Analysis of Ohio's Fine and Coarse Aggregate Reserve Balances

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16. Abstract

The primary goal of this research project was to assist the Ohio Department of Transportation (ODOT) in identifying fine or coarse aggregates that might be subject to supply shortfalls in the future, estimate the financial impact to ODOT of these shortfalls, and recommend appropriate policy options to pursue in the event of shortfalls in aggregate supply. To start, the state of Ohio was first divided into five different study regions based on aggregate availability and population distribution. The amounts of aggregates produced and consumed in each study region were estimated using information obtained from ODOT and the Ohio Department of Natural Resources (ODNR). In addition, local aggregate reserves in each study region were estimated using information for individual mines, and different models were used to predict the number of years until these reserves are fully depleted. Zoning laws related to aggregate mining in Ohio were examined in this study and information was gathered from several representatives of the aggregate industry to document obstacles to expanding existing aggregate mine boundaries or opening new mines. This research study confirmed that the eastern half of the state has limited amounts of crushed carbonate stone (limestone/dolostone) reserves, while the southern and northwest regions of the state have limited amounts of sand and gravel reserves, making it necessary to import aggregates from other regions to meet local needs or use locally available aggregates that may be lower in quality. In addition, this study identified areas within the state where aggregate resources may become depleted at some point in the future. At the current time, the central region of the state has moderate amounts of reserves of limestone/dolostone as well as sand and gravel. However, these aggregates are being depleted rapidly, especially for mines located in the Columbus area. If the demand for aggregates in this region continues to increase at the current rate, the aggregate reserves are expected to become significantly diminished in the next thirty to forty years, with the financial effect of the aggregate shortage occurring in the next twenty to thirty years.

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1. Problem Statement

Aggregates are used by the Ohio Department of Transportation (ODOT) in a wide variety of applications, including embankment construction, structural backfill, aggregate bases, asphalt concrete, chip seal and micro-surfacing applications, Portland cement concrete (for pavement and structural applications), mortar or grout, berm and shoulder construction, slope and channel protection, and water quality structures (ODOT C&MS 2019). The Ohio Department of Natural Resources (ODNR) estimates that approximately 105 million tons of industrial aggregates were produced in Ohio in 2019, with nearly two thirds of these aggregates obtained from limestone and dolostone (or dolomite) sources and the remaining third obtained from natural sand and gravel deposits.

Nearly all aggregates that are mined in Ohio are used within the state (OAIMA 2020). In general, most aggregates are used in projects that are relatively close to the aggregate source. These aggregates are typically transported from the aggregate source or processing plant to the project site or mixing plant by truck. However, aggregates may also be shipped by rail or over water for longer distances when good quality aggregates are not available nearby. As the cost per ton of aggregate depends heavily on the haul distance, the availability of local sources of aggregates in Ohio may be a critical factor in determining the cost of this material.

While the geographic distribution of aggregate sources in Ohio may appear to be adequate to meet ODOT's current needs, the supply of aggregates may not continue indefinitely, as existing sources of aggregate are mined out and others may be faced with local opposition if the mine operators wish to expand the operation. Should local reserves of good quality aggregates become scarce in a given area, the stone needed for construction projects may be sourced from other regions within Ohio or outside the state at an additional cost. Consequently, in certain regions in Ohio, there is a concern that the supply balance of aggregates of sufficient quality might become critically low at some point in the future.

Markets may also experience demand shocks as well as supply shocks, and these types of events can influence not only the price but also the quantity of materials available in a given region. One recent example in Ohio is a demand shock for aggregates in Eastern Ohio, where oil and gas development activity over the past decade has resulted in a drastic increase in demand for aggregates in that region. As Eastern Ohio did not have sufficient local reserves of quality stone, it was necessary to transport aggregates from outside the region by rail or via barge on the Ohio River.

In order to aid ODOT to anticipate and better plan for potential future shortages in obtaining quality aggregates for its construction projects and maintenance activities, research is needed to provide ODOT with a better understanding of the supply and demand for fine and coarse aggregate materials in different regions within the state and estimate the economic impact on future ODOT construction projects in regions with low supply balances.

2. Objectives of the Study

The primary goal of this research project is to assist ODOT in identifying fine or coarse aggregates that might be subject to supply shortfalls in the future, estimate the financial impact to ODOT of these shortfalls, and recommend appropriate policy options to pursue in the event of shortfalls in aggregate supply. The specific objectives of the proposed project include:

- Divide the state of Ohio into different study regions based on aggregate availability and population distribution.
- Estimate the amount of fine and coarse aggregates produced and consumed in each study region in Ohio.
- Study the origin and destination of aggregates produced in one study region and exported to another, including the primary means of transportation and net tonnage.
- Estimate the local reserves of aggregates in each study region in Ohio.
- Estimate the depletion rate of aggregates and estimate the number of years the local reserves will last in each study region.
- Determine the economic impact on future ODOT construction projects in regions with low supply balances.
- Document the barriers to mining current reserves of construction quality aggregates as well as barriers to opening new mines.
- Develop a list of policy recommendations for dealing with regions with low supply balances taking into account the perspectives of multiple stake holders as well as the availability of alternative materials that are currently available or may potentially be available in the future.

3. Research Approach

Figure 1 presents a flow chart of the research approach that was followed in this project.

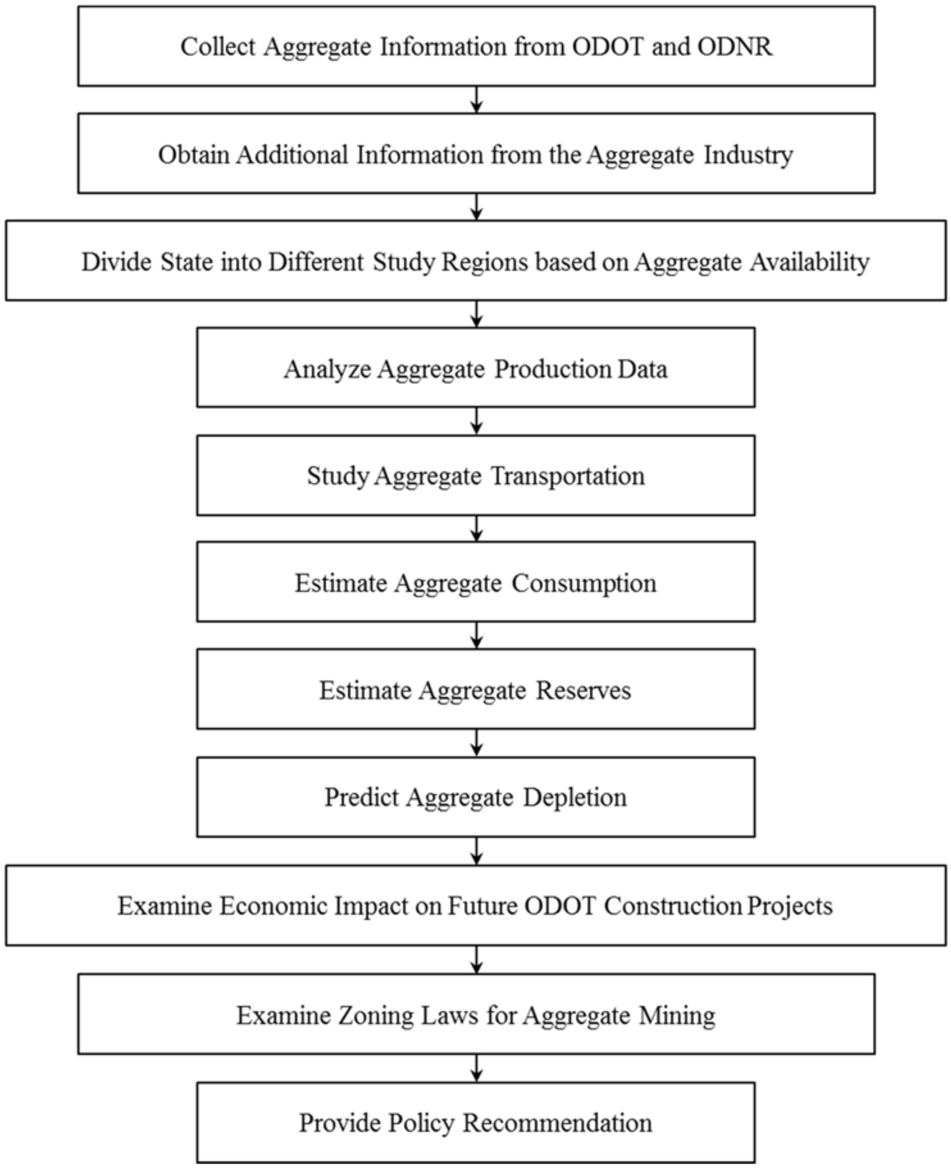


Figure 1. Flow Chart of Research Approach.

As presented in Figure 1, different types of information were first obtained from ODOT, ODNR, and the aggregate industry. ODOT Aggregate Section provided an aggregate tonnage report in Excel format summarizing the aggregate quantities used in ODOT construction projects during the period from 2011 to 2019. This report, which contained information about the aggregate source and the destination project, allowed for a closer examination of the origin and destination of aggregates used by ODOT. ODNR Division of Geological Survey provided information about aggregate production in Ohio, and ODNR Division of Mineral Resource Management provided information that was useful in estimating aggregate reserves for aggregate mines in the state. The research team also met with representatives from the aggregate industry to discuss aggregate quality and availability across Ohio as well as barriers to mining current reserves of construction quality aggregates or opening new mines. Detailed information about the approach used to analyze the collected information is discussed in the following subsections.

3.1 Study Regions

Figure 2 presents a map showing the locations of ODOT-approved aggregate sources in Ohio and neighboring states for different types of aggregates including dolostone, limestone, sand and gravel, and slag. As can be noticed from this figure, these aggregates are not evenly distributed across Ohio. Dolostones (or dolomite) are primarily found in the Silurian and Devonian aged rock in western Ohio (Figure 3), while the limestone sources are scattered across the state, with additional sources just across the borders with neighboring states (Liang and Chyi 2000). These aggregates are obtained from surface and underground mines by blasting large seams of rock and crushing the rock to aggregates of usable sizes. Limestone and dolostone are sedimentary rocks deposited in both fresh and marine environments. The former consists mainly of calcium carbonate ($CaCO_3$) and contains minerals like calcite and aragonite, while the latter consists mainly of calcium magnesium carbonate ($CaMg(CO_3)_2$).

Figure 2 also shows that sand and gravel are more widely available but are concentrated in a band that runs from the northeast to southwest Ohio. Natural sand and gravel deposits in Ohio are often found as river or stream deposits or obtained from pits in glacial river or outwash deposits within the glaciated areas of the state. While alluvial-derived gravel aggregates are round in shape, angular gravel can be produced using mechanical crushers to reduce the particle size and obtain sharp-edged particles. In addition, Figure 2 shows that slag – including air cooled blast furnace slag (or iron slag) and electric arc furnace slag (or steel slag) – is available in only a few select locations that have or used to have iron and steel production facilities such as Cleveland, Youngstown, Toledo, and Cincinnati.

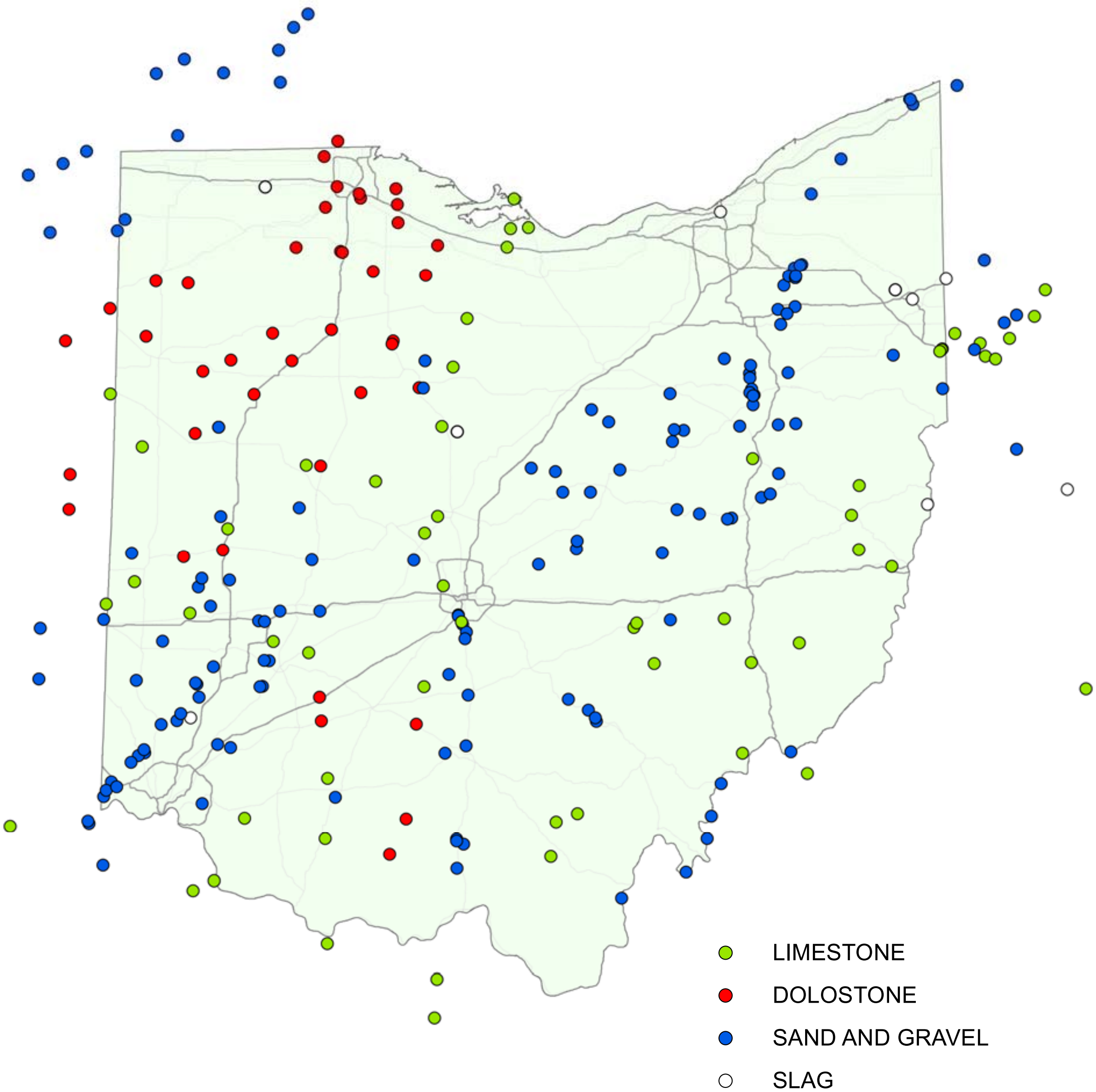


Figure 2. ODOT-Approved Aggregate Sources.

To compensate for the lack of local aggregate sources in the eastern half of Ohio, a number of distribution yards have been established in the northeast and southeast portions of the state as well as the Cincinnati and Toledo areas. Figure 4 presents the locations of the distribution yards in Ohio that supply ODOT-approved aggregates. It is noted that most distribution yards are located along rail lines or along the shores of the Ohio River and Lake Erie. As discussed in the following sections, aggregates are typically shipped to these distribution yards by rail (especially for yards that are inland), by barge (on the Ohio River), and by lake freighter (on the Lake Erie).

What Figure 2 doesn't show is the limiting nature with regard to aggregate resources and their ability to meet ODOT specifications. In its Construction and Material Specifications (C&MS), ODOT stipulates a wide range of chemical and physical properties that need to be met by an aggregate source in order for it to be approved for use in ODOT's construction projects. These specifications have been developed to ensure that aggregates will meet the performance demands of transportation infrastructure. The majority of the aggregate specifications for fine and coarse aggregates are documented in ODOT CM&S Item 703 for different types of applications, including Portland cement concrete (Item 703.02), mortar or grout (Item 703.03), asphalt concrete base (Item 703.04), asphalt concrete for surface and intermediate courses (Item 703.05), sand cover (Item 703.06), mineral filler (Item 703.07), granulated slag (Item 703.08), screenings (Item 703.10), and structural backfill (Item 703.11). Other sections of ODOT's C&MS specification book (e.g., Item 422 and Item 424) as well as ODOT Supplemental Specifications (e.g., SS-838 and SS-840) contain additional aggregate property requirements. The primary tests used by ODOT to ensure that aggregates are of sufficient quality and durability include the Los Angeles abrasion test (AASHTO T 96), micro-Deval (AASHTO T 327), percent by weight of deleterious materials (e.g., shale, limonite, chert, clay, soft pieces, and coal) (ODOT Supplement 1029), soundness test (AASHTO T 104), and freeze-thaw test (ASTM C 666, Procedure B).

Since the chemical and physical properties of rock strata and natural sand and gravel deposits found in different regions in Ohio can vary, these properties can severely limit the usefulness of a single quarry or regional aggregate resources, as only those aggregates meeting the specified properties can be used in ODOT construction projects. For example, limestone aggregates from some sources may have suitable hardness for a wide variety of applications, while limestone from other sources may be softer and cannot meet the soundness specification (per AASHTO T 104) for pavement quality aggregates. In addition, some limestone sources in Ohio do not meet ODOT's requirements for rapid freezing and thawing (ASTM C 666, Procedure B), while others are restricted from use in asphalt surface courses due to concerns about skid resistance. Another example pertains to the chemical properties of aggregates used in fine-graded polymer asphalt concrete mixture (Item 424). For this type of asphalt mixture, natural sand must have 50% silicon dioxide by weight (according to ASTM C 146) to provide suitable abrasion resistance, as the use of natural sand that has a high content of soft materials (such as shale) would result in polishing of road surfaces paved with such a mixture. Some aggregate properties (e.g. deleterious content) can be improved through processing (e.g., crushing), blending, and selective mining, while some other properties cannot be improved due to the nature of the rock. While it is beyond the scope of this research project to evaluate the effectiveness or the limiting nature of current aggregate specifications, it is a point worth considering when interpreting reserves of aggregate resources for construction use. To compensate for the lack of local aggregate sources in the eastern half of Ohio, a number of distribution yards have been established in the northeast and southeast portions of the state as well as the Cincinnati and Toledo areas. Figure 4 presents the locations of the distribution yards in Ohio that supply ODOT-approved aggregates. It is noted that most distribution yards are located along rail lines or along the shores of the Ohio River and Lake Erie. As discussed in the following sections, aggregates are typically shipped to these distribution yards by rail (especially for yards that are inland), by barge (on the Ohio River), and by lake freighter (on the Lake Erie).

