-style-type: none"> • In the east, climate division 3206 is well- gaged and only requires maintenance of the existing network. Fargo, the largest city in the state, is also located in this division. • Climate divisions 3201, 3202, and 3203, along the state's northern border lack stream monitoring. This could be due to lack of communication between American and foreign gaging, limiting monitoring on transnational streams.

State	Current Status	Specific Climate Division Improvements
		<ul style="list-style-type: none"> Divisions 3204, 3205, and 3209 all lack gaging in the state's interior. These areas lack significant populations, limiting the importance of gaging.
South Dakota	South Dakota is relatively well-gaged, with the exception of its central corridor.	<ul style="list-style-type: none"> Climate divisions 3902 and 3906 are largely ungaged. These regions follow the Missouri River's path through the state's interior and include a large portion of reservation lands in each. Most of the state's ungaged areas follow the path of the Missouri River through the state's center, passing through a variety of communities on its path.
Wyoming	Wyoming is only lacking gages along its southern border while most of the state maintains adequate monitoring capabilities.	<ul style="list-style-type: none"> Climate division 4810, representing the Upper Platte, lacks gaging throughout. Within it is a portion of the Rocky Mountains, which could be impeding adequate gaging.
Nebraska	Nebraska is well-gaged in the eastern portion of the state; however, in the south and western portions it lacks sufficient streamgaging.	<ul style="list-style-type: none"> Climate Division 2501, the western panhandle of the state, is largely ungaged. This includes urban areas such as Scottsbluff and North Platte, as well as both the North and South Platte rivers. Located along Nebraska's southern border, climate division 2508 is also largely ungaged. This includes large portions of the Platte and Republican rivers, as well as larger communities such as Kearney, Grand Island, and Hastings. Climate division 2503, located in the northeast, also lacks gaging where it borders the Missouri River.

Climate Justifications for Expanded Gaging

Unlike other regions in the continental United States, the Northern Great Plains maintains a high variability in its climate. Streamflows are projected to have a slight decrease overall; however, the more dramatic impact will be the extreme inter-year variability. Surface water availability depends mostly on precipitation and snowpack, as both vary dramatically on an

annual basis, resulting in alternating drought and flood conditions. These alternating periods are projected to become more extreme as a result of climate change, emphasizing the importance of real-time streamgage data for communities and water managers. The Northern Great Plains saw an example of this with the record 2011 flooding on the Upper Missouri River followed by a severe drought in 2012. Expanding gaging capabilities would offer extensive data to improve understanding of these patterns and help manage the current conditions with the most information.

Shifting precipitation patterns is predicted to have a large impact on the variation in surface water quantities throughout the region. Snowpack across the Northern Great Plains is projected to decrease, leading to earlier melt times and peak streamflow, which could lead to drought conditions later in the season. Only about ten percent of precipitation across the region reaches the Missouri River as runoff due to the high rates of evapotranspiration, making snowmelt from Montana and Wyoming one of the main sources of streamflow. While total snowfall is projected to decrease, there is a projected increase in winter and spring precipitation in the form of rain earlier in the year. The changes in precipitation form will not only impact the timings of maximum streamflow, but also the timings of major floods. Historically, the Northern Great Plains are wettest in the summers and tend to flood during that time; however, with earlier rainfalls and snowmelt due to increasing temperatures, this could shift major flood events into the early spring. Expanding streamgaging would allow for better monitoring to predict high flow events. Beyond flooding, drought also poses a major concern for the semi-arid region. As precipitation is projected to fall earlier in the year, late summers will likely experience increased dryness. This could have enormous impacts on the agricultural sector across the region and

reduce crop yields. By adding streamgages to the under monitored climate divisions, water managers will have the appropriate data to monitor and plan for the variable conditions.

Southern Great Plains

Kansas, Oklahoma, and Texas are the three states that constitute the Southern Great Plains in the National Climate Assessment.

Current Regional Status of the Streamgauge Network

- The eastern portion of the region is well-covered by monitoring sites.
- Urban areas are much more well-gaged than their rural counter parts.
- Gaging in the western portion of the region where they border the Southwest Region is dramatically sparser. This is the more arid half of the region as well, limiting the ability of water managers to monitor both drought and extreme flow events.
- Texas' Gulf Coast lacks adequate stream monitoring, limiting the ability to both measure the quantity and quality of the water that flows into the Gulf. Additionally, gages are needed along the coast for monitoring sea level changes.

