Reconnaissance Investigation of Sand, Gravel, and Quarried Bedrock Resources in the Toppenish 1:100,000 Quadrangle, Washington

by Andrew B. Dunn

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Reconnaissance Investigation of Sand, Gravel, and Quarried Bedrock Resources in the Toppenish 1:100,000 Quadrangle, Washington

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INTRODUCTION

Background

During its 1998 session, the Washington State Legislature, acting on a recommendation from the Governor's Land Use Study Commission, asked the Washington Department of Natural Resources (WADNR) to map gravel and bedrock resources that could be used for maintenance and construction of homes and infrastructure. The Study Commission sought this information to assess the need to protect these resources from urban sprawl and other intensive land uses. These data would, in turn, result in better long-range planning and possible legislation to aid in designating mineral resource lands under the Growth Management Act (Revised Code of Washington [RCW] 36.70A; Lingley and Jazdzewski, 1994).

Although the data are presented herein in the traditional text and map format, this report is part of a project to prepare a geographic information systems (GIS) database that delineates the locations of some of the significant construction aggregate resources (sand, gravel, and bedrock) of Washington State. The digital version of this report, including ArcInfo coverages, is available through the Washington Division of Geology and Earth Resources *(see back of title page for address)*.

The Toppenish 1:100,000 quadrangle is located east of the Cascade Range in south-central Washington from 46 to 46.5 degrees north latitude and 120 to 121 degrees west longitude (Fig. 1). Approximately ten percent of the quadrangle is in Klickitat County while the other ninety percent is in Yakima County. The Yakama Indian Reservation, with a population of about 30,000, covers approximately 80 percent of the quadrangle (Yates and Yates, 2000, p. 262; Plate 1). The population of the entire quadrangle is about 75,000, with the largest population center at Sunnyside (population ~13,000). Overall, the population of Klickitat County is about 19,000 and that of Yakima County is about 213,000 (Washington Office of Financial Management, 2000).

Intended Audience

This inventory was created primarily for use by local government planners to help refine comprehensive plans and other zoning determinations. It will also aid legislators and other policy makers in assessing the importance of largely nonrenewable sand, gravel, and quarried bedrock resources. The study should also benefit engineers, transportation departments, and industry.

Primary Products

This inventory includes the following products:

1. Databases containing the location, thickness, quality, and volume of some sand, gravel, and bedrock resources (Appendices 3–5).
2. A map showing the probable extent of bedrock (in pink) and gravel (in yellow) resources (Plate 1). Thickness contours (isopachs) are shown within those sand and gravel deposits for which we have sufficient data.
3. The location of active mines, borrow pits, some depleted mines, and large proposed mines (Plate 1).
4. Brief descriptions of geologic units known to contain aggregate resources (Appendix 6).
5. A description of the geology and mining history of construction aggregates in the Toppenish quadrangle (see text).

A glossary of terms used in this report can be found in Appendix 1, and a complete discussion of the methods used in this study can be found in Appendix 2.

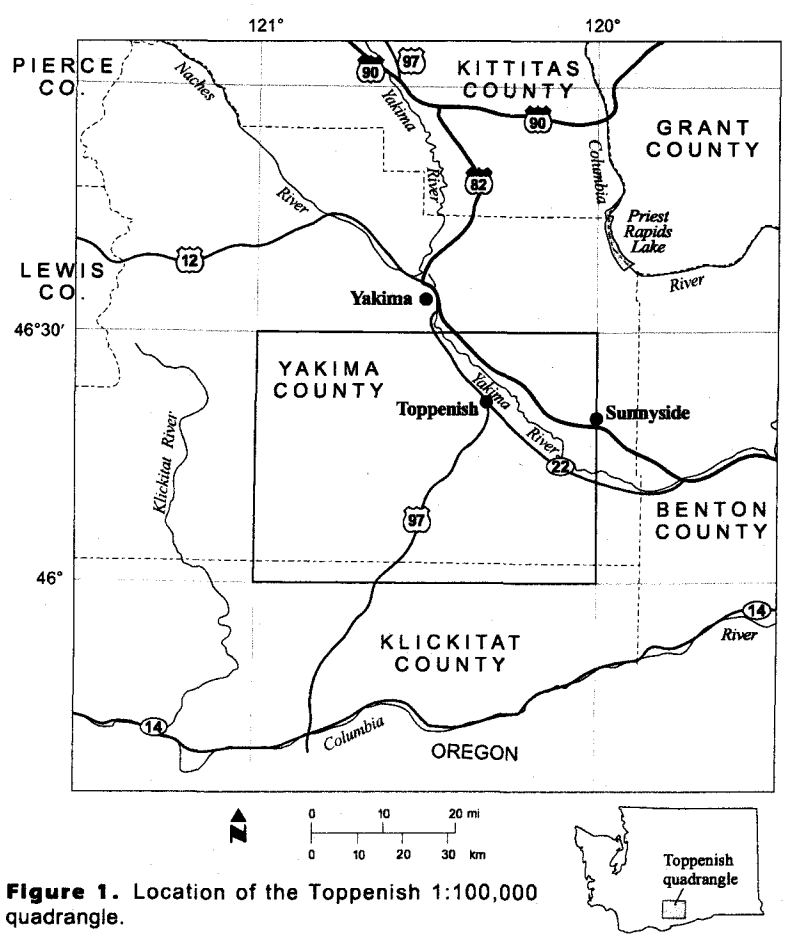

Figure 1. Location of the Toppenish 1:100,000 quadrangle.

Accuracy of Estimates

We emphasize that this report almost certainly overestimates the volume of construction aggregate within the area inventoried in the Toppenish quadrangle that is available under current market conditions, because of factors such as shallow bedrock under surficial gravels, diminishing rock quality with depth, unmapped areas of thick overburden, and lateral geologic variation. Furthermore, history indicates that future drilling and mining are more likely to yield disappointing results than to add significantly to hypothetical aggregate reserves. Finally, a rise in the price of construction aggregate could make some of today's subeconomic resources (such as clay-rich gravel deposits or rock buried under thick layers of overburden) commercially attractive in the future.

Table 1. Some specifications for construction aggregate products *(after Washington State Department of Transportation, 1999)*. Los Angeles Abrasion and Percent Passing U.S. No. 200 Sieve measurements are in weight percent. Los Angeles Abrasion and Degradation specifications for coarse portland cement concrete aggregate are not rigorous because the gravel is seldom exposed on the outside of concrete structures, such as foundations or sidewalks

	Product			
Laboratory test	Asphalt-treated base	Crushed (road) surfacing, top course	Coarse aggregate for portland cement concrete	Ballast (road subgrade)
Los Angeles Abrasion	≤30%	≤35%	≤35%	≤40%
Washington Degradation	≥15	≥25	not used	≥15
Sand Equivalent	≥30%	≥35%	not used	≥30%
Percent Passing U.S. No. 200 Sieve (<0.0025 in.)	2–9%	0–7.5%	0–0.5%	0–9%

Threshold of Significant Resources

Because this study is primarily designed as an aid to land-use planning, we inventoried only those resources deemed as significant to the long-term economic health of the region. Therefore, we restricted our investigation to those resources that meet the following threshold criteria:

1. The thickness of the sand and gravel or bedrock deposit appears to be in excess of 25 feet (7.5 m).
2. The 'stripping ratio' (ratio of overburden to gravel or overburden to bedrock) is less than one to three (1:3).
3. The strength and durability of the rock meets the Washington State Department of Transportation's (WSDOT) minimum specifications for asphalt-treated base, a rock product used to construct some lower layers of asphalt roads (Table 1).
4. The area of the deposit exposed at the surface exceeds 160 acres and measures at least 1,500 feet (450 m) across the minimum dimension of the deposit, or the reserves exceed 10 million cubic yards. However, a few exceptions are included where unusually thick deposits or resources of special local importance are present.

In some markets, a lack of quality gravel and bedrock has forced producers to mine lower-quality deposits. Homes and infrastructure constructed with weak gravel or bedrock generally have relatively short life cycles. We have not inventoried these lower-quality deposits because they do not meet the criteria of this study. However, Appendices 3 through 5 will serve as guides to the locations of some of the poorer-quality deposits as well as resources buried under thick overburden layers which may become more attractive under future market conditions.

Scope of Deposits Inventoried

In order to produce an objective analysis, we have inventoried all deposits meeting the threshold criteria—except those that lie within the Yakama Indian Reservation—without consideration of environmental impacts or land-use conflicts that may be involved in permitting or extracting these resources. For example, the Yakima River flood plain has historically been a major gravel resource, and numerous mines still operate beside the river. However, future mining operations in flood plains will likely have more difficulty in obtaining permits because alluvial mining can adversely impact aquatic and riparian habitat (Norman and others, 1998). Nevertheless, all Yakima River sand and gravel deposits meeting the threshold criteria are depicted in this report. Therefore, this inventory must be used with maps of environmentally sensitive areas and land-use status in order to obtain a complete picture of available aggregate within the quadrangle.

Previous Aggregate Reserve Studies

Prior to this study, the only public assessments of aggregate reserves in the Toppenish 1:100,000 quadrangle were a study by Campbell (1995) performed for Yakima County, a preliminary assessment of mine reserves by the Yakima County Planning Department in 1999 (unpub. data), and a statewide reconnaissance investigation of aggregate reserves (Lingley and Manson, 1992). Additionally, information on two previously proposed gravel pits is contained in their environmental impact statements (Hammett and Sziebert, 1979; Yakima County Planning Department, 1976).

GEOLOGY OF CONSTRUCTION AGGREGATES IN THE TOPPENISH QUADRANGLE

The following discussion of the geology of the Toppenish quadrangle emphasizes those units that are significant sources of aggregate. More detailed geologic descriptions of units being mined or considered a resource can be found in Appendix 6.

Sand and Gravel Geology

Three types of sand and gravel deposits are present in the Toppenish quadrangle:

1. Recent alluvial deposits.
2. Quaternary (Pleistocene) river terrace deposits.
3. Older (Miocene), commonly cemented, alluvial and volcaniclastic deposits generally mapped as sedimentary rock units (mainly the Ellensburg Formation, which includes sand and gravel deposited by the ancestral Columbia River).

Alluvial gravel deposits along the Yakima River (unit Qa) are composed mainly of basalt clasts derived locally from the Columbia River Basalt Group and clasts of other volcanic rocks such as andesite and dacite from the Cascade Range to the west (Campbell, 1983). Minor amounts (10–15%) of granitic, metamorphic, and sedimentary clasts are also present in the gravel deposits. WSDOT strength and durability testing of these gravels indicate that they meet the threshold criteria of this study and

should be considered significant resources. Alluvium along small sidestreams commonly contains high quantities of silt and clay and therefore is not considered a significant resource.

Campbell (1983) noted that two Pleistocene terraces (unit Qt) approximately 16 and 30 feet (5 and 10 m) above the present Yakima River flood plain occur roughly upstream of the town of Emerald (sec. 33, T10N R22E). These terraces consist of lithologies similar to those found on the modern Yakima River flood plain, although the cobbles tend to be slightly more weathered. WSDOT strength and durability testing of the lower terrace gravels indicates that they meet the threshold criteria of this study and should be considered significant resources (Plate 1). Currently, upper terrace gravels have not been tested sufficiently to determine if they should also be considered significant resources.