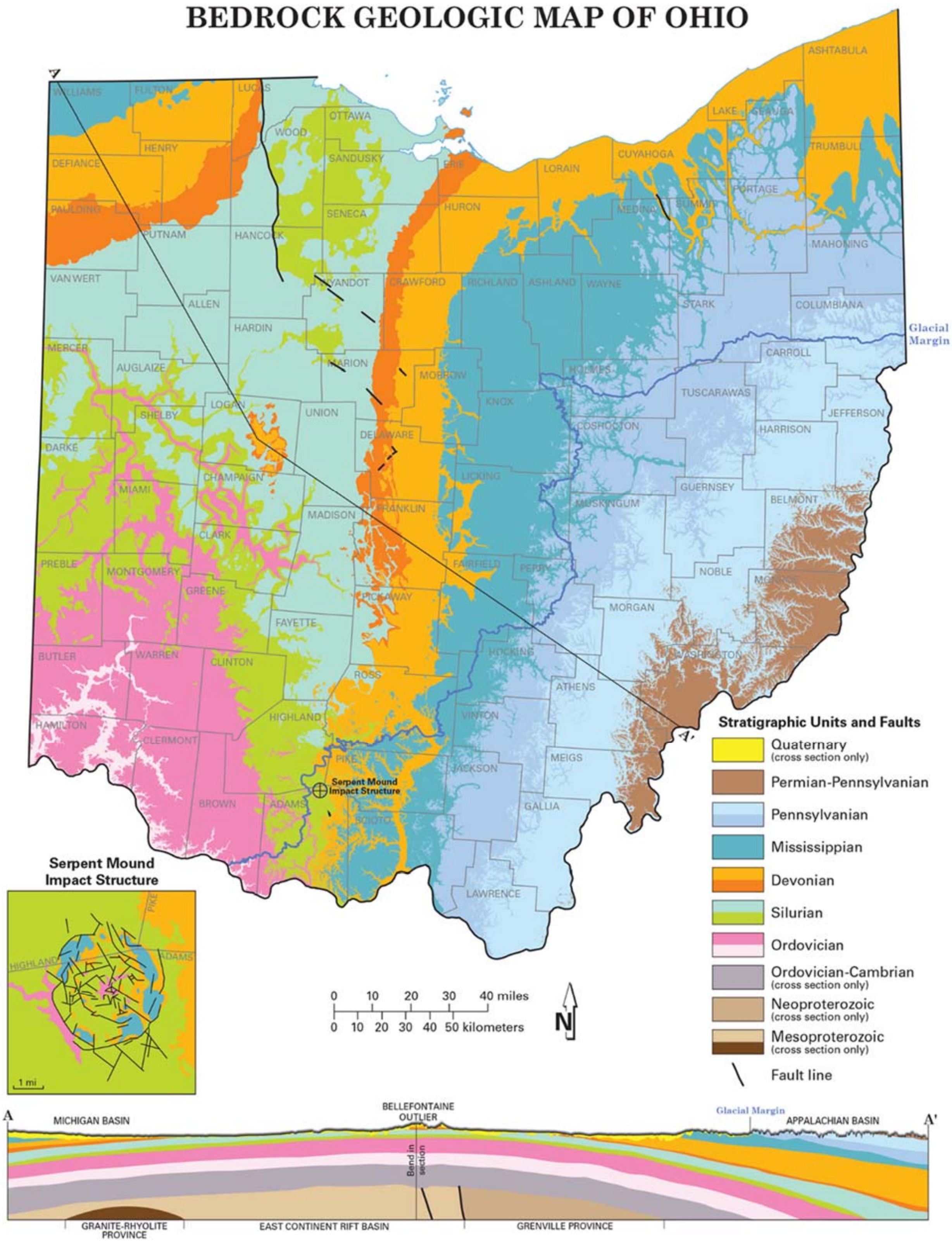


Figure 3. Geologic Map of Ohio Bedrock (Slucher et al. 2006).

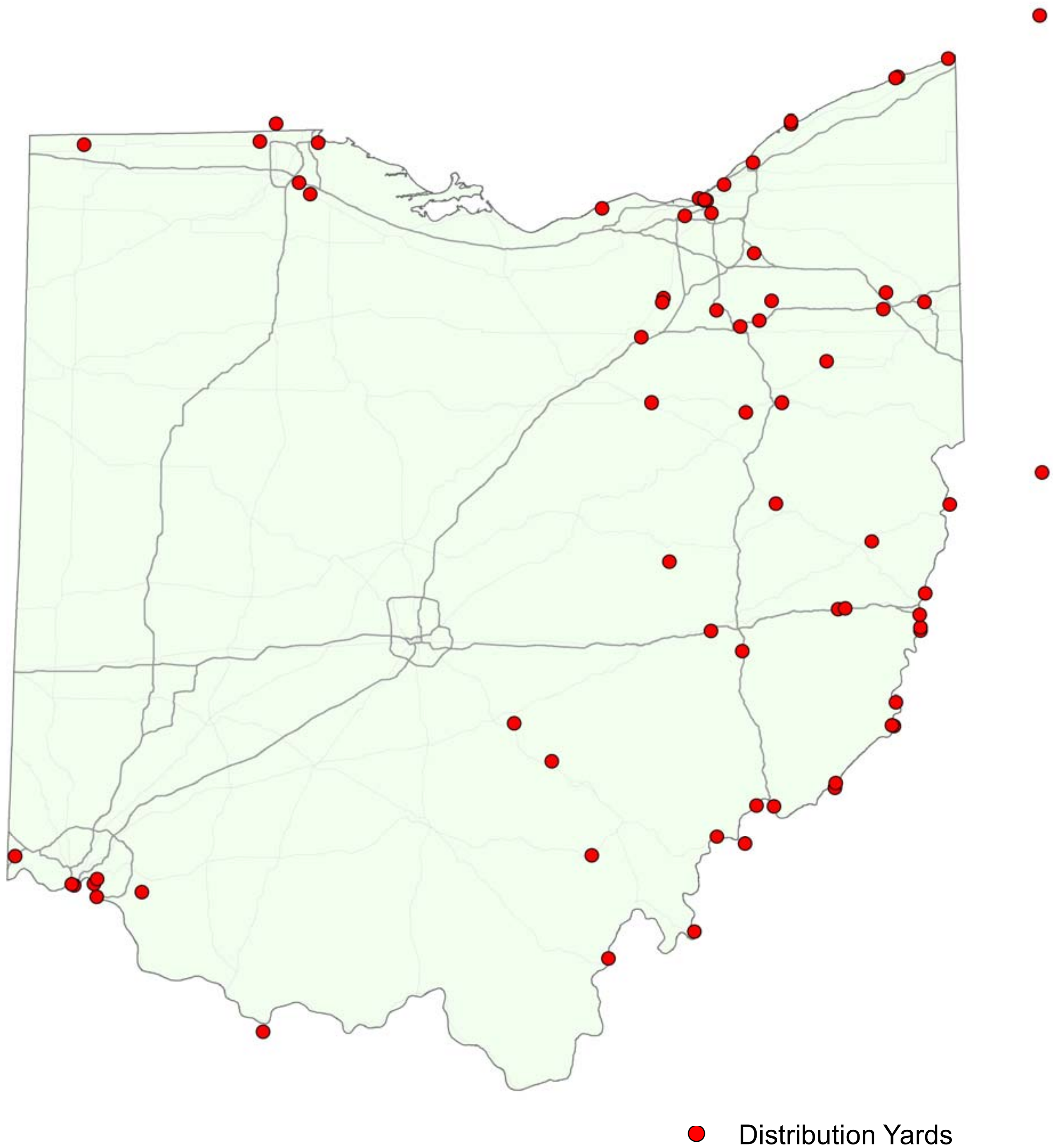


Figure 4. ODOT-Approved Aggregate Distribution Yards.

In consultation with ODOT Aggregate Section and the Ohio Aggregate and Industrial Minerals Association (OAIMA), Ohio was divided into five study regions based on the distribution of different aggregate sources and aggregate distribution yards, as shown in Figures 5 and 6:

- Northeast Ohio (NE), shown in pink, features mainly sand and gravel operations. A limited number of limestone mines are located in the southern part and far eastern edge of this region. Sources of slag are found in the Cleveland and Youngstown areas. To compensate for the lack of limestone and dolostone aggregates in this region, numerous distribution yards have been established to stockpile these types of aggregates.
- Northwest Ohio (NW), shown in orange, has numerous dolostone sources, with some limestone operations near the eastern and western boundaries of the region. This region has a limited number of sand and gravel operations and a single source of slag in the Toledo area.
- Central Ohio (CE), shown in blue, features several sand and gravel and some limestone operations (primarily mined from the Columbus and Delaware limestone formations). Only one source of slag is located in this region, in Marion County.
- Southeast Ohio (SE), shown in yellow, has limited sources of sand and gravel as well as limestone (primarily mined from the Maxville and Van Port limestone formations). In addition, no sources of dolostone or slag are located in this region. Similar to the NE region, several aggregate distribution yards have been established in this region mainly along rail lines and the Ohio River.
- Southwest Ohio (SW), shown in green, has numerous limestone, dolostone and sand and gravel sources. This region has also one source of slag in Butler County.

The selection of the five regions also considered the distribution of the population in Ohio and the presence of three large metropolitan areas (Cleveland-Akron-Canton, Columbus, and Cincinnati-Dayton), where the consumption of aggregates is expected to be higher than other areas of the state. As discussed in the following sections, these five regions were used as the basis for the analysis of the aggregate production, aggregate consumption, aggregate reserves, and aggregate depletion in Ohio.

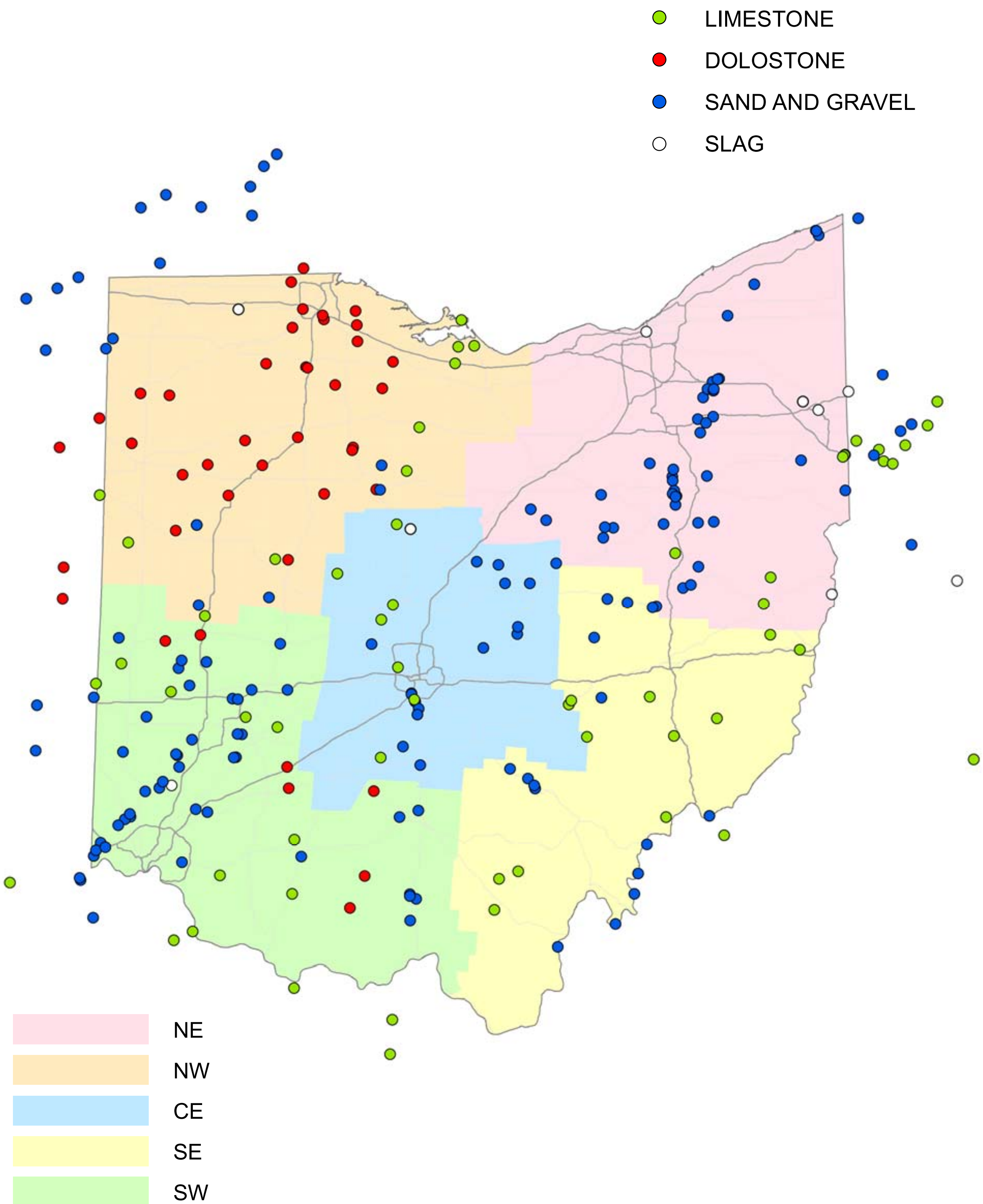


Figure 5. Aggregate Sources in the Five Study Regions.

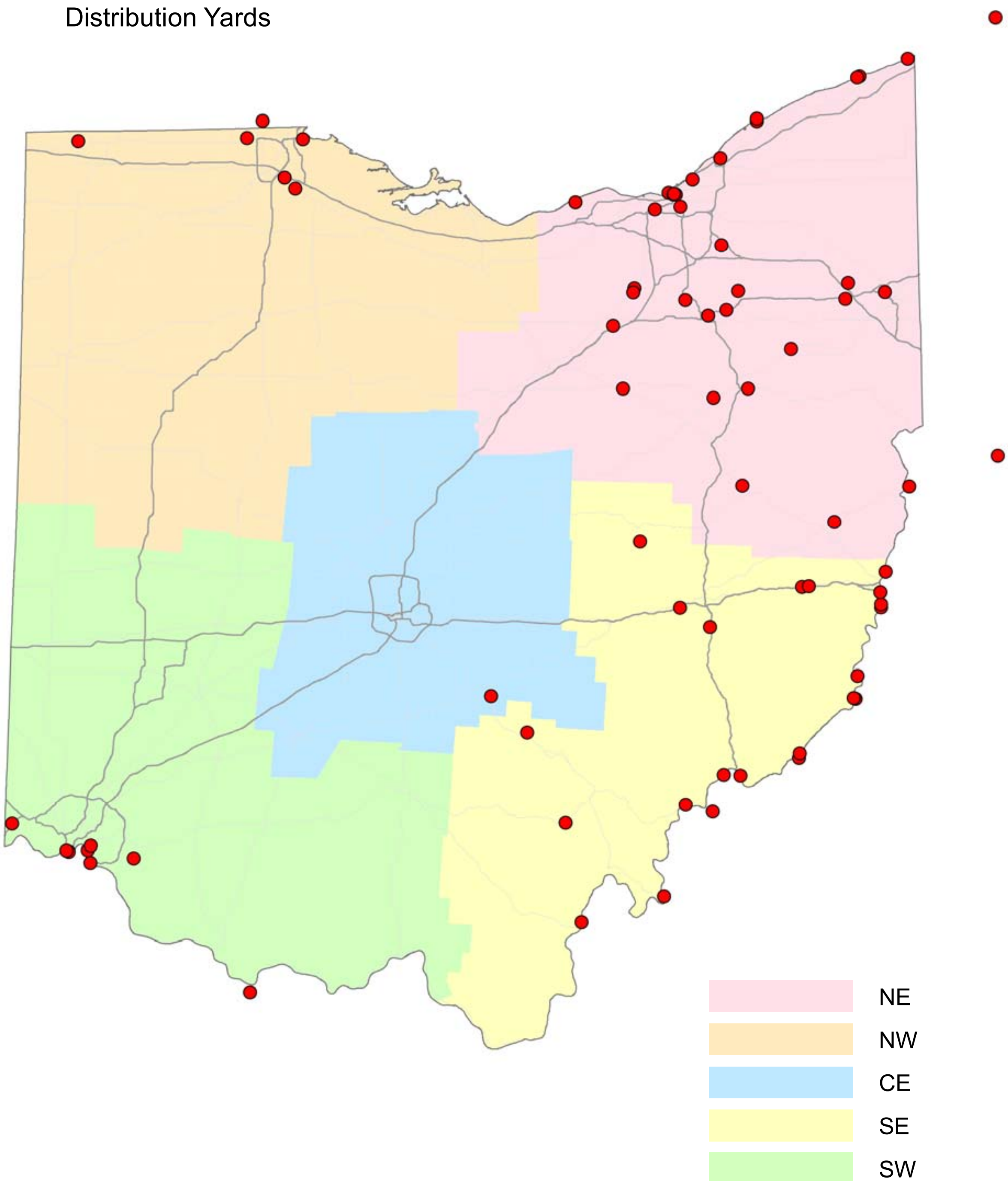


Figure 6. Aggregate Distribution Yards in the Five Study Regions.

3.2 Aggregate Production

Aggregate production and aggregate sales information for aggregate mines in Ohio are reported by aggregate producers to the ODNR Division of Geological Survey on an annual basis using a standard form called the Industrial Mineral Report. This report includes a total of ten sections. Three sections are of interest to this study: Identification (Section 1), Limestone and Dolomite (Section 3), and Sand and Gravel (Section 4). The Identification section (Section 1) seeks information about the operator of the mine and the location of the mine (including the management permit number), the geological formation/unit that was mined, the status of the mine (abandoned, reclaiming only, temporarily shut down, active nonproducing mine, or active producing mine), and a checkbox to indicate if the mine involves an underground operation. The Limestone and Dolostone section (Section 3) asks mine operators to indicate the amount of limestone/dolostone in tons sold for different applications (such as riprap, Portland cement concrete, asphalt mixture, road construction/resurfacing, and other uses), total tons sold, total tons produced, and the "freight on board" (FOB) sale value for the total tonnage sold during the year (excluding transportation). The Sand and Gravel section (Section 4) asks mine operators to list the tonnage produced and sold for sand and gravel. If the operator does not track tonnage for sand and gravel separately, the form asks the operator to include the approximate percentages of each. In addition, the form requests a combined FOB sale value for both sand and gravel. It should be noted that sales (in tons) does not necessarily equal production (in tons), as some producers may not sell all the aggregates they produce in a given year, and some operations that are no longer actively producing aggregates may still be selling material from existing stockpiles.

The aggregate production data obtained from ODNR was analyzed to examine the trends in aggregate production over time in Ohio. Figure 7 shows the total amounts of aggregates produced in the state from 1996 to 2019. As discussed earlier, the Industrial Mineral Report does not have separate categories for limestone and dolostone aggregates, while sand and gravel are reported separately by mine operators. In this figure, combined totals are shown for "Limestone/Dolostone" and for "Sand and Gravel". As can be noticed from Figure 7, aggregate production between 1996 and 2006 was near or over 120 million tons per year but dropped to around 70 million tons in 2009 and has increased slowly to slightly over 100 million tons per year in recent years. It can also be noticed from this figure that the total annual production of limestone/dolostone aggregates over the last ten years is approximately two thirds of the total aggregates produced in the state with the remaining balance coming from sand and gravel aggregates.

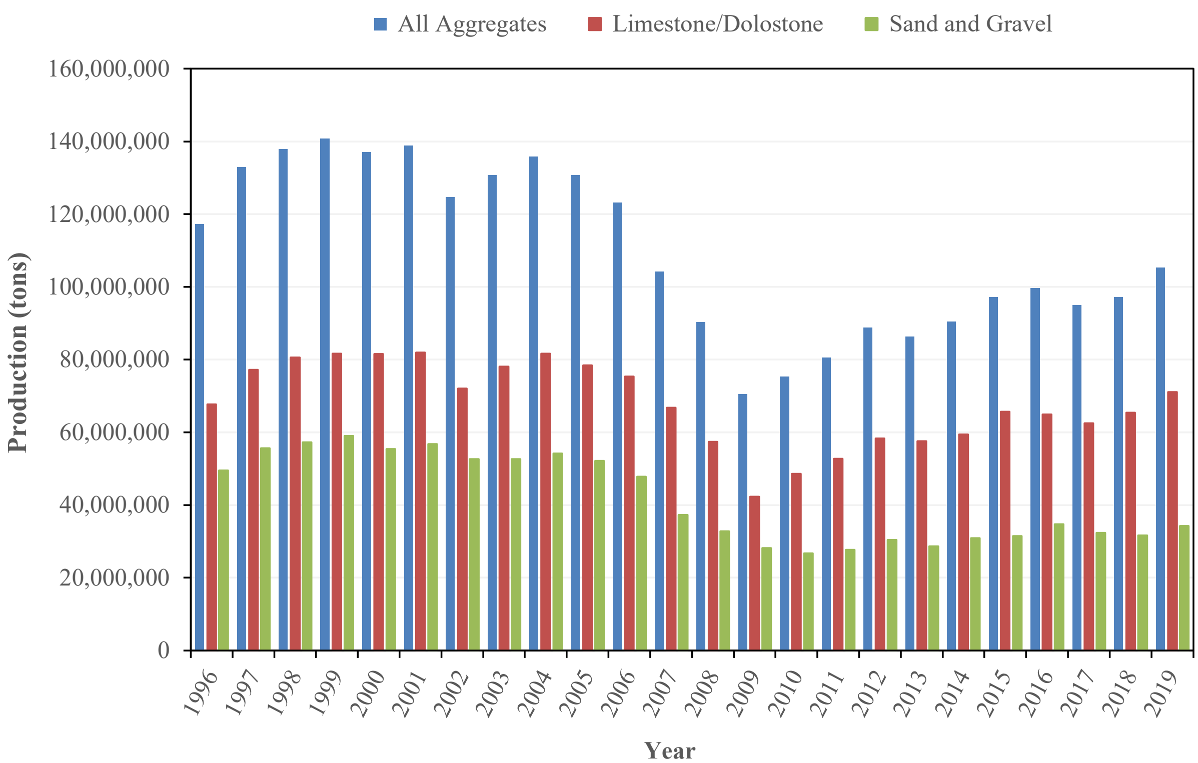


Figure 7. Aggregate Production in Ohio from 1996 to 2019.