Locations for Gage Expansion

State	Current Status	Specific Climate Division Improvements
Kansas	Much of Southwestern Kansas is deemed a priority for expanded gaging.	<ul style="list-style-type: none"> • Divisions 1407 and 1408 are especially in need of additional gage sites. These line Kansas's southern border. • Other climate divisions in the state are better represented in these metrics, with maintenance as a priority.
Oklahoma	In almost the entirety of Oklahoma (outside of major urban areas), additional stream monitoring sites are needed.	<ul style="list-style-type: none"> • Climate division 3401, 3402, and 3404, located in the panhandle, all require additional gage sites to be added. • Climate division 3406, located in along the eastern border, also lacks appropriate streamgaging. This could be due to the location of reservation lands.

State	Current Status	Specific Climate Division Improvements
		<ul style="list-style-type: none"> The unged HUC12s are concentrated in the western portion of the state, where the climate is more arid and susceptible to drought and extreme precipitation events.
Texas	Like the other states in the region, Texas lacks streamgaging in the western portion of the state as well as along its coastline.	<ul style="list-style-type: none"> Climate divisions 4101 and 4106, located in the northern portion of the state, are well-represented in urban areas but lack gaging in more rural spaces. Coastal climate division 4108, 4109, and 4110 all lack adequate monitoring. Climate division 4105 in the central portion of the state also lacks adequate monitoring, likely due to the increasing altitude.

Climate Justifications for Expanded Gaging

These gauges need to be implemented in the region to account for the variety of water resources challenges that the region is current facing. According to the National Climate Assessment, the region is projected to see an increase of extreme weather events that impact water resources dramatically, such as hurricanes, high precipitation events, and droughts. An increase in gage monitoring can help understand how climate change is influencing these events and their severity.

Hurricanes and the coastal flooding that accompanies them are currently the biggest threat to the region. Hurricane Harvey demonstrated how devastating these events are. It was the costliest natural disaster in American history, severely impacting the Texas Coastline. The city of Houston experienced some of the most extreme coastal flooding, with some areas receiving up to 9 inches of rain in ninety minutes.

As climate change induces warmer temperatures, the length of hurricane season could be extended, allowing more time for hurricanes to form, which could result in an increase in

cyclone frequency. This increases the probability that a storm of this intensity will hit the region again, yielding Harvey's level of severity. Additionally, sea level has also risen 5-17 inches along the Texas coastline in the last century, increasing the impact and reach of coastal flooding.

These impacts can have enormous implications on the region's population. A significant portion of the region's population lives along the coastline, meaning that effective stream gauging can help monitor changes and therefore significantly facilitate impact mitigation efforts.

Additionally, the region is projected to experience dramatic changes in precipitation patterns, vacillating between periods of extended drought and extreme precipitation events. The region overall has experienced a decrease in overall precipitation, sending portions of it into drought. According to the National Climate Assessment, the 2011 drought in the region not only limited crop irrigation and its associated economic gains, but also limited power generation in the region. These can have enormous impacts on the populations in addition to the food supply line. Without stream gauges, there is not a meaningful way to understand the impacts and severity of these dry periods on the food-water-energy nexus.

Coupled with these periods of drought, extreme precipitation events are projected to increase. Models demonstrate that this will shift how the region receives its water and at what times. This likely shift will alter water supply patterns for both municipal and irrigative water use. Moreover, these events are likely to damage crops, harming the region's economic prospects. The streamgauge program would allow the region to collect data to measure both the impacts of these extreme events and the long-term impact on flows.

Northwest

The constituents of the Northwest are Washington, Oregon, and Idaho according to the National Climate Assessment.

Current Regional Status of the Streamgage Network

- The region’s coastlines are largely unmonitored. Western Oregon and the Puget Sound areas both need more gaging capabilities.
- The areas west of the Cascade Range are well-covered, especially in urban areas.
- The Cascade Range itself is largely lacking streamgaging.
- Eastern Idaho is also well-covered, with small portions in the south and west portions of the state lacking adequate gaging.

Locations for Gage Expansion

State	Current Status	Specific Climate Division Improvements
Washington	Washington’s coasts and the southeastern portion of the state are deemed priority regions.	<ul style="list-style-type: none"> • Divisions 4502, 4503, 4508, and 4510 are most in need of expanded gaging. 4502 and 4503 surround the Puget Sound, while 4508 and 4510 are located from the Central Basin to the Palouse Blue Mountains. • Other climate divisions in the state are well-gaged and only require the maintenance of existing gages.
Oregon	Oregon lacks gaging on the Pacific coast and in the interior of the state.	<ul style="list-style-type: none"> • Divisions 3501, 3505, 3506, and 3507 are most in need of additional streamgaging. Division 3501 spans the entirety of the Oregon Coast, while the others cover the High Plateau and the central corridor of the state. • Urban areas appear to be better gaged, with Portland and Eugene being well covered.

