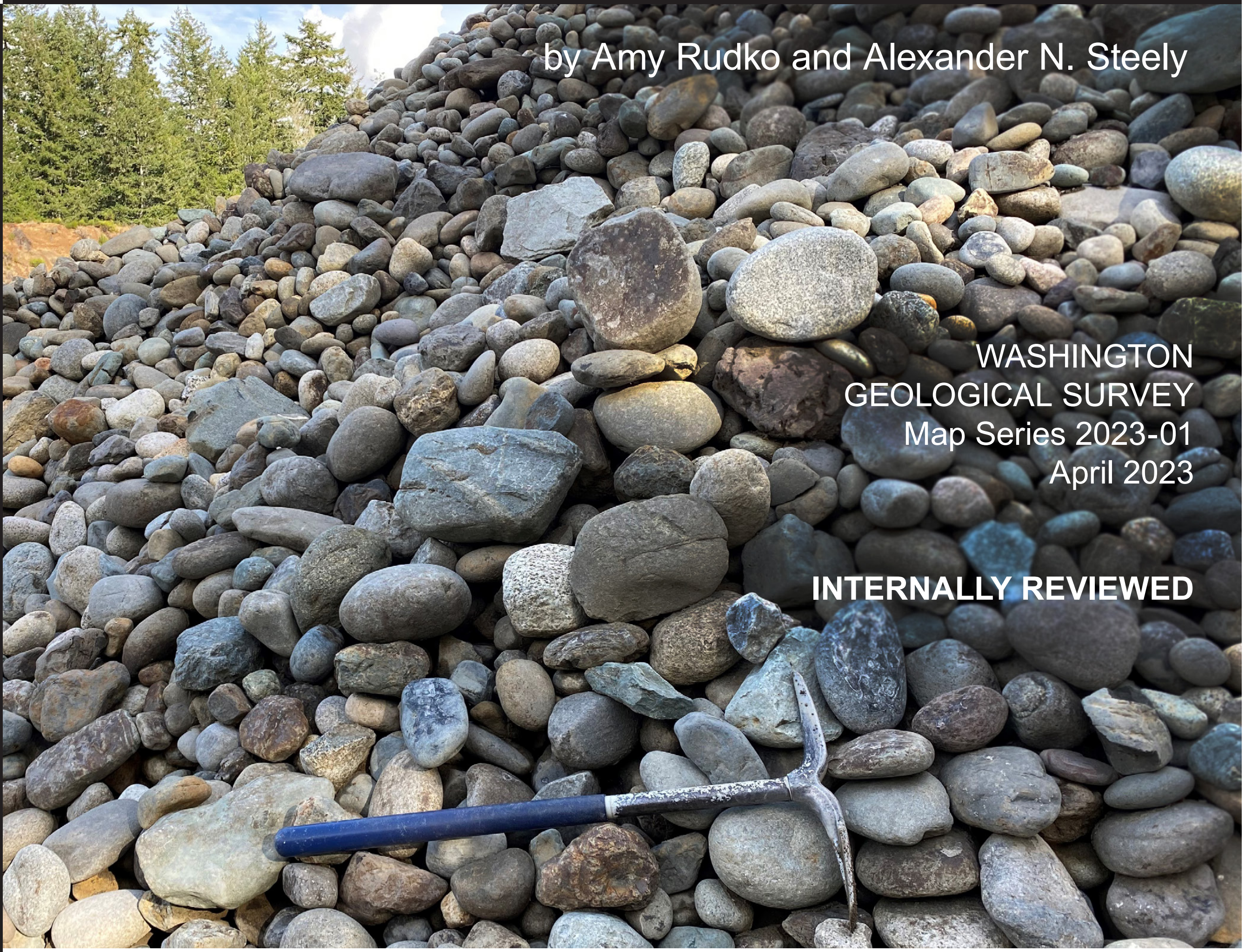
NATURAL RESOURCES

AGGREGATE RESOURCE INVENTORY OF KITSAP COUNTY, WASHINGTON



by Amy Rudko and Alexander N. Steely

WASHINGTON
GEOLOGICAL SURVEY
Map Series 2023-01
April 2023

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WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY

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This publication has been subject to an iterative technical review process by at least one Survey geologist who is not an author. This publication has also been subject to an iterative review process with Survey editors and cartographers.

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Cover Image: Stockpile of aggregate material in the Holly Pit surface mine site in Kitsap County. Photo by Amy Rudko.

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ALEXANDER STEELY

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Aggregate Resource Inventory of Kitsap County, Washington

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ABSTRACT

We present an inventory of aggregate resources for Kitsap County. The inventory identifies potential sources of aggregate—both sand and gravel, and bedrock (rock and stone)—using a combination of surficial and bedrock geologic mapping, subsurface information from boreholes and water wells, aggregate testing data, and records of current and historical mining activity. Our aggregate resource classification scheme assesses both the quality and quantity of potential resources, and communicates that assessment using four classifications: Demonstrated, Inferred, Speculative, and Not a Resource. In total, our inventory classifies 64,396 acres of land as having the potential for economically significant aggregate resources, which is about 25 percent of the county's land area. For sand and gravel resources mapped as Demonstrated and Inferred (our highest-certainty resource classifications), we estimate 600 million to 1.3 billion cubic yards of aggregate (970 million to 2.3 billion tons). Due to the difficulty of quantifying the thickness of bedrock aggregate resources, we did not estimate their volume or tonnage.

Approximately 11,400 acres—or 18 percent—of areas we identify as potential sources of aggregate may be inaccessible for resource extraction because they are on land classified as developed according to the National Land Cover Database. A service-area analysis reveals two areas that are currently farthest from active aggregate mines: the northern tip of Kitsap County near Hansville and the southern half of Bainbridge Island. A second analysis explores opportunities to minimize transportation costs by prioritizing future sources of aggregate nearest to areas of aggregate demand. This analysis uses a road-network transportation analysis that identifies 65 percent of the aggregate resource areas in the inventory as being within a 10-mile driving distance from Bremerton, Port Orchard, Bainbridge Island, or Poulsbo.

INTRODUCTION

Overview and Purpose

Sand, gravel, and bedrock may be mined or quarried to produce raw materials known as construction aggregate. Construction aggregate is used in the manufacturing of concrete, asphalt, and other critical materials for roads, homes, businesses, and bridges. Effective planning for the needs and uses of aggregate resources faces a number of challenges. Although aggregate resources are sometimes thought of as ubiquitous, in reality they are deposited only in specific geologic areas, and their quality and quantity can vary significantly. Additionally, aggregate resources are not uniformly distributed throughout the state, and transporting these resources has many costs including fuel and time spent on long deliveries, physical wear of roadways by large trucks, and greenhouse gas emissions. Furthermore, once land has been developed, any aggregate resources present beneath the surface are no longer accessible for extraction. For these reasons, identifying and protecting sources of aggregate is critical to promoting sustainable economic development and ensuring the health, safety, and high quality of life enjoyed by people in Washington State.

In 1990 the Washington State Legislature enacted the Growth Management Act (GMA) to guide planning for growth and development in Washington State. To meet the goals of Washington Administrative Code (WAC) 365-190-070, the Washington Geological Survey (WGS) is publishing county-scale aggregate resource maps. These publications are intended to aid county and city planners and other local officials with land-use planning decisions related to identifying and designating aggregate resources of long-term significance. We also intend these publications to aid policy makers in assessing the importance of our nonrenewable sand, gravel, and quarried bedrock resources. Furthermore, these publications may also benefit engineers, transportation departments, and industry by identifying areas where geologic conditions suggest the presence of aggregate resources.

Inventory Products

This publication consists of two parts: (1) this pamphlet, which includes our rationale, data sources, methods, and a county-level summary of results; and (2) a Map Sheet that shows our resource inventory, the locations of active and historical mines, aggregate testing locations, and subsurface record sites. The geospatial data used to develop the Map Sheet are available as a zip file download package with accompanying metadata on our website. An interactive web-based version of the Aggregate Resources database is also available on the WGS Geologic Information Portal at geologyportal.dnr.wa.gov.

Study Area

This report covers the full extent of Kitsap County without regard for current land ownership or use. Kitsap County is located in the center of the Puget Lowland on the Kitsap Peninsula (Fig. 1). The population of Kitsap County is approximately 276,000 according to the 2020 federal census. We do not intend for this publication to suggest that lands with aggregate resources and conflicting land ownership or designations (for example, county or state parks, tribal land, or military reservations) should be re-designated to allow mining activities. Rather, we recognize that the underlying geologic phenomena that create aggregate resources do not stop at property boundaries, so we map their full geologic extent and entrust policymakers, land-use planners, and mine operators to make decisions that best implement their priorities and constraints.

GEOLOGY OF AGGREGATE RESOURCES IN KITSAP COUNTY

Here we summarize the geologic history of the Puget Lowland as it relates to aggregate resources in Kitsap County. Our aim is to explain the geologic processes that control the distribution of aggregate resources, providing the reader with a sense for the natural systems that our methods work to quantify.