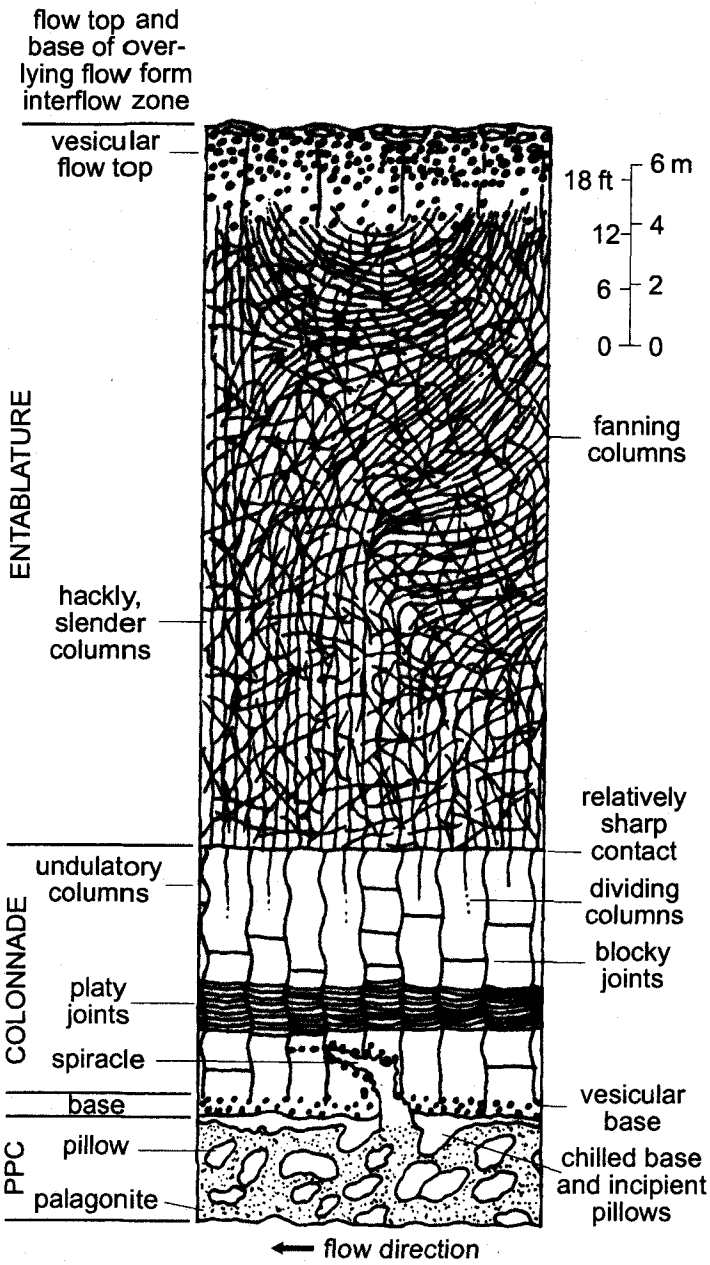

Figure 2. Cross section of a typical flow in the Columbia River Basalt Group showing, in idealized form, jointing patterns and other structures. PPC, pillow-palagonite (hyaloclastite) complex, which is present at the base of flows that entered water. *(Modified from Swanson, 1967, and Swanson and Wright, 1978.)*

Poorly consolidated Middle and Upper Miocene deposits of the Ellensburg Formation (units Mc and Mcg) contain sand and gravel. Unit Mc, the finer-grained facies of the Ellensburg Formation (Schuster, 1994), is the most prevalent and overlies and is interbedded with the Columbia River Basalt Group (Smith, 1988). This unit is composed mainly of volcaniclastic conglomerates, sandstones, mudstones, and lahar deposits derived from the Cascade Range and whose deposition is unrelated to the modern Yakima River drainage (Smith, 1988). Gravel clasts within unit Mc tend to be weathered and are often surrounded by large volumes of fine-grained material (clays, silts, and sands). Therefore, unit Mc is not considered a significant resource.

The ancestral Columbia River gravels of the Ellensburg Formation (unit Mcg), which have also been called the conglomerate of Snipes Mountain (Bentley and others, 1980) and the Hood River conglomerate (Warren, 1939), interfinger with the other facies of the Ellensburg Formation. These gravels were deposited by the Columbia River and contain considerably different lithologies than both the Yakima River deposits and other Ellensburg Formation deposits. The ancestral Columbia River gravels crop out in a band running northeast–southwest across the eastern half of the quadrangle. The largest deposits are located on the Rattlesnake Hills, Snipes Mountain, and the Horse Heaven Hills. The well-rounded clasts within unit Mcg are dominated by quartzite, with lesser amounts of andesitic, granitic, and gneissic clasts (Schuster, 1994). WSDOT strength and durability testing of these gravels indicate that they meet the threshold criteria of this study and should be considered significant resources.

Bedrock Geology

Bedrock in the Toppenish quadrangle can be assigned to one of two geologic groups or formations. These are the volcanics of the Simcoe Mountains and the Columbia River Basalt Group. The discussion below emphasizes the Columbia River Basalt Group, which consistently meets the threshold criteria of this study and is considered a significant resource.

The youngest bedrock units in the quadrangle are the Simcoe Mountains volcanics (unit QTs and its subdivisions in Walsh, 1986; unit QRv and its subdivisions in digital data available through WADNR), which cover much of the southwestern corner of the quadrangle. This group of volcanic units includes basalt flows, dacite domes, and rhyolite flows and domes as well as debris flows, breccia, and tuff. The basalt flows are amygdaloidal, are commonly less than 40 feet (12 m) thick, and contain porphyritic plagioclase phenocrysts and a moderate amount of volcanic glass (Timothy J. Walsh, Wash. Div. of Geology and Earth Resources, oral commun., 2001; Sheppard, 1967). No strength and durability testing has been performed on the basalt flows within this unit to determine if they would pass the criteria of this inventory. Due to the uncertain quality and relatively thin nature of the basalt flows, as well as the abundance of high-quality Columbia River Basalt Group basalt flows nearby, this unit is not considered a significant bedrock resource.

Most of the bedrock within the Toppenish quadrangle consists of Columbia River Basalt Group flood basalts (unit Mv and its subdivisions in Schuster, 1994; units Ts, Tw, Tg and their subdivisions in Walsh, 1986). Numerous flows make up the Columbia River Basalt Group, each of which contains thick zones suitable for use as crushed aggregate (Weberling and others, 2001). The components of a typical Columbia River Basalt Group flow are shown in Figure 2. The entablature and colonnade (Fig. 2) provide high-quality crushed aggregate, quarry stone, riprap,

Table 2. Most WADNR-permitted sand and gravel pits in the Toppenish quadrangle. 'Setups' refers to the number of projects or sessions of active mining that are expected during the life of the mine. All information was obtained from mine operators

Mine Name	Operator	Location	Reserves (million tons)	Annual production (million tons)	Estimated life (years)	(setups)
O. L. Luther pit	O. L. Luther Co., Inc.	2 mi southeast of Granger	3.2	0.12		
Walker pit	Columbia Ready-Mix	0.5 mi southwest of Zillah	1	0		
Heffron pit	Columbia Ready-Mix	1.5 mi southwest of Sunnyside	0.08	0		
Van Wyk site (proposed)	pending	4.5 mi northeast of Zillah	8	0		
George pit (within Yakama Indian Reservation)	Yakima County Public Works	4 mi northwest of Wapato	1	0.06	15	
Progressive pit (within Yakama Indian Reservation)	Yakima County Public Works	2 mi south of Wapato	0.48		15	
McDonald pit [1] (within Yakama Indian Reservation)	Yakima County Public Works	3 mi southwest of Wapato	0.24		10	1 or 2
Branch pit (within Yakama Indian Reservation)	Yakima County Public Works	2.3 mi southwest of Wapato	0.16		10	1
McKay pit (within Yakama Indian Reservation)	Yakima County Public Works	6 mi southwest of Wapato	0.008	minimal		

[1] The McDonald pit is looking to expand

and decorative 'shale' rock. In these zones, the rock usually is very hard and durable, has undergone little weathering, and contains many fractures and joints that developed during the cooling process or deformation. Erosion has locally removed vesicular tops, and the pillow-palagonite bases occur only if the lava cooled under the waters of a Miocene lake. The cumulative basalt flow sequence exceeds several thousand feet in thickness. The basalt of the Columbia River Basalt Group has been designated as a bedrock resource wherever it is mapped by Walsh (1986) and Schuster (1994) within the area inventoried in the Toppenish quadrangle (Plate 1). Fine-grained Ellensburg Formation deposits (unit Mc), which were discussed in the preceding section and are not considered a resource, form interbeds that commonly separate individual basalt flows of the Columbia River Basalt Group. These interbeds are usually 5 to 50 feet (1.5–15 m) thick. When the interbed thickness exceeds 30 to 40 feet (9–12 m), mining the underlying basalt may be prohibitively expensive.

Table 3. WADNR-permitted bedrock quarries in the Toppenish quadrangle. 'Setups' refers to the number of projects or sessions of active mining that are expected during the life of the mine. All information was obtained from the mine operators

Mine Name	Operator	Location	Reserves (million tons)	Annual production (million tons)	Estimated Life (years)	(setups)
Black Star quarry	Jeff Gamache Farms, Inc.	7 mi north of Zillah	0.25	0.01		
QS-E-206 [1]	WSDOT	8 mi northeast of Zillah	1.2	0	15	
Liberty quarry [2]	Yakima County Public Works	5 mi northeast of Zillah	1	0		2 or 3
Holloway quarry	Yakima County Public Works	1.5 mi northwest of Bluelight	0.15		10	
Ingram quarry	Klickitat County Road Department	7 mi west of Bluelight	minor	minimal		

[1] QS-E-206 is to be used again in 5 years

[2] The Liberty quarry may expand to the east

Table 4. Summary of aggregate quality data. Asphalt-treated base specifications: Los Angeles (LA) Abrasion ≤30%; Degradation ≥15; Sand Equivalent ≥30%. Favorable samples have Stabilometer R Value >70. CRBG, Columbia River Basalt Group; n/a, not applicable

	Geologic unit	No. of mines (permitted)	Rock type	LA Abrasion		Degradation		Sand Equivalent		Stabilometer R Value	
				Range	Mean (n)	Range	Mean (n)	Range	Mean (n)	Range	Mean (n)
SAND AND GRAVEL	Qa	58 (17)	gravel	8.5–20.8	15.1 (46)	63–90	77 (23)	9–94	60 (38)	65–86	77 (24)
	Qt	18 (3)	gravel	10.5–19.3	14.6 (12)	67–85	76 (8)	33–90	65 (10)	79–81	80 (4)
	Mcg	11 (4)	gravel	14.7–25	19.3 (10)	38–82	62 (8)	17–59	44 (8)	60–77	69 (4)
BEDROCK	all CRBG	22 (7)	basalt	10.9–27	17.6 (14)	28–84	62 (10)	17	17 (1)	n/a	n/a

AGGREGATE MINING AND SIGNIFICANT DEPOSITS

In the following text, the use of the terms 'active' and 'terminated' refers only to mines that have WADNR permit numbers. Small pits and quarries that have not been permitted are referred to as borrow pits.

Aggregate has been mined at more than 58 sites within the area inventoried in the Toppenish quadrangle (Appendix 3). Within this area there are 3 permitted gravel pits and 5 permitted rock quarries currently operating (Tables 2 and 3). Of these 8 permitted mines, half are operated by government agencies (WSDOT, Yakima County Public Works, or the Klickitat County Road Department).

Most of the larger terminated gravel pits within the quadrangle were used during the initial construction of Interstate 82. Additionally, five terminated mines produced silt and sand from glacial flood deposits (unit Qfs in Schuster, 1994) located on the north flank of Snipes Mountain. Currently, there are no active pits within this unit, which is not considered a significant resource based on the criteria of this inventory.

Sand and Gravel Resources

Gravel mining within the Toppenish quadrangle has produced high-quality aggregate from units deposited by both the Yakima River (parts of units Qa and Qt) and the ancestral Columbia River (unit Mcg). The Yakima River deposits are located adjacent to that river, while the ancestral Columbia River deposits are exposed on ridges within the quadrangle (Plate 1).

YAKIMA RIVER ALLUVIUM AND TERRACE DEPOSITS

Historical gravel mining combined with WSDOT strength and durability test data show that alluvium and terrace deposits along the Yakima River (units Qa and Qt) roughly northwest of the town of Emerald are consistently of high quality (Table 4). Most of the gravel pits located within the flood plain were mined during the initial construction of Interstate 82 in the late 1970s. Currently, both the Yakima River alluvium and terrace gravels are mined in the Toppenish quadrangle.