State	Current Status	Specific Climate Division Improvements
		<ul style="list-style-type: none"> • Portions of divisions 3503 and 3509 also need increased gaging, but in a less drastic measure than the other regions.
Idaho	Idaho is well-gaged relative to Oregon and Washington, but is lacking gages along its borders with states outside the region.	<ul style="list-style-type: none"> • Divisions 1002, 1003, and 1006 require the most gage expansion. Divisions 1002 and 1003 are located on the Washington border and cover the North Central Prairies and Canyons. Division 1006 covers the Southwestern Highlands and borders Nevada and Utah. • Again, urban areas such as Boise are better gaged than the rural areas. • Divisions 1004, 1005, and 1007, located on Idaho's Southern Border also need expanded gaging, but less dramatically so than those above.

Climate Justifications for Expanded Gaging

This region is expected to be significantly impacted by climate change because of the massive role natural resources play in its economic sectors. One impact sector that is particularly vulnerable is water resources. Increased gauging in this region can monitor these impacts. These gauges are especially necessary along the coastlines of Oregon and Washington, which will be increasingly susceptible to coastal flooding. This could be in the form of increased El Nino winter storms, flooding low-lying areas along the coasts. Rising sea levels could increase the reach of storm surges, flooding coastal communities and population centers such as the Puget Sound and Portland. Increased gaging would monitor coastal streams' patterns and offer more data following storm surges.

One of the biggest shifts as a result of climate change is earlier snowpack melt. As winters in the region are projected to become shorter, the snowpack on its mountains and plains will melt earlier in the year, shifting the timing the of peak stream flows and water supply to the

region. This would likely leave the summers with longer windows of low flows, harming the agriculture in the region and potentially worsening droughts in the region. This is projected to increase wildfire occurrences in the region, impacting both the natural resources and human infrastructure, in addition to worsening drought conditions. Increased gauge monitoring would provide more information on these shifting patterns and help track the timing changes of flow patterns.

Shifting precipitation patterns in the region will likely also influence water resources and require an increase in streamgaging data to monitor. Idaho is particularly projected to be impacted by these shifts. As winters become shorter and warmer, there would be more rain than snowfall in winter. This not only has implications for the landslides and infrastructure damages associated with increased rain, but also in the seasonal streamflow. More rain fills channels and can lead to rain-on-snow excess runoff events, flooding communities that rarely do. Streamgage monitoring can track these patterns and be used to create community preparedness plans to respond to these disasters.

Southwest

According to the National Climate Assessment Regions, the states that constitute the Southwest Region are California, Nevada, Utah, Colorado, Arizona, and New Mexico.

Current Regional Status of the Streamgauge Network

- This region lacks gaging more dramatically than others in the continental United States. Its geographic features make stream monitoring difficult.
- In the region's interior, the mountainous terrain has impeded extensive gaging, leaving many of its climate divisions unmonitored.
- The climate divisions along the Pacific Coast also require expanded streamgaging, with most divisions lacking gaging in nearly half of their streams.
- In a similar trend with other regions, interior urban areas have more adequate monitoring than the surrounding rural ones.

Locations for Gage Expansion

State	Current Status	Specific Climate Division Improvements
California	California exemplifies the struggles of streamgaging in this region, lacking adequate monitoring along the coast and in the state's mountainous interior.	<ul style="list-style-type: none"> • Climate divisions 0401, 0404, and 0406, located along California's Pacific Coast, lack adequate gaging, and require expansion. These under-monitored climate divisions include the state's largest cities such as San Francisco, San Jose, and Los Angeles. • In the state's mountainous interior, climate divisions 0403, 0405, and 0407 all require expanded stream monitoring. • The Northern California interior is adequately gaged and only requires maintenance of existing gages in climate division 0402.
Nevada	Nevada lacks adequate gaging across the entire	<ul style="list-style-type: none"> • The lack of gaging is uniform across the state, showing little change with

State	Current Status	Specific Climate Division Improvements
	state, with climate divisions averaging approximately 50 percent of their total area unmonitored.	<p>topography or population concentration.</p> <ul style="list-style-type: none"> • Nevada contains some of the region's most extreme topography, with much of the state at high elevations that impede gaging.
Utah	Throughout Utah, stream monitoring is limited by the topographical obstacles of the region, including the basin and range areas and the Rocky Mountains. This is particularly prominent along the state's borders.	<ul style="list-style-type: none"> • Along its western border, climate divisions 4201 and 4202 require additional gaging. These divisions are at the edge of the basin and range region. • Climate divisions 4205, 4206, and 4207 include portions of the Rocky Mountains and thus, lack adequate gaging. • The central climate divisions (4203 and 4204) are well-gaged, and only require additional maintenance. These divisions include the large urban area of Salt Lake City, making gaging of greater importance.
Colorado	Compared to neighboring states, Colorado has a much more extensive stream monitoring program.	<ul style="list-style-type: none"> • Climate division 0505, in the southwest corner, lacks appropriate streamgaging. The division also has three of the state's tallest mountains, making additional gaging much more difficult. • In the east, climate division 0503 is also under-monitored. This division represents the state's drier, drought-prone plains. • Urban areas across the state are well monitored, largely due to Coloradan water rights regulations.
New Mexico	New Mexico predominantly lacks gaging in the state's interior.	<ul style="list-style-type: none"> • Climate division 2904, along New Mexico's southern border, has limited streamgaging, likely due to the mountains. • In the central and southern portions of the state, climate divisions 2905, 2906, 2907, and 2908 lack monitoring. These areas are at a much lower altitude than other portions of the state; however, they form the majority