Figures 8 and 9 present the total production of "limestone/dolostone" and "sand and gravel" aggregates, respectively, in each study region from 1996 to 2019. It can be noticed from Figure 8 that most limestone/dolostone aggregates are produced by operations in the northwest region (~35M tons in 2019), the central region (~17M tons in 2019), and the southwest region (~13M tons in 2019). Relatively small amounts of limestone are produced in the two regions in the eastern part of the state (less than 5M tons produced in each region in 2019). Figure 9 shows that the most sand and gravel aggregates are produced in the northeast region (~13M tons in 2019), the southwest region (~12M tons in 2019), and the central region (~6M tons in 2019). In addition, fewer than 5M tons of sand and gravel were produced in the southeast and northwest regions of the state in 2019.

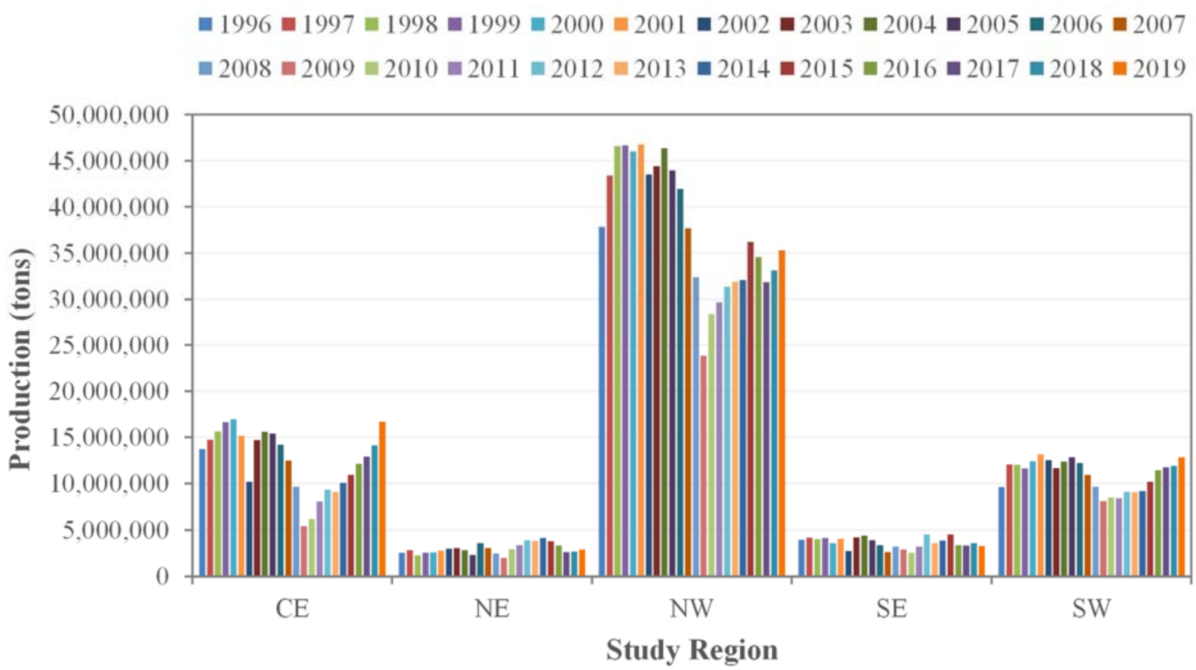


Figure 8. Limestone/Dolostone Production (in tons)
in the Five Study Regions (from 1996 to 2019).

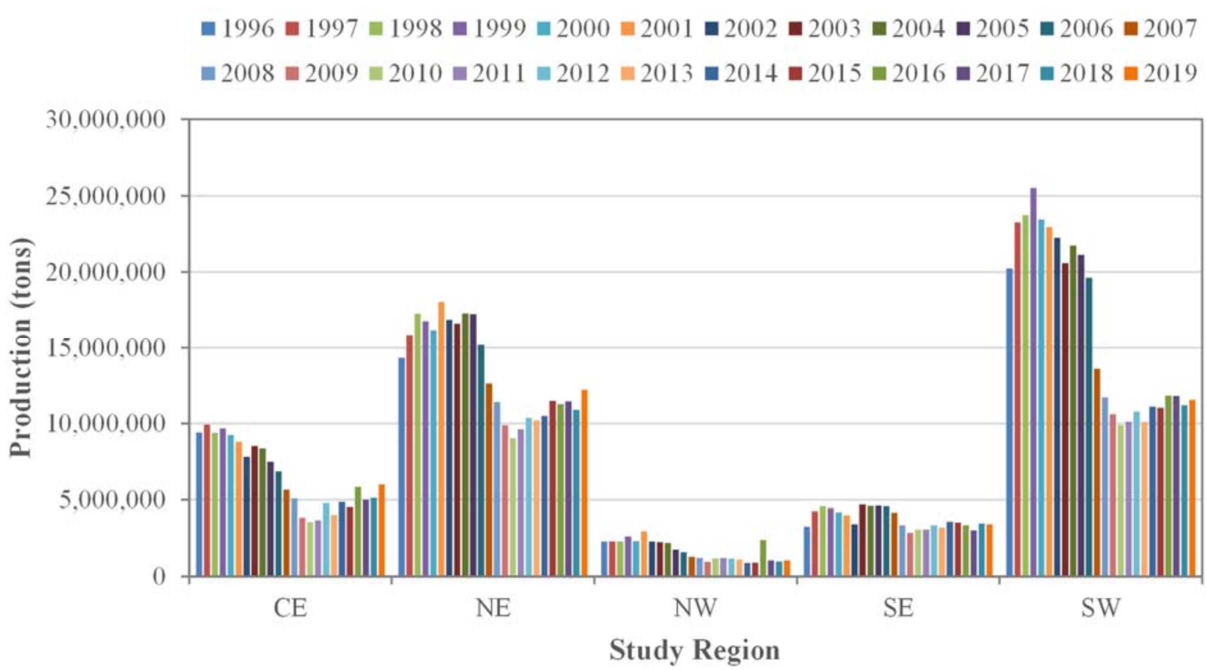


Figure 9. Sand and Gravel Production (in tons)
in the Five Study Regions (from 1996 to 2019).

To gain a better understanding of the aggregate production in each of the five study regions, the research team analyzed the ODNR aggregate production data from 2019 to determine the main sources of aggregates in each region. Figure 10 shows locations of the “limestone/dolostone” and “sand and gravel” aggregate sources in Ohio represented by a triangle (pink for limestone/dolostone and blue for sand and gravel), with the size of the triangle indicating the relative amount of aggregates produced at that particular aggregate source. It can be noticed from this map that the largest “limestone/dolostone” operations are located in the northwestern and central regions of the state and that the larger sand and gravel operations are located in the northeastern and southwestern regions.

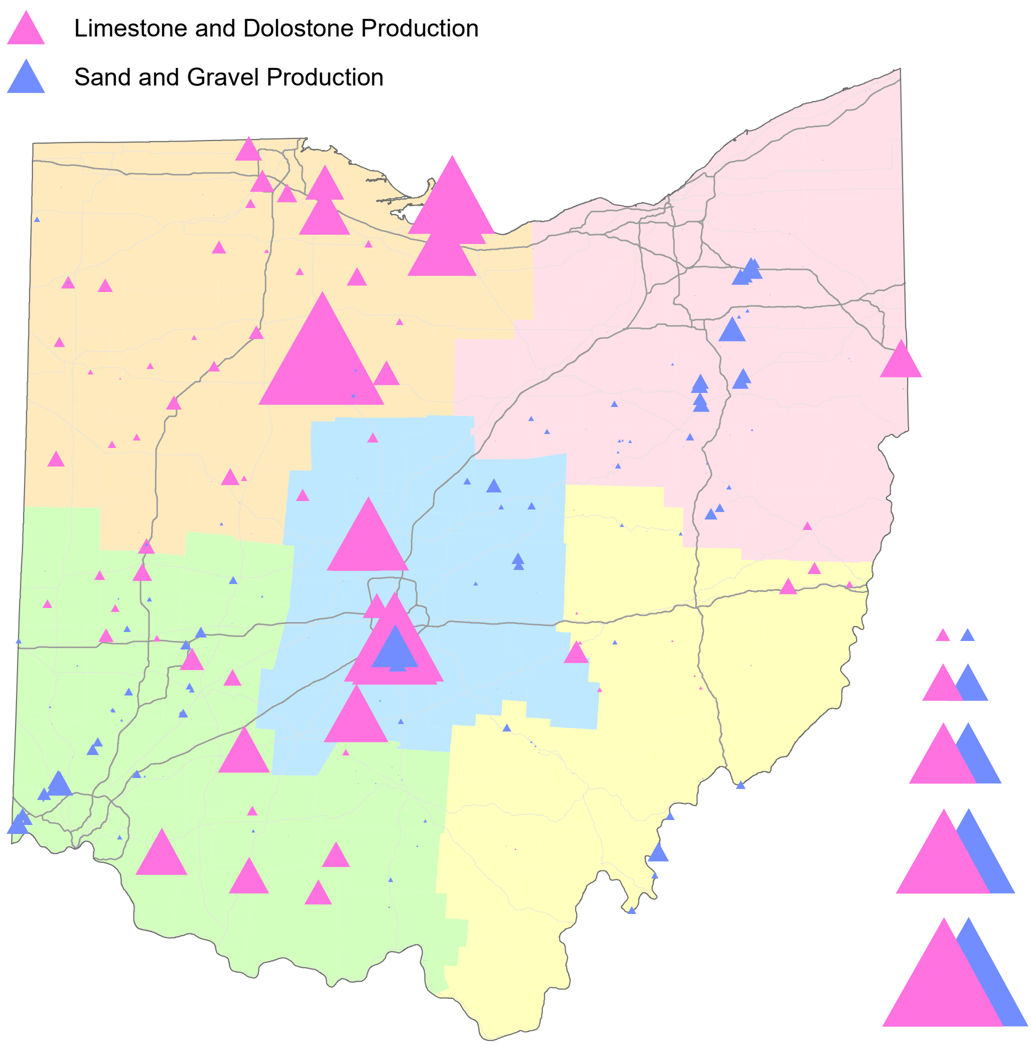


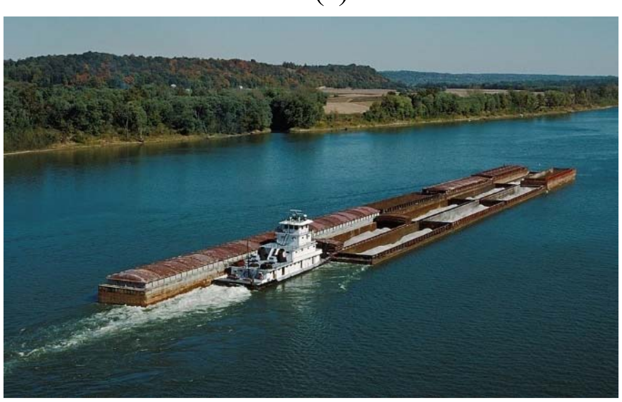
Figure 10. Locations of Aggregate Sources and 2019 Aggregate Production for Limestone and Dolostone (*Pink*) and Sand and Gravel (*Blue*) Mining Operations.

3.3 Aggregate Transportation

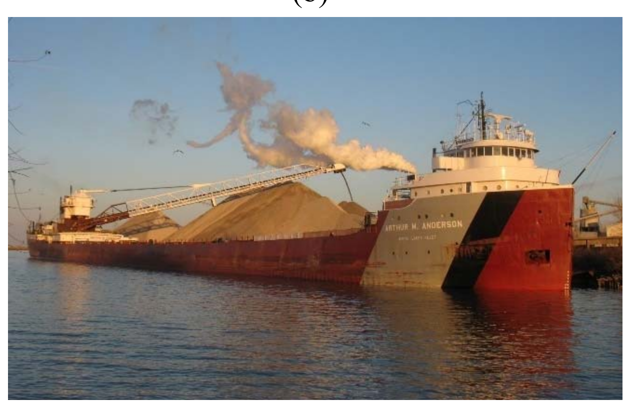
As discussed in the previous sections, not all study regions in Ohio have a sufficient amount of locally available quality aggregates to meet their needs. Therefore, aggregates are shipped to these regions from other regions in Ohio or surrounding states by truck, rail, barge, or lake freighters (Figure 11). Figure 12 presents a map showing the active rail lines in Ohio as well as ports along Lake Erie and the Ohio River. An aggregate hauler truck has a capacity of around 20 tons, while a train can generally transport around 5,000 tons (100 tons per railcar and 50 railcars per train). A typical lake freighter has a load capacity of around 20,000 to 30,000 tons, and a push boat with a large group of barges (with a capacity of up to 2,000 tons per barge and a maximum of 15 barges per boat) will have a similar capacity. Due to the heavy weight of aggregates and limited capacity of trucks, it is relatively expensive to transport aggregates over long distances using trucks. Therefore, it is more common to ship aggregates to distant locations over land by rail and over water by barges or lake freighters.

(a)

(b)



(c)



(d)

Figure 11. Aggregate Transportation: (a) Truck, (b) Railcar, (c) Barge, and (d) Lake Freighter (Sources: Stout Trucking 2021, National Steel Car Ltd. 2021, Alden III 1987, and Myers 2008).

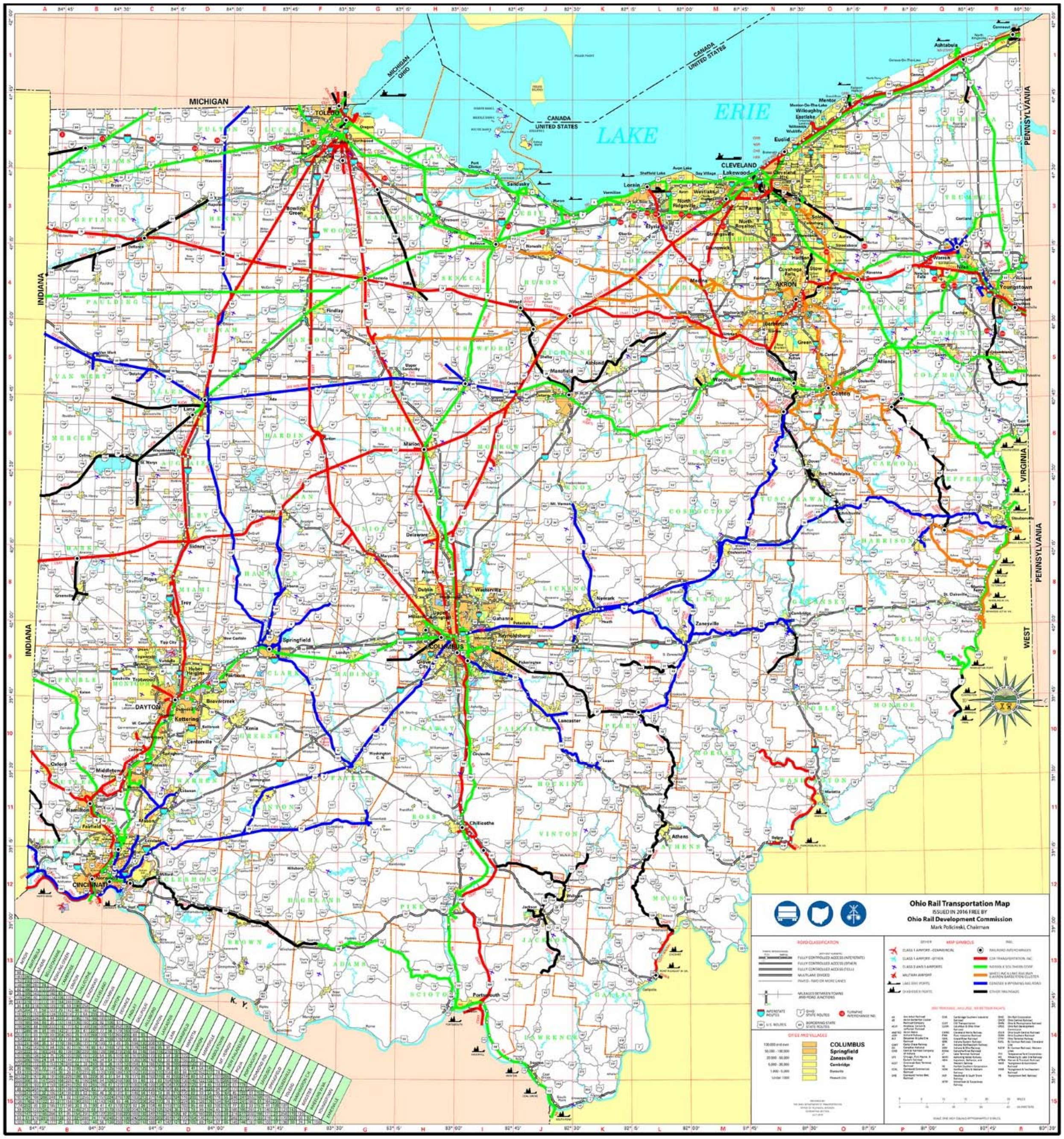


Figure 12. Active Rail Routes in Ohio and Ports along Lake Erie and the Ohio River (Ohio Rail Development Commission 2016).

Aggregate transportation into and out of the five study regions in Ohio is summarized below:

- The northeast region produces adequate amounts of sand and gravel but limited amounts of limestone. To compensate for the lack of crushed stone aggregates, this region typically obtains these aggregates from the northwest region as well as from Pennsylvania (mostly by rail to distribution yards along the rail lines) and from Michigan and Canada (mostly by lake freighters to ports along the shore of Lake Erie). Smaller quantities of limestone/dolostone are also shipped to the southern part of this region by barge on the Ohio River from northern Kentucky or from other aggregate sources along the Ohio River.

- The northwest region produces large amounts of limestone and dolostone aggregates but limited amounts of sand and gravel. Not all the limestone and dolostone aggregates produced in this region are used locally. Limestone and dolostone aggregates are shipped by rail to distribution yards in the northeast and southeast regions of Ohio. Some of the aggregates are also shipped out of state to Indiana and Michigan.
- The central region produces sizeable amounts of limestone and dolostone as well as sand and gravel. Due to the relatively high demand for industrial aggregates in this region, the majority of the aggregates produced in the region are consumed in the region, and additional aggregates are brought into the region from neighboring counties.
- The southeast region produces small amounts of limestone as well as sand and gravel. The majority of the aggregates produced in this region are consumed locally. Any additional aggregates that are needed are imported from other regions in Ohio and from neighboring states. In addition to receiving stone by rail and barge from the southwest region and by rail and truck from the central and northeast regions, some aggregates are shipped into this region by barge from Kentucky, and a very small amount of aggregates is brought in from West Virginia.
- The southwest region produces adequate amounts of limestone and dolostone as well as sand and gravel. Therefore, the majority of aggregates consumed in this region are produced within the region. In addition to locally sourced aggregates, this region also receives aggregates from northern Kentucky that are shipped by barge to distribution yards along the Ohio River.