The many small gravel polygons shown on Plate 1 along the northeastern boundary of the Yakama Indian Reservation are all within Yakima River alluvium and terrace deposits. The gravel polygons do not extend the length of the Yakima River, but end south of Snipes Mountain where thick glacial flood deposits of sand and silt overlie older gravels. The thickest gravel I could justify contouring in this valley is 75 feet (23 m), with a thickness of up to 101 feet (30 m) identified in a water well near the town of Buena (sec. 21, T11N R20E). Within the gravel deposits in the area inventoried, there are one active mine (WADNR permit no. 12192), 9 terminated mines (WADNR permit nos. 10057, 10146, 10435, 10728, 11442, 11458, 11622, 11623, and 11976), and 11 borrow pits, covering a total of more than 205 acres. Additionally, there are five active mines (WADNR permit nos. 10630, 10632, 10634, 10729, and 10730) and 4 terminated mines (WADNR permit nos. 10350, 10814, 11638, and 12229) that are or were permitted by the WADNR within the boundary of the Yakama Indian Reservation, covering a total of more than 162 acres (not shown on Plate 1).

ANCESTRAL COLUMBIA RIVER GRAVEL

Recently, interest in upland gravel sites has increased. The highest-quality upland gravel sites are located in the ancestral Columbia River gravel (unit Mcg). The largest mine currently producing from this unit is the O. L. Luther pit on Snipes Mountain (sec. 25, T10N R21E; Fig. 3). Additionally, the proposed Van Wyk site would include 96 acres of this unit on the Rattlesnake Hills (sec. 9, T11N R21E). Although Table 4 reveals that the av-

Figure 3. O. L. Luther pit on Snipes Mountain. This operation mines and processes ancestral Columbia River gravels (unit Mcg). View is to the west along the crest of the hill.

erage strength and durability of the sand and gravel within this unit are slightly lower than that of the gravel deposited by the Yakima River, the aggregate produced from this unit still meets the criteria of this inventory. However, this unit locally has some characteristics undesirable for aggregate production: it can be well cemented, occasionally has intense staining on the clasts, and can have more fine sand, silt, and clay than is desirable. An advantage of mining deposits of this unit is that they lie in undeveloped areas, commonly within the boundaries of a single ranch. While the distance from market will lead to higher transportation costs, these sites are likely easier to permit than a comparable volume of resources along the Yakima River.

This unit was not contoured due to a lack of sufficient subsurface data. The water wells that were drilled through this unit identified thicknesses of up to 245 feet (75 m) on Snipes Mountain (sec. 30, T10N R22E) and 192 feet (58 m) on the Rattlesnake Hills (sec. 17, T11N R21E). Within unit Mcg in the area inventoried, there are two active mines (WADNR permit nos. 12359 and 12907), two terminated mines (WADNR permit nos. 10056 and 11033), one proposed mine, and 5 borrow pits, covering a total of more than 275 acres.

Bedrock Resources

Bedrock quarrying within the area inventoried in the Toppenish quadrangle has produced high-quality aggregate solely from the basalt flows of the Columbia River Basalt Group. This unit is the only significant bedrock resource shown on Plate 1.

COLUMBIA RIVER BASALT GROUP

The Columbia River Basalt Group is composed of about 140 separate flows. Analyses show that all flows tested contain high-quality rock (Weberling and others, 2001; Table 4; Appendices 4 and 5). The entablature (Fig. 2) is generally the best rock for making crushed aggregate because columns within the entablature are commonly less than 1 foot in diameter and fractured. Two problems have been encountered when mining the colonnade (Fig. 2) to produce crushed aggregate. First, some of the columns are too large (>2 feet) to fit in a typical crusher. Second, columns with platy joints (often referred to as 'shale') can be excessively weathered where joints are closely spaced. Rock from vesicular tops and pillow-palagonite bases is generally discarded in quarry operations due to weathering and large clay contents. Fortunately, the vesicular tops and pillow-palagonite bases constitute less than 20 percent of each flow, and the vesicular tops are locally eroded away and pillow-palagonite bases occur only if the lava cooled underwater.

Basalt flows of the Columbia River Basalt Group cover approximately one-quarter of the quadrangle, and represent a very large aggregate resource. The WSDOT, Yakima County Public Works, and the Klickitat County Road Department operate almost all of the bedrock quarries in the area inventoried in the Toppenish quadrangle. The only commercial quarry is the Black Star quarry (WADNR permit no. 12851) located on the north flank of the Rattlesnake Hills (sec. 29, T12N R21E) (Plate 1). The aggregate produced by this quarry is used on properties owned by the operator and by consumers in the Moxee Valley, north of the Toppenish quadrangle. Within the Columbia River Basalt Group in the area inventoried, there are five active mines (WADNR permit nos. 10736, 10780, 10801, 11152, and 12851), one terminated mine (WADNR permit no. 10802), and 9 borrow pits, covering a total of more than 30 acres. Additionally, there is one terminated mine that was permitted by the WADNR (WADNR permit no. 12477) within the boundary of the Yakama Indian Reservation that covered 5 acres (not shown on Plate 1).

VOLUME OF AGGREGATE

The volume of aggregate currently available in permitted mines was tabulated using data supplied by mine operators in March 2001 (Tables 2 and 3). Reserves in tons were obtained by multiplying cubic yards by conversion factors of 1.6 tons per cubic yard for sand and gravel and 2.4 tons per cubic yard for basalt. Depletion was estimated either by field observation or by multiplying the average annual production rate by the number of years of past production. In many cases the operator confirmed the percent depletion.

Currently permitted gravel pits within the area inventoried contain about 4.3 million tons (2.7 million cubic yards) of resource in reserve. Additionally, there are 5 gravel pits permitted by WADNR within the Yakama Indian Reservation that contain about 1.9 million tons (1.2 million cubic yards) of resource in reserve. Currently permitted bedrock quarries have about 2.6 million tons (1 million cubic yards) of resource in reserve. Since most of the gravel pits and quarries are government-owned and are used for road construction and maintenance, which typically involves mining for a specific project followed by 10 to 20 years of inactivity, it is not realistic to claim annual production rates.

SUMMARY

The area inventoried within the Toppenish 1:100,000 quadrangle—exclusive of the Yakama Indian Reservation—contains a moderate volume of high-quality gravel and abundant high-quality bedrock (Table 4; Plate 1). The significant gravel deposits are Yakima River alluvium, Yakima River terrace deposits, and ancestral Columbia River gravels. The only significant bedrock unit is the Columbia River Basalt Group.

Strength and durability testing indicate that the Yakima River alluvium and lower terrace deposits contain high-quality sand and gravel. Most of the pits within the flood plain of the Yakima River operated during the initial construction of Interstate 82 during the late 1970s. South of Snipes Mountain, alluvium along the Yakima River is not a resource because it is composed mainly of silt and sand reworked from glacial flood deposits.

Deposits of ancestral Columbia River gravels are a potentially significant upland sand and gravel resource. This unit is currently being mined on Snipes Mountain, and a mine is proposed within this unit on the Rattlesnake Hills. Strength and durability testing from this unit indicate that, on average, it is slightly lower in quality than the Yakima River alluvial and terrace deposits, but still meets the criteria of this study.

Outcrops of the Columbia River Basalt Group cover approximately one-quarter of the map area, and each flow contains high-quality bedrock. All bedrock quarries produce aggregate from the basalt flows of the Columbia River Basalt Group.

Half of the pits and quarries within the area inventoried are or were operated by the WSDOT, Yakima County Public Works, or the Klickitat County Road Department. Operation of these mines is typically characterized by production for a particular project and then an extended idle period until aggregate for the next local project is needed. Currently permitted gravel pits within the area inventoried contain about 4.3 million tons (2.7 million cubic yards) of resource in reserve. Currently permitted bedrock quarries within the area inventoried have about 2.6 million tons (1 million cubic yards) of resource in reserve.

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REFERENCES CITED

American Geological Institute, compiler, 1997, Dictionary of mining, mineral, and related terms; 2nd ed.: American Geological Institute, 646 p.

Bentley, R. D.; Anderson, J. L.; Campbell, N. P.; Swanson, D. A., 1980, Stratigraphy and structure of the Yakima Indian Reservation, with emphasis on the Columbia River Basalt Group: U.S. Geological Survey Open-File Report 80-200, 85 p., 1 plate.

Bentley, R. D.; Campbell, N. P.; Powell, J. E., 1993, Geologic maps of part of the Yakima fold belt, northeastern Yakima County, Washington: Washington Division of Geology and Earth Resources Open File Report 93-3, 13 p., 5 plates.

Campbell, N. P., 1983, Correlation of late Cenozoic gravel deposits along the Yakima River drainage from Ellensburg to Richland, Washington: Northwest Science, v. 57, no. 3, p. 179-193.

Campbell, N. P., 1995, Yakima County mineral resources map: Newell P. Campbell [under contract to] Yakima County Commissioners, 16 p., 1 plate, 1 CD.

Campbell, N. P.; Gusey, D. L., 1992, Geology of the Naches Ranger District, Wenatchee National Forest, Kittitas and Yakima Counties, Washington: Washington Division of Geology and Earth Resources Open File Report 92-3, 12 p., 2 plates.

Hammett, Bill; Sziebert, Steve, 1979, Draft environmental impact statement on a proposal to surface mine, process aggregates and produce asphalt mixtures by Northwest Paving and Rock Products: Yakima County Planning Department, 32 p.

Jackson, J. A., editor, 1997, Glossary of geology; 4th ed.: American Geological Institute, 769 p.

Kroft, D. J., 1972, Sand and gravel deposits in western King County, Washington: University of Washington Master of Science thesis, 62 p.

Lingley, W. S., Jr.; Jazdzewski, S. P., 1994, Aspects of growth management planning for mineral resource lands: Washington Geology, v. 22, no. 2, p. 36-45.

Lingley, W. S., Jr.; Manson, C. J., 1992, Directory of Washington mining operations, 1992: Washington Division of Geology and Earth Resources Information Circular 87, 76 p.

Loen, J. S.; Lingley, W. S., Jr.; Anderson, Garth; Lapen, T. J., 2001, Reconnaissance investigation of sand, gravel, and quarried bedrock resources in the Bellingham 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Information Circular 91, 45 p., 1 plate.

McKay, D. T., Jr.; Norman, D. K.; Shawver, M. A.; Teissere, R. F., 2001, Directory of Washington mines, 2001: Washington Division of Geology and Earth Resources Information Circular 94, 107 p.

Norman, D. K.; Cederholm, C. J.; Lingley, W. S., Jr., 1998, Flood plains, salmon habitat, and sand and gravel mining: Washington Geology, v. 26, no. 2/3, p. 3-20.

Norman, D. K.; Lingley, W. S., Jr., 1992, Reclamation of sand and gravel mines: Washington Geology, v. 20, no. 3, p. 20-31.

Schuster, J. E., compiler, 1994, Geologic map of the east half of the Toppenish 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-10, 15 p., 1 plate.

Schuster, J. E.; Gulick, C. W.; Reidel, S. P.; Fecht, K. R.; Zurenko, Stephanie, 1997, Geologic map of Washington—Southeast quadrant: Washington Division of Geology and Earth Resources Geologic Map GM-45, 2 sheets, scale 1:250,000, with 20 p. text.

Sheppard, R. A., 1967, Geology of the Simcoe Mountains volcanic area, Washington: Washington Division of Mines and Geology Geologic Map GM-3, 1 sheet, scale 1:125,000.

Smith, G. A., 1988, Neogene synvolcanic and syntectonic sedimentation in central Washington: Geological Society of America Bulletin, v. 100, no. 9, p. 1479-1492.

Swanson, D. A., 1967, Yakima Basalt of the Tieton River area, south-central Washington: Geological Society of America Bulletin, v. 78, no. 9, p. 1077-1109.

Swanson, D. A.; Wright, T. L., 1978, Bedrock geology of the northern Columbia Plateau and adjacent areas. *In* Baker, V. R.; Nummedal, Dag, editors, The channeled scablands—A guide to the geomorphology of the Columbia Basin, Washington: U.S. National Aeronautics and Space Administration, p. 37-57.

U.S. Geological Survey, 1976, Principles of the mineral resource classification system of the U.S. Bureau of Mines and U.S. Geological Survey: U.S. Geological Survey Bulletin 1450-A, 5 p.

Walsh, T. J., compiler, 1986, Geologic map of the west half of the Toppenish quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 86-3, 1 sheet, scale 1:100,000, with 7 p. text.

Warren, C. R., 1939, The Hood River conglomerate in southern central Washington: Yale University Doctor of Philosophy thesis, 282 p., 2 plates.

Washington Office of Financial Management, 2000, 1999 data book: Washington Office of Financial Management [*accessed July 27, 2001 at* http://www.ofm.wa.gov/databook/index.htm].