Summary Geologic History

Kitsap County has been glaciated repeatedly during the last two million years. During the most recent glacial event—the Vashon Stade of the Fraser Glaciation—a thick ice sheet known as the Puget Lobe overrode all of the Puget Lowland, including the Kitsap Peninsula (Fig. 1). By about 18,000 years ago, the ice sheet reached a maximum thickness of approximately 3,000 ft near modern-day Bremerton (Fig. 1). Around this time it reached its maximum extent south of Olympia, and then retreated rapidly leaving the area ice-free by about 16,000 years ago (Polenz and others, 2015). Although the Kitsap Peninsula has been glaciated many times previously, the landscape of the peninsula was largely shaped by extensive deposition and erosion during, or shortly after, the most-recent glaciation. Vashon-age glacial deposits locally exceed 300 ft in thickness and typically include—from bottom to top—advance outwash, dense glacial till known as glacial lodgment till, and recessional outwash.

While most of Kitsap County's surficial geology consists of thick glacial deposits, there are some exposures of bedrock that can be mined to produce rock and stone aggregate materials. Rocks of the Coast Range terrane that extend from southern Oregon to southern Vancouver Island are exposed in Green Mountain and Gold Mountain (Fig. 1). These include Eocene submarine and subaerial basalts of the Crescent Formation with small amounts of interbedded sedimentary rock (Tabor and others, 2011). Eocene to Miocene marine sedimentary and volcanic-lithic rocks known as the Blakely Formation and Blakely Harbor Formation are exposed in a few locations, mostly at the southern end of Bainbridge Island (Haugerud, 2005).

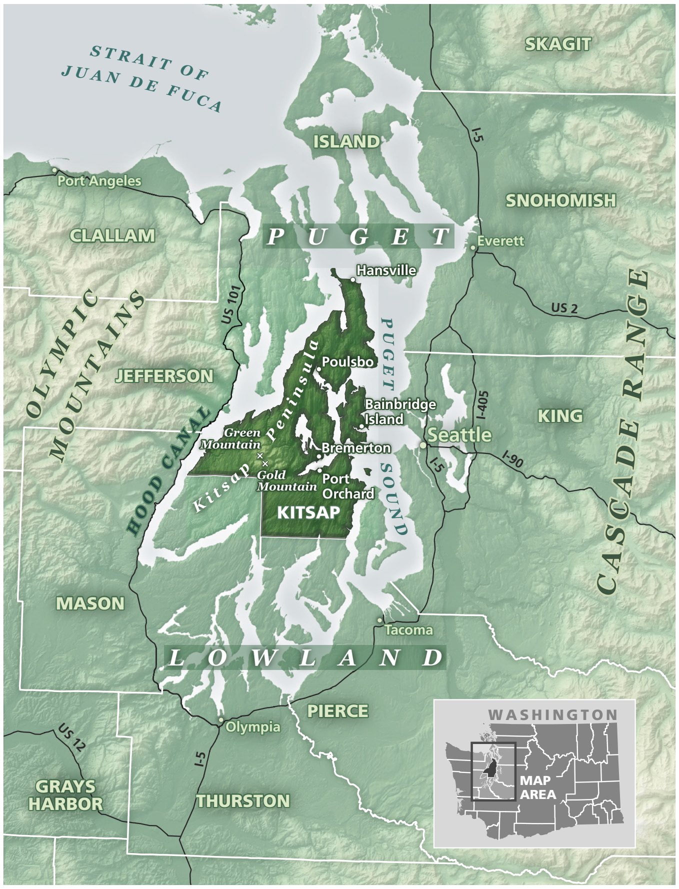

Figure 1. Location of the study area, Kitsap County, within western Washington State.

For further details and discussion of the geologic history of this region, the interested reader should consult the detailed and well-written geologic unit descriptions and summaries provided in the source maps of this report (see Map Sheet). For the purpose of this effort, we found it helpful to generalize the mapped geologic units into simplified categories relevant to aggregate resource quality. The following sections provide brief summaries of these geologic materials.

Sand and Gravel Resources

In general, the following geologic deposits are good sources of sand and gravel in the study area.

VASHON STADE GLACIAL OUTWASH DEPOSITS

Geologic environments where there is good hydraulic sorting and rounding provide the highest-quality aggregate. For this reason, large modern and ancient river systems are often excellent sources of aggregate resources. A typical succession of glacial deposits in the Puget Lowland includes sediments deposited by river systems emanating from the advancing glacier (advance outwash), deposits of the glacier itself as it advances and overrides its outwash plain (glacial till), and deposits from the river system emanating from the glacier as it retreats (recessional outwash). While the till directly deposited by glaciers does not typically produce good aggregate, the voluminous rivers of meltwater that emanate from glaciers efficiently round and sort the material crushed by the glacier into high-quality aggregate. Therefore, glacial outwash deposits of the Vashon Stade are excellent sources of aggregate.

In Kitsap County, we interpret advance outwash, recessional outwash, recessional alluvial fans, and deltas as generally excellent sources of aggregate; most sand and gravel aggregate mines work in these deposits. Ideally, for aggregate extraction, the advance and recessional outwash would be separated by only a thin layer of till, making it possible to mine both deposits in one location. However, the reality of glacial deposition is more complex. During glacial advance, meltwater rivers deposit outwash sand and gravel in front of the glacier as it advances southward. Continued advancement leads to the glacier over-riding the advance outwash deposit and either scouring it away or covering it with a layer of glacial till. As the glacier retreats, it leaves behind a modified landscape of elongate hills and valleys (drumlins) and ice-dammed lakes. Meltwater from the glacier continues to flow through this modified terrain, depositing recessional outwash into low-lying areas of the landscape and forming deltas where rivers flowed into large lakes. These depositional processes produce varying thicknesses of glacial till between outwash deposits, complicating the accessibility of advance outwash deposits below the glacial till.

VASHON STADE GLACIAL ICE-CONTACT AND ICE-MARGINAL DEPOSITS

Though the deposits of glaciers themselves (till or diamicton) are generally unsuitable for aggregate, other near-glacier deposits can be excellent sources of aggregate. Eskers are sinuous landforms composed of sand and gravel deposited by rivers beneath the glacier. Because of their depositional setting, eskers are sometimes classified as ice-contact units despite essentially being river deposits, and thus a good source of aggregate. However, esker deposits are sometimes too narrow to be commercially useful. We interpret other near-glacier deposits that have a strong indication of the influence of moving water as potential sources of aggregate, including kame terraces, stratified drift, ice-contact deposits, kame and kettle deposits, and pockmarked terrain. We consulted lidar elevation data extensively during the classification of these geologic deposits to ensure that we excluded surfaces that clearly had glacial drumlins (indicating the likely presence of glacial till).

NONGLACIAL ALLUVIUM

Alluvium is a deposit left by a stream or river. For the purposes of this study, we refer to the generalized unit of alluvium as deposits left by non-glacial streams or rivers. Where a river is large enough to round and sort the material it carries (such as large rivers from the Olympic Mountains or Cascade Range), their deposits can be suitable for aggregate. Where alluvium is deposited by small and (or) intermittent streams, there is usually insufficient sorting and rounding, and the deposits are typically quite thin. Because of this, we generally only consider alluvium from large river systems to be suitable for aggregate, and usually require additional evidence to classify any alluvium deposits as potential sources of aggregate.

DEPOSITS THAT ARE TYPICALLY NOT A RESOURCE

In general, the following geologic deposits are not suitable sources of sand and gravel aggregate in the study area. In rare cases, some of our resource areas may intersect with these surficial geologic deposits if we found alternative data sources suggesting a good source of aggregate is present.

- Unsorted deposits (clay through boulders) that are compact (hard) are characteristic of deposition beneath a glacier; these glacial till deposits are unsuitable for aggregate due to their high clay and silt content and the difficulty of mining them. For similar reasons, we excluded drift, glaciomarine drift, and other pre-Vashon-age glacial tills or diamicts.
- Deposits that contain abundant fine-grained material (silt and clay) and (or) organic material (peat) are also unsuitable for aggregate because they typically do not contain a sufficient amount of sand and gravel. Because of this, we excluded glacio-lacustrine deposits such as the Lawton Clay, wetland deposits, peat or marsh deposits, and beach or tidal flat deposits.
- Deposits older than the Vashon glaciation are rare in Kitsap County, and where exposed are typically fine grained or poorly sorted, compact, and weathered. Though there may be some pre-Vashon deposits that would be good sources of aggregate but are currently covered by other deposits, the few exposures of these deposits lead us to interpret them as generally unsuitable for aggregate.
- Poorly sorted deposits often include clay and silt, which make it difficult to produce clean aggregate. Because of this, we generally interpret deposits such as alluvial fans, alluvium from small streams, old alluvium, altered land, and artificial fill as unsuitable for aggregate.

Bedrock Resources

CRESCENT FORMATION

The Crescent Formation is well exposed around Green Mountain and Gold Mountain, where it is mapped in detail by Tabor and others (2011). These authors map four different rock units that we consider possible sources of aggregate: massive basaltic lava flows; felsic intrusive rocks; leucogabbro and pegmatite; and sheeted dikes of basalt and diabase. We classify these rock types as Speculative, Inferred, or Demonstrated resources depending on testing data and mining activity.

The eastern portion of the area around Green Mountain and Gold Mountain has not been mapped in as much detail as the western portion (Yount and Gower, 1991). On the eastern side, only a single geologic unit was mapped (compared to seven farther west). Because some types of rock within the Crescent Formation are not suitable sources of aggregate (see below) and may be present within the eastern part of the area around Green Mountain and Gold Mountain, we suspect that the amount of suitable aggregate material may be overestimated in this area.

Although more information is needed to confirm our preliminary observations, we believe that much of the Crescent Formation in this area is in fact suitable as a source of bedrock aggregate. Based on visual inspection of lidar, the Crescent Formation does not appear to contain thick beds of volcaniclastic rock that would otherwise make it unsuitable.