3.4 Aggregate Consumption

To estimate aggregate consumption in the five study regions, the research team analyzed the tonnage report data provided by ODOT from 2011 to 2019 in order to determine the origin and destination of aggregates produced by each ODOT-approved aggregate source. This information was then used to estimate the quantities of aggregates consumed in the region of origin as well as the other destination regions for that particular aggregate source. Figure 13 presents an example showing the origin and destination of aggregates produced by a single aggregate source in central Ohio in 2019. In this figure, the aggregate quantities are depicted using colored lines extending from the aggregate source to the destination county in which the ODOT projects were constructed, where the color of the line represents the total quantity of aggregates used in that county (yellow indicates that less than 5,000 tons of aggregates were used, orange indicates that between 5,000 to 50,000 tons of aggregates were used, and red indicates that more than 50,000 tons of aggregates were used). For this aggregate source, it was estimated that 98% of the aggregates (575 thousand tons) were consumed in the CE region, while only 2% of the aggregates (12 thousand tons) were consumed in the SE region and negligible amounts of aggregates were consumed in the remaining regions.

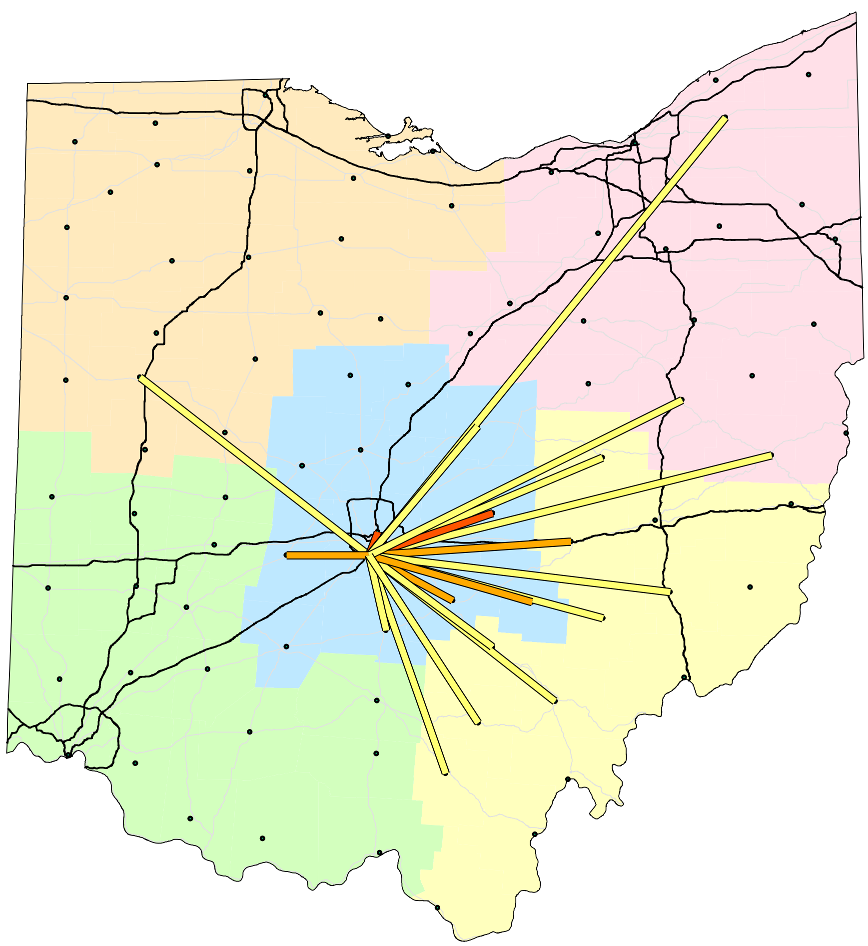


Figure 13. Origin-Destination of Aggregates Produced by an Aggregate Source in Central Ohio in 2019 (Yellow < 5,000 tons, Orange between 5,000 and 50,000 tons, and Red > 50,000 tons).

The same process was repeated for all ODOT-approved aggregate sources to determine the percentages of aggregates sourced within each region and the corresponding regions where the aggregates were consumed during the period from 2011 to 2019. The origin-destination analysis results for all years are presented in Appendix A. The analysis results for limestone/dolostone, sand and gravel, and all ODOT-approved aggregate sources for 2019 are presented in Tables 1, 2, and 3, respectively. From these tables, it can be noticed that the majority of the aggregates sourced in the NE, CE, and SW regions in 2019 were consumed within the same region. This applies to both limestone/dolostone as well as sand and gravel aggregates. As for aggregates produced in the NW region, it can be observed from Table 3 that 52.6% of the aggregates were consumed within the region, while a significant percentage (41.7%) was consumed in the NE region, with the main contribution coming from limestone/dolostone aggregates. For aggregate produced in the SE region, 68.9% were consumed within the region, while 27.0% were transported to the CE region and negligible amounts have destinations elsewhere.

Table 1. Origin-Destination of ODOT-Approved Limestone/Dolostone Aggregates in 2019.

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	96.7%	0.0%	0.0%	3.3%	0.0%
	NW	42.3%	52.4%	0.9%	3.1%	1.3%
	CE	0.1%	0.3%	98.4%	1.2%	0.0%
	SE	5.0%	0.0%	15.0%	78.0%	2.0%
	SW	0.0%	0.0%	2.3%	8.0%	89.7%

Table 2. Origin-Destination of ODOT-Approved Sand and Gravel Aggregates in 2019.

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	83.2%	3.3%	1.6%	11.6%	0.3%
	NW	0.0%	67.5%	4.7%	0.0%	27.8%
	CE	13.9%	3.9%	81.4%	0.3%	0.5%
	SE	2.2%	0.0%	34.9%	62.9%	0.0%
	SW	0.0%	1.5%	1.0%	5.8%	91.7%

Table 3. Origin-Destination of All ODOT-Approved Aggregates in 2019.

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	84.2%	3.1%	1.4%	11.0%	0.3%
	NW	41.7%	52.6%	1.0%	3.0%	1.7%
	CE	3.3%	1.2%	94.4%	1.0%	0.1%
	SE	3.3%	0.0%	27.0%	68.9%	0.8%
	SW	0.0%	0.5%	1.9%	7.4%	90.2%

To estimate limestone/dolostone as well as sand and gravel aggregate consumption in the five study regions in 2019, the percentages shown in each row of Tables 1 to 2 were multiplied by the aggregate production in 2019 for the corresponding aggregate type in the region of origin. The estimated aggregate quantities were then combined to estimate the aggregate consumption in each destination region, as shown in Table 4. Additional details about the calculation of aggregate consumption in each study region during the period from 2011 to 2019 are presented in Appendix B.

Table 4. Estimated Aggregate Consumption
in the Five Study Regions in 2019 (in Thousand Tons).

Region	Limestone/Dolostone	Sand and Gravel	All Aggregates
NE	17,948	11,086	29,034
NW	18,566	1,523	20,089
CE	17,536	6,439	23,975
SE	4,987	4,271	9,257
SW	12,012	10,935	22,947
Total	71,048	34,253	105,301

A regression model was also developed to predict future aggregate consumption in the five study regions. As discussed in Appendix C, a fixed-effects model with a different intercept for each region was used for the analysis. Future population estimates for each region (estimated using United States Census Bureau data), annual change in population in each region (estimated using US Census Bureau data), number of housing permits for single and multi-family units in each region (obtained from the US Census Bureau), and number of construction workers in each region (obtained from the Bureau of Labor Statistics) were used as time-variant variables. The predicted future aggregate consumption in each study region is presented in Figure 14. As can be noticed this figure, the regression model predicts that aggregate consumption will significantly increase in the CE and SW regions, moderately increase in the NE and NW regions, and remain relatively constant in the SE region over the next forty years. The significant increases in aggregate consumptions predicted in the CE and SW regions are consistent with the predicted trends for population growth in these two regions.

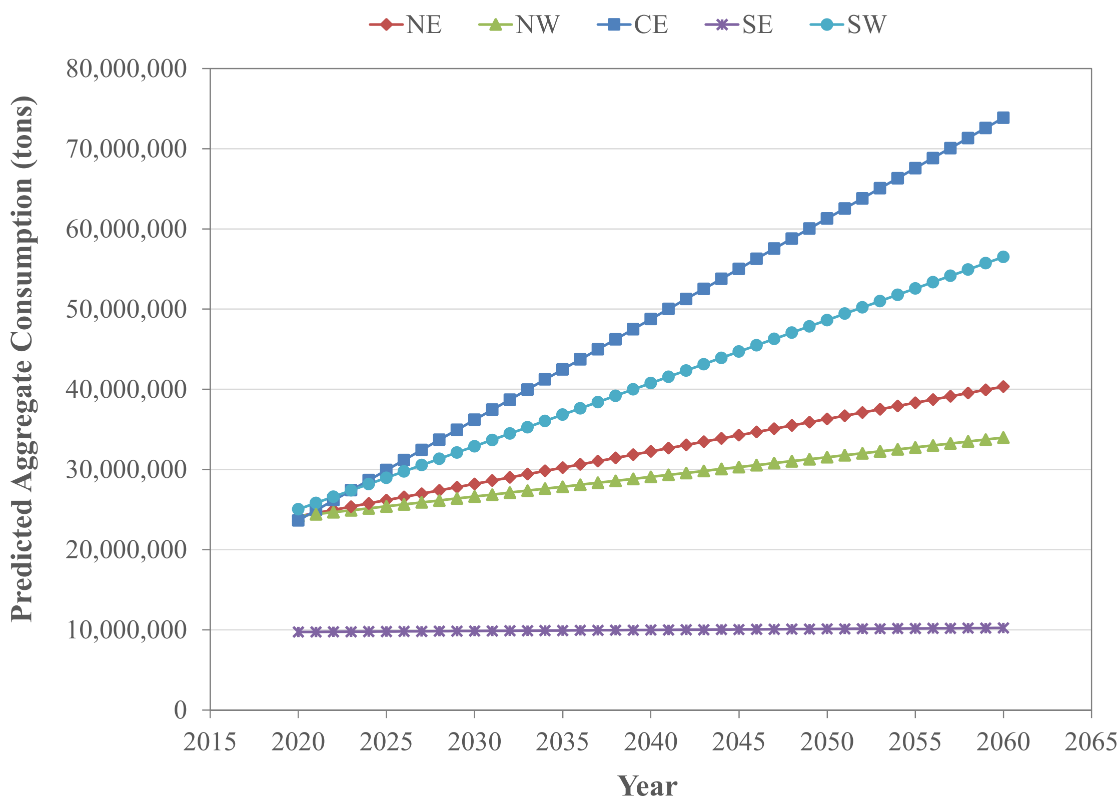


Figure 14. Predicted Aggregate Consumption in the Five Study Regions.

3.5 Aggregate Reserves

Aggregate reserves were estimated using information obtained from ODNR Division of Mineral Resources Management regarding the permitted area, affected area (area where some activity has taken place), area to be reclaimed (area where mining has ceased), original surface elevation, current surface elevation, and elevation of the permitted bottom of mine for limestone/dolostone mines and sand and gravel operations. This information was combined with digital satellite images from Google Earth Pro showing an aerial view of the mine. The surface elevation profile and the historical imagery options in Google Earth Pro were also used to obtain the current surface elevation at different locations within the mine and to monitor the mining activities over time, respectively. The drift thickness map for the state of Ohio, which was obtained from ODNR Division of Geological Survey, was also used to obtain the thickness of the overburden soil above the bedrock for limestone/dolostone mines.

The process for estimating the aggregate reserves involved reviewing the aggregate production data (for the last twenty years) and the historical images for all mines to determine which mines need to be included in the analysis and which mines have little to no reserves and can be excluded from the analysis. To estimate the aggregate reserves for limestone/dolostone mines, the research team first estimated the total volume of rock that is available to be mined using the total area of the mine, the active area of the mine, the current surface elevation, the mining depth, and the overburden soil thickness. The total and active areas of the mine were traced and measured using Google Earth Pro (as shown in Figure 15), the current surface elevation showing the current bottom of excavation was obtained using the surface elevation profile option in Google Earth Pro, the mining depth was estimated from mine sections provided by ODNR Division of Mineral Resources Management (refer to Figure 16 for an example), and the overburden soil thickness was estimated from the Ohio drift thickness map provided by ODNR Division of Geological Survey (see Figure 17). The resulting volume was then converted to weight using a unit weight of 165 lb/ft^3 for limestone/dolostone. Based on feedback from several aggregate producers, only 90% of the total area of the mine was used in the analysis to account for the buffer zone or setback along the border of the mine. The research team also reviewed available maps of limestone/dolostone mines from ODNR Division of Mineral Resources Management to determine if any parts of the mine needs to be excluded from the estimation of aggregate reserves. Furthermore, it was assumed that 80% of the aggregates would be sellable due to the presence of waste rock and tailings.

Figure 15. A Limestone/Dolostone Mine, as shown on Google Earth.

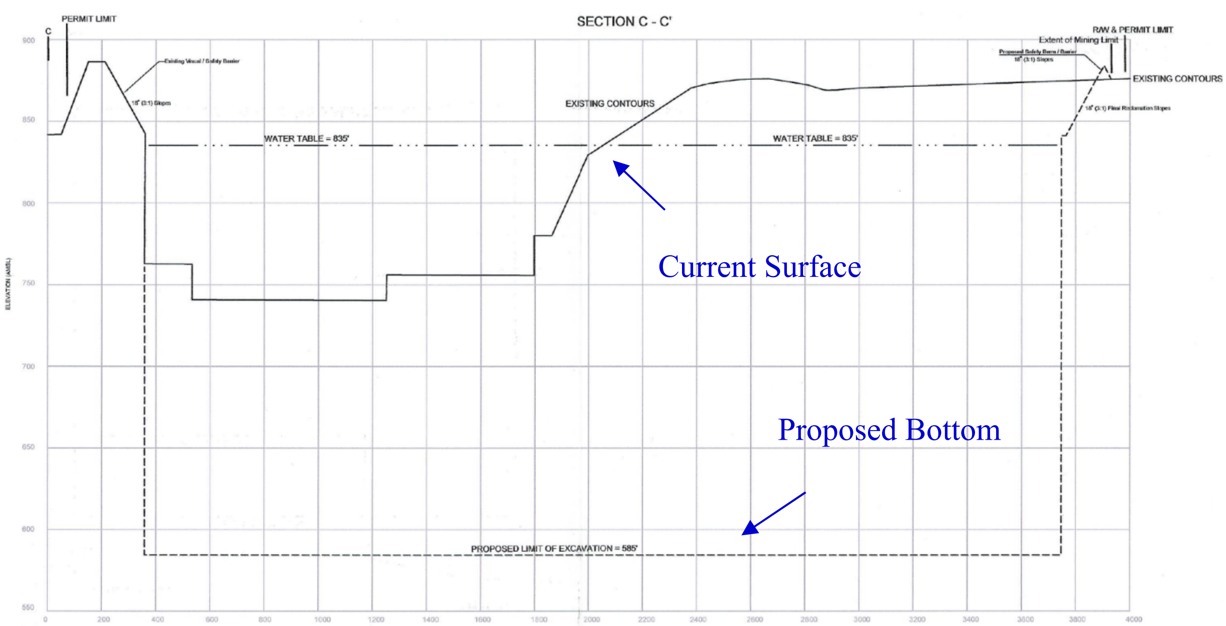


Figure 16. Cross Section of a Limestone/Dolostone Mine.

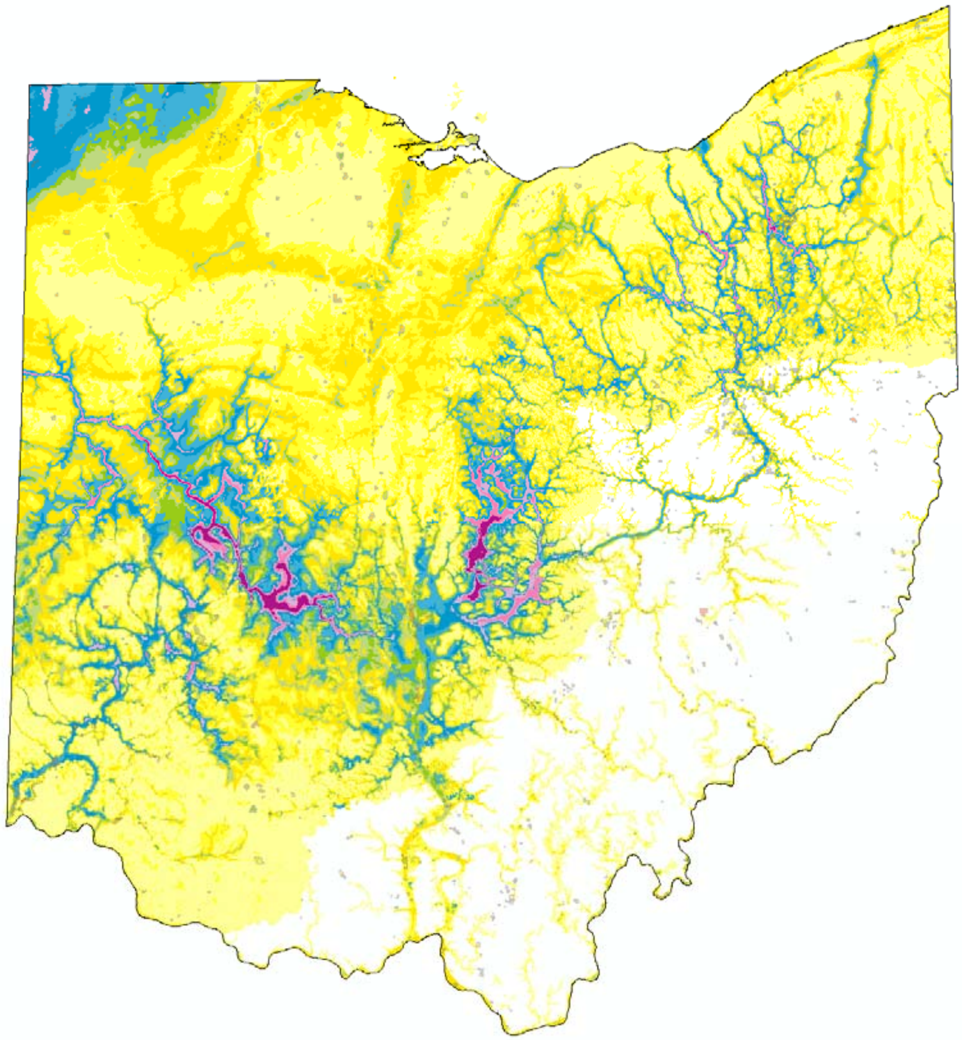


Figure 17. Ohio Drift Thickness Map Provided by ODNR.

A similar process was used to estimate the aggregate reserves for sand and gravel deposits. However, for such operations, dredging equipment is commonly used to mine these deposits, and a lake is generally formed at the location where dredging has taken place, as shown in Figure 18. For the estimation of aggregate reserves for sand and gravel mines, it was assumed that no reserves are remaining in areas covered by water. In addition, a unit weight of 120 lb/ft^3 was used to convert the aggregate reserves for sand and gravel from volume to weight. While a vertical slope can be used for limestone/dolostone mining operations, a sloped side is generally used for sand and gravel operations to ensure the long-term stability of the side of the mine (refer to Figure 19 for an example). Consequently, only 80% of the total area of the mine was used in the estimation of the aggregate reserves for sand and gravel mines (as compared to 90% used for limestone mines).

Available maps of sand and gravel mines from ODNR Division of Mineral Resources Management were also reviewed to determine if any parts of the mine need to be excluded from the estimation of aggregate reserves. Moreover, 80% of the aggregates were assumed to be sellable.

Figure 18. A Sand and Gravel Mine, as shown on Google Earth.