Washington State Department of Transportation, 1999, Standard specifications for road, bridge, and municipal construction, 2000—English units: Washington State Department of Transportation, 1 v.

Weberling, K. D.; Dunn, A. B.; Powell, J. E., 2001, Reconnaissance investigation of sand, gravel, and quarried bedrock resources in the Yakima 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Information Circular 92, 34 p., 1 plate.

Yakima County Planning Department, 1976, Final environmental impact statement on a proposal to mine and process aggregate along the Yakima River by Valley Ready Mix Concrete Company: Yakima County Planning Department, 1 v.

Yates, Richard; Yates, Charity, editors, 2000, Washington State yearbook—A guide to government in the Evergreen State: Public Sector Information, Inc. [Eugene, Ore.], 312 p. ■

Appendix 1. Glossary of mining-related terms

The terms defined below are modified from Jackson (1997), American Geological Institute (1997), and Washington State Department of Transportation (1999).

Aggregate, construction aggregate – A mixture of sand and gravel or sand and crushed rock used in portland cement concrete, asphaltic concrete, mortar, plaster, or graded fill. Gravel and crushed stone that are in grain-to-grain contact in the aggregate are strong enough to support the weight of roads, buildings, or other infrastructure. The sand keeps the coarse aggregate in grain-to-grain contact by limiting the ability of the larger particles to shift laterally.

Alluvium – Unconsolidated boulders, cobbles, pebbles, sand, silt, and (or) clay deposited relatively recently from a stream or river and sorted by the current velocity.

Andesite – A dark-colored volcanic rock. When it is porphyritic, it contains phenocrysts of plagioclase and one or more mafic minerals, commonly biotite, hornblende, or pyroxene. The fine-grained groundmass consists of mineralogy similar to the phenocrysts with the inclusion of quartz. This rock is usually deposited as lava flows or shallowly intruded sills.

Asphalt – Heavy oil (tar) produced from oil wells that is used to make asphalt roads.

Asphaltic concrete – Concrete made of asphalt and crushed aggregate.

Asphalt-treated base – A specific construction aggregate used to prepare the base of an asphaltic concrete road.

Basalt – A black volcanic rock that is finely crystalline. Basalt is the most common rock in the earth's crust and forms the floor of almost all of the oceans. In Washington, basalt covers the entire Columbia Basin and much of the Cascade Range and high Olympic Mountains. Basalt that erupted on land (for example, the Columbia River Basalt Group) is hard and makes excellent crushed aggregate, whereas basalt that erupted on the sea floor is commonly weak (for example, much of the Crescent Formation basalts).

Batching, batch plant – A concrete manufacturing process or plant that mixes aggregate and portland cement or aggregate and asphaltic cement to manufacture concrete. Basically, a batch plant functions like a gigantic eggbeater and bowl.

Blend(ing) sand – Sand that is combined with coarse aggregate in order to achieve the appropriate grading for an end product. The sand must be clean and hard with a Sand Equivalent of at least 27.

Boulder – A rock fragment larger than 10 inches (256 mm) in diameter that has been somewhat rounded by abrasion in the course of transport.

Cement – (1) baked limestone dust and water that glues aggregate particles together to form concrete; (2) minerals, usually precipitated from hydrothermal fluids, that naturally glue the grains of a rock together creating a hard sediment or harder rock.

Clast – A rock fragment of any size, initially broken off bedrock by the force of water freezing in cracks or by impact from another rock. Clasts become smaller as they roll off a hillside and (or) down a stream.

Clay – Sediment composed of particles that are plastic, consolidated when dry, and are smaller than 0.000079 inch (0.002 mm) in diameter. Clay will not support weight (it behaves as a paste) because it is composed primarily of platy clay minerals. Clay is unsuitable for use in construction aggregates, and even small amounts must be washed off coarser aggregate.

Coarse aggregate – Gravel or crushed stone that is larger than ¼ inch (4.76 mm) in diameter. All clasts in coarse aggregate are larger than pea gravel (pebbles, cobbles, and boulders).

Cobble – A rock fragment larger than a pebble, but smaller than a boulder, having a diameter in the range of 2.5 to 10 inches (64–256 mm) that has been somewhat rounded by abrasion in the course of transport.

Construction aggregate – *see Aggregate*

Cross-bed – A bed inclined at an angle to the main plane of stratification. Usually indicates deposition in a delta.

Crushed stone – Bedrock, cobbles, or boulders that have been crushed with a mechanical crusher to gravel-size rock fragments with at least three freshly broken faces. Crushed stone makes an excellent base course for road construction because the rock fragments tend to form an interlocking matrix. It is the only material suitable for asphaltic concrete because asphalt only sticks to freshly broken surfaces.

Degradation Test – A laboratory test designed to test the durability of rock under wet conditions. The degradation number indicates the percentage of rock remaining intact after tumbling with steel balls in a wet chamber. Large numbers indicate favorable rock.

Fine aggregate – Sand and gravel or crushed stone that will pass through a ¼-inch (4.76 mm) sieve, but will be trapped in a 200 mesh (ultrafine) sieve.

Granite – A light gray or pink, coarsely crystalline (typically ⅛-inch crystals) intrusive igneous rock composed of the hard minerals quartz and feldspar with minor amounts of black mica and black iron-magnesium-rich minerals. Granite and closely related rocks can make excellent construction aggregate.

Gravel – An unconsolidated natural accumulation of typically rounded rock fragments resulting from erosion and consisting predominantly of particles larger than sand, such as boulders, cobbles, and pebbles, in any combination.

Intrusive rock – Igneous rock that was emplaced below the earth's surface as a magma that cooled very slowly to form a coarsely crystalline rock.

Kame – A hummock, terrace, or short ridge composed of stratified sand and gravel deposited at the margin of a glacier as a delta or fan. In Washington, the term is generally applied to landforms created by deposition in the low area between the margin of a glacial ice sheet and the confining hills. After the ice has melted away, a high-quality sand and gravel deposit frequently remains.

Limestone – A rock composed of the mineral calcite. Normally, these are rocks deposited in the ocean from materials that are by-products or remnants of shells. Limestone is an important source of construction aggregate in much of the nation.

Los Angeles Abrasion Test – A laboratory test to assess the strength of aggregate under dry conditions. A 100-pound sample is placed in a tumbler resembling a washing machine with a tungsten carbide ball weighing about five pounds. The tumbler is revolved 500 times and then the sample is passed through a U.S. Standard No. 4 sieve. The larger the percent of the sample that passes through the sieve, the weaker the sample. The Los Angeles Abrasion number indicates the percent of the sample that has passed through the sieve.

Outwash – Sand, gravel, and coarser round rock deposited from streams and rivers issuing from alpine or continental (ice-age) glaciers. Proximal outwash was deposited relatively close to the snout of a glacier and is poorly sorted and has a large fraction of cobbles and boulders. Distal outwash was deposited miles from the edge of the glacier and is relatively well sorted and dominated by sand.

Overburden – The material that overlies an aggregate or mineral resource and must be removed before mining the underlying material.

Pebble – A stone, usually rounded by water transport, 1/16 to 2.5 inches (4–64 mm) in diameter—the size of a small pea to that of a tennis ball.

Pebble imbrication – A sedimentary fabric characterized by disk-shaped or elongate pebbles dipping in a preferred direction at an angle to the bedding. It is commonly displayed by pebbles on a stream bed, where flowing water tips the pebbles so that their flat surfaces dip upstream.

Pit – This term is restricted herein to sand and gravel mines, regardless of size. A borrow pit is a small (<3 acre) mine that periodically produces unprocessed gravel and other sediment, generally for use as fill.

Pit run – Unprocessed material taken directly from the undisturbed geologic formation.

Portland cement – Cement made by heating limestone to about 2,700°F (calcining) to form lime. This lime is mixed with small amounts of water and dries to a hard adhesive that can glue aggregate together to form portland cement concrete. Portland cement by itself does not have great compressive strength, and it is costly because of the heat used in its manufacture. For these reasons, aggregate is added to form concrete. The gravel in portland cement concrete has great compressive strength and adds inexpensive filler to the mix.

Quarry – Used exclusively herein for mines that produce aggregate by blasting bedrock.

Round rock, round rock aggregate – Coarse aggregate that has been rounded by the process of stream or glacial transport. It generally has greater value than crushed aggregate because it is less expensive to mine, easy to mix in batch plants, and easy to finish to a smooth surface with trowels or other tools when used in concrete. Asphalt does not adhere effectively to round rock aggregate.

Sand Equivalent Test – A laboratory test that measures the cleanness of a sample in terms of the relative proportion of fine-grained dust or clay. High numbers indicate less dust and (or) clay, whereas low numbers indicate greater plasticity. Favorable samples have values greater than 30.

Silt – Sediment composed of particles that are unconsolidated or poorly consolidated when dry and will pass a U.S. Standard No. 200 sieve (0.0025 in. or 0.074 mm) but are larger than clay (0.000079 in. or 0.002 mm). Silt has little or no cohesive strength because it contains a small proportion of clay minerals. Abundant silt can render a gravel deposit unsuitable for use in construction aggregates.

Specific gravity – The specific gravity of a sample is the weight of the substance relative to the weight of an equal volume of water. The specific gravities of water, weak aggregate, granite, limestone, and basalt are 1.0, 1.95, 2.65, 2.72, and 3.2 grams per cubic centimeter, respectively.

Stabilometer R Value Test – A laboratory test that measures horizontal deformation when a vertical weight is applied. High numbers indicate stronger materials. Favorable samples have values greater than 70.

Till – Very poorly sorted clay, silt, sand, gravel, cobbles, and boulders deposited directly from glacial ice in the form of a moraine or a compact blanket of sediment under the ice. Generally, till is unsuitable for construction aggregate.

Appendix 2. Methods

INVENTORY PHILOSOPHY

Two end-member philosophies for resource inventory have been employed in Washington: (1) strictly factual reporting showing only those sand, gravel, and bedrock resources that have been proven to exist because they are part of active mines, and (2) a speculative approach that reports all of the potential aggregate deposits that might exist, as determined from surficial geologic or soils mapping. Both approaches have shortcomings. The first philosophy results in underestimation of available aggregate in any given area by ignoring high-quality deposits that have not been mined. The second philosophy results in overestimation of the resource because this method cannot adequately account for the heterogeneous nature of aggregate-bearing geologic units. In this study, we attempt to achieve a balance between these two philosophies using a method developed by William S. Lingley, Jr. (Loen and others, 2001) that includes the geologic and engineering criteria described below.

The accuracy of any assessment of undiscovered gravel or bedrock resources, whether performed as a proprietary exploration project or as a governmental or academic research study, is largely controlled by the quantity and quality of available subsurface data. As a general rule, subsurface information is not readily available for undeveloped deposits. Consequently, mineral economists categorize resources based on degree of certainty that any given deposit actually exists, mainly as determined from subsurface and other data.

The most commonly used categories are identified and undiscovered reserves, which are further subdivided as shown on Table 5. In order to demonstrate that an identified (or commercially viable) resource exists, the geology of the deposit must be very well known and (or) the deposit must have been defined by closely spaced exploratory drilling. Such costly work is beyond the scope of this study. Conversely, studies that rely solely on surficial information in order to delineate speculative undiscovered reserves are of little value to industry and have led to poor land-use decisions.

In this study, we mapped hypothetical (and some speculative) undiscovered reserves throughout the state as defined in Table 5 and shown on Plate 1. The most widely available source of subsurface geological data for mapping hypothetical reserves is water-well logs, but the accuracy of information on these logs is generally very poor or even misleading. To reduce the inherent uncertainty introduced by use of these logs, we depict hypothetical reserves only where the average of data from several water wells, together with other information such as landform analysis (geomorphology), geotechnical bores, outcrop descriptions, hydrologic data, and mine data allow reasonable extrapolation of surficial data into the subsurface. These hypothetical reserves are shown on Plate 1 with isopachs (thickness contours) for the gravel deposits. Elsewhere, speculative undiscovered reserves are mapped, but only where several data sets strongly suggest the presence of a deposit meeting the threshold criteria. These speculative reserves are shown on Plate 1 as simple polygons showing the extent of high-quality sand, gravel, or bedrock at the surface.