ROCKS THAT ARE TYPICALLY NOT A RESOURCE

Two types of rock within the Crescent Formation mapped by Tabor and others (2011) are likely unsuitable for aggregate: a fine-grained weathered quartz latite with significant alteration minerals, and interbedded volcaniclastic rocks. We tested the volcaniclastic rocks in this study (see Appendix A for test results) and found those rocks were unsuitable for aggregate.

We also interpret rocks of the Blakeley Formation and Blakely Harbor Formation to be unsuitable for aggregate. These rocks, which are typically quite weathered, consist of marine sandstone rich in volcanic debris, siltstone, claystone, and abundant marine shells (Haugerud, 2005). To our knowledge, there are no available testing data for these units, they have not been previously mined for aggregate, and their geologic descriptions make it very unlikely they would pass our quality thresholds.

METHODS

Overview

To map aggregate resource areas, we compiled geologic units from previously published geologic maps and refined their geometry based on subsurface geology, geomorphic data, aggregate testing, and current and historical mining activity. We classified potential aggregate resources based on their quality and quantity, and then performed proximity and land-use analyses on the results.

This section describes the data we used, our resource classification scheme, and our classification workflow. We also describe how we calculated the volume and tonnage of resources, how we determined how much of our classified resource areas are inaccessible due to land-use development, and how we calculated the proximity of aggregate resources to major markets.

Sources of Data

In preparation for classifying aggregate resources throughout the study area, we compiled surficial and bedrock geologic mapping, subsurface information from boreholes and water wells, aggregate testing data, and any other available datasets. These data sources are described in more detail in the sections below.

SURFACE GEOLOGY AND RELATED DATA

Geologic maps vary in the level of detail they provide about the types of rocks and deposits that yield usable aggregate. In general, the most detailed mapping is completed at 1:24,000 scale, and these publications often have excellent descriptions of the geologic units that were mapped. For this analysis, the most useful 1:24,000-scale geologic maps are those that have a lidar basemap (typically those published in the early 2000s and thereafter), as these provide a high level of detail for mapping the extent of different geologic units. Where 1:24,000-scale geologic maps are not available, we used less detailed 1:100,000-scale maps.

We compiled the surface geology from all published geologic maps within Kitsap County at all scales greater than or equal to 1:100,000 (see geologic data sources on the Map Sheet). About 70 percent of the county has been mapped at 1:24,000 scale, and most of those maps have a lidar basemap. We also use a 1:36,000-scale regional geomorphic map that is based on lidar and gives a good description of the glacial and post-glacial landforms (Haugerud, 2009). We supplemented these maps with detailed stratigraphic descriptions and cross sections from Deeter (1979).

SUBSURFACE DATA

Two main data sources provide direct information about materials found underground, and both require drilling. The first is water wells, which are drilled in a variety of locations, most commonly for residential water supply. While drilling water wells, the driller notes what type of material they are drilling through and this information is provided to the Department of Ecology, where it is made publicly available. The other type of subsurface information comes from geotechnical borings. Similar to water wells, these are holes drilled in the ground, but they differ in that the materials are reviewed and described by a trained professional for the purpose of evaluating the geotechnical properties of the subsurface. Therefore, the information from geotechnical borings is often much more detailed and accurate. However, most borings are relatively shallow (typically less than 20 ft) whereas water wells often reach depths of a few hundred feet.

We used both water wells and geotechnical borings to help constrain the thickness of potential resources and to identify and characterize the thickness of overburden (sediments above an aggregate deposit that must be removed before mining). Subsurface data enables us to identify areas where a resource exists beneath a thin layer of material that we would not classify as a resource based only on the geologic mapping (for example, a thick layer of outwash sand and gravel beneath a thin layer of glacial till at the surface).

To compile subsurface records for our analysis, we first gathered records from a subsurface database developed by WGS (Jeschke and others, 2023). The subsurface database[1] contains records from many sources including water wells and geotechnical boreholes. In total, 2,029 subsurface records were used for this project. From the WGS subsurface database, we selected 1,282 subsurface records located in Kitsap County. We supplemented these records with 747 well records from the Department of Ecology, located by the U.S. Geological Survey (USGS) during a hydrogeology effort (Welch and others, 2014).

AGGREGATE TESTING DATA

In order to determine the quality of potential aggregate resources, we reviewed aggregate testing data that assess the ability of a given sample to withstand the standard Los Angeles (LA) Abrasion test and the Washington Degradation test. Our aggregate quality threshold required an LA Abrasion test result of <30 percent and Washington Degradation test result of >30 percent, as specified in the 2023 standards for Hot Mix Asphalt (HMA). Current

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[1] The subsurface database is available online through our Geologic Information Portal at geologyportal.dnr.wa.gov.

and historical test data is available from the Washington State Department of Transportation (WSDOT) Aggregate Source Approval (ASA) database (WSDOT, 2022a). For this project, WSDOT provided us with test-site spatial data that is viewable on their ASA Web Mapping App. We downloaded and digitized all available ASA report attributes to the site location data for the county (57 sites and 73 test results). Because the Washington Degradation test was not regularly used until after 1972, we interpreted all test data from before then as Incomplete Pass or Incomplete Fail, depending on the result from the LA Abrasion test. In addition to WSDOT data, we collected four sand and gravel samples and three bedrock samples in fall 2022 from public land, public road sides, or currently active sand and gravel mines. These samples were tested by Materials Testing & Consulting, Inc. and the results are reported in Appendix A. Our samples represent a broader range of rocks and deposits than the existing testing data captured.

SURFACE MINE LOCATION DATA

We used the locations of active, inactive, and historical surface mines to help guide our classification of resources. We assumed that active mines are likely located in good sources of aggregate, while inactive, historical, and small mining operations may be located in good sources of aggregate, but with less certainty. We accessed the locations of current active permitted mines from the Washington Department of Natural Resources (DNR) Surface Mine Reclamation Program (SMRP) database (Washington Geological Survey, 2022a), and were provided access to SMRP records of inactive (cancelled or terminated) permitted mines, permit boundaries, and reclaimed boundaries (Robert Berwick, Washington Geological Survey, written commun., 2022). As of November 2022, there were 26 active permitted mines and 22 inactive (cancelled or terminated) permitted mines in Kitsap County. In addition, we received information from SMRP's chief reclamation geologist on active permitted sites that have transitioned from resource extraction to site reclamation (Rian Skov, Washington Geological Survey, written commun., 2022). Any areas within active permitted mine sites we knew to be undergoing reclamation (or areas that were fully reclaimed) were classified as Not a Resource, since reclaimed mines are almost never mined again. We also included prospect- and mine-related point features[2] (points that were not included in the SMRP database) from digitized 1936–1994 USGS topographic maps (Horton and San Juan, 2021). This included 49 gravel/borrow pits and 7 open pit mines or quarries within Kitsap County.

LIDAR

Airborne lidar is detailed topographic data collected by airplane, typically with a horizontal resolution of 3 ft and a vertical accuracy of <1 ft. It provides a detailed view of the land surface that can be used to interpret geologic phenomena. We used lidar to check that the map units on each geologic map matched the landforms seen in the lidar. In some limited cases we also used lidar to provide a basis for adjusting the boundaries of resource polygons when the geologic mapping was either insufficiently detailed or there was a mismatch in adjacent published maps. We used lidar data collected in 2017–2018 over all of Kitsap County (Washington Geological Survey, 2018).

OTHER MAPS AND DATA

In 2014, the USGS produced a 3D Hydrogeologic Framework study of the Kitsap Peninsula (Welch and others, 2014). In that report they used subsurface data and surface geology to develop an understanding of the thickness and distribution of aquifers and aquicludes. In Kitsap County, aquifers tend to be thick deposits of outwash sand and gravel and aquicludes are typically either glacial till or fine-grained silt or clay. In general, outwash sand and gravel tends to be a good source of aggregate, and glacial till and fine-grained deposits tend to be bad sources of aggregate. In some locations we referenced the aquifer and aquiclude thickness maps and models of Welch and others (2014) to help assess the distribution and thickness of potential aggregate resources and non-resources in the subsurface.

Landslide areas and deposits are generally not good sources of aggregate. For this reason, we chose to exclude areas that intersect with the best available landslide mapping for Kitsap County, which is WGS's Washington State Landslide Inventory Database (Washington Geological Survey, 2022b). This dataset shows landslides compiled from a variety of sources, spanning the past few decades. Note that the landslide inventory for Kitsap County had not been updated to the lidar-based protocol of Slaughter and others (2017) at the time of our analysis. The absence of landslide data in a particular location does not necessarily mean that landslides are absent or that there is no landslide risk. The inclusion of these landslide data into our study is not intended as a substitute for a detailed investigation of potential slope instability by a qualified practitioner.

Resource Classification Scheme

OVERVIEW

Our classification scheme (Fig. 2) provides a framework for making consistent decisions and interpretations about aggregate resources from available data. Similar to other aggregate classifications (for example, California Division of Mines and Geology, 2000; Jennings and Kostka, 2014; Eungard and Czajkowski, 2015; Associated Earth Sciences, Inc., 2017) we divide resources by their quality and available thickness and impose threshold limits on what we consider a viable resource. The quality of aggregate varies substantially based on the type of rock or deposit from which it is sourced. Some uses of aggregate—such as gravel forest roads—can use lower-quality aggregate, whereas other uses—such as bridges—require high-quality aggregate. Because the use will dictate the characteristics of what is considered acceptable aggregate, we choose one of the most common uses—Hot Mix Asphalt—and assess quality based on the requirements of this product, as detailed by the 2023 Standard Specifications of the Washington State Department of Transportation (WSDOT, 2023). This choice means that our quality thresholds (discussed further below) may be too restrictive for some low-quality aggregate uses, and too permissive for some high-quality aggregate uses.