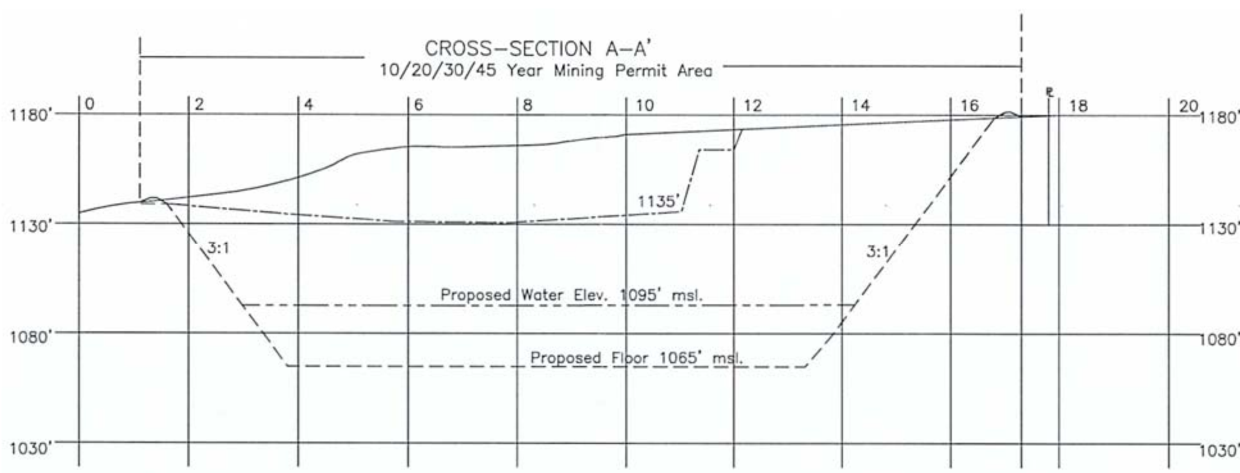


Figure 19. Cross Section of a Sand and Gravel Mine.

Several steps were followed to check the information used for the estimation of the aggregate reserves for each aggregate mine. This included checking the estimated mining depth for the aggregate mine to make sure it is consistent with other nearby mines and consistent with the annual production rate for that aggregate mine. The estimated aggregate reserves were also checked to make sure they are reasonable for the remaining area to be mined.

Figures 20 and 21 show the estimated mining depth and the estimated aggregate reserves, respectively, for limestone/dolostone mines. As can be noticed from Figure 20, the limestone/dolostone mines in the NW region are relatively deeper (with a mining depth greater than 250 ft for some mines) than those in the other regions. Figure 21 also shows the limestone/dolostone reserves are mainly concentrated in the western half of the state. Figures 22 and 23 show the estimated mining depth and the estimated aggregate reserves, respectively, for sand and gravel mines. As can be noticed from Figure 22, a large number of sand and gravel mines in the NE and SW regions have relatively deep mineable deposits (that may extend to more than 150 ft for some mines), while the majority of the sand and gravel mines in the NW, CE, and SE regions are relatively shallow (with a mining depth smaller than 60 ft for most mines). A similar trend can be seen in Figure 23 in that higher sand and gravel reserves are available in the NE and SW regions than the NW, CE, and SE regions. It is noted that several sand and gravel mines in the NE and SW have large areas remaining to be mined, which explains the relatively large amounts of aggregate reserves for these mines.

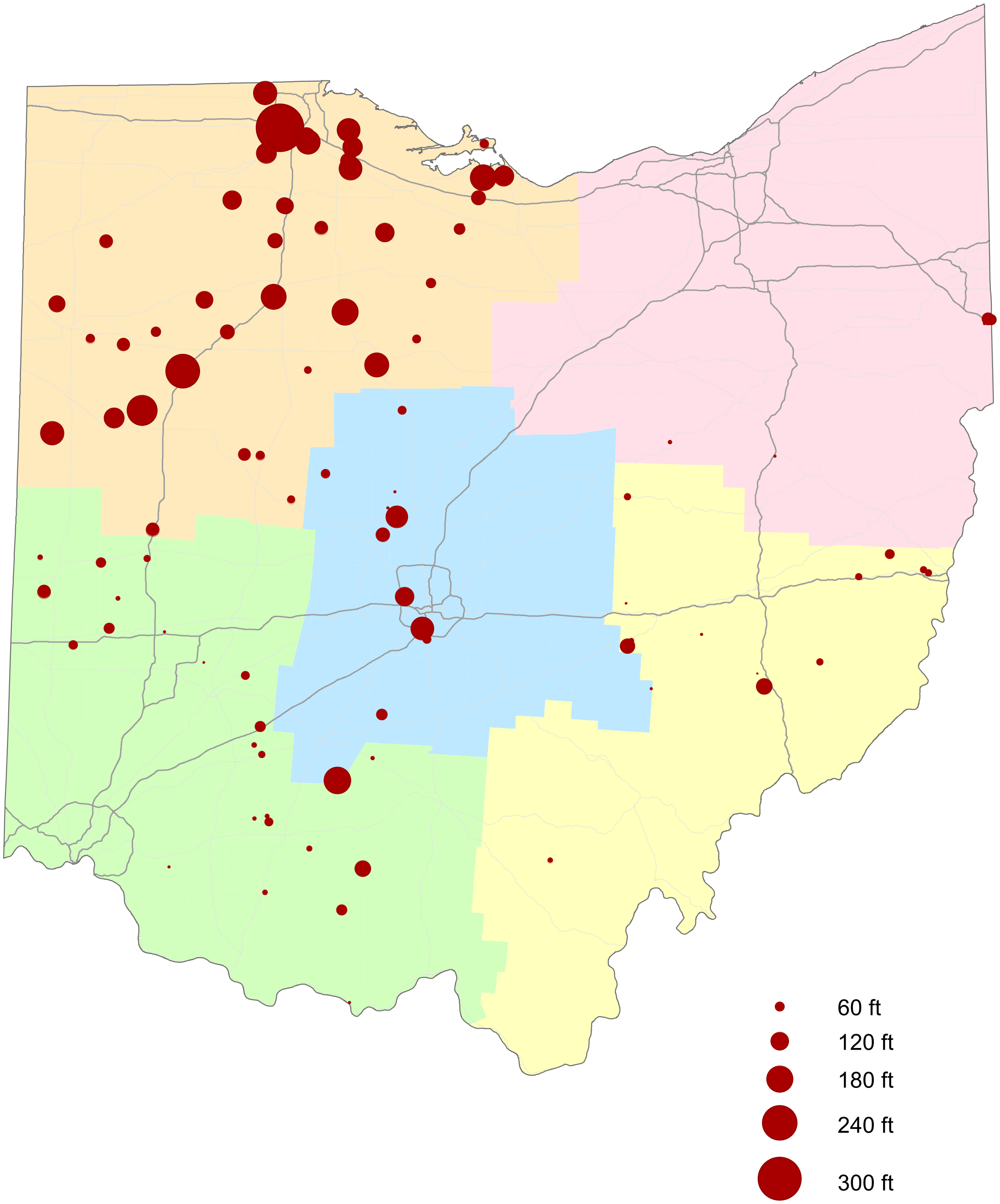


Figure 20. Limestone/Dolostone Mining Depth.

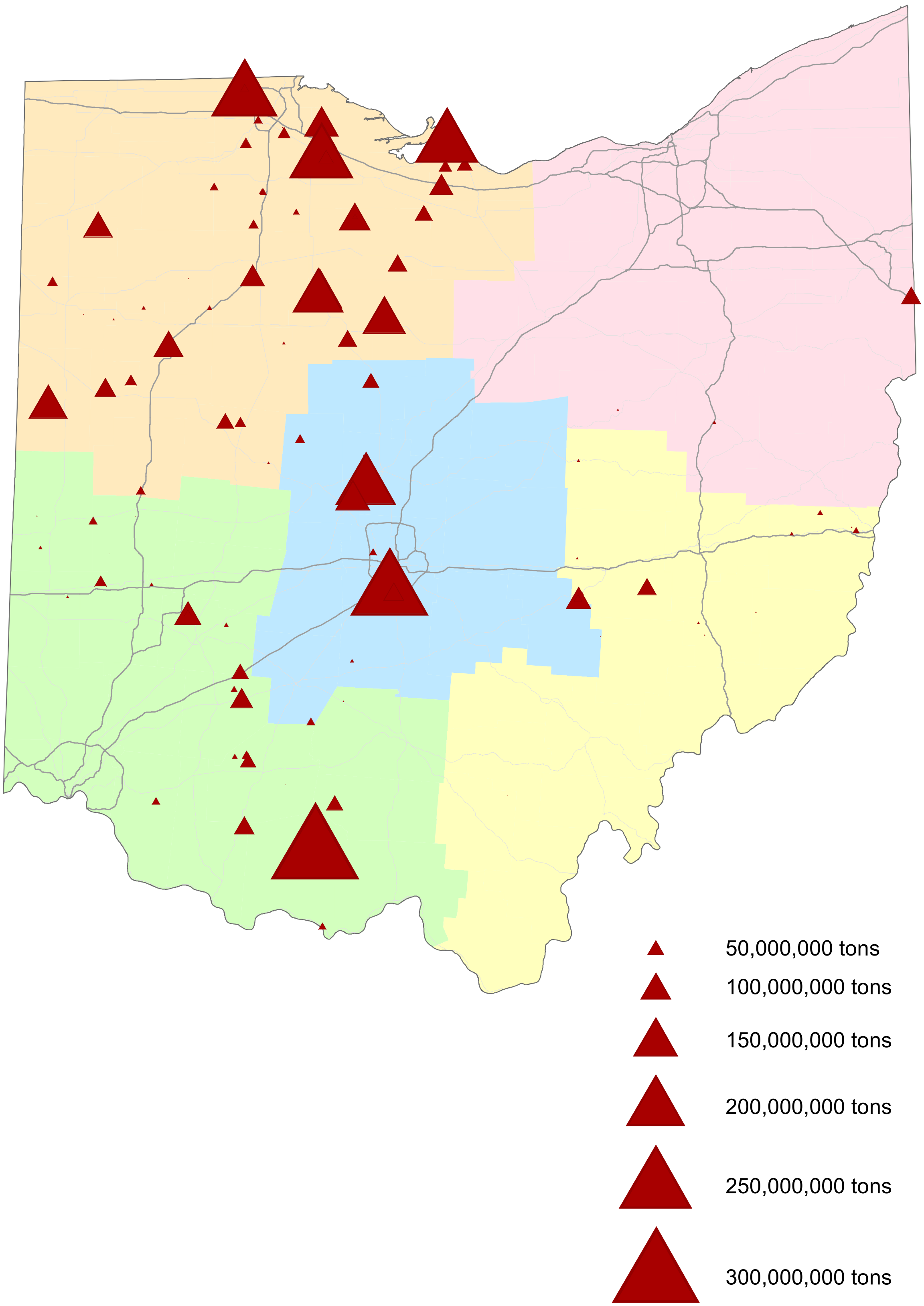


Figure 21. Limestone/Dolostone Reserves.

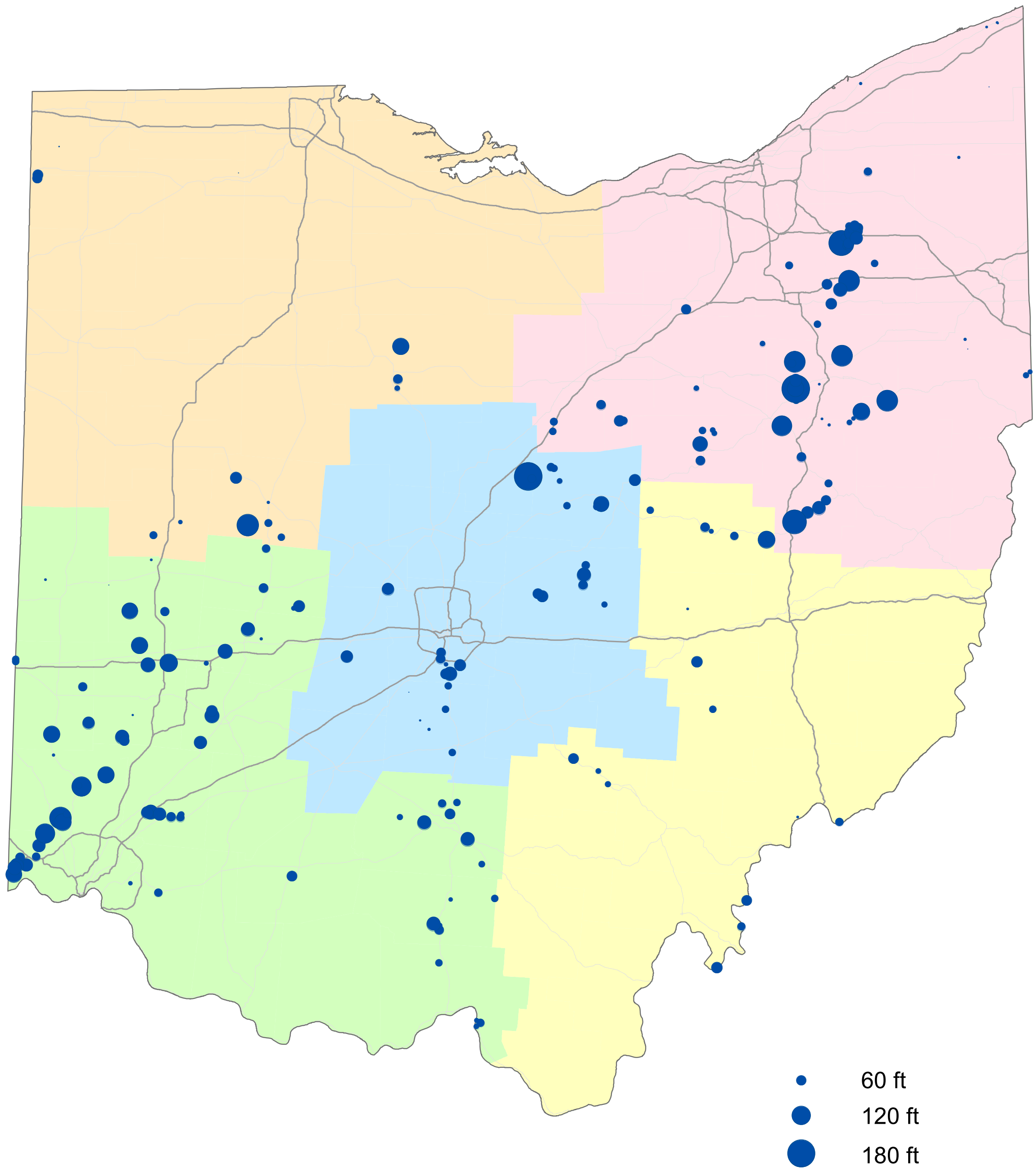


Figure 22. Sand and Gravel Mining Depth.

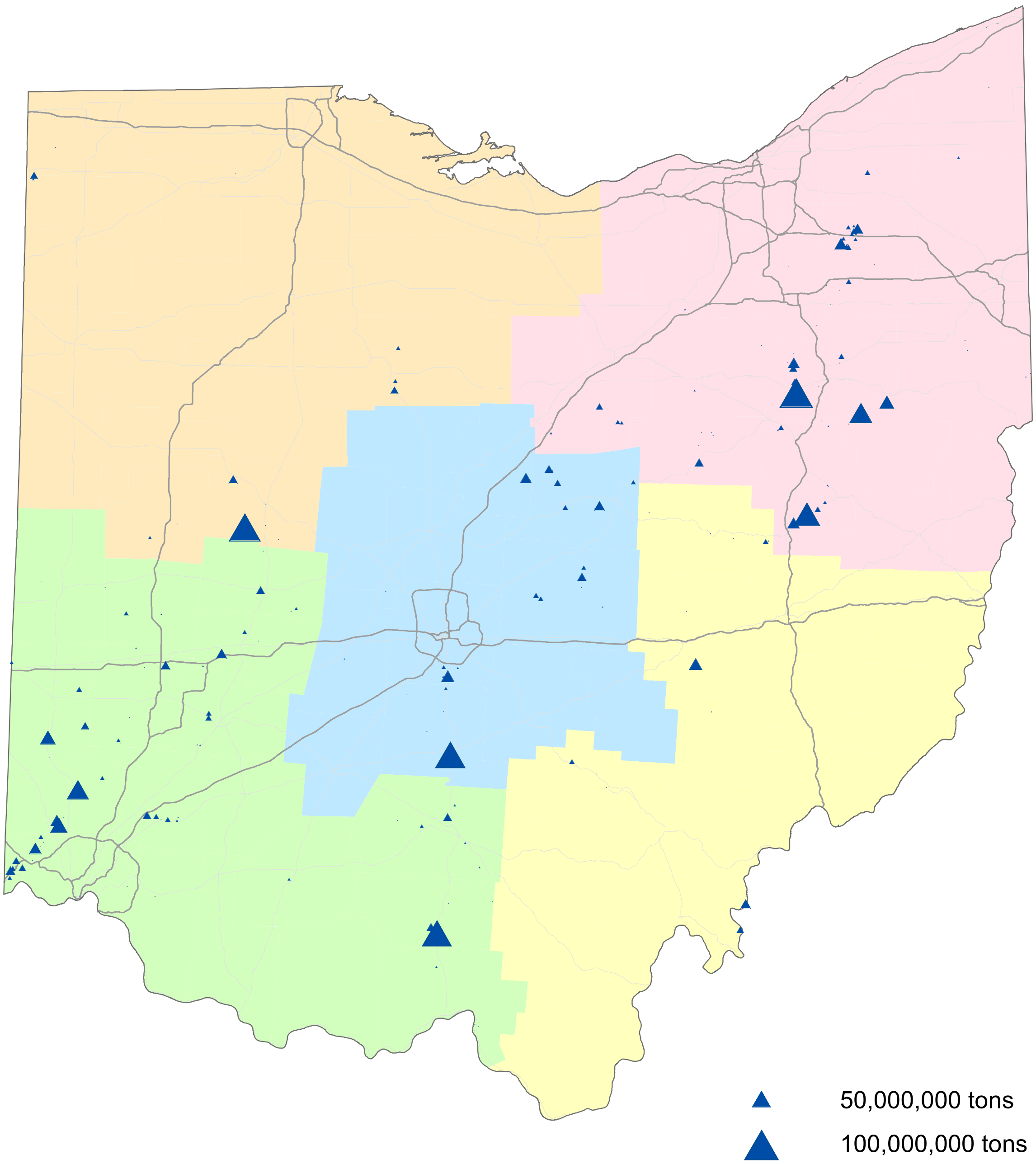


Figure 23. Sand and Gravel Reserves.

3.6 Aggregate Depletion

The research team utilized the estimated aggregate reserves and the predicted aggregate consumption in the five study regions to estimate the number of years it will take for local aggregate reserves to be fully depleted in each study region. Two methods were used to conduct the depletion analysis. The first method, Method 1, assumed a constant aggregate consumption in each study region and utilized the 2019 aggregate consumption predictions presented in Table 4. The second method, Method 2, assumed varying aggregate consumption in the five study regions and utilized the regression model predictions presented in Figure 14 for the total aggregate consumption in each region. The depletion analysis for sand and gravel was conducted separately than that for limestone/dolostone. The percentage of sand and gravel versus limestone consumed in each region was assumed to be the same as that for 2019. The analysis for the second method was conducted for a period forty years, as the accuracy of any aggregate consumption predictions beyond that time period would be highly uncertain.

Table 5 presents the estimated number of years for aggregates to be fully depleted in each study region using Method 1 (Constant Aggregate Consumption). As can be noticed from this table, the NE region has large amounts of sand and gravel reserves that are predicted to last around 90 years, but limited amounts of limestone reserves. The NW region has large amounts of limestone reserves that are predicted to last more than 170 years, but limited amounts of sand and gravel reserves, which could explain the small amounts of sand and gravel consumed within the region. The CE region has sand and gravel reserves and limestone reserves that are predicted to last 70 years and 50 years, respectively. The SE region, which is known to have limited aggregate availability, has sand and gravel reserves and limestone reserves that are expected to last 41 years and 65 years, respectively. Finally, the SW region has large amounts of reserves for both sand and gravel and for limestone that are expected to last around 100 years and more than 80 years, respectively.