DEFINITION OF SIGNIFICANT RESOURCES

This study is limited to assessing significant aggregate resources. Significant aggregate resources are defined herein as those hard and durable sand and gravel or bedrock deposits that are likely to yield at least 10 million cubic yards of recoverable aggregate. Ten million cubic yards is the approximate volume necessary to maintain existing infrastructure in a 100,000-person market during the 20-year period mandated by the Growth Management Act, calculated as follows. Lingley and Manson (1992) estimated that the total annual per capita demand for sand, gravel, and crushed rock products in Washington is approximately 12 cubic yards. An informal rule of thumb used in industry and government is that about half of the demand for construction aggregates in any market will be used to repave roads, rebuild bridges, and remodel existing buildings, and half is used for new construction. Therefore, a hypothetical maintenance level of production for a 100,000-person market can be approximated as follows:

100,000 persons x 12 cubic yards/year x 20 years x 50%
= ~10 million cubic yards

Keep in mind that local governments are required to designate at least double this volume for every 100,000 people in order to comply with the Growth Management Act in accounting for new construction as well as maintenance (Lingley and Jazdzewski, 1994).

THRESHOLD CRITERIA USED IN PREPARING THIS INVENTORY

Inherent weaknesses in many common lithologies in the earth's crust, such as claystone or layered sedimentary and metamorphic rocks, coupled with unfavorable alteration and weathering processes render much of the outcropping bedrock and gravel unsuitable for construction aggregates. Furthermore, extraction or development costs may exceed expected return under current market conditions. In order to reduce the probability of includ-

Table 5. Classification of gravel and bedrock resources *(modified from U.S. Geological Survey, 1976)*

IDENTIFIED RESERVES			UNDISCOVERED RESERVES	
Measured	**Indicated**	**Inferred**	**Hypothetical**	**Speculative**
Deposit whose engineering properties, reserves in tons or cubic yards, and grain sizes are measured with a margin of error <20% (that is, a mine or a well-drilled prospect)	Deposit whose measurements, together with reasonable geologic projections, can be used to compute reserves in tons or cubic yards	Reasonable extension of indicated or measured deposit (generally <0.50 miles); thickness contours can be drawn with confidence	Undiscovered resources that may reasonably be expected to exist; applicable where landforms, water wells, proximal mines, or geophysical data justify such extension	Unexplored surficial deposit with no subsurface data
Active mine	Densely drilled deposit	Deposit with good subsurface control	Possible deposit defined only by poor subsurface control	Possible deposit; surficial data only

ing weak or insignificant resources, we have developed the following threshold criteria to determine which resources should be included in our inventory.

THICKNESS—Only those deposits that are known or likely to exceed 25 feet (~7.5 m) in the thickest portions are depicted. Thin gravel deposits rarely contain significant reserves. For example, a 20-foot-thick deposit covering 20 acres would yield only about 500,000 cubic yards of sand and gravel, and the value of the gravel might not exceed proceeds from selling the land in its undisturbed state for its real estate value. Moreover, current mining technology does not allow efficient excavation of thin veneers of sediment or bedrock. Thin deposits must spread over a large area in order to contain a significant volume of gravel, but relatively inexpensive excavating equipment (that is, front-end wheel loaders) cannot be used to carry pit run long distances within the mine. Finally, thinner deposits require greater surface disturbance per unit of aggregate produced, and damage to the plant/soil ecosystem increases in proportion to the surface area of mining. Therefore, permitting costs per unit of resource generally increase as a function of decreasing thickness.

SURFACE AREA AND DIMENSIONS OF THE DEPOSIT—Gravel deposits are seldom more than 100 feet thick and, consequently, the deposit must cover a large area to contain significant volumes of construction aggregate. The smallest geologic polygons inventoried as significant gravel resources cover at least 0.25 square miles (160 acres). The volume of a 50-foot-thick gravel unit of this size would be about 10 million cubic yards. Additionally, we map only those deposits that have minimum widths of 1,500 feet (450 m). As noted above, deposits with long, narrow map patterns are generally inefficient to operate. Although environmental issues are not considered herein, long narrow deposits are generally associated with rivers or streams where mining cannot take place owing to environmental considerations.

The surface area of each deposit was initially estimated using 1:100,000-scale geologic maps compiled by the Washington Division of Geology and Earth Resources (Schuster, 1994; Walsh, 1986) and other geologic maps (Bentley and others, 1980, 1993). The resulting polygons were modified where the portion of the deposit meeting the threshold criteria is less extensive than the mapped surface area of the deposit. Most of the geologic polygons depicted on this compilation contain existing mines or engineering tests of outcrops that prove at least some of the rock or sediment meets the threshold criteria. This approach, taken to expedite the inventory process, probably results in omission of a few significant resources.

OVERBURDEN—Only those deposits that have stripping ratios (ratios of overburden to gravel or overburden to rock) of less than 1 to 3 are included in this inventory. Overburden can cost from $0.35 to more than $1.50 per ton to remove. Typically, miners try to achieve a net profit of $1.00 per ton, so the overburden volume must be much less than the volume of underlying aggregate if the mine is to be commercially viable. The stripping ratio can be larger where supply restrictions, favorable topography, or other considerations allow the overburden to be removed profitably. The largest stripping ratio for a profitable mine in Washington was 1 to 2, or 0.50.

The practice of topsoil sales and (or) synthesis is one method of profitably disposing of thicker organic or clay-rich overburden, but as a general rule, most overburden must be saved for reclamation (Norman and others, 1998; Norman and Lingley, 1992). Historically, few gravel deposits with more than 10 feet (3 m) of overburden have been mined.

STRENGTH AND DURABILITY—In order to perform adequately as construction aggregate, gravel or bedrock must have high compressive strength and resist degradation when wet. Without these characteristics, the aggregate cannot support the weight of roads or buildings. Much of the vertical compressive strength, or load-bearing capacity, comes from grain-to-grain contact among individual pebbles that are effectively stacked up and prevented from shifting by cement and fine aggregate. Stronger aggregate commands a higher price, but weak rock is of no use. Minimum specifications for strength and durability of various rock products are published by the Washington State Department of Transportation in the Standard Specifications for Road, Bridge, and Municipal Construction, 2000 (Washington State Department of Transportation, 1999), a key reference book for the industry that is updated periodically. Specifications for gravel and bedrock are determined with laboratory tests including Los Angeles Abrasion, Degradation, Sand Equivalent, Specific Gravity, and Stabilometer tests (Appendix 1). Table 1 identifies some of the specifications required for certain uses of aggregate.

For this study, we inventory gravel and bedrock that meet WSDOT specifications for asphalt-treated base (Table 1). Asphalt-treated base is a compacted layer of aggregate treated with asphalt for stability and weatherproofing and placed directly on bulldozed earth or rock of the subgrade. The minimum acceptable test results are: Los Angeles Abrasion ≤30%, Degradation ≥15, Sand Equivalent ≥30%, specific gravity >1.95 grams per cubic centimeter, and weight percent passing a U.S. Standard No. 200 sieve <9%. If most of the deposit appears to meet these specifications, then we depict the entire deposit as meeting the strength and durability threshold criteria (Plate 1; Appendices 3 and 4).

OTHER CONSIDERATIONS—Typically, sand and gravel deposits should have a sand-to-gravel ratio of 40:60 and be free of weak or deleterious materials such as foliated metamorphic rock, poorly indurated clasts, clay, iron oxides, sulfides, glassy volcanic rock, and organic matter (Kroft, 1972; Washington State Department of Transportation, 1999).

SOURCES OF DATA

The locations of most mines in Washington are given in Lingley and Manson (1992); an update of this mining directory was recently published (McKay and others, 2001). Data for existing and terminated mines are archived in Washington Department of Natural Resources permit files, Washington State Department of Transportation pit site files, and U.S. Forest Service mine files. The thicknesses of mined units, for example, are taken from Washington Department of Natural Resources Form SM-2 or from other permit-related documentation such as Environmental Impact Statements. The surface extent of geologic units are depicted on Washington Division of Geology and Earth Resources 1:100,000-scale geologic maps (Schuster, 1994; Walsh, 1986). Hydrology studies are particularly useful in assessing the stratigraphy of gravel deposits. Such reports are included in various types of environmental documentation, wellhead protection studies, and water resource reports. Logs of geotechnical bores (for example, bores for foundation engineering studies) are frequently useful. Water-well logs and some logs of geotechnical borings are archived by the Washington Department of Ecology and the Washington State Department of Transportation, respectively.

Appendix 3. Mine Database

This database contains information about most small active and terminated borrow pits or quarries and large active, terminated, and proposed mines in the area inventoried in the Toppenish 1:100,000 quadrangle, as well as WADNR-permitted mines within the boundary of the Yakama Indian Reservation. All of the borrow pits, quarries, and mines in this database are plotted on Plate 1. The information contained herein is available digitally as part of the geographic information system (GIS) files for the Toppenish quadrangle. The columns that are not self-explanatory are defined as follows:

WADNR unique number – The Washington Department of Natural Resources (WADNR) unique number used by the geographic information system (GIS) to relate a feature on Plate 1 to a row in the database. The first four digits of the number identify the 7.5-minute quadrangle map in which the mine is located. The last four digits are a unique number in each 7.5-minute quadrangle.

WADNR data type code – The code number that indicates the type and size of the mine, as follows: 15 = small borrow pit or quarry (point); 16 = small terminated/depleted borrow pit or quarry (point); 18 = large active mine (polygon); 21 = large terminated/depleted mine (polygon); 22 = large proposed mine (polygon).

WADNR permit number – The five-digit number on Washington Department of Natural Resources Form SM-2, *Application for Surface Mining Reclamation Permit* (for a permitted mine).

WSDOT site number – The number assigned by the Washington State Department of Transportation (WSDOT) that links results of strength and durability testing to a particular mine. The number consists of a letter that identifies the county the site is in, followed by a sequentially assigned number.

¼ ¼ section, ¼ section, Section, Township, Range, Meridian – Legal description of the mine with reference to the Government Land Office grid. Townships and ranges are shown on Plate 1.

Product – The material being mined: rock, sand, or gravel.

Rock type – The type of rock that is being quarried at the site, if the mine is a quarry.

Geologic unit – The short label that identifies a particular unit on a geologic map. This field indicates the unit in which the mine is located as identified in Walsh (1986) and Schuster (1994), using the updated geologic unit labels consistent with Schuster (1994). Some units are described in Appendix 6.

Qualifier – Indicates either that the thickness shown in the adjacent column is exact because the mine penetrates all the way through the resource (blank) or that the actual resource thickness is greater than the thickness reported because the bottom of the resource was not identified (>).

Resource thickness (feet) – The thickness, in feet, of the sand, gravel, or bedrock that is being mined.

Million cubic yards – The estimated volume (in millions of cubic yards) of aggregate resource present within the permitted boundary of a mine as of March 2001.

Million tons – The reserve weight calculation based on reserve volume estimates. Conversion factors are 1.6 tons per cubic yard for sand and gravel, 2.4 tons per cubic yard for basalt and gabbro, and 2.2 tons per cubic yard for siliceous igneous rocks.

Acres – Typically the number of acres permitted on Washington Department of Natural Resources Form SM-2, *Application for Surface Mining Reclamation Permit*. For unpermitted mines, indicates the estimated area of the mine. Includes not only areas of aggregate extraction, but also all operations associated with the mine (stockpiling, crushing, screening, scales, etc.).

Percent depletion – The percentage by which the resource within the mine boundary has been depleted by mining, determined by communication with the mine operators or by field investigations.

Overburden thickness (feet) – The thickness, in feet, of soil, clay, or non-commercial aggregate that must be removed in order to reach the aggregate resource.

Stripping ratio – The overburden thickness divided by the resource thickness. A value of less than 0.33 (ratio of less than 1:3) is preferred.

Los Angeles Abrasion, Degradation, Specific Gravity, Sand Equivalent, and Stabilometer R Value tests – Results of laboratory tests, conducted mainly by the WSDOT, that reflect the quality of the deposit. See the glossary (Appendix 1) for explanation of tests.

Percent >2½ inches, Percent ¼–2½ inches, Percent <¼ inch, Percent <U.S. No. 200 sieve – Results of laboratory grain-size analysis of samples. Values are given in weight percent. The first three fields divide the whole sample, and the fourth field refers to the amount of silt and clay in the entire sample.