Our generalized classification scheme divides our inventory into Demonstrated, Inferred, Speculative, and Not a Resource quality categories (Fig. 2). Demonstrated resources are those

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[2] Mine data compiled from USGS topographic maps are available at mrdata.usgs.gov/usmin/

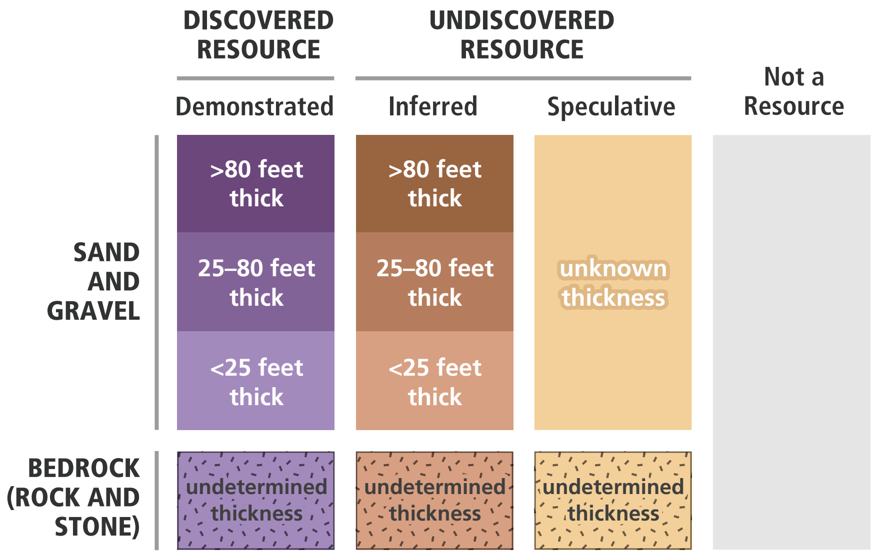

Figure 2. Generalized aggregate resource classification scheme used in this study. In general, the level of knowledge and certainty decreases from Demonstrated resources to Speculative resources; regions classified as Not a Resource may or may not have a high level of knowledge and certainty. Note that bedrock resources are mined for rock and stone commodities and we use these terms interchangeably.

for which we have the highest level of certainty that they meet our quality thresholds; they almost universally have an active or recently active surface mine nearby, thus *demonstrating* their viability. Inferred resources are less certain than Demonstrated resources, but are more certain than Speculative resources; we *infer* their viability as an aggregate resource based on available data. Speculative resources have enough information for us to *speculate* there is a resource, but further work would be needed to confirm its existence and quality. Regions classified as Not a Resource may vary in level of knowledge and certainty.

For sand and gravel resources, we subdivide Demonstrated and Inferred resources into three bins according to their estimated thickness: <25 ft thick, 25–80 ft thick, and >80 ft thick (Fig. 2). Resources that are <25 ft thick may be too thin to be economically viable for resource extraction because the cost of extraction may be greater than the value of the aggregate material. We included these potentially thin resources in the inventory to acknowledge that changes to extraction cost or aggregate value may make them economically viable in the future. Because the thickness of bedrock resources is difficult or illogical to quantify in most geologic situations, we did not divide bedrock into thickness categories.

DETERMINING RESOURCE QUALITY

To make consistent classification decisions and ensure transparency in our decision-making process, we developed a detailed set of criteria for classifying resource polygons based on their quality (Table 1). The left side of Table 1 lists the types of data we considered in our resource classification workflow, and describes the typical characteristics of supporting evidence for each of quality classifications: Demonstrated, Inferred, Speculative, and Not a Resource

Table 1 should not be interpreted as a simple decision tree. In order to overcome the challenge of missing, inconsistent, and (or) conflicting data on aggregate quality and thickness, we apply a holistic review process that considers all evidence available. While Table 1 is a complete description of our decision process, it was purposefully designed to allow for some latitude in classification to avoid biasing too heavily against a resource simply because we lacked detailed evidence of its quality or thickness. Note that Table 1 generally ranks input data types from high priority at the top to lower priority at the bottom, acknowledging that some types of evidence provide greater discriminating power than others.

Resource Classification Workflow

OVERVIEW

Here we describe how we produced the aggregate resource inventory by compiling data sources and interpreting them using our resource classification scheme (Table 1). Although we began by compiling geologic units at the best available scale, the boundaries of our mapped resource polygons may deviate from the geologic source data wherever we refined their extents based on additional data.

WORKFLOW

We started by compiling all of the data described in the *Sources of Data* section while excluding land that falls outside the scope of our work. For Kitsap County, excluded areas include those that intersect with the WGS landslide database. Federal Wilderness Areas and National Parks would also be excluded, but neither of these exist in Kitsap County. We clipped the remaining data to the shoreline of 1:100,000-scale geologic maps. Any other water features present in the input geologic mapping were retained. Following these steps produced a database of geologic unit polygons bounded by a seamless shoreline and excluding areas with landslides.

Resource classification began with reviewing the geologic unit descriptions and classifying units that were very unlikely to be resources as Not a Resource. We then determined which of the remaining geologic units had aggregate mining or aggregate testing history, and if the results were favorable for aggregate quality. Where there is an active surface mine boundary according

Table 1. Holistic decision table describing the types, consistency, and quality of evidence that support each of the aggregate quality classifications (Demonstrated, Inferred, Speculative, and Not a Resource). Reading down the table provides a description of the typical evidence that supported the quality classification of a resource polygon. Not all data were available for all resource polygons, and when data conflicted, we generally gave higher priority to data types listed higher in the table. The Not a Resource classification may or may not have a high level of knowledge and (or) certainty.

		More data available, data more consistent ↔ *Less data available, data less consistent*			
	Resource-quality input data	**Demonstrated**	**Inferred**	**Speculative**	**Not a Resource**
Higher priority evidence ↑	**Material description of sand and gravel or bedrock** Sources: Geologic and geomorphic maps (1:24,000 to 1:100,000 scale), subsurface data, and other geologic descriptions when available	Material descriptions are typically consistent and indicate a good-quality resource* with minor, if any, material of lesser quality. Example: A 1:24,000-scale geologic map describes in detail a well-sorted gravelly glacial outwash deposit.	Material descriptions vary in level of detail and (or) indicate the resource quality varies and may include some minor material that is not of good quality.* Examples: A 1:24,000-scale geologic map describes in detail a unit that contains mostly sand and gravel but also lenses of till, or a 1:100,000-scale geologic map describes a unit that generally contains sand and gravel.	Material descriptions vary in level of detail and (or) indicate the resource may include minor to moderate amounts of lower-quality material.* Example: A 1:100,000-scale geologic map describes a glacial ice-contact unit which may contain a mixture of good material (esker gravels) and low-quality material (clayey till).	Material descriptions available indicate material does not meet our aggregate resource material requirements.* Example: A 1:24,000-scale geologic map describes a poorly sorted glacial till with significant clay content.
	Active permitted mining activity Sources: SMRP records of active mines	Typically intersects with or adjacent to active (permitted) aggregate mines or quarries.	Sometimes adjacent to active (permitted) aggregate mines or quarries.	Rarely near or adjacent to active (permitted) aggregate mines or quarries.	Rarely near or adjacent to active (permitted) aggregate mines or quarries.
	Subsurface data (where available) Sources: Water-well logs, geotechnical borings	Subsurface data are typically available, well-located, evenly distributed, and indicate good-quality aggregate material throughout the resource area.	Subsurface data are typically available, but may be located with variable precision. Generally indicate good-quality aggregate material. Some records may indicate lower-quality material.	Subsurface data are sometimes available, located with variable precision, have uneven distribution, and (or) indicate variable quality aggregate material.	Subsurface data may or may not be available. Where available, data generally indicate material does not meet our aggregate resource material requirements.*
	Other Mining activity (if available) Sources: SMRP records of inactive mines, USGS topo maps	Typically intersects with or adjacent to small mining operations, inactive (cancelled or terminated permit) aggregate mines or quarries, or historical mining activity.	Sometimes intersects with or adjacent to small mining operations, inactive (cancelled or terminated permit) aggregate mines or quarries, or historical mining activity.	Sometimes intersects with or adjacent to small mining operations, inactive (cancelled or terminated permit) aggregate mines or quarries, or historical mining activity.	Rarely intersects with or adjacent to historical or small mining operations. OR Sometimes intersects with or adjacent to previously reclaimed or cancelled permitted mines.
↓ *Lower priority evidence*	**Aggregate testing data** (where available)	Test results are sometimes available. Available results typically pass our testing thresholds.†	Test results are sometimes available, but may be inconsistent. Available results sometimes pass our testing thresholds.†	Test results are rarely available and often inconsistent. Available results sometimes pass our testing thresholds.†	Test results are rarely available and often inconsistent. Available results typically fail our testing thresholds† or are incomplete.
	Consistency of evidence	Most to all data indicate a good-quality resource; rarely data may indicate lower quality material.	Most to some data indicate a good-quality resource; some data may indicate lower-quality material.	At least some data indicate a good-quality resource; some data may indicate lower-quality material.	Most to all data indicate that the material is not a good aggregate resource; rarely data may indicate a good-quality resource.
	Criteria that all resource polygons must meet (Demonstrated, Inferred, and Speculative polygons)	(1) When subsurface data are available and indicate the presence of an overburden, it is typically <10 feet thick with a stripping ratio of 1:3 or better (the overburden should be no more than a third of the resource thickness). (2) Mapped polygon is larger than 1 acre and not too narrow (generally >200 feet across at its narrowest dimension).			Criteria (1) or (2) are not met.