State	Current Status	Specific Climate Division Improvements
Arizona	While it is well-gaged in the northern and eastern portions of the state, Arizona largely lacks gaging in the southern and western areas.	<p>of the state's desert, adding challenges to monitoring.</p> <ul style="list-style-type: none"> • Larger urban areas across the state also need expanded gaging capacities. Albuquerque, New Mexico's largest city in the Central Valley (climate division 2905), is largely ungaged. • Climate division 0201, representing the western mountains, lacks streamgaging throughout. • In the south, climate divisions 0205, 0206, and 0207 also lack stream monitoring. These regions have much less elevation than the rest of the state, making it much more of a desert and plains region. • Large urban areas across the state, such as Phoenix, Tucson, and Flagstaff, have more thorough stream monitoring than surrounding areas.

Climate Justifications for Expanded Gaging

The Southwest presents one of the most urgent cases for expanded streamgaging. The majority of the region lacks appropriate stream monitoring while undergoing extreme water resource challenges, adding difficulty for water managers. The most widespread challenge facing the Southwest is drought. These conditions are driven by a lack of precipitation and decreasing snowpack as a result of rising temperatures. In the montane areas, snowfall is declining in both overall quantity and its proportion of total precipitation, releasing water earlier in the year and spurring drought in the late summer. The region is projected to see continued declines in surface water levels as a result of higher levels of evaporation. At present, the Colorado River basin has experienced drought conditions for over two decades; this impacts not only water-intensive sectors such as agriculture and hydropower, but also urban populations. Drought conditions also create the ideal environments for wildfires, which can then further the drought. These conditions

are expected to become more severe with climate change, emphasizing the need for continued streamgaging to monitor drought conditions and enact more stringent management policies.

While drought is currently the most visible water resources concern in the region, flooding also poses a major risk. Overall precipitation will likely be concentrated into large scale events. New Mexico and Arizona already experience these through their monsoon seasons, but the rest of the region could begin experiencing similar but more extreme phenomena through the rise of atmospheric rivers as a result of shifting evaporation patterns. They can release enormous amounts of water over an area, relieving drought conditions but also inundating communities. In early 2023, atmospheric rivers provided drought relief to the Southwest while also flooding huge swaths of land. These sudden high-precipitation events exemplify the importance of real-time stream monitoring to minimize impact on communities and industry. In addition to inland flooding, the California coast is also susceptible to flooding induced by rising sea levels. This could impact major population centers such as San Francisco, San Diego, and Oakland, emphasizing the importance of monitoring coastal streams to protect communities.

With its stark shifts in water resources availability, the Southwest is in dire need of expanded gaging capabilities to allow water managers to enact dynamic polices that reflect the most immediate conditions.

Conclusions

This report provides an in-depth and explicit definition of the gaps within the USGS's streamgage system coupled with justifications for future expansions through the lens of climate change impacts. Each region will face immense challenges under climate change, and this report

strives to provide a strong advocacy plan to help water managers to advocate for expanding their region's gage capacity. The following priorities are recommended:

- Coastal regions must be prioritized first for network expansion, particularly along the Eastern Seaboard. The Northeast and Southeast regions will face the some of the most extreme effects of climate change in terms of coastal flooding and increased hurricane risk, requiring more water managers to need more extensive, real-time data to prioritize gaging.
- Drought-prone areas in the Northwest, Southwest, Southern Great Plains, and Northern Great Plains also must receive priority gage expansion in terms of population and economic impacts. Without adequate flow accounts, water managers cannot make impactful policies to mitigate drought conditions to help their constituents, and expanded gaging would provide them with the information to make such policies. More populous climate divisions must receive priority to ensure that communities have the resources that they need to make appropriate response decisions.
- Flooding is a universal threat across all the regions, and additional gages for the sole purpose of flood monitoring should be implemented depending on the surrounding populations and economic activity. Improved gaging should first be placed around larger urban areas to protect human life. The second priority should be for navigable rivers and their larger tributaries. The most prominent example of this along the Ohio River in the southern portion of the Midwest region.

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