IDENTIFIER						LOCATION							RESERVES									QUALITY										
WADNR unique number	WADNR data type code	WADNR permit no.	WSDOT site number	Mine name	Permit holder	¼ ¼ section	¼ section	Section	Township (N)	Range	Meridian	County	Product	Rock type	Geologic unit	Qualifier	Resource thickness (feet)	Million cubic yards	Million tons	Acres	Percent depletion	Overburden thickness (feet)	Stripping ratio	Los Angeles Abrasion	Degradation	Specific Gravity	Sand Equivalent	Stabilometer R Value	Percent >2½ inches	Percent ¼–2½ inches	Percent <¼ inch	Percent <U.S. No. 200 sieve
24330001	15					SW	SW	16	6	15	E	Klickitat	rock	basalt	Mv_{wfs}																	
24380001	15	10780	Z-121	Ingram quarry	Klickitat County Road Department		SW	4	6	20	E	Klickitat	rock	basalt	Mv_{su}		50			5		0	0.00	12		2.67	17					
24390005	16		E-153			E	NW	20	7	21	E	Yakima	rock	basalt	Mv_{sp}																	
24390004	16		E-151			SW	SW	29	7	21	E	Yakima	rock	basalt	Mv_{sem}	>	30						0.00	18								
24390003	15	10801		Holloway quarry	Yakima County Public Works	NW	NE	31	7	21	E	Yakima	rock	basalt	Mv_{sem}		35	0.6	0.15	6.93		1	0.03									
24400006	16	10802		Breckenridge quarry	Yakima County Public Works	NW	SE	2	7	22	E	Yakima	rock	basalt	Mv_{sem}		40			3		1	0.02									
24400005	15					SW	SW	3	7	22	E	Yakima	rock	basalt	Mv_{su}																	
24400003	15					W	SW	7	7	22	E	Yakima	rock	basalt	Mv_{sp}																	
24400004	15					NW	SE	7	7	22	E	Yakima	rock	basalt	Mv_{su}																	
23400002	16		E-142			SE	SE	26	8	22	E	Yakima	gravel		Qafo	>	150					0	0.00	19					27	60	13	1
23400001	16		E-179			N	NW	35	8	22	E	Yakima	rock	basalt	Mv_{sp}	>	20					0	0.00	11		2.82						
22400019	16		E-18		Valley Ready-Mix Concrete, Inc.	SE	NW	6	9	22	E	Yakima	gravel		Qa									16	75	2.67	82		0	82	18	2
22400021	16	10146		Emerald pit	Valley Ready-Mix Concrete, Inc.	E	NE	6	9	22	E	Yakima	gravel		Qa		30			4		1	0.03									
22400020	16		E-3			SE	SE	6	9	22	E	Yakima	gravel		Qa																	
22400009	16		E-174			SE	SE	13	9	22	E	Yakima	sand		Qfs							1										
22340004	15	11683	E-195		WSDOT	NW	NW	24	10	16	E	Yakima	gravel		Qa		14			9.6		2	0.14	13		2.74	9		4	21	75	48
22370010	15	10630		McKay pit	Yakima County Public Works	NE	NW	7	10	19	E	Yakima	gravel		Qt	>	25	0.005	0.008	7	95	2	0.08									
22380015	21	11638	E-115		WSDOT	NE	NE	23	10	20	E	Yakima	gravel		Qa		20			13.7		1	0.05	20	75	2.7	41					
22380005	16	12477		Johnson talus quarry	North Central Construction	NE	SW	33	10	20	E	Yakima	rock	basalt	Mv_{sem}		25			5		0	0.00									
22390058	16		E-105			NE	SE	17	10	21	E	Yakima	gravel		Qa		20					2	0.10			2.76			8	51	41	0
22390044	16		E-249			NE	SE	21	10	21	E	Yakima	gravel		Qa	>	13					0	0.00	14	73	2.71	69	76	13	71	16	1
22390045	16		E-2				SW	22	10	21	E	Yakima	gravel		Qa																	
22390046	16		E-208			SE	SW	22	10	21	E	Yakima	gravel		Mcg		100					0	0.00	22	55	2.66	50	75	8	73	19	2
22390048	21	12032		Bagley pit	J. J. Welcome Construction Co., Inc.	S	NE	22	10	21	E	Yakima	sand/ silt		Qfs		40			50		1	0.02									
22390050	21	12065		Meyer borrow site	J. J. Welcome Construction Co., Inc.	N	SE	22	10	21	E	Yakima	sand/ silt		Qfs		60			15		1	0.02									
22390054	21	12029		Sizer pit	J. J. Welcome Construction Co., Inc.	NE	SW	23	10	21	E	Yakima	sand/ silt		Qfs		10			30		1	0.10									
22390056	21	11700	E-306		WSDOT	N	SW	24	10	21	E	Yakima	sand		Qfs		35			90		2	0.06				6	53	0	0	100	81
22390100	18	12359		O. L. Luther pit	O. L. Luther Co., Inc.		SE	25	10	21	E	Yakima	gravel		Mcg		100	2	3.2	187	30	2	0.02									
22390033	21	12229	E-323	Rasmussen pit	M. A. Segale, Inc.	SE	SW	28	10	21	E	Yakima	gravel		Qa		25			5		1	0.04	16		2.69			0	82	18	3

IDENTIFIER						LOCATION							RESERVES									QUALITY										
WADNR unique number	WADNR data type code	WADNR permit no.	WSDOT site number	Mine name	Permit holder	¼ ¼ section	¼ section	Section	Township (N)	Range	Meridian	County	Product	Rock type	Geologic unit	Qualifier	Resource thickness (feet)	Million cubic yards	Million tons	Acres	Percent depletion	Overburden thickness (feet)	Stripping ratio	Los Angeles Abrasion	Degradation	Specific Gravity	Sand Equivalent	Stabilometer R Value	Percent >2½ inches	Percent ¼–2½ inches	Percent <¼ inch	Percent <U.S. No. 200 sieve
22400048	16					SE	SW	26	10	22	E	Yakima	gravel		Mcg																	
22400047	21	12704		Woodworth pit	J. J. Welcome Construction Co., Inc.	S	SE	29	10	22	E	Yakima	sand/ silt		Qfs		45			20		1	0.02									
22400029	15					NW	NW	32	10	22	E	Yakima	gravel		Mcg																	
22400030	16	10056	E-201		WSDOT	NE	NW	32	10	22	E	Yakima	gravel		Mcg	>	14			15.05		3	0.21	15	69	2.65	54	77	18	59	23	3
22400036	18	12907	E-291	Heffron pit	Columbia Ready-Mix	N	SW	34	10	22	E	Yakima	gravel/ rock		Mcg/ Mv_{sem}		120	0.05	0.08	15	90	4	0.03	25	38	2.69	17	60	4	63	33	12
22400037	16					SE	SW	34	10	22	E	Yakima	gravel		Mcg																	
22400038	16					NE	SW	34	10	22	E	Yakima	gravel		Mcg																	
22400040	21	11033			Snipes Mountain Gravel	SE	NE	34	10	22	E	Yakima	gravel		Mcg		20			10.09		10	0.50									
21370074	21	11442	E-310		WSDOT	NW	SE	1	11	19	E	Yakima	gravel		Qa		30			17		1.5	0.05				76	75	7	69	24	1
21370072	21	10435	E-285	Bridgeman Estate	WSDOT	S	NE	2	11	19	E	Yakima	gravel		Qa		16			5		0	0.00				82	76	30	54	16	1
21370023	18	10632	E-226	Progressive pit	Yakima County Public Works	W	NE	27	11	19	E	Yakima	gravel		Qa		30	0.3	0.48	36		2	0.07	15	85	2.65	60		14	70	16	2
21370016	18	10730	E-182	Branch pit	Yakima County Public Works	SE	SW	30	11	19	E	Yakima	gravel		Qt		35	0.1	0.16	14		1.5	0.04	12	84	2.7	69		19	56	25	1
21370009	18	10729	E-150	McDonald pit	Yakima County Public Works	SW	SW	31	11	19	E	Yakima	gravel		Qt	>	30	0.15	0.24	17		1	0.03	15					16	66	18	1
21380071	16					NW	SW	1	11	20	E	Yakima	sand		Mc																	
21380070	16		E-6			E	NE	2	11	20	E	Yakima	sand		Mc		10					2	0.20									
21380062	15					SW	NE	7	11	20	E	Yakima	gravel		Qa																	
21380065	16					SE	NE	10	11	20	E	Yakima	sand		Mc																	
21380052	21	11623	E-311		WSDOT		S	17	11	20	E	Yakima	gravel		Qa		30			51		1.5	0.05	17	82	2.79		65				
21380045	21	11458	E-300		WSDOT	SW	SE	21	11	20	E	Yakima	gravel		Qa		30			30		1.5	0.05	14	79	2.74	57	73	7	71	22	1
21380019	16					SE	SE	26	11	20	E	Yakima	gravel		Qa																	
21380038	16		E-143			NE	NW	27	11	20	E	Yakima	gravel		Qa											2.75						
21380040	21	11976			Northwest Construction Inc.		NE	27	11	20	E	Yakima	gravel		Qa	>	11			11		1	0.09									
21380011	16	10814	E-227		WSDOT	SE	NE	31	11	20	E	Yakima	gravel		Qa		25			2		1	0.04	19	70	2.69	77		7	54	39	2
21380013	21	10350	E-158	Graham & Morris pit	Graham & Morris Construction Co., Inc.	SW	SE	32	11	20	E	Yakima	gravel		Qa		30	0	0	18	100	2	0.07	16	63	2.73						
21380017	21	10728		Zillah bridge pit	Yakima County Public Works	NE	NE	35	11	20	E	Yakima	gravel		Qa		30	0	0	10	100	1	0.03									
21380018	16		E-73			NE	NE	35	11	20	E	Yakima	gravel		Qa							1		13		2.7			19	52	29	0
21380021	16		E-185			SE	NE	35	11	20	E	Yakima	gravel		Qa	>	11						0.00	13		2.73	69	78	16	61	23	1
21380022	18	12192	E-325	Walker pit	Columbia Ready-Mix	W	NW	36	11	20	E	Yakima	gravel		Qa		50	0.63	1	36		3	0.06	14	88	2.69	48		34	63	3	0
21390033	22		E-351	Van Wyk site	Alan Van Wyk		S	9	11	21	E	Yakima	gravel		Mcg	>	20	5	8	96	0			22	81	2.64						

IDENTIFIER						LOCATION							RESERVES									QUALITY										
WADNR unique number	WADNR data type code	WADNR permit no.	WSDOT site number	Mine name	Permit holder	¼ ¼ section	¼ section	Section	Township (N)	Range	Meridian	County	Product	Rock type	Geologic unit	Qualifier	Resource thickness (feet)	Million cubic yards	Million tons	Acres	Percent depletion	Overburden thickness (feet)	Stripping ratio	Los Angeles Abrasion	Degradation	Specific Gravity	Sand Equivalent	Stabilometer R Value	Percent >2½ inches	Percent ¼–2½ inches	Percent <¼ inch	Percent <U.S. No. 200 sieve
21390017	18	10736	E-332	Liberty quarry	Yakima County Public Works		NE	23	11	21	E	Yakima	rock	basalt	Mv_{sem}		50	0.4	1	14		3	0.06	27	46	2.55						
21390018	15					E	NW	24	11	21	E	Yakima	rock	basalt	Mv_{sem}																	
21400003	16		E-189			SW	NW	27	11	22	E	Yakima	rock	basalt	Mv_{sem}		20					2	0.10	21		2.66						
21400001	16		E-145			S	SW	31	11	22	E	Yakima	gravel		Qfs	>	6						0.00	14					18	48	34	4
21370099	18	10634	E-253	George pit	Yakima County Public Works	W	SW	28	12	19	E	Yakima	gravel		Qa		30	0.6	1	50		1.5	0.05	18	82	2.75	63		27	56	17	4
21370093	21	11622	E-301		WSDOT	SW	SE	35	12	19	E	Yakima	gravel		Qa		30			36		1.5	0.05	18	73	2.74	41	76	1	66	33	5
21370089	16	10057	E-159		WSDOT	SE	SW	35	12	19	E	Yakima	gravel		Qa		20			5		0	0.00	14	74			86	15	65	20	2
21380075	15					SE	SW	26	12	20	E	Yakima	sand		Mc																	
21380072	16					SE	SW	36	12	20	E	Yakima	sand		Mc																	
21380073	16					SW	SE	36	12	20	E	Yakima	sand		Mc																	
21390032	18	12851		Black Star quarry	Jeff Gamache Farms Inc.	N	SE	29	12	21	E	Yakima	rock	basalt	Mv_{sp}		25	0.1	0.25	15	15	6	0.24									
21390031	18	11152	E-206		WSDOT	NW	NE	35	12	21	E	Yakima	rock	basalt	Mv_{sem}	>	100			9		1	0.01	17	77	2.79						

Appendix 4. Outcrop Database

This database contains information about outcrops on which strength and durability testing was performed, but mining did not take place. These locations are plotted on Plate 1. The information contained herein is available digitally as part of the geographic information system (GIS) files for the Toppenish 1:100,000 quadrangle. The columns that are not self-explanatory are defined as follows:

WADNR unique number – The Washington Department of Natural Resources (WADNR) unique number used by the geographic information system (GIS) to relate a feature on Plate 1 to a row in the database. The first four digits of the number identify the 7.5-minute quadrangle map in which the outcrop is located. The last four digits are a unique number on each 7.5-minute quadrangle.