* Good-quality sand and gravel resource: Material description indicates sand and gravel with little to no organic material, silt, or clay. These deposits are typically unweathered, generally stratified, moderately to well rounded, and well sorted. Good-quality bedrock resource: Material description indicates little to no weathering, little indication of physical or chemical alteration, and other details that correspond with strong and durable rock.

† We adopt the 2023 specifications for Hot Mix Asphalt (HMA) as our aggregate testing threshold: LA Abrasion values of <30% and Washington Degradation values of >30%.

to the Surface Mine Reclamation Program database, we used this boundary for a Demonstrated resource. Areas surrounding an active surface mine were in some cases classified as Inferred or Speculative based on our classification scheme (Fig. 1). Inactive and historical mines and small mining operations may or may not be classified as Inferred or Speculative resources depending on the availability of detailed geologic, subsurface, or testing data in their vicinity (Table 1).

We used subsurface data (in conjunction with geologic unit descriptions) to estimate the thickness of each resource polygon and modify the boundaries of the geologic unit polygons that form the initial basis of our database. Subsurface records were classified as Good, Thin, or Bad. Subsurface records that indicate >25 ft of good aggregate material were interpreted as Good; those that indicate material unsuitable for aggregate or with <10 ft of good aggregate material, or with >10 ft of non-resource overburden, were interpreted as Bad. Subsurface records that indicate <25 ft of good aggregate material were interpreted as Thin since aggregate resources <25 feet thick may not be economically viable to extract. For all records, the actual thickness of aggregate material and overburden was also recorded, and these data were used to estimate the average thickness (and therefore the thickness classification) of each resource polygon.

In three situations, data from subsurface records led us to modify a resource boundary from that of the original geologic unit polygon. In the first, a resource was expanded (or reduced) to include (or exclude) a specific subsurface record. The second situation is where a substantial change in the thickness of the aggregate material existed within a single geologic unit. In this case the polygon was divided into separate resource polygons with internally consistent thicknesses. The final situation occurs when a relatively thin (<10 ft thick) surficial geologic unit that is considered Not a Resource overlies a thick deposit of good aggregate material. This occurs in Kitsap County where thin glacial till—not a resource—is underlain by glacial advance outwash deposits—an excellent resource. To ensure that we did not overlook potential resource areas covered by a thin glacial till overburden, we reviewed data from subsurface records, the hydrogeologic framework of Welch and others (2014), lidar, and geomorphology data (Haugerud, 2009).

The suitability of alluvial deposits (those from non-glacial streams and rivers) as aggregate resources depends on the size of the river system and the geology and geometry of the drainage basin. We assumed that deposits from small or seasonal streams are not significant resources because they are typically poorly sorted, relatively thin, and narrow. However, deposits from major river systems could be sources of aggregate because such rivers typically produce well sorted, thick, and extensive sand and gravel deposits. Our workflow included reviewing all alluvial geologic units and excluding those that are too thin, too restricted in area, and those that are likely to be poorly sorted. We did not consider any land-use or environmental restrictions (such as stream buffers) in our resource mapping.

Our geologic data were compiled from 1:24,000-scale and 1:100,000-scale sources, and there are sometimes inconsistencies where these maps meet at their boundaries. We used geomorphology and lidar data to reinterpret these areas for our resource mapping. This process sometimes resulted in the modification of resource polygons in order to create a cohesive, county-wide map. In general, our data are intended to be used at no finer a scale than the geologic map from which it was sourced. In some situations, very narrow portions or slivers of resource polygons (typically those <75 ft wide) were trimmed, extended, or merged to achieve readability at 1:24,000 scale.

Estimating Resource Volume and Tonnage

We estimated resource volume in cubic yards and weight in tons using simple geometric equations, estimates of thickness, and assumed values for recoverability and aggregate unit weight. We only estimated volume for Demonstrated and Inferred sand and gravel resources because we generally lacked thickness information for Speculative sand and gravel resources and did not determine the thickness of bedrock resources. We present all of our equations and assumptions below so that the end user can understand our methods and alter or update our assumed values based on new, improved, or additional information.

FACTORS THAT AFFECT USEABLE RESOURCE

Several factors affect the amount of aggregate that can be recovered from a potential resource, and we explicitly considered five of them: resource area, thickness of the resource, how much of the actual geologic deposit is usable as aggregate (geologic recoverability), how much the land surface deviates from our assumption of uniform flatness (topographic recoverability), and how much of the usable material must be kept on site for reclamation purposes (operations recoverability).

Low and high resource-thickness values, which we used to calculate ranges of resource volume and tonnage, were estimated from the minimum and maximum thicknesses reported in available subsurface data within the resource polygon and (or) unit descriptions from geologic maps. Resource thicknesses exclude any overburden. The surface area of each aggregate resource polygon was calculated from our resource inventory map.

We used a range of geologic recoverability values based on the primary geologic material present in the deposit (Table 2). High geologic recoverability means that most of the material in the deposit is usable as aggregate and requires only minimal processing. Low geologic recoverability means that there may be some portions of the deposit that are not usable or require extra processing (for example, too much fine-grained material or dispersed lenses of glacial till). We employ a topographic recoverability factor to account for the amount of material that has been removed by erosion. High values (90–95%) indicate a relatively flat surface in the region where we are estimating volume; lower values (70–90%) indicate more rugged topography or the presence of deep gullies or canyons (where some of the aggregate resource has potentially been removed by erosion). We use a single operations recovery factor (90%) because we assume 10 percent of the total material must remain on site.

ESTIMATING VOLUME AND TONNAGE

We modeled the three-dimensional shape of each aggregate resource as its mapped polygon extruded to its thickness (Fig. 3). If the resource polygon contains a surface mine, then we modeled the volume of the mine as a frustum (a truncated pyramid) and

Table 2. Recoverability values used in this study.

Variable	Conditions	Recoverability
Geologic recoverability (R_{gl} and R_{gh})	Glacial outwash deposits	80–90%
	Ice-contact and ice-marginal deposits	75–85%
	Alluvial deposits	75–85%
Operations recovery factor (R_w)		90%
Topographic recoverability (R_t)	Flat surface	95%
	Gently undulating surface	90%
	Gently incised surface	85%
	Moderately incised surface	80%
	Strongly incised surface	75%
	Deep and pervasively incised surface	70%

subtracted the mined volume from that of the whole resource polygon (Fig. 3).

The low and high volumes for each resource polygon (V_{low} and V_{high}) were calculated using:

Equation 1. $V_{low} = A \times D_{low} \times R_{gl} \times R_t \times R_w \times C - V_{mined}$

Equation 2. $V_{high} = A \times D_{high} \times R_{gh} \times R_t \times R_w \times C - V_{mined}$

Where A is the area of the resource polygon in acres, D_{low} and D_{high} are the low and high values for the thickness of the resource in feet, R_{gl} and R_{gh} are the low and high values for the geologic recoverability factor, R_t is the topographic recovery factor, R_w is the operations recovery factor, C is a conversion constant from acre-feet to cubic yards, and V_{mined} is the volume of material already removed by mining in cubic yards.

To approximate the volume of material removed by any active mines within a resource polygon (V_{mined}), we determined the average mine height (H, in feet) from lidar and the mine bottom and top areas in acres (S_1 and S_2 respectively) from the most recently available NAIP aerial imagery (2021 for Kitsap County) and lidar (Fig. 3). V_{mined} was calculated with:

Equation 3. $V_{mined} = \frac{H \times C}{3}\left(S_1 + S_2 + \sqrt{S_1 \times S_2}\right)$

To convert our volume estimates (Equations 1 and 2) into tonnages (T_{low} and T_{high}), we used:

Equation 4. $T_{low} = V_{low} \times W_{low}$

Equation 5. $T_{high} = V_{high} \times W_{high}$

Where W_{low} and W_{high} are aggregate weights of 1.6 and 1.8 tons per cubic yard, respectively (Koloski and others, 1989). This range represents the low and high estimates of dry densities of aggregate materials.

Table 3. Explanation of variables and abbreviations.

Abbreviation	Meaning
A	Surface area of the deposit (in acres)
V_{low} V_{high}	Low and high estimates of resource volume (in cubic yards)
T_{low} T_{high}	Low and high estimates of resource tonnage (in tons)
D_{low} D_{high}	Low and high estimates of average resource thickness/depth (in ft)
R_{gl} R_{gh}	Low and high estimates of geologic recoverability (as percent, see Table 2)
R_w	Operations recovery factor (assumed to be 90%)
R_t	Topographic recovery factor (as percent, see Table 2)
C	Conversion factor from acre-ft to cubic yards (1,613.33 cubic yards per acre-ft)
W_{low} W_{high}	Low and high estimates of aggregate weight (ranges from 1.6 to 1.8 tons per cubic yard)
V_m	Volume of material removed by active aggregate mine (cubic yards)
H	Average measured mine height (ft)
S_1	Area of aggregate mine floor (in acres) (bottom of the excavated area within the mine)
S_2	Area of top of aggregate mine (in acres) (disturbed area within the permit boundary)

ACCURACY OF ESTIMATES

Aggregate deposits are products of complex natural systems and many factors can affect the amount of usable aggregate in any region. Our approach to estimating volume and tonnage tries to account for the inherent uncertainty around our input variables (listed in Table 3) by integrating low and high values into our calculations. We chose a conservative range of input values for thickness of deposit, geologic recoverability, and aggregate weight to provide a higher likelihood that the true total volume and tonnage of aggregate fall within our estimated range. Our volume and tonnage estimates are based only upon publicly available data and therefore lack the detailed data about aggregate quality and quantity that many, if not most, mine operators have available to them. Because of this, detailed site-specific information and analysis should generally be viewed as a more robust indicator of local aggregate quality and quantity than this county-level report.