Table 6 presents the estimated number of years for aggregates to be fully depleted in each study region using Method 2 (Varying Aggregate Consumption). As can be noticed from this table, the most significant difference in predicted aggregate depletion between the two methods is for the CE region. The second method, which considers the expected future growth in the CE region, estimates that limestone aggregates will be depleted within 30 years and that sand and gravel aggregates will be depleted within 37 years, assuming that no additional reserves will become available.

Information about the permitting record for aggregate mines was obtained from the ODNR Division of Mineral Resources Management and analyzed to determine the total acreage permitted for sand and gravel deposits and limestone mines in each study region (Table 7). In this table, a positive value indicates that more acres were added to mine permits than removed in a particular year, while a negative value indicates that more acres were removed in that year. As presented in this table, the CE region had the lowest number of acres permitted in the state during the period from 2011 to 2021, with a grand total of 217.9 acres. By dividing this grand total by eleven years, it can be estimated that an average of 20 acres per year was permitted in that region. Due to the relatively small additional area permitted per year in the CE region, it is reasonable to assume no increase in aggregate reserves in that region for the depletion analysis.

Table 5. Estimated Aggregate Depletion using Method 1 (Constant Aggregate Consumption).

Region	Aggregate Type	Reserves**	Depletion (Years)
NE	Limestone/Dolostone	161,840,283	9
	Sand and Gravel	994,569,341	90
NW	Limestone/Dolostone	3,182,953,318	171
	Sand and Gravel	136,500,274	90
CE	Limestone/Dolostone	875,636,055	50
	Sand and Gravel	449,589,381	70
SE	Limestone/Dolostone	326,114,084	65
	Sand and Gravel	174,488,686	41
SW	Limestone/Dolostone	1,057,208,108	88
	Sand and Gravel	1,098,483,970	100
Statewide	Limestone/Dolostone	5,603,751,847	79
	Sand and Gravel	2,853,631,652	83

** Green: High aggregate reserves, Orange: Moderate aggregate reserves, and Red: Low aggregate reserves.

Table 6. Estimated Aggregate Depletion using Method 2 (Varying Aggregate Consumption).

Region	Aggregate Type	Reserves**	Depletion (Years)
NE	Limestone/Dolostone	161,840,283	11
	Sand and Gravel	994,569,341	> 40
NW	Limestone/Dolostone	3,182,953,318	> 40
	Sand and Gravel	136,500,274	> 40
CE	Limestone/Dolostone	875,636,055	30
	Sand and Gravel	449,589,381	37
SE	Limestone/Dolostone	326,114,084	> 40
	Sand and Gravel	174,488,686	38
SW	Limestone/Dolostone	1,057,208,108	> 40
	Sand and Gravel	1,098,483,970	> 40
Statewide	Limestone/Dolostone	5,603,751,847	> 40
	Sand and Gravel	2,853,631,652	> 40

** Green: High aggregate reserves, Orange: Moderate aggregate reserves, and Red: Low aggregate reserves.

Table 7. Total Acreage Permitted for Aggregate Mines in Each Region between 2011 and 2021.

Year	NE	NW	CE	SE	SW	Total
2011	190.4	477.7	-16.2	131.9	10.5	794.3
2012	255.9	77.4	-9.6	549.8	201.2	1074.7
2013	243.9	-7	440.5	152	511.5	1340.9
2014	493.3	-24.4	70.8	27.2	88.6	655.5
2015	142.1	99.4	20.9	156.6	81.3	500.3
2016	113.6	8.3	50	162.9	-19.3	315.5
2017	-301.7	43.6	-148.9	254.1	458.3	305.4
2018	403.6	67.5	-181.3	160.5	530.6	980.9
2019	217.6	96.2	53.7	391.4	-15.5	743.4
2020	309.5	24.1	86	153.4	10.2	583.2
2021	457.3	77.5	-148	56.8	8.6	452.2
Total	2525.5	940.3	217.9	2196.6	1866	7746.3

3.7 Zoning Laws for Aggregate Mining

Potential use of land in Ohio for purposes of aggregate mining would affect Ohio's economy and infrastructure as well as citizens in local communities and aggregate producers. On one hand, the mining of aggregates contributes to the economy and supplies materials that are needed to build and maintain public infrastructure (including roads, bridges, and schools), and it provides jobs to workers in the aggregate industry. On the other hand, local zoning policies that ensure separation of land uses can help to maintain public health (via ordinances regarding dust and noise, for example), community character, and the value of residential properties, as well as to protect the natural environment of an area. In recent years, the aggregate industry has voiced concern that local zoning might make it more difficult to access aggregate reserves that may be needed in the future.

The research team examined the zoning laws in Ohio that pertain to aggregate mining. Below is a summary of recent legislation introduced or passed at the state level that are related to zoning of aggregate mines:

- *Ohio Revised Code 1514.023 (Zoning Resolutions or Ordinances):* This law, which went into effect on March 15, 2002, specifically addressed the enforcement of zoning resolutions or ordinances related to "other surface mining." This rule reaffirmed home rule, as it indicated that Ohio law does not prevent "any county, township, or municipal corporation from enacting, adopting, or enforcing zoning resolutions or ordinances." It also clarified that the Chief of ODNR Division of Mineral Resources Management does not have the authority to enforce local zoning resolutions or ordinances (Ohio Legislative Service Commission, 2002).
- *Senate Bill 191 and House Bill 400:* In 2005, Senate Bill 191 and its companion bill (House Bill 400) were introduced in the Ohio legislature that would have revised county and township zoning laws concerning industrial minerals mining (Ohio General Assembly Archives 2021, Ohio Legislative Service Committee 2021). The Ohio Township Association (OTA) expressed concern that the legislation would preempt or dictate exactly how the land use issue of zoning for aggregate mines would be handled by counties and townships. Another concern was that the proposed legislation would take away from township residents the right of referendum for the permitting of aggregate facilities, especially for those people living in residential areas where aggregate deposits are located. OTA proposed revisions to the bills in an attempt to find a way to simplify the process of siting aggregate mining facilities that would be mutually

beneficial to counties and townships and the aggregate industry. In the end, neither of the two bills were passed by the Ohio legislature.

- *Ohio Revised Code Section 519.141 (Conditional Zoning Certificates for Surface Mining Activities):* This law went into effect on April 6, 2007 (Ohio Secretary of State 2007). The new law does not necessarily affect the authority of the township to set its own zoning rules. The law only applies to townships that treat aggregate mining as a *conditional use* under their current zoning resolutions. Townships that already treat aggregate mining as a *permitted use* and will continue to do will not be affected by the new law. Under conditional use, any applicant for an aggregate mining permit can be required by the township board of zoning appeals to meet specific conditions listed in Ohio Revised Code Section 519.14. These conditions require the applicant to have inspections of structures and water wells near the mining site to determine structural integrity and water levels; comply with applicable federal, state, and local laws and regulations; identify specific roads that will be used as the primary routes to and from the proposed site of aggregate mining; comply with reasonable noise abatement measures; comply with reasonable dust abatement measures; establish setbacks, berms, and buffers for the proposed activity; establish a complaint procedure; and follow other measures that are reasonably related to the health and safety of the general public. For townships that have adopted conditional use, the following restrictions apply: the board of zoning appeals of the township is not allowed to consider or base its determination for a conditional use permit on matters that are regulated by any federal, state or local agency; the township cannot designate the haul route for the mined aggregates – the county engineer and county commissioners have the authority to designate the haul route, not the township, per Ohio Revised Code Section 303.141 (Conditional Zoning Certificates for Surface Mining Activities); and townships that treat aggregate mining as a conditional use no longer have the right of referendum (Griggs undated, pp. 4–5).

Legislation at the federal level that focuses on the sourcing of aggregates has also been recently considered. The Rebuilding Our Communities by Keeping Aggregates Sustainable (ROCKS) Act was first introduced in November 2019 and sponsored by Rep. Greg Stanton of Arizona's 9th District and Troy Balderson of Ohio's 12th District (U.S. Congress, 2019). This bill never came to a vote in Congress. The ROCKS Act was re-introduced in the US House of

Representatives in January 2021 as H.R. 611 and introduced in the US Senate by Senators Mark Kelly of Arizona and Senator Rob Portman of Ohio in May 2021 (Kelly 2021; U.S. Congress, 2021). The ROCKS Act was approved in May 2021 by the Senate Environment and Public Works Committee and has been included in the Surface Transportation Reauthorization Act of 2021 that is currently being debated in Congress. The ROCKS Act would establish a working group of stakeholders at the federal, state and local levels to study the use of aggregates and ensure that policy makers are taking into account access to identifiable aggregates when making decisions regarding infrastructure development (NNSGA 2021a). This includes having state geologic surveys partner with stakeholders to provide the knowledge needed to make informed decisions during the planning process and providing financial support to federal, state, and tribal geologists to evaluate existing aggregate sources, identify new sources of aggregates, and provide communities with validated information to help them manage sustainable access to aggregate sources (NNSGA 2021b).

3.8 Economic Impact Analysis

Figures 24 and 25 present the average cost of sand and gravel as well as limestone/dolostone aggregates, respectively, in the five study regions for the period from 1999 to 2019. These averages were calculated using "freight on board" (FOB) sale value (excluding transportation) and total tonnage information reported on an annual basis by aggregate producers to ODNR Division of Geological Survey. As presented in Figure 24, the average limestone/dolostone aggregates increased from approximately $4.50 per ton to approximately $10.50 per ton in the twenty-year period, which represents an average increase in cost of approximately $0.30 per ton per year. During the same period, the average cost of sand and gravel aggregates increased from approximately $4 per ton to approximately $8 per ton (Figure 25), which represents an average increase in cost of approximately $0.20 per ton per year.

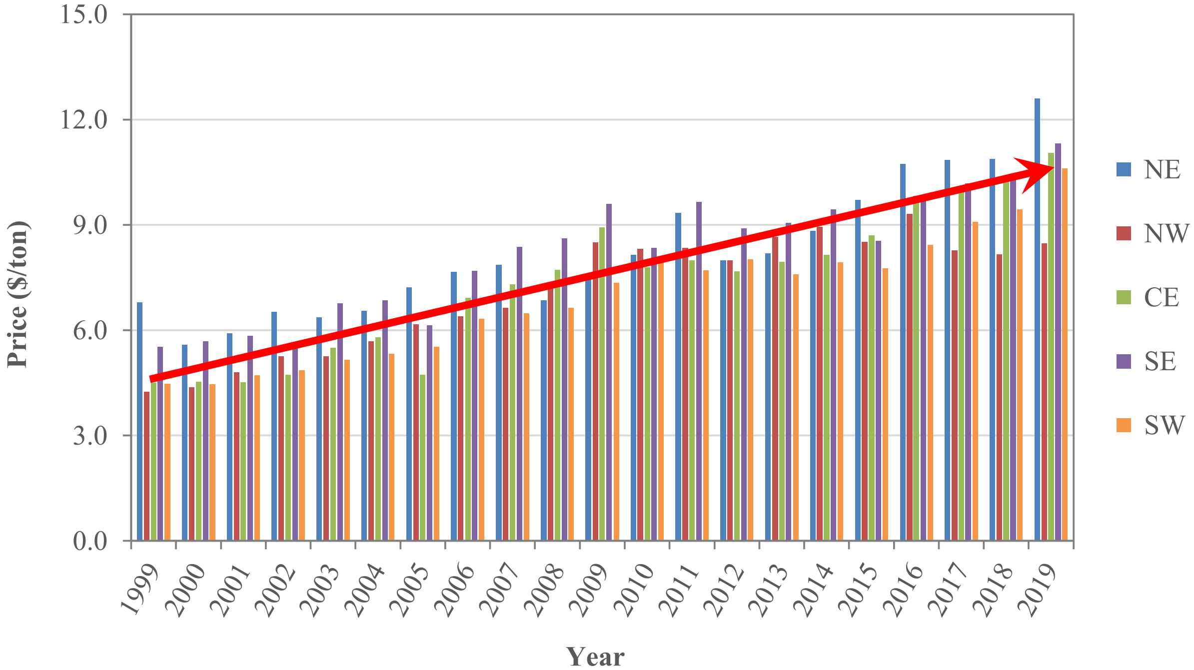


Figure 24. Average Cost of Limestone/Dolostone Aggregates in the Five Study Regions.

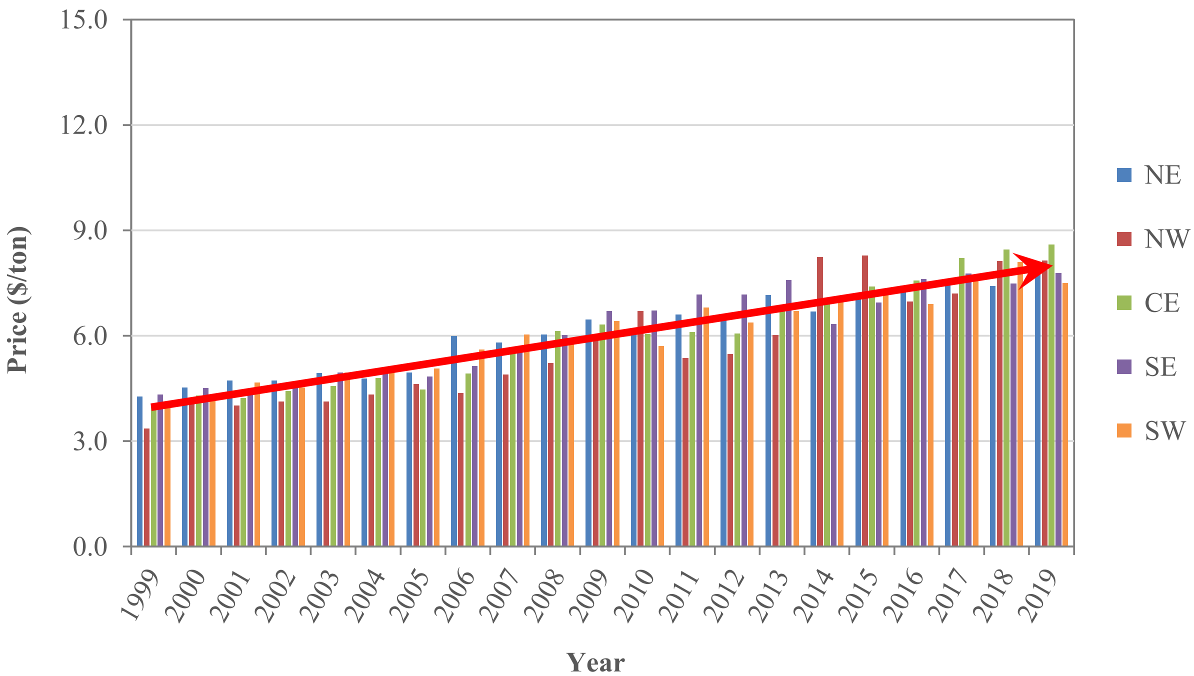


Figure 25. Average Cost of Sand and Gravel in the Five Study Regions.

In the next twenty years, the cost of aggregates is expected to follow the same trends as suggested in Figures 24 and 25 for limestone/dolostone and sand and gravel aggregates, respectively. However, in the long term (more than twenty years from now), some aggregates are expected to become more scarce in certain regions (such as limestone/dolostone aggregates in the CE region), resulting in higher annual increases in the cost of these aggregates. Another factor that is expected to affect the annual rate of increase in aggregate cost is the number of aggregate companies that are in operation in a particular region and the size of their operation (i.e., local competition). Table 8 presents the market share (based on aggregate production in 2019) for the fifteen largest aggregate producers in Ohio grouped based on ultimate owner (a parent company that owns 51% or more voting stock in another company or a subsidiary). The market share for the four largest ultimate owners (4-Firm Concentration Ratio) as well as the market share for the single largest aggregate producer in each of the five study regions are presented in Table 9. As can be noticed from this table, more than 95% of the aggregates produced in 2019 in the CE region were produced by four ultimate owners. Further concentration in the aggregate market in this region may increase as some mine become depleted in the future, resulting in higher annual increase in the cost of aggregates.

Table 8. Market Share of the Fifteen Largest Aggregate Producers.

Company No.	NE	NW	CE	SE	SW	Statewide
Oldcastle/CRH	11.7%	20.0%	42.7%	48.4%	0.2%	22.8%
National Lime & Stone	0.0%	34.5%	16.2%	0.0%	0.0%	17.3%
Heidelberg Cement Group	0.0%	17.5%	0.0%	0.0%	17.2%	9.8%
Kokosing	2.5%	4.1%	27.1%	0.0%	0.0%	9.3%
Jurgensen	0.0%	0.0%	9.6%	0.0%	30.5%	8.5%
Martin Marietta	3.7%	0.0%	0.0%	7.7%	17.9%	4.5%
Lafarge-Holcim	0.0%	8.9%	0.0%	0.0%	0.0%	3.3%
Watson Gravel	0.0%	0.0%	0.0%	0.0%	12.8%	2.5%
East Fairfield Coal Co.	15.5%	0.0%	0.0%	0.0%	0.0%	1.7%
Gerken	0.0%	3.6%	0.0%	0.0%	0.0%	1.3%
Shelly and Sands	5.3%	0.0%	0.0%	11.9%	0.0%	1.1%
Suffield Aggregate	9.5%	0.0%	0.0%	0.0%	0.0%	1.0%
Barrett/Colas Group	0.0%	1.9%	0.0%	0.0%	1.7%	1.0%
Stocker	8.0%	0.0%	0.0%	0.0%	0.0%	0.9%
Sidwell Materials	0.0%	0.0%	0.0%	17.9%	0.0%	0.8%
Others	43.8%	9.5%	4.3%	14.2%	19.7%	14.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9. Market Share of the Four Largest Aggregate Producers in Each Study Region.

Region	4-Firm Concentration Ratio	Highest Market Share	Ultimate Owners
NE	44.7%	15.5%	27
NW	80.9%	34.5%	15
CE	95.7%	42.7%	12
SE	85.8%	48.4%	11
SW	78.4%	30.5%	22
Statewide	59.2%	22.8%	74

The most common way for a mine operator to increase aggregate reserves at an existing mine is to go through the permitting and zoning processes to expand the total area of the mine. However, this may not be an option for some aggregate mines in metropolitan areas due to limited access to additional acreage because of urbanization. This is expected to be the case for the CE region, as several limestone/dolostone mines in the Columbus area become depleted. Therefore, to meet the demand for quality aggregates in this region, some companies may pursue opening new mines in the CE region that are farther away from Columbus or start new underground mines in areas closer to Columbus. Alternatively, aggregates may be transported by truck or rail from other regions in Ohio (such as the NW or SW regions where quality limestone/dolostone aggregates are available) to the CE region. Assuming an aggregate transportation cost of $0.30 per ton per mile for trucks and $0.15 per ton per mile for rail, the estimated cost to transport aggregates over a distance of 50 miles – the distance from the border of the CE region to Columbus – is $15 per ton for trucks and $7.50 per ton for rail. To support the transportation of aggregates by rail, some investment in the rail network might be needed. It may also be necessary to establish some aggregate redistribution yards in the CE region along the rail lines.