WADNR data type code – The code number that indicates the type of investigation, as follows: 13 = strength and durability outcrop test location (point).

WSDOT site number – The number assigned by the Washington State Department of Transportation (WSDOT) that links results of strength and durability testing to a particular outcrop. The number consists of a letter that identifies the county the site is in, followed by a sequentially assigned number.

¼ ¼ section, ¼ section, Section, Township, Range, Meridian – Legal description of the outcrop with reference to the Government Land Office grid. Townships and ranges are shown on Plate 1.

Product – The material of interest at the location: rock, sand, or gravel.

Rock type – The type of rock at the location, if the outcrop is a bedrock unit.

Geologic unit – The short label that identifies a particular unit on a geologic map. This field indicates the unit in which the outcrop is located as identified in Walsh (1986) and Schuster (1994), using the updated geologic unit labels consistent with Schuster (1994). Some units are described in Appendix 6.

Qualifier – Applies only to the deepest resource thickness reported (see following columns) and indicates either that the thickness is exact because the whole section could be measured (blank) or that the actual resource thickness is greater than the thickness reported because the bottom of the resource was not identified (>).

1st resource thickness (feet), 1st interbed thickness (feet), 2nd resource thickness (feet) – These fields refer to the bedding identified in the outcrop by the authors, starting at the top. 'Resource thickness' refers to the thickness of a likely aggregate resource, whereas 'interbeds' are non-commercial materials such as silt and clay.

Dip, Strike – Indicate orientation of sedimentary bedding in a bedrock resource; if horizontal or no data, fields are blank.

Induration – The relative quality of a rock as determined in the field with a one-pound ball peen hammer. Estimates range from rebound (highest quality) through fracture, pit, and dent (lowest quality).

Overburden thickness (feet) – Thickness, in feet, of soil, clay, or non-commercial aggregate that must be removed in order to reach the aggregate resource.

Stripping ratio – The overburden thickness divided by the resource thickness. A value of less than 0.33 (ratio of less than 1:3) is preferred.

Los Angeles Abrasion, Degradation, Specific Gravity, Sand Equivalent, and Stabilometer R Value tests – Results of laboratory tests, conducted mainly by the WSDOT, that reflect the quality of the deposit. See the glossary (Appendix 1) for explanation of tests.

Lab (L) or visual (V) – This code indicates whether grain-size analysis is from a laboratory test (L) or estimated visually in the field (V).

Percent >2½ inches, Percent ¼–2½ inches, Percent <¼ inch, Percent <U.S. No. 200 sieve – Results of laboratory grain-size analysis of samples. Values are given in weight percent. The first three fields divide the whole sample, and the fourth field refers to the amount of silt and clay in the entire sample.

IDENTIFIER				LOCATION							MATERIAL							QUALITY													
WADNR unique number	WADNR data type code	WSDOT site number	Site name/ description	¼ ¼ section	¼ section	Section	Township (N)	Range	Meridian	County	Product	Rock type	Geologic unit	Qualifier	1st resource thickness (feet)	1st interbed thickness (feet)	2nd resource thickness (feet)	Dip	Strike	Induration	Overburden thickness	Stripping ratio	Los Angeles Abrasion	Degradation	Specific Gravity	Sand Equivalent	Stabilometer R Value	Lab (L) or visual (V)	Percent >2½ inches	¼–2½ inches	Percent <¼ inch	Percent <U.S. No. 200 sieve
22400022	13	E-213		NW	SE	5	9	22	E	Yakima	gravel		Qa	>	20						0	0.00	11		2.65							
22390051	13	E-305		NW	SW	23	10	21	E	Yakima	sand		Qfs		10						0	0.00				1	51	L	0	0	100	85
22390041	13	E-176		NE	NW	25	10	21	E	Yakima	gravel		Mcg		14						2	0.14	15.6		2.64			L	28	53	19	3
22390062	13	E-324			E	25	10	21	E	Yakima	gravel		Mcg										18	54	2.66	59		L	13	71	16	1
22390063	13	E-180		NE	SE	25	10	21	E	Yakima	rock	basalt	Mv_{sem}										12	54	2.79							
22390037	13	E-295			S	26	10	21	E	Yakima	gravel		Qa		30						6	0.20	15.8	78	2.68	57	76	L	2	70	28	2
22390061	13	E-271		SW	SW	12	10	22	E	Yakima	sand		Qfs		15						0	0.00				0.01	45	L	0	0	100	70
22400050	13	E-209		NW	SW	30	10	22	E	Yakima	gravel		Mcg		65								20	62	2.66	40		L	20	56	24	2
22400031	13	E-292		SE	SW	33	10	22	E	Yakima	gravel		Mcg	>	30													L			4	
22400033	13	E-316		NE	SE	33	10	22	E	Yakima	gravel		Mcg	>	15						2	0.10	21.5	58	2.64	38	65	L	9	61	30	7
21380069	13	E-96		SW	SE	4	11	20	E	Yakima	sand		Mc		15						0	0.00										
21380051	13	E-298		SE	SE	7	11	20	E	Yakima	gravel		Qa		30						0	0.00				22		L	2	23	75	28
21380061	13	E-156		NE	NW	7	11	20	E	Yakima	gravel		Qa	>	10						2	0.20	11.3					L	4	65	31	2
21380066	13	E-315		NE	NE	10	11	20	E	Yakima	gravel		Mc	>	25								24	25	2.57	36		L	2	62	36	5
21380056	13	E-215		SW	NW	16	11	20	E	Yakima	gravel		Qa		5						0	0.00				79	76	L	0	59	41	3
21380057	13	E-214		NE	SW	16	11	20	E	Yakima	gravel		Qfs	>	5						1	0.20				88	77	L	11	65	24	1
21380058	13	E-31		SE	SW	16	11	20	E	Yakima	gravel		Qa	>	12						0	0.00						L	20	73	7	
21380042	13	E-302		W	E	20	11	20	E	Yakima	gravel		Qa	>	11						1	0.09	20.8	74		36	77	L	14	60	26	3
21380046	13	E-219		NE	SE	21	11	20	E	Yakima	gravel		Qa	>	2						1	0.50				94	77	L	5	65	30	1
21380047	13	E-202		NE	NW	21	11	20	E	Yakima	gravel		Qa	>	6						1	0.17				87	77	L	21	54	25	1
21380048	13	E-216		NW	NE	21	11	20	E	Yakima	gravel		Qa	>	6						0	0.00				90	80	L	10	65	25	1
21380036	13	E-28		N	SW	27	11	20	E	Yakima	gravel		Qa										11		2.73	78	78	L	13	63	24	2
21380037	13	E-17			E	27	11	20	E	Yakima	gravel		Qa															L	2	68	30	0
21380039	13	E-299		NW	SE	27	11	20	E	Yakima	gravel		Qa	>	11						2	0.18	16.8	77	2.73	38	75	L	12	62	26	4
21380029	13	E-15		SE	NW	28	11	20	E	Yakima	gravel		Qa																			
21380030	13	E-221A			NE	28	11	20	E	Yakima	gravel		Qa	>	9						0	0.00	11.2	90	2.75	86		L	27	50	23	1
21370087	13	E-296		SW	NW	35	12	19	E	Yakima	gravel		Qa	>	10						2	0.20	15.1	79	2.75	47	76	L	23	45	32	3
21380074	13	E-350		N	SW	28	12	20	E	Yakima	gravel		Mc										18									

Appendix 5. Well Database

This database contains information about all water wells and geotechnical bores that are plotted on Plate 1. The information contained herein is available digitally as part of the geographic information system (GIS) files for the Toppenish 1:100,000 quadrangle. The columns that are not self-explanatory are defined as follows:

WADNR unique number – The Washington Department of Natural Resources (WADNR) unique number is used by the geographic information system (GIS) to relate a feature on Plate 1 to a row in the database. The first four digits of the number identify the 7.5-minute quadrangle map in which the well is located. The last four digits are a unique number on each 7.5-minute quadrangle.

WADNR data type code – The code number that indicates the type of drill hole, as follows: 11 = water well (point); 12 = geotechnical or other bore (point).

WADOE well number – One of a variety of numbers found on the Washington Department of Ecology (WADOE) water-well report forms. The possible types include start card, application, or permit numbers.

Data verified? – Relates to the quality of data. 'Y' indicates that the drill log is from a geotechnical bore or has been verified by a consulting firm; otherwise, the field is blank.

Well location – Gives the street address of the well or the nearest geographical feature. Washington State Department of Transportation bores are referenced to the bridge, intersection, or street location where the bore is drilled.

¼ ¼ section, ¼ section, Section, Township, Range, Meridian – Legal description of the well with reference to the Government Land Office grid. Townships and ranges are shown on Plate 1.

Geologic unit – The short label that identifies a particular unit on a geologic map. This field indicates the unit in which the well is located on the surface as identified in Walsh (1986) and Schuster (1994), using the updated geologic unit labels consistent with Schuster (1994). Some units are described in Appendix 6.

Qualifier – Applies only to the deepest gravel thickness reported (see following columns) and indicates that either the thickness is exact because the whole layer is penetrated by the well (blank) or that the actual gravel thickness is greater than the thickness reported because the bottom of the gravel was not identified in the well log (>).

Overburden thickness (feet) – The thickness, in feet, of soil, clay, or non-commercial aggregate that must be removed in order to reach the aggregate resource.

1st gravel thickness (feet), 1st interbed thickness (feet), 2nd gravel thickness (feet), 2nd interbed thickness (feet), 3rd gravel thickness (feet) – These fields refer to the interpretation of the well log by the authors, starting at the ground surface. 'Gravel thickness' refers to the thickness of a likely aggregate resource, whereas 'interbeds' are non-commercial materials such as silt and clay.

Depth to water-bearing zone (feet) – Gives depth, in feet, to top of the first water-bearing unit encountered during drilling.

Bedrock penetrated? – This column contains either a Y (yes), N (no), or blank (unknown) indicating whether or not the well was drilled to the depth of bedrock.

Reference – The source of data for the well log, if other than the Washington Department of Ecology water-well log archives.