Developed Land Classification

Aggregate resources on land that has already been developed are generally unavailable for extraction. Our inventory workflow method did not consider the current land use in deciding the quantity and quality of a resource. This resulted in an inventory that overestimates the amount of available resource where there is significant developed land. To mitigate this effect, we used data from the National Land Cover Database (NLCD) to estimate how

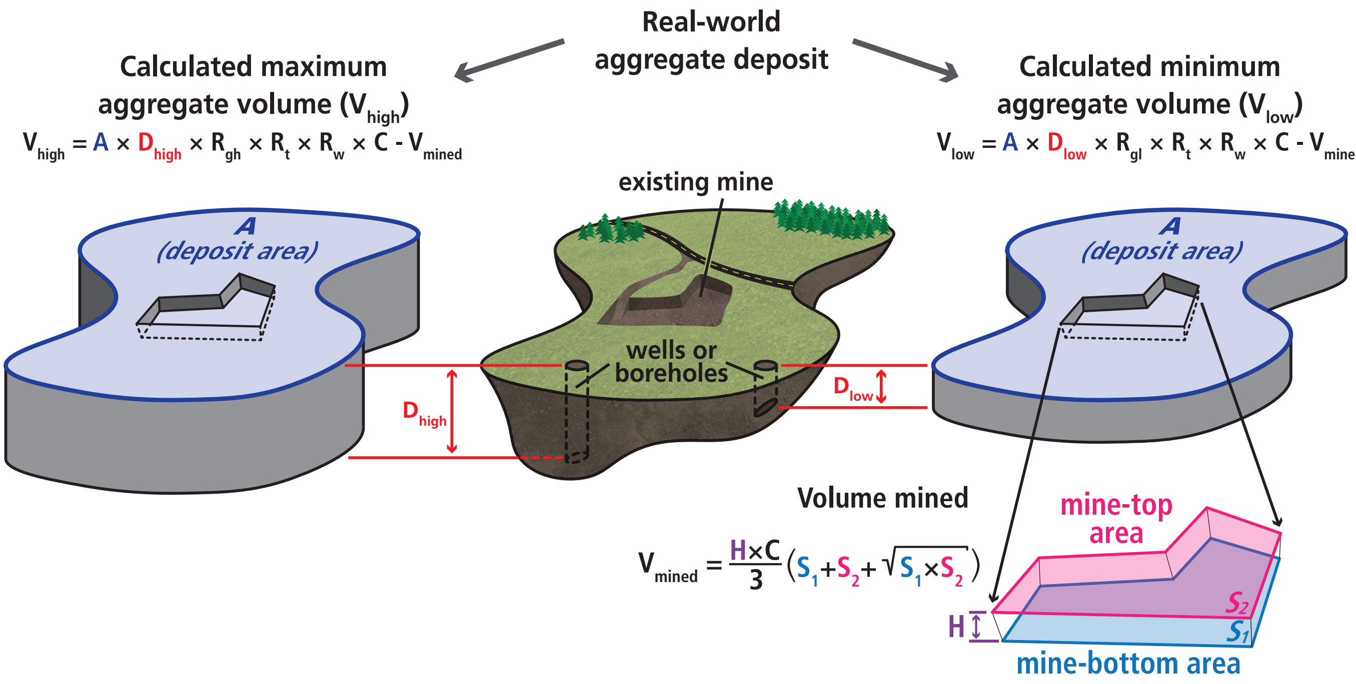

Figure 3. Method used to calculate the volume of a resource polygon. If a surface mine was present, we subtracted the volume of material that had already been removed from the volume of the whole aggregate deposit. Variables are explained in Table 3.

our resource polygons are impacted by existing development. The NLCD categorizes land-use at 30-m (328-ft) resolution across the entire country (Dewitz, 2021). We considered developed land to be any region the NLCD categorizes as low-, medium-, or high-intensity developed land. We accessed the 2019 data release of the NLCD from mrlc.gov/viewer in December, 2022. These data were added to our working GIS database and we then calculated the portion of each resource polygon covered by land classified as developed. In our results we present estimates of area, volume, and tonnage with and without this analysis to help illustrate the effect of land development on resource availability.

Resource Proximity to Markets Analyses

The proximity of plentiful, high-quality aggregate resources to locations where such resources are needed is an important consideration for both planners and mine operators. The cost of aggregate (and its economic feasibility) is largely controlled by how far it must be trucked from source to sites where it is needed; a county in which resources are located far from where they are needed will have higher aggregate costs and consequently higher construction costs. Furthermore, reducing aggregate transport distance directly reduces the number of miles driven by heavy vehicles on state and county roads, thereby reducing potential vehicle accidents, road wear, and carbon emissions. Given the significant costs of aggregate transport, it makes sense to plan for the long-term availability of resources in a variety of locations.

In order to evaluate the accessibility of current and potential future aggregate resources to communities in Kitsap County, we performed two analyses. The first calculates aggregate transportation distances along roads from active mines in Kitsap County. This analysis reveals areas in the county that have limited road access (typically undeveloped areas) or areas that are far from active permitted aggregate mines (‘aggregate deserts’). These ‘aggregate deserts’ are areas that might benefit from reduced aggregate transportation costs if closer aggregate resource deposits were developed. In this analysis, we used the locations of permitted surface mines in Kitsap County actively extracting material and calculated a 10-mile service area from each of these sources of aggregate along the public road transportation network. Our analysis used 18 active permitted surface mines, including county operated mines. Our analysis excluded any mines that have canceled or terminated permits and active permitted mines that are no longer extracting material or are in the reclamation phase (Rian Skov, Washington Geological Survey, written commun., 2022). We did not consider the quality or quantity of aggregate available at the included active mines. To keep this scenario focused on Kitsap County, we did not include any permitted mines from neighboring counties in this analysis, though such mines could possibly supply aggregate in some situations.

The second analysis shows which of the mapped aggregate resources in our inventory are located closest to four cities in the county: Port Orchard, Poulsbo, Bremerton, and Bainbridge Island (locations on Fig. 1). We selected these four cities because they participate in aggregate needs and use planning under the Growth Management Act. This analysis shows which aggregate resource areas are close to these populated areas, presenting an opportunity to source aggregate closer to where it is needed and reduce transportation costs. In this analysis, we modeled a 5- and 10-mile driving distance from four aggregate demand points located at major road intersections near the four selected cities. The aggregate demand points represent generalized locations of aggregate demand and therefore may not align with the traditional mapped centers of the four cities.

For both proximity analysis scenarios, we used the ‘Isochrones from Layer’ analysis tool within the Openrouteservice

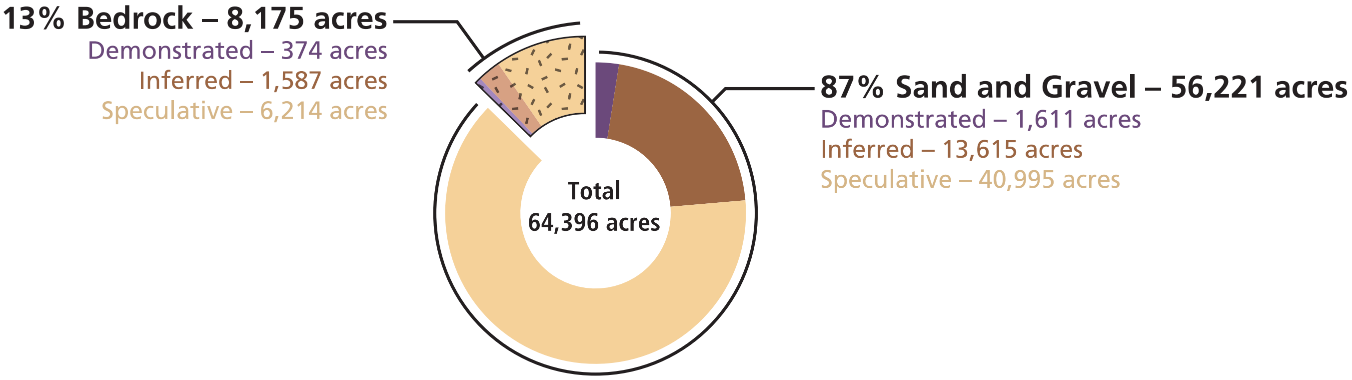

Figure 4. Distribution of material types and quality classifications of potential aggregate resources in the inventory.

(ORS) Toolbox in QGIS Desktop 3.28.2. The tool automatically fetches road data from the OpenStreetMap transportation network through the ORS API (accessed December 2022). We used the 'driving hgv' (heavy goods vehicle) setting that models a transportation network usable by large trucks. We assume that this transportation network, the network settings, and the driving distances are representative of aggregate delivery in the study area. The driving distances are intended to reflect a feasible distance analysis, but may not reflect the distance analysis needs of all readers.