4. Research Findings and Conclusions

This research project aimed to identify fine or coarse aggregates in Ohio that might be subject to supply shortfalls in the future, estimate the financial impact to ODOT of these shortfalls, and recommend appropriate policy options to pursue in the event of shortfalls in aggregate supply. Below is a summary of the main findings and conclusions of this research study:

- Limestone/dolostone and sand and gravel aggregates are the most common types of aggregates produced and consumed in Ohio. This study revealed that the supplies of these aggregates are sufficient to meet the needs of the state for more than forty years. However, the geologic deposits of these aggregates are not uniformly distributed across the state. The eastern half of the state has limited amounts of limestone reserves, while the southern and northwest regions of the state have limited amounts of sand and gravel reserves, making it necessary to import aggregates from other regions to meet local needs or use locally available aggregates that may be lower in quality. The northeast region of the state provides an example of the need to import large quantities of aggregates from other regions. Due to the limited supply of limestone aggregates in this region, large amounts of limestone and dolostone are shipped into the region by rail from the northwest region as well as by lake freighters on Lake Erie from the northwest region and out-of-state aggregate sources in Michigan and Canada. Another example of the need to import large quantities of aggregates from other regions is the recent experience with the shale oil and gas development in the eastern region of the state. Because it is relatively expensive to transport aggregates by truck, the majority of the aggregates needed by the oil and gas industry to use in the construction of new wells were transported into the region by rail from the northwest region and by barge from in-state and out-of-state sources along the Ohio River.

- This research study also identified areas within the state where available aggregates may become depleted at some point in the future. At the current time, the central region of the state has moderate amounts of reserves of limestone/dolostone as well as sand and gravel. However, these aggregates are being rapidly depleted, especially from mines that are located in the Columbus area. Due to the rapid growth in housing and commercial development in the greater Columbus area, it will be difficult if not impossible to increase the size and production from these mines. Consequently, if the demand for aggregates in the central region continues to increase at the same rate as in the past ten years, the aggregate reserves in this region are expected to become significantly diminished in the next thirty to forty years, with the effect of the aggregate shortage likely being felt in the next twenty to thirty years. To meet the demand for quality aggregates in this region in the future, some aggregate producers may pursue opening new mines in the central region that are farther away from Columbus or start new underground mines in areas closer to Columbus. Alternatively, aggregates may be transported by truck or rail from other regions in Ohio where quality aggregates are available.
- Zoning laws related to aggregate mining in Ohio were examined in this study and information was gathered from several representatives of the aggregate industry to document barriers to expanding existing aggregate mines or opening new mines. At the present time, there has been more effort to expanding existing operations than opening a new mine due to challenges in obtaining the required zoning approval. That said, the ability to expand existing operations may be limited in regions of the state with higher populations such as the Cleveland, Columbus, and Cincinnati metropolitan areas. In addition to zoning issues, some land tracts in Ohio (particularly in the northeast region) are designated as wetlands, and regulations for protecting

these wetlands may preclude land uses such as aggregate mining due the relatively high cost of wetland mitigation, which would result in higher costs for aggregate mining in these areas.

- In recent years, the majority of zoning change applications for aggregate mining were submitted to townships that treat aggregate mining as a conditional use. Ohio Revised Code Section 519.141 (Conditional Zoning Certificates for Surface Mining Activities) that went into effect in 2007 provided guidance regarding this process. Despite having a more clear process for requesting modifications to zoning permits to expand or open an aggregate mine in these townships, the aggregate industry maintains that it is time-consuming and expensive to obtain the zoning changes. It is argued that some aggregate producers (especially smaller producers) may not be able to afford the legal costs for challenging permit denials in court and the delays created by this process that may extend to several years.

5. Recommendations for Implementation

The following recommendations are made based on the findings of this research study:

- Aggregates in central Ohio are being depleted at a faster rate than new aggregate reserves are being added. If the aggregate demand in this region continues to increase at the same rate as in the past ten years, the existing aggregate reserves are expected to become significantly diminished in the next thirty to forty years, with the effect of the aggregate shortage being felt in the next twenty to thirty years. To ensure adequate access to locally available aggregate sources in the region, it would be useful for the state to engage with a broad group of stakeholders – including local planning authorities, representatives of the aggregate industry, different state agencies such as the Ohio Department of Transportation (ODOT) and the Ohio Department of Natural Resources (ODNR), and others – to discuss strategies to avert potential future shortages in aggregate supply in this region.
- In the event of aggregate shortages in the central region in the future, some aggregate producers may pursue opening new mines in areas with suitable aggregates. Alternatively, aggregates may need to be transported from other regions in Ohio. It is prohibitively expensive to transport aggregates for long distances over land using trucks. A less expensive option would be to transport aggregates into the central region by rail. To support the transportation of aggregates by rail, some investment in the rail network might be needed.

- In addition to aggregate transportation, one of the factors that has been reported by the aggregate industry to affect aggregate cost is ODOT aggregate specifications. Even though ODOT consumes less than 10% of the aggregates produced in the state, several state and local agencies in Ohio refer to ODOT aggregate specifications when specifying the required quality of aggregates to be used in their construction projects. Therefore, ODOT aggregate specifications play a significant role in determining which aggregate sources can or cannot be used for different applications, the amount of aggregate rejects produced at a particular source, as well as the need to ship aggregates from sources that are farther away from the project site because the local sources are deemed to be unsuitable. Recommendations for any specific changes to aggregate specifications are beyond the scope of this research project. Additional research to examine the effect of aggregate properties on the performance of constructed structures is needed before ODOT can consider any potential changes to its aggregate specifications.

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Appendix A

Origin and Destination of ODOT-Approved Aggregates

Table A.1. Origin and Destination of ODOT-Approved Aggregates in 2011.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	100.0%	0.0%	0.0%	0.0%	0.0%
	NW	13.5%	82.6%	0.0%	0.0%	3.9%
	CE	0.0%	0.1%	79.5%	20.4%	0.0%
	SE	0.0%	0.0%	0.1%	99.9%	0.0%
	SW	0.0%	0.0%	0.2%	1.4%	98.4%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	98.8%	0.2%	0.0%	0.9%	0.1%
	NW	0.0%	100.0%	0.0%	0.0%	0.0%
	CE	0.0%	7.7%	86.0%	6.3%	0.0%
	SE	0.0%	0.0%	0.0%	100.0%	0.0%
	SW	0.0%	1.5%	0.1%	0.0%	98.4%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	99.2%	0.1%	0.0%	0.6%	0.1%
	NW	13.5%	82.7%	0.0%	0.0%	3.8%
	CE	0.0%	2.7%	81.9%	15.4%	0.0%
	SE	0.0%	0.0%	0.0%	100.0%	0.0%
	SW	0.0%	0.9%	0.1%	0.6%	98.4%

Table A.2. Origin and Destination of ODOT-Approved Aggregates in 2012.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	98.3%	0.0%	0.0%	1.7%	0.0%
	NW	29.0%	63.5%	3.0%	2.5%	2.0%
	CE	0.0%	0.4%	75.9%	23.6%	0.1%
	SE	0.0%	0.0%	3.9%	96.1%	0.0%
	SW	0.0%	0.0%	1.7%	3.4%	94.9%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	78.5%	0.9%	1.9%	18.3%	0.4%
	NW	0.0%	97.8%	0.0%	0.0%	2.2%
	CE	5.7%	0.5%	89.3%	2.9%	1.6%
	SE	1.3%	0.6%	1.7%	96.4%	0.0%
	SW	0.0%	0.3%	1.7%	8.8%	89.2%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	80.2%	0.9%	1.7%	16.8%	0.4%
	NW	27.6%	65.1%	2.9%	2.4%	2.0%
	CE	1.9%	0.4%	80.3%	16.8%	0.6%
	SE	0.9%	0.4%	2.5%	96.2%	0.0%
	SW	0.0%	0.1%	1.7%	5.3%	92.9%

Table A.3. Origin and Destination of ODOT-Approved Aggregates in 2013.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	98.1%	0.0%	0.0%	1.9%	0.0%
	NW	29.8%	62.2%	4.3%	2.0%	1.7%
	CE	0.0%	0.0%	95.7%	4.3%	0.0%
	SE	6.6%	0.0%	18.1%	73.3%	2.0%
	SW	0.0%	0.0%	13.6%	5.7%	80.7%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	94.2%	1.2%	0.1%	2.7%	1.8%
	NW	0.0%	97.5%	0.4%	0.0%	2.1%
	CE	3.4%	0.1%	92.0%	4.5%	0.0%
	SE	1.1%	0.0%	24.3%	73.8%	0.8%
	SW	0.0%	0.6%	2.6%	4.7%	92.1%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	94.4%	1.1%	0.1%	2.7%	1.7%
	NW	27.9%	64.5%	4.0%	1.9%	1.7%
	CE	1.2%	0.0%	94.4%	4.4%	0.0%
	SE	3.6%	0.0%	21.4%	73.6%	1.4%
	SW	0.0%	0.4%	7.1%	5.1%	87.4%

Table A.4. Origin and Destination of ODOT-Approved Aggregates in 2014.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	100.0%	0.0%	0.0%	0.0%	0.0%
	NW	25.1%	63.0%	5.6%	2.0%	4.3%
	CE	0.5%	0.6%	92.7%	6.1%	0.1%
	SE	2.2%	0.0%	25.2%	71.2%	1.4%
	SW	0.0%	0.0%	3.3%	5.2%	91.5%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	73.9%	2.8%	0.5%	5.4%	17.4%
	NW	0.0%	82.3%	0.3%	0.0%	17.4%
	CE	0.4%	1.1%	97.4%	0.3%	0.8%
	SE	0.4%	0.1%	23.8%	75.6%	0.1%
	SW	0.0%	2.1%	0.5%	7.1%	90.3%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	74.9%	2.7%	0.5%	5.2%	16.7%
	NW	24.4%	63.5%	5.4%	2.0%	4.7%
	CE	0.4%	0.8%	94.9%	3.5%	0.4%
	SE	0.9%	0.0%	24.2%	74.4%	0.5%
	SW	0.0%	0.7%	2.4%	5.8%	91.1%

Table A.5. Origin and Destination of ODOT-Approved Aggregates in 2015.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	99.4%	0.0%	0.6%	0.0%	0.0%
	NW	29.6%	59.8%	0.3%	2.1%	8.2%
	CE	0.4%	1.6%	85.0%	13.0%	0.0%
	SE	0.0%	0.0%	29.6%	68.5%	1.9%
	SW	0.0%	0.0%	4.6%	6.7%	88.7%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	65.0%	2.3%	0.0%	13.6%	19.1%
	NW	4.3%	80.5%	0.4%	0.0%	14.8%
	CE	12.2%	2.4%	76.8%	3.5%	5.1%
	SE	0.8%	0.0%	28.1%	71.1%	0.0%
	SW	0.0%	1.2%	0.6%	7.0%	91.2%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	67.5%	2.1%	0.1%	12.6%	17.7%
	NW	29.2%	60.1%	0.3%	2.1%	8.3%
	CE	3.0%	1.8%	83.1%	10.9%	1.2%
	SE	0.5%	0.0%	28.7%	70.1%	0.7%
	SW	0.0%	0.5%	3.0%	6.8%	89.7%

Table A.6. Origin and Destination of ODOT-Approved Aggregates in 2016.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	98.7%	0.3%	0.0%	1.0%	0.0%
	NW	27.0%	68.4%	0.3%	1.7%	2.6%
	CE	0.2%	0.6%	96.3%	2.3%	0.6%
	SE	1.4%	0.0%	35.0%	63.2%	0.4%
	SW	0.0%	0.0%	2.3%	7.3%	90.4%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	86.2%	1.2%	0.0%	10.0%	2.6%
	NW	1.5%	79.7%	0.0%	0.0%	18.8%
	CE	9.7%	1.8%	86.8%	0.1%	1.6%
	SE	0.0%	0.0%	42.6%	57.2%	0.2%
	SW	0.0%	1.4%	2.0%	8.2%	88.4%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	87.0%	1.1%	0.0%	9.4%	2.5%
	NW	26.7%	68.5%	0.3%	1.7%	2.8%
	CE	3.0%	1.0%	93.5%	1.6%	0.9%
	SE	0.6%	0.0%	39.5%	59.6%	0.3%
	SW	0.0%	0.6%	2.2%	7.7%	89.5%

Table A.7. Origin and Destination of ODOT-Approved Aggregates in 2017.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	99.2%	0.0%	0.0%	0.8%	0.0%
	NW	20.3%	74.1%	0.3%	3.7%	1.6%
	CE	0.2%	0.1%	95.9%	3.6%	0.2%
	SE	0.3%	0.0%	30.2%	69.5%	0.0%
	SW	0.0%	0.0%	4.1%	11.8%	84.1%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	81.6%	1.7%	1.3%	7.0%	8.4%
	NW	0.0%	67.4%	1.2%	0.0%	31.4%
	CE	1.7%	2.3%	93.2%	0.1%	2.7%
	SE	0.5%	0.0%	17.6%	80.7%	1.2%
	SW	0.2%	0.2%	1.9%	6.6%	91.1%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	83.9%	1.5%	1.1%	6.2%	7.3%
	NW	20.0%	74.1%	0.3%	3.6%	2.0%
	CE	0.6%	0.7%	95.2%	2.7%	0.8%
	SE	0.4%	0.0%	22.6%	76.3%	0.7%
	SW	0.0%	0.1%	3.4%	10.2%	86.3%

Table A.8. Origin and Destination of ODOT-Approved Aggregates in 2018.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	99.6%	0.0%	0.0%	0.4%	0.0%
	NW	33.3%	62.5%	0.5%	2.9%	0.8%
	CE	0.1%	0.4%	95.2%	4.1%	0.2%
	SE	2.7%	0.0%	15.2%	82.1%	0.0%
	SW	0.0%	0.0%	1.0%	15.9%	83.1%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	91.4%	1.2%	0.9%	5.2%	1.3%
	NW	0.0%	93.7%	0.9%	0.0%	5.4%
	CE	9.7%	0.9%	86.3%	2.2%	0.9%
	SE	1.4%	0.0%	10.4%	88.2%	0.0%
	SW	0.0%	1.0%	7.9%	8.2%	82.9%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	92.1%	1.1%	0.8%	4.8%	1.2%
	NW	32.9%	62.9%	0.5%	2.9%	0.8%
	CE	2.6%	0.5%	92.9%	3.6%	0.4%
	SE	2.0%	0.0%	12.4%	85.6%	0.0%
	SW	0.0%	0.4%	3.9%	12.6%	83.1%

Table A.9. Origin and Destination of ODOT-Approved Aggregates in 2019.

a) Limestone/Dolostone:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	96.7%	0.0%	0.0%	3.3%	0.0%
	NW	42.3%	52.4%	0.9%	3.1%	1.3%
	CE	0.1%	0.3%	98.4%	1.2%	0.0%
	SE	5.0%	0.0%	15.0%	78.0%	2.0%
	SW	0.0%	0.0%	2.3%	8.0%	89.7%

b) Sand and Gravel:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	83.2%	3.3%	1.6%	11.6%	0.3%
	NW	0.0%	67.5%	4.7%	0.0%	27.8%
	CE	13.9%	3.9%	81.4%	0.3%	0.5%
	SE	2.2%	0.0%	34.9%	62.9%	0.0%
	SW	0.0%	1.5%	1.0%	5.8%	91.7%

c) All Aggregates:

		Destination Region				
		NE	NW	CE	SE	SW
Origin Region	NE	84.2%	3.1%	1.4%	11.0%	0.3%
	NW	41.7%	52.6%	1.0%	3.0%	1.7%
	CE	3.3%	1.2%	94.4%	1.0%	0.1%
	SE	3.3%	0.0%	27.0%	68.9%	0.8%
	SW	0.0%	0.5%	1.9%	7.4%	90.2%

Appendix B

Aggregate Consumption in the Different Study Regions from 2011 to 2019

Table B.1. Aggregate Production in the Different Study Regions from 2011 to 2019.

a) Limestone/Dolostone:

Year	NE	NW	CE	SE	SW	State
2011	3,378,857	29,658,018	8,044,833	3,236,895	8,391,572	52,710,175
2012	3,944,645	31,364,487	9,321,085	4,559,658	9,115,631	58,305,506
2013	3,869,970	31,880,238	9,120,309	3,633,366	9,058,709	57,562,592
2014	4,175,230	32,084,352	10,089,305	3,908,037	9,171,983	59,428,907
2015	3,803,128	36,209,955	10,919,582	4,545,761	10,176,569	65,654,995
2016	3,343,214	34,583,009	12,152,504	3,400,595	11,442,111	64,921,433
2017	2,661,120	31,841,679	12,896,793	3,341,215	11,761,508	62,502,315
2018	2,692,951	33,121,974	14,116,916	3,612,950	11,914,170	65,458,961
2019	2,924,899	35,305,325	16,690,785	3,305,447	12,821,419	71,047,875

b) Sand and Gravel:

Year	NE	NW	CE	SE	SW	State
2011	9,632,072	1,228,580	3,674,561	3,071,617	10,135,360	27,742,189
2012	10,395,016	1,177,792	4,780,850	3,347,207	10,779,117	30,479,982
2013	10,221,395	1,123,713	4,047,933	3,213,316	10,102,226	28,708,583
2014	10,502,485	880,214	4,851,841	3,585,393	11,122,359	30,942,292
2015	11,484,187	904,550	4,542,166	3,542,032	11,043,037	31,515,972
2016	11,285,718	2,399,682	5,849,690	3,355,636	11,830,619	34,721,345
2017	11,461,926	1,056,849	5,013,122	3,031,152	11,812,385	32,375,434
2018	10,896,821	979,051	5,140,354	3,474,212	11,210,270	31,700,708
2019	12,220,614	1,045,528	6,012,760	3,424,257	11,550,209	34,253,368

c) All Aggregates:

Year	NE	NW	CE	SE	SW	State
2011	13,010,928	30,886,598	11,719,394	6,308,512	18,526,932	80,452,364
2012	14,339,661	32,542,280	14,101,935	7,906,865	19,894,748	88,785,488
2013	14,091,365	33,003,951	13,168,242	6,846,682	19,160,935	86,271,175
2014	14,677,715	32,964,566	14,941,146	7,493,430	20,294,342	90,371,199
2015	15,287,315	37,114,505	15,461,748	8,087,793	21,219,606	97,170,967
2016	14,628,932	36,982,691	18,002,194	6,756,231	23,272,730	99,642,778
2017	14,123,046	32,898,528	17,909,915	6,372,367	23,573,893	94,877,749
2018	13,589,772	34,101,025	19,257,270	7,087,162	23,124,440	97,159,669
2019	15,145,513	36,350,853	22,703,545	6,729,704	24,371,628	105,301,243

Table B.2. Estimated Aggregate Consumption in the Different Study Regions from 2011 to 2019.

a) Limestone/Dolostone:

Year	NE	NW	CE	SE	SW	State
2011	7,387,066	24,501,050	6,427,465	4,994,849	9,399,746	52,710,175
2012	12,983,918	19,965,874	8,348,228	7,731,481	9,276,006	58,305,506
2013	13,550,462	19,824,427	11,987,335	4,279,970	7,920,398	57,562,592
2014	12,354,592	20,283,497	12,424,007	4,529,585	9,837,225	59,428,907
2015	14,525,736	21,803,772	11,227,016	5,986,439	12,112,032	65,654,995
2016	12,702,204	23,763,943	13,240,304	3,895,038	11,319,943	64,921,433
2017	9,129,300	23,632,661	13,950,868	5,359,836	10,429,650	62,502,315
2018	13,834,800	20,760,632	14,261,098	6,410,652	10,191,779	65,458,961
2019	17,947,600*	18,565,714	17,535,522	4,986,920	12,012,120	71,047,875

* Example: Limestone/dolostone aggregate consumption in the NE region in 2019 =

[A] Limestone/Dolostone Aggregate Production in 2019 (Table B.1)		[B] Origin and Destination of Limestone/Dolostone Aggregates in 2019 (Table A.9)		[A] × [B]
17,947,600	×	96.7%	=	2,827,685
18,565,714	×	42.3%	=	14,941,258
17,535,522	×	0.1%	=	11,903
4,986,920	×	5.0%	=	166,685
12,012,120	×	0.0%	=	69
				17,947,600
				(Table B.2)

b) Sand and Gravel:

Year	NE	NW	CE	SE	SW	State
2011	9,509,302	1,690,265	3,171,138	3,390,141	9,981,343	27,742,189
2012	8,472,008	1,317,489	4,702,763	6,221,305	9,766,417	30,479,982
2013	9,807,131	1,284,906	4,774,672	3,298,186	9,543,688	28,708,583
2014	7,783,427	1,314,197	5,702,638	4,080,811	12,061,219	30,942,292
2015	8,080,124	1,238,225	4,552,329	5,018,003	12,627,291	31,515,972
2016	10,334,964	2,307,853	6,756,003	4,018,162	11,304,364	34,721,345
2017	9,473,159	1,053,022	5,590,031	4,039,543	12,219,678	32,375,434
2018	10,513,230	1,206,844	5,798,543	4,651,789	9,530,303	31,700,708
2019	11,086,097	1,522,993	6,438,980	4,270,562	10,934,735	34,253,368

c) All Aggregates:

Year	NE	NW	CE	SE	SW	State
2011	16,896,367	26,191,315	9,598,602	8,384,990	19,381,089	80,452,364
2012	21,455,926	21,283,363	13,050,991	13,952,785	19,042,423	88,785,488
2013	23,357,592	21,109,333	16,762,007	7,578,156	17,464,086	86,271,175
2014	20,138,019	21,597,694	18,126,645	8,610,397	21,898,444	90,371,199
2015	22,605,860	23,041,997	15,779,344	11,004,443	24,739,323	97,170,967
2016	23,037,168	26,071,796	19,996,307	7,913,200	22,624,307	99,642,778
2017	18,602,459	24,685,683	19,540,899	9,399,380	22,649,328	94,877,749
2018	24,348,029	21,967,476	20,059,642	11,062,441	19,722,081	97,159,669
2019	29,033,697	20,088,707	23,974,503	9,257,482	22,946,855	105,301,243

Appendix C

Future Aggregate Consumption in the Different Study Regions

Table C.1. Regression Model Data for NE Region.