AGGREGATE RESOURCE INVENTORY RESULTS

Resource Estimates

Our results identify Demonstrated, Inferred, and Speculative sand-and-gravel and bedrock aggregate resources in Kitsap County (see Map Sheet). In total, we identify 64,396 acres of land as having the potential for substantial aggregate resources, which is about 25 percent of the county (Table 4). This total is divided into 8,175 acres of potential bedrock aggregate resources and 56,221 acres of potential sand and gravel resources (Fig. 4). For sand and gravel resources mapped as Inferred and Demonstrated (our two highest-certainty classifications), we estimate 600 million to 1.3 billion cubic yards of aggregate—approximately 970 million to 2.3 billion tons (Fig. 5). For comparison, the United States consumed approximately 945 million tons of sand and gravel aggregate in 2022 (USGS, 2023). Due to the difficulty of quantifying the thickness of bedrock aggregate resources, we did not estimate their volume or tonnage.

DEMONSTRATED RESOURCES

Demonstrated resources are those for which there is the most evidence that the geologic deposit meets or exceeds our threshold criteria; these are the deposits that we are the most certain about and they are almost always near an active or recently active mine. Within the county, there are a total of 1,985 acres of Demonstrated resources (Table 4), which include 1,611 acres of sand and gravel resources and 374 acres of bedrock resources. We estimate between 122 million and 142 million cubic yards of sand and gravel within this category (Fig. 5). Based on the NLCD data, about 12 percent of the Demonstrated sand and

Table 4. Area, volume, and tonnage estimates for potential aggregate resources in Kitsap County broken down by aggregate type, classification, and land-use filtering. Bolded numbers are for all resources mapped in the county without filtering for land use. Numbers in parentheses refer only to resources located in areas that are classified as undeveloped in the NLCD. We do not report volume or tonnage for bedrock resources.

	Area in acres	Low volume in millions of cubic yards	High volume in millions of cubic yards	Low tonnage in millions of tons	High tonnage in millions of tons
Sand and gravel					
Demonstrated	**1,611** *(1,419)*	**123** *(107)*	**142** *(125)*	**196** *(172)*	**256** *(225)*
Inferred	**13,615** *(9,866)*	**485** *(361)*	**1,154** *(871)*	**776** *(577)*	**2,077** *(1,567)*
Speculative	**40,995** *(33,667)*				
Subtotal	**56,221** *(44,952)*	**607** *(468)*	**1,296** *(995)*	**972** *(749)*	**2,333** *(1,792)*
Bedrock/rock and stone					
Demonstrated	**374** *(362)*				
Inferred	**1,587** *(1,519)*				
Speculative	**6,214** *(6,200)*				
Subtotal	**8,175** (8,081)				
Total area of all aggregate resources					
Total	**64,396** *(53,034)*				

Bold = entire inventory
(Italics) = undeveloped areas only

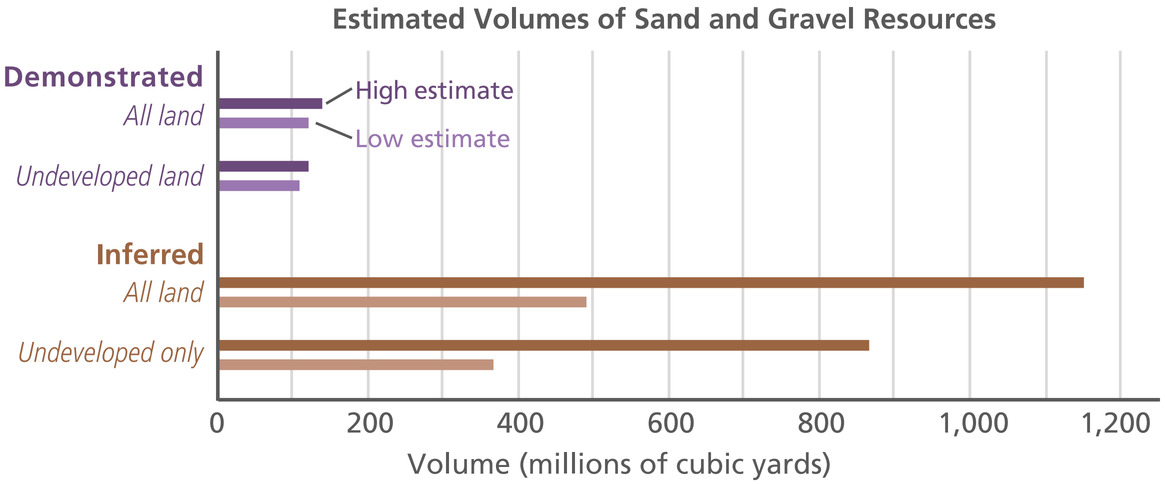

Figure 5. Volume estimates of Demonstrated and Inferred sand and gravel aggregate resources. 'All land' denotes volumes for the full inventory without consideration of land use, while 'undeveloped land' filters the inventory to only areas classified as undeveloped by the NLCD.

gravel resources are located on developed land; about 3 percent of bedrock resources are on developed land. Demonstrated resource areas contain 22 active mines and 13 inactive mines.

INFERRED RESOURCES

Inferred resources are those for which there is often good geologic and subsurface evidence that the deposit meets or exceeds our threshold criteria, but we may lack specific confirming data or there may be inconsistent lines of evidence; these are deposits that we infer to be a good source of aggregate but some additional geologic study is probably necessary. Within the county, there are a total of 15,202 acres of Inferred resources (Table 4), which include 13,615 acres of sand and gravel resources and 1,587 acres of bedrock resources. We estimate Inferred resources contain between 485 million and 1.1 billion cubic yards of sand and gravel (Fig. 5). According to the NLCD data, about 25 percent of Inferred sand and gravel resources and 4 percent of inferred bedrock resources are on developed land.

SPECULATIVE RESOURCES

Speculative resources are those for which there is some evidence, often in the form of geologic unit descriptions, that suggests the deposit aligns with our criteria, but we lack sufficient data to make a more certain determination. These are deposits that we speculate could be a good source of aggregate but additional geologic study is necessary. Within the county, there are a total of 47,209 acres of Speculative resources (Table 4), which include 40,995 acres of sand and gravel resources and 6,214 acres of bedrock resources. Because we lack thickness information for speculative resources, we do not estimate their volume or tonnage. According to the NLCD data, about 18 percent of Speculative sand and gravel resources and <1 percent of bedrock resources are on developed land.

Impact of Developed Lands

Current land use was not a factor in classifying aggregate resources throughout the county because our inventory is based on underlying geologic phenomena. However, we used land cover data from the National Land Cover Database (NLCD) to estimate the area of aggregate resources that may no longer be accessible due to development. Overall, about 18 percent of the total area we classified as having potential for aggregate resources—about 11,400 acres—is considered developed and likely to be inaccessible for resource extraction. Total areas of potential aggregate resources in undeveloped areas are provided in Table 4.

Resource Proximity to Markets Results

Because aggregate resources are heavy and can only be sourced from specific geologic depositional areas, there are significant economic, physical, social, and environmental costs that factor into the placement of aggregate mines. Our proximity analyses are not intended to suggest which land or resources should or should not be protected for future aggregate extraction. Nor are these analyses intended to define significant travel distances for all readers. Rather, they are meant to illustrate how the location of aggregate mines and resources may affect the transportation of aggregate resources from source to market.

The first proximity analysis models a 10-mile service area around actively extracting mines in Kitsap County (Fig. 6). We interpret the areas outside of the service area as possible “aggregate deserts”, meaning they appear to be far from actively extracting aggregate mines and therefore may require transportation of aggregate resources from farther away. Figure 6 shows that approximately 21 percent of the county could be interpreted this way, though some of these areas may be outside the 10-mile service area because they lack roads (for example, the area around Green Mountain and Gold Mountain). Figure 6 shows that the northern tip of Kitsap County near Hansville and the southern half of Bainbridge Island require aggregate to be delivered from relatively distant mines, incurring higher aggregate transportation costs.

The second proximity analysis models a 5- and 10-mile transportation distance outward from four large populated areas in the county (Bremerton, Port Orchard, Poulsbo, and Bainbridge Island), showing which resources are close to these four cities (Fig. 7). About 25 percent of land classified as having

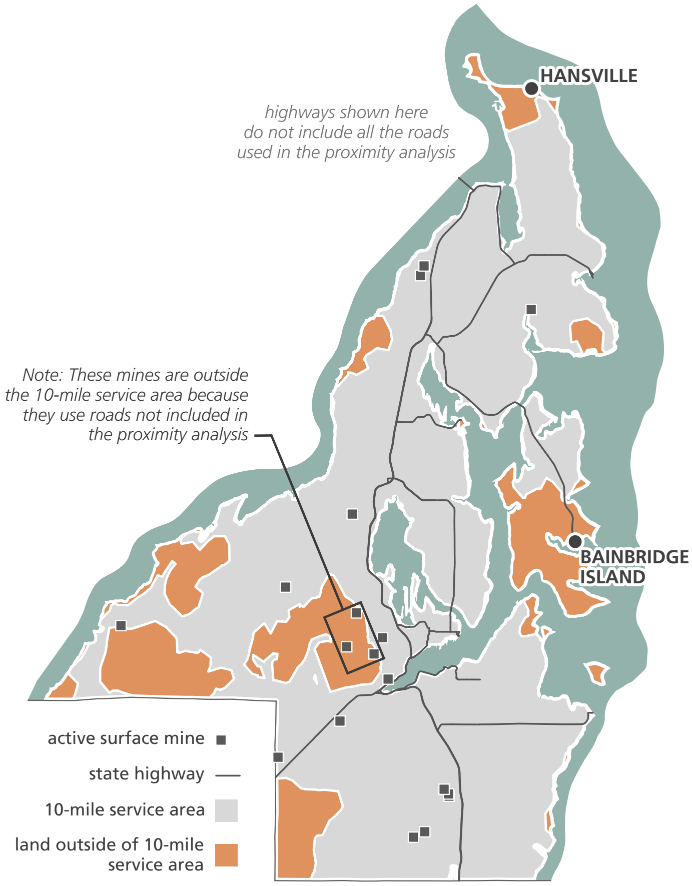

Figure 6. Proximity analysis using currently active aggregate mines in Kitsap County and a 10-mile service area. Gray shading shows the service area; orange shading highlights areas that fall outside of the service area and may experience higher aggregate transportation costs.

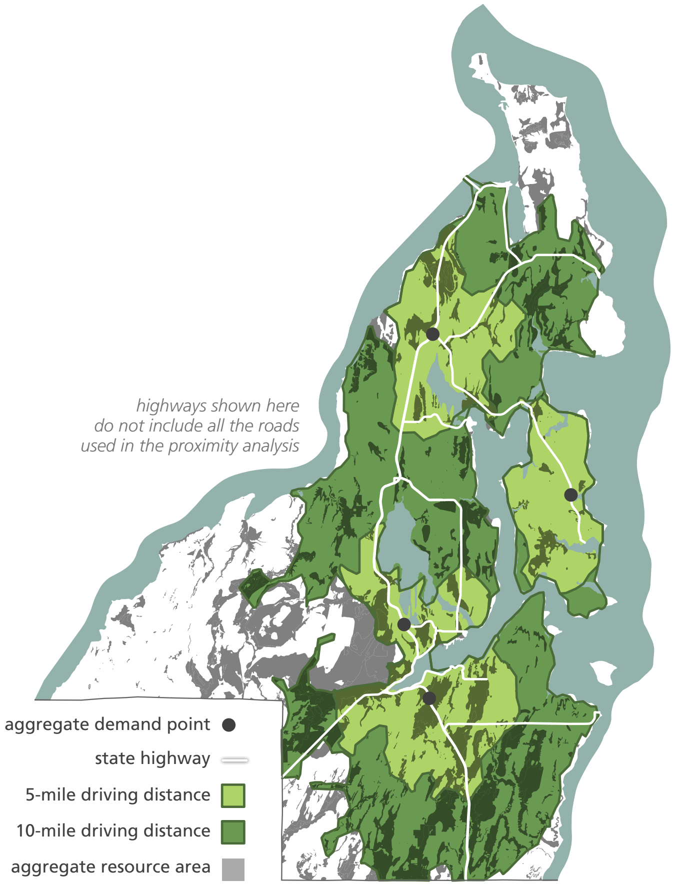

Figure 7. Proximity analysis showing a 5-mile and 10-mile outward service area from four points of aggregate demand: Port Orchard, Bremerton, Bainbridge Island, and Poulsbo.

the potential for aggregate resources is within 5 miles of the four cities, and about 65 percent are within 10 miles. About 35 percent of the total aggregate resources are more than 10 miles from the selected cities. Resource areas close to populated areas present an opportunity to source aggregate closer to where it is needed and reduce transportation costs. Resource polygons that fall outside of these transportation zones may represent future aggregate resources that could serve different or future populated areas outside of this analysis.

CONCLUSIONS

This report inventories and classifies potential aggregate resources of long-term significance with the goal of assisting county and city planners and other local officials with land-use planning decisions related to the Growth Management Act. Our inventory identifies 64,396 acres—25 percent of Kitsap County's land area—as having the potential for aggregate resources. A majority of this inventory, 56,221 acres, represents sand and gravel resources deposited during the most recent glaciation, while 8,175 acres represent sources of bedrock aggregate. For sand and gravel resources mapped as Demonstrated and Inferred, we estimate 600 million to 1.3 billion cubic yards of aggregate (970 million to 2.3 billion tons).

An analysis of the proximity of resources to areas of aggregate demand reveals that approximately 65 percent of our inventory falls within a 10-mile drive from four inferred centers of aggregate demand. We also find that approximately 11,400 acres—or 18 percent—of areas we identify as potential aggregate resources may be inaccessible for resource extraction because they are on land classified as developed according to the NLCD. This leaves a majority of the areas identified in our inventory as potentially accessible future resources.

ACKNOWLEDGMENTS

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Appendix A. New Aggregate Testing Data

We collected and tested seven new aggregate samples to provide additional constraints on the quality of some geologic materials that were not well represented by existing testing data. Each sample was collected from public land, from public right-of-ways along major roads, or from currently permitted aggregate mines in coordination with mine operators. We collected two five-gallon buckets at each site. For bedrock samples we crushed the collected rock at our lab facility to 1.5 in. or smaller using a small sledge hammer and a chipmunk mill; for sand and gravel samples we did no additional processing. All the samples were sent to Materials Testing & Consulting, Inc. for testing according to standard practice described in the Washington Department of Transportation Materials Manual (WSDOT, 2022b) in mid-November, 2022 and the results are provided below in Table A1.

Table A1. New aggregate testing data from this study.

Sample ID	Test Date	LA Abrasion Value	Degradation Value	Overall Test Result
WGS-KP-1	11/22/2022	16	8	Partial Fail

Latitude	47.584639	Sampling Notes: Sampled from unit Tcbs (Tabor and others, 2011). Sampled from what appeared to be an old quarry area with several meter-diameter boulders with adjacent bedrock outcrops. Rock was manually crushed and processed using a chipmunk rock crusher to make test-appropriate sized pieces in WGS's rock lab.
Longitude	-122.815669	
Generalized Aggregate Unit	Igneous bedrock	
Commodity	Rock and stone	

Sample ID	Test Date	LA Abrasion Value	Degradation Value	Overall Test Result
WGS-KP-2	11/22/2022	13	36	Pass

Latitude	47.575633	Sampling Notes: Sampled from unit Tegd (Tabor and others, 2011). Sampled from a natural cobble and boulder field from the side of forest road. Rock was manually crushed and processed using a chipmunk rock crusher to make test-appropriate sized pieces in WGS's rock lab.
Longitude	-122.808318	
Generalized Aggregate Unit	Igneous bedrock	
Commodity	Rock and stone	

Sample ID	Test Date	LA Abrasion Value	Degradation Value	Overall Test Result
WGS-KP-3	11/22/2022	21	45	Pass

Latitude	47.566069	Sampling Notes: Sampled from unit Tegd (Tabor and others, 2011). Sampled from a forest road cut. Chipped new pieces from bedrock exposure and picked up pieces from base of outcrop. Included both Leucogabbro and fine-grained basalt in sample to match Tegd's geologic unit description. Rock was manually crushed and processed using a chipmunk rock crusher to make test-appropriate sized pieces in WGS's rock lab.
Longitude	-122.807206	
Generalized Aggregate Unit	Igneous bedrock	
Commodity	Rock and stone	

Sample ID	Test Date	LA Abrasion Value	Degradation Value	Overall Test Result
WGS-KP-4	11/10/2022	11	8	Partial Fail

Latitude	47.594508	Sampling Notes: Sampled from unit Qvrt7 (Tabor and others, 2011). Sampled from a sand and gravel pile near a 5-foot deep hole. Small rock pile thought to be the tailings of a hole dug for sewage infrastructure.
Longitude	-122.837827	
Generalized Aggregate Unit	Glacial outwash deposits	
Commodity	Sand and gravel	

Sample ID	Test Date	LA Abrasion Value	Degradation Value	Overall Test Result
WGS-KP-5	11/10/2022	11	17	Partial Fail
Latitude	47.434866	Sampling Notes: Sampled from unit Qgic (Polenz and others, 2009). Sampled from the bottom portion of 30-foot deposit with seams of sand, gravel, minor fines, and localized oxidized deposits. Deposit outcrop was compact and not cemented.		
Longitude	-122.657195			
Generalized Aggregate Unit	Glacial outwash deposits			
Commodity	Sand and gravel			

Sample ID	Test Date	LA Abrasion Value	Degradation Value	Overall Test Result
WGS-KP-6	11/10/2022	12	75	Pass
Latitude	47.588329	Sampling Notes: Sampled from unit Qgo (Yount and others, 1993). Sampled from an exposure of well-graded fine to medium sand with trace coarse sand, gravel, and rare cobble. Sample collected from a hillslope on Kitsap County storage pit property.		
Longitude	-122.724425			
Generalized Aggregate Unit	Glacial outwash deposits			
Commodity	Sand and gravel			

Sample ID	Test Date	LA Abrasion Value	Degradation Value	Overall Test Result
WGS-KP-7	11/10/2022	10	50	Pass
Latitude	47.569965	Sampling Notes: Sampled from unit Qgog (Contreras and others, 2012b). Sampled from exposed outcrop of large gravel and cobble with fine to coarse sand with little fines. Minor oxidation and oxidized clay on exterior of deposit clasts. Sampled from the Holly Pit Kitsap County surface mine site.		
Longitude	-122.950334			
Generalized Aggregate Unit	Glacial outwash deposits			
Commodity	Sand and gravel			