Year	Population (Persons)	Change in Population (Persons)	Construction Employment (Employees)	Housing Permits (Permits)	Aggregate Consumption (Tons)
2011	4,341,367	-11,136	65,374	3,683	16,896,367
2012	4,330,743	-10,624	66,716	4,006	21,455,926
2013	4,331,355	612	67,360	4,843	23,357,592
2014	4,329,858	-1,497	70,518	4,948	20,138,019
2015	4,319,842	-10,016	71,120	5,225	22,605,860
2016	4,309,539	-10,303	72,989	5,466	23,037,168
2017	4,299,417	-10,122	75,477	5,500	18,602,459
2018	4,291,217	-8,200	77,020	5,601	24,348,029
2019	4,281,889	-9,328	78,026	5,417	29,033,697

Table C.2. Regression Model Data for NW Region.

Year	Population (Persons)	Change in Population (Persons)	Construction Employment (Employees)	Housing Permits (Permits)	Aggregate Consumption (Tons)
2011	1,550,367	- 3,546	24,049	1,384	26,191,315
2012	1,545,918	- 4,449	25,067	1,610	21,283,363
2013	1,543,172	- 2,746	25,417	1,735	21,109,333
2014	1,539,639	- 3,533	26,631	1,926	21,597,694
2015	1,535,509	- 4,130	27,633	1,817	23,041,997
2016	1,532,355	- 3,154	28,951	2,136	26,071,796
2017	1,529,608	- 2,747	29,428	2,317	24,685,683
2018	1,526,723	- 2,885	29,988	2,234	21,967,476
2019	1,524,492	- 2,231	31,493	2,609	20,088,707

Table C.3. Regression Model Data for CE Region.

Year	Population (Persons)	Change in Population (Persons)	Construction Employment (Employees)	Housing Permits (Permits)	Aggregate Consumption (Tons)
2011	2,053,621	20,419	29,069	4,941	9,598,602
2012	2,073,712	20,091	29,985	7,001	13,050,991
2013	2,100,916	27,204	31,545	8,603	16,762,007
2014	2,128,333	27,417	33,129	7,272	18,126,645
2015	2,154,111	25,778	34,704	7,704	15,779,344
2016	2,178,845	24,734	37,018	8,849	19,996,307
2017	2,209,131	30,286	38,674	9,105	19,540,899
2018	2,231,817	22,686	40,938	9,638	20,059,642
2019	2,249,947	18,130	43,076	8,397	23,974,503

Table C.4. Regression Model Data for SE Region.

Year	Population (Persons)	Change in Population (Persons)	Construction Employment (Employees)	Housing Permits (Permits)	Aggregate Consumption (Tons)
2011	597,357	146	6,926	264	8,384,990
2012	594,366	- 2,991	5,660	263	13,952,785
2013	592,417	- 1,949	7,675	291	7,578,156
2014	591,048	- 1,369	7,071	371	8,610,397
2015	589,990	- 1,058	8,577	450	11,004,443
2016	588,620	- 1,370	7,634	230	7,913,200
2017	586,908	- 1,712	8,069	268	9,399,380
2018	584,260	- 2,648	8,060	311	11,062,441
2019	582,550	- 1,710	7,750	221	9,257,482

Table C.5. Regression Model Data for SW Region.

Year	Population (Persons)	Change in Population (Persons)	Construction Employment (Employees)	Housing Permits (Permits)	Aggregate Consumption (Tons)
2011	3,001,951	2,598	44,689	3,490	19,381,089
2012	3,004,184	2,233	45,008	4,025	19,042,423
2013	3,008,824	4,640	45,396	4,493	17,464,086
2014	3,013,822	4,998	47,969	5,420	21,898,444
2015	3,018,075	4,253	50,617	4,800	24,739,323
2016	3,025,011	6,936	53,444	6,073	22,624,307
2017	3,034,586	9,575	54,573	6,658	22,649,328
2018	3,042,324	7,738	55,086	6,362	19,722,081
2019	3,050,222	7,898	55,920	6,348	22,946,855

Table C.6. Statistical Results for Fixed-Effects Regression Model for Aggregate Consumption.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.920923192
R Square	0.848099525
Adjusted R Square	0.814343864
Standard Error	2454888.259
Observations	45

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8	1.21131E+15	1.51413E+14	25.12466051	1.54733E-12
Residual	36	2.16953E+14	6.02648E+12		
Total	44	1.42826E+15			

	Coefficients	*Stand. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-61291751.7	40362937.4	-1.5	0.1	-143151582.8	20568079.4	-143151582.8	20568079.4
Population	22.0	13.7	1.6	0.1	-5.8	49.8	-5.8	49.8
dPopulation	-46.6	159.4	-0.3	0.8	-370.0	276.8	-370.0	276.8
ConstruEmp	265.0	188.3	1.4	0.2	-116.8	646.8	-116.8	646.8
hpermits	548.0	931.0	0.6	0.6	-1340.2	2436.3	-1340.2	2436.3
Region_NW	41828047.3	19708823.7	2.1	0.0	1856700.2	81799394.5	1856700.2	81799394.5
Region_NE	-33540795.5	18069085.4	-1.9	0.1	-70186599.3	3105008.2	-70186599.3	3105008.2
Region_CE	18749920.0	13210092.3	1.4	0.2	-8041388.9	45541228.9	-8041388.9	45541228.9
Region_SE	55779078.1	32346846.0	1.7	0.1	-9823366.1	121381522.4	-9823366.1	121381522.4

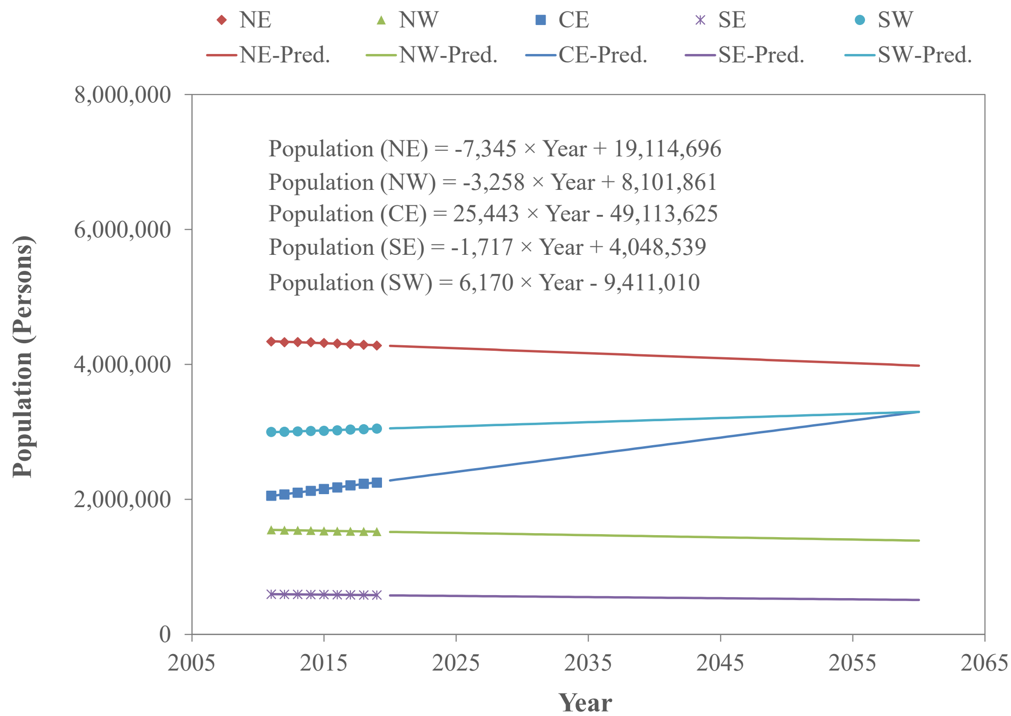

Figure C.1. Future Population in the Different Study Regions.

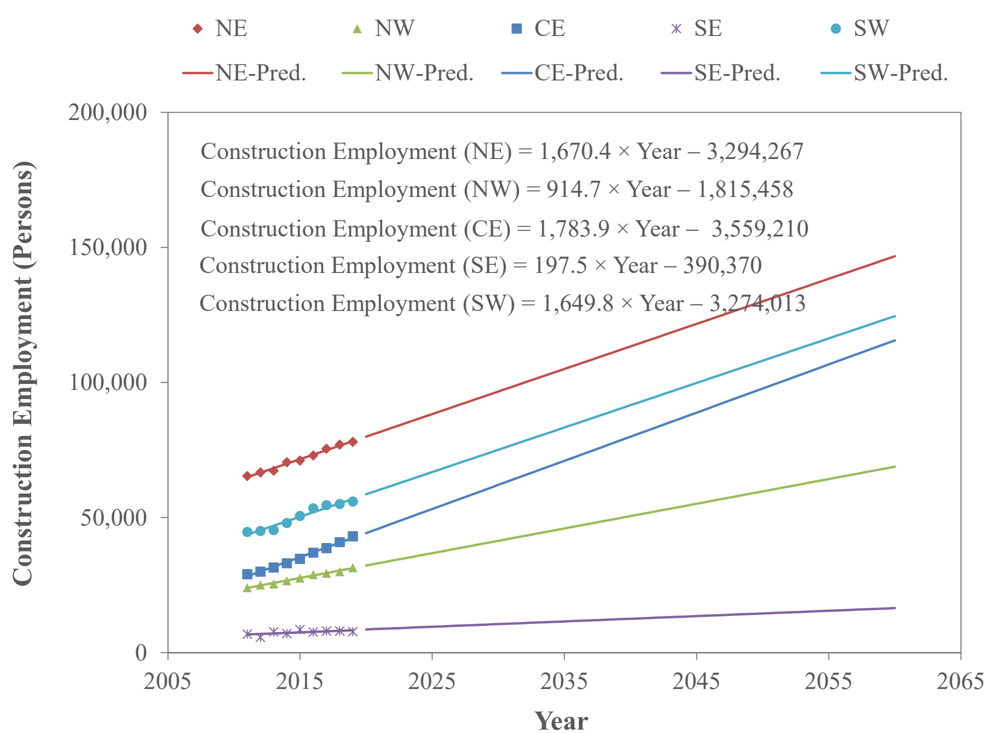

Figure C.2. Future Construction Employment in the Different Study Regions.

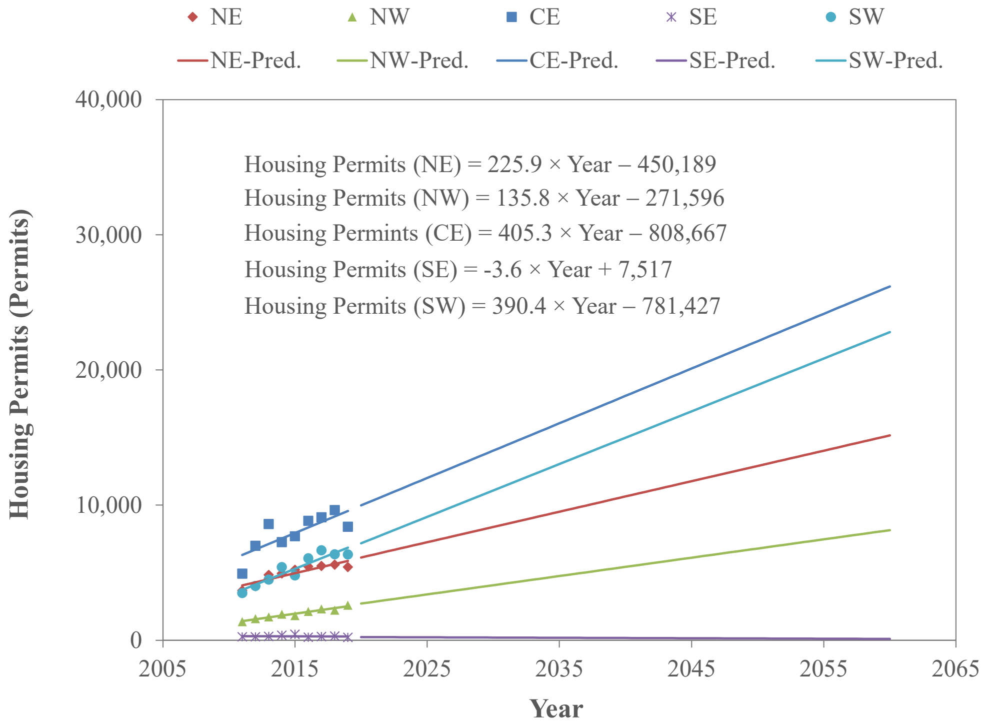

Figure C.3. Future Housing Permits in the Different Study Regions.

Table C.7. Fixed-Effects Regression Model for Aggregate Consumption.

Region	Aggregate Consumption Model
NE	= -61,291,751.7 – 33,540,795.5 + 22.0 × Population NE (Year) – 46.6 × -7,345 + 265.0 × Construction Employment NE (Year) + 548.0 × Housing Permits NE (Year)
NW	= -61,291,751.7 + 41,828,047.3 + 22.0 × Population NW (Year) – 46.6 × -3,258 + 265.0 × Construction Employment NW (Year) + 548.0 × Housing Permits NW (Year)
CE	= -61,291,751.7 + 18,749,920.0 + 22.0 × Population CE (Year) – 46.6 × 25,443 + 265.0 × Construction Employment CE (Year) + 548.0 × Housing Permits CE (Year)
SE	= -61,291,751.7 + 55,779,078.1 + 22.0 × Population SE (Year) – 46.6 × -1,717 + 265.0 × Construction Employment SE (Year) + 548.0 × Housing Permits SE (Year)
SW	= -61,291,751.7 + 22.0 × Population SW (Year) – 46.6 × 6,170 + 265.0 × Construction Employment SW (Year) + 548.0 × Housing Permits SW (Year)

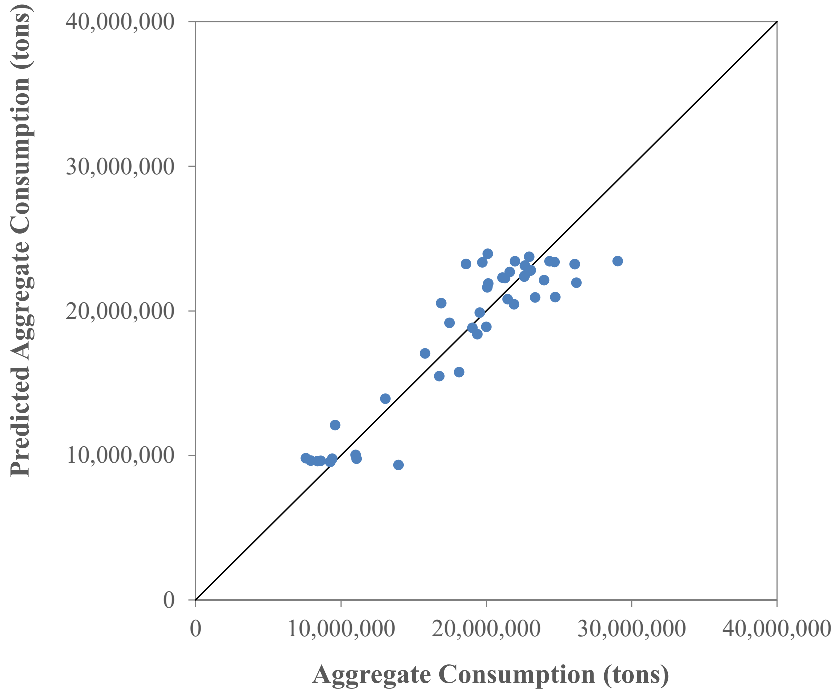

Figure C.4. Quality of Fit of Regression Model for the Period from 2011 to 2019.

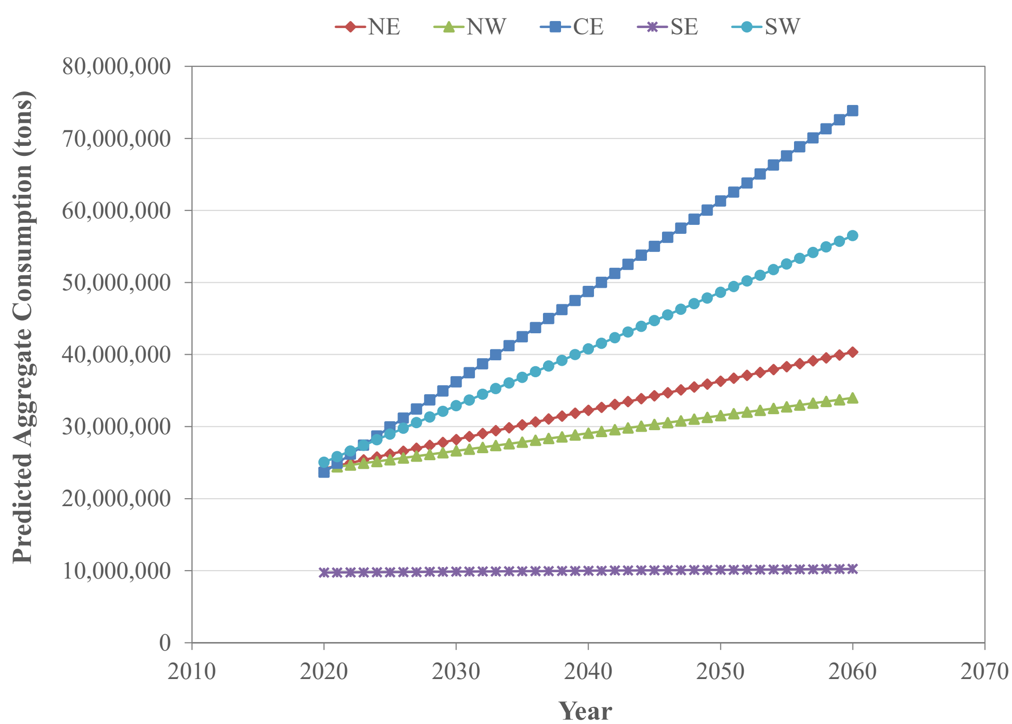

Figure C.5. Predicted Future Aggregate Consumption for the Period from 2020 to 2060.