IDENTIFIER						LOCATION									WELL LOG										
WADNR unique number	WADNR data type code	WADOE well number	Data verified?	Well name	Original well owner	Well location	¼ ¼ section	¼ section	Section	Township (N)	Range	Meridian	County	Geologic unit	Qualifier	Overburden thickness (feet)	1st gravel thickness (feet)	1st interbed thickness (feet)	2nd gravel thickness (feet)	2nd interbed thickness (feet)	3rd gravel thickness (feet)	Depth to water bearing zone (feet)	Well total depth (feet)	Bedrock penetrated?	Reference
24390001	11				Laurence Giles		SW	W	15	6	21	E	Klickitat	Ql		8						207	220	Y	
24390002	11				Ronald Mains		SW	SW	32	7	21	E	Yakima	Ql		3						45	240	Y	
24400002	11	W092380			Gordon King	Ridge Road		SW	17	7	22	E	Yakima	Ql		7							510	Y	
24400001	11	49314			Ralph Mains	Glade Cemetery	SW	NW	20	7	22	E	Yakima	Ql		4						186	218	Y	
22400026	11				Thomas Dekker		SE	NW	1	9	22	E	Yakima	Qa	>	115	10						125	N	
22400025	11	25301			Doug Pecheos		SE	SE	2	9	22	E	Yakima	Qa	>	70	12						82	N	
22400024	11	R-04624		#2	Port of Sunnyside	NW corner of Emerald & Randel Roads	SW	SW	4	9	22	E	Yakima	Qa			0						24	N	
22400023	11			1	S. S. Steiner Inc.		E	NW	5	9	22	E	Yakima	Qfs		60	175	55	20				406	Y	
22400013	11	216912			Emerald Ranches	1730 S Emerald	SE	NE	8	9	22	E	Yakima	Qa	>	53	17					67	70	N	
22400014	11			1	Johnson & Betancourt	500′ W of S Emerald & Randel Roads	NE	NE	8	9	22	E	Yakima	Qa		50	145						500		
22400015	11	83989			Dave Riddle		NE	SE	9	9	22	E	Yakima	Qa	>	69	1						70	N	
22400016	11	W049257			Jim Hazzard		SW	NW	10	9	22	E	Yakima	Qfs		22	29					82	158	N	
22400017	11				Van de Graaf Ranches, Inc.	1300′ E & 1000′ N from SW section corner	SW	SW	12	9	22	E	Yakima	Qa		48	62						310	Y	
22400018	11	W090062			Lester Sellers		NE	NE	12	9	22	E	Yakima	Qa	>	77	3						80	N	
22400008	11	W087618			Juan Benitez	1861 Green Valley Road	SW	SW	14	9	22	E	Yakima	Qa	>	68	34					28	102	N	
22400007	11	W49843			Dick Top	2561 Green Valley Road	SE	SW	15	9	22	E	Yakima	Qa	>	61	40					10	101	N	
22400006	11				John & Albert Newhouse		NW	NW	16	9	22	E	Yakima	Qa		0	12	40	48				117	N	
22400005	11	8501		1	Fred Rupley Jr.	Center of ¼ section		SE	17	9	22	E	Yakima	Qa	>	58	20					40	78	N	
22400001	11	W094356			Wash. Dept. of Fish and Wildlife		NW	SE	22	9	22	E	Yakima	Qa	>	68	30					30	98	N	
22400002	11	36318			Krouse	5th Avenue	NE	NE	22	9	22	E	Yakima	Qa		15	5						170	Y	
22400003	11	W122062			Sergeo Verduzco	Parcel # 220923-14402	SE	NE	23	9	22	E	Yakima	Qa	>	75	10						85	N	
22400004	11	83988			Jill Suttleworth		NW	NW	24	9	22	E	Yakima	Qa	>	87	3						90	N	
23400007	11	216660			Rick Sauve	200 Dwinell Road	NE	SW	24	9	22	E	Yakima	Qa											
23400008	11	48426			Apol-Biehl	McGee Road	NE	NE	25	9	22	E	Yakima	Qa	>	78	7					16	85	N	
21390002	11	36424			Steve Delp	315 Railroad Avenue	NW	NE	6	10	21	E	Yakima	Qfs	>	70	20	50	3			85	143	N	
22390060	11	83517		2	Shephard & Meyers	Parcel #211008-12006	NW	NE	8	10	21	E	Yakima	Qfs	>	68	47	15	10			68	140	N	
22390047	11	7659			Bill Omta		N	NW	22	10	21	E	Yakima	Qfs		18	57					210	230	Y	
22390049	11				Bob Lincoln		NW	SE	22	10	21	E	Yakima	Qfs		6	36						241		
22390052	11				Garold Getsinger		SW	SW	23	10	21	E	Yakima	Qfs		2	68						185	Y	
22390053	11	7690			D & B Farms		S	SW	23	10	21	E	Yakima	Qfs	>	40	40						80	N	
22390055	11	W113369			Arlee Willis	1800 Gap Road	SW	SE	23	10	21	E	Yakima	Qfs		60	10					60	175	N	
22390039	11	W092350			Dean Sizer	Parcel #211025-23001	SW	NW	25	10	21	E	Yakima	Mcg		1	64	10	13				485	Y	
22390040	11				Eric Carlson		SW	SE	25	10	21	E	Yakima	Qfs		20	18	35	57				145	N	
22390038	11	W113358			Dean Sizer	1241 Nass Road	SW	NE	26	10	21	E	Yakima	Qfs		28	45						245	Y	
22390036	11	W049254			Bill Malzahn	Parcel #211027-11001	NE	NE	27	10	21	E	Yakima	Mcg		1	115						370	Y	
22400049	11	W039172			Sunnyside Housing		E	NE	25	10	22	E	Yakima	Qa		48	44						350		

IDENTIFIER						LOCATION									WELL LOG										
WADNR unique number	WADNR data type code	WADOE well number	Data verified?	Well name	Original well owner	Well location	¼ ¼ section	¼ section	Section	Township (N)	Range	Meridian	County	Geologic unit	Qualifier	Overburden thickness (feet)	1st gravel thickness (feet)	1st interbed thickness (feet)	2nd gravel thickness (feet)	2nd interbed thickness (feet)	3rd gravel thickness (feet)	Depth to water bearing zone (feet)	Well total depth (feet)	Bedrock penetrated?	Reference
22400041	11	W039173			Yakima County Public Works	Snipes Mountain landfill	SW	SW	30	10	22	E	Yakima	Mcg		0	70					250	415	Y	
22400044	11			MW-4	Yakima County Public Works	Snipes Mountain landfill	NW	NW	30	10	22	E	Yakima	Mcg		0	202						320	Y	
22400042	11				O. L. Luther		NW	SW	30	10	22	E	Yakima	Mcg		15	245						320	Y	
22400043	11				WADNR		SW	NW	30	10	22	E	Yakima	Qfs		27	4	20	349				885	Y	
22400045	11				David Hathaway		SW	NE	30	10	22	E	Yakima	Qfs	>	35	55	215	37				342	N	
22400046	11	W22632			Dave Parker		SE	NE	30	10	22	E	Yakima	Qfs	>	55	39	207	22				323	N	
22400027	11	7682			Melvin Newhouse		SW	SW	31	10	22	E	Yakima	Qfs		35	40						129	Y	
22400028	11				Irving Newhouse		SW	NE	31	10	22	E	Yakima	Qfs		3	43						400	Y	
22400032	11	7651			Rod Van de Graff		NW	SE	33	10	22	E	Yakima	Qfs		30	160	60	65				369	Y	
22400034	11	W087609			John Heffron	4652 Gap Road	NW	NW	33	10	22	E	Yakima	Qfs		24	238					220	318		
22400035	11	214930			Steve Newhouse		SE	NE	33	10	22	E	Yakima	Qfs		32	131						530	Y	
22400039	11	7679			Mel Curfman		NE	NW	34	10	22	E	Yakima	Qfs		4	51	15	54				168	Y	
21370073	11	W048388			Felipe Reynose		NW	NW	1	11	19	E	Yakima	Qa	>	2	58					44	60	N	
21370075	11	W44832		Epic five	S. D. L.		SE	NE	1	11	19	E	Yakima	Qfs		18	143						279	Y	
21380067	11	79535			Parker Heights Presbyterian Church	5453 Konowac Pass Road	SW	SW	6	11	20	E	Yakima	Qfs	>	17	43						60	N	
21380068	11	W087788			Kelly Stother	5461 Yakima Valley Hwy	SW	SE	6	11	20	E	Yakima	Qfs	>	19	41					36	60	N	
21380063	11	W123118			John Babcock	173 Lombard Loop Road	SW	NE	7	11	20	E	Yakima	Qfs	>	25	45					45	70	N	
21380064	11	81095		1	June Leininger		SE	NE	7	11	20	E	Yakima	Qfs	>	40	22						62	N	
21380059	11	10894			Clark Sandoz	481 Buena Road	SE	SE	16	11	20	E	Yakima	Qfs		23	12					53	70		
21380053	11	R040601		AEF 716	WSDOT	Pit Site E-311	NW	SE	17	11	20	E	Yakima	Qa	>	5	45					5	50	N	
21380054	11			1	Bill Medley		SW	SE	17	11	20	E	Yakima	Qa	>	3	64						67	N	
21380055	11	W108815			Jamie Muffett	7560 Yakima Valley Hwy	SE	NE	17	11	20	E	Yakima	Qa	>	5	64	11	7	8	15	8	110	N	
21380043	11	W108810			David Applhof	381 Elmore Road	NE	NW	21	11	20	E	Yakima	Qa		3	86					10	120		
21380044	11	W108817			Jose Arias	180 Blackburn Road	SE	SW	21	11	20	E	Yakima	Qa		1	101					6	130		
21380049	11	10182			Catherine Sanders		SW	NW	22	11	20	E	Yakima	Qa	>	12	28					12	40	N	
21380034	12		Y	H-1	WSDOT	I-82; SR-22 interchange undercrossing	NW	NW	27	11	20	E	Yakima	Qa	>	0	49					6	49	N	WSDOT
21380035	12		Y	H-7	WSDOT	SR-22; Yakima River overflow bridge	SW	NW	27	11	20	E	Yakima	Qa	>	0	52					14	52	N	WSDOT
21380033	11				Eva Patterson		NE	NE	28	11	20	E	Yakima	Qa	>	2	48					33	50	N	
21380020	12		Y	H-2	WSDOT	I-82; west Zillah interchange undercrossing	NW	NE	35	11	20	E	Yakima	Qa	>	4	46					4	50	N	WSDOT
21390030	11				Gene Pennington		NE	SW	8	11	21	E	Yakima	Mc			0					115	118		
21390029	11	W086113			Paul Van Wyk		NE	NE	15	11	21	E	Yakima	Mc		46	72						896	Y	
21390026	11			Ramsier no. 1	WADNR		SE	SW	16	11	21	E	Yakima	Mcg		8	32						1200	Y	
21390027	11				Pat Clyde		W	SW	16	11	21	E	Yakima	Mcg		0	40						794	Y	
21390028	11				Ole Berg			SE	16	11	21	E	Yakima	Mcg		4	19						683	Y	
21390020	11				Lloyd Garretson Co.		NW	NW	17	11	21	E	Yakima	Mcg		0	30						1040	Y	

IDENTIFIER						LOCATION									WELL LOG										
WADNR unique number	WADNR data type code	WADOE well number	Data verified?	Well name	Original well owner	Well location	¼ ¼ section	¼ section	Section	Township (N)	Range	Meridian	County	Geologic unit	Qualifier	Overburden thickness (feet)	1st gravel thickness (feet)	1st interbed thickness (feet)	2nd gravel thickness (feet)	2nd interbed thickness (feet)	3rd gravel thickness (feet)	Depth to water bearing zone (feet)	Well total depth (feet)	Bedrock penetrated?	Reference
21390021	11	W087448			Marty Clevenger	3301 Lucy Lane	NW	SW	17	11	21	E	Yakima	Mc		5	43					10	485	Y	
21390022	11	205712			RIC Orchards Ranch #2		SE	NW	17	11	21	E	Yakima	Mc		2	19						700	Y	
21390023	11			1	Jerry Hensley		NW	SE	17	11	21	E	Yakima	Mcg		3	192						440	Y	
21390024	11			1	Dave Schmidt		SW	SE	17	11	21	E	Yakima	Mcg		9	19	8	14	27	18		1060	Y	
21390025	11				Dave Schmidt Farms		SE	SE	17	11	21	E	Yakima	Mcg		0	77					185	370	Y	
21390019	11			1	Bill Gammie Ranch		NE	NE	18	11	21	E	Yakima	Mcg		0	11						535		
21390004	11	424673			Ronald Dahlin		NW	NW	21	11	21	E	Yakima	Mc		0	13						382	Y	
21390005	11				Al Ambrose Farms, Inc.		NW	NW	21	11	21	E	Yakima	Mcg		5	113	86	36				460	Y	
21390006	11	100311			Tom Case		NW	NE	21	11	21	E	Yakima	Mcg			0						280		
21390007	11				McBros. Unlimited		NE	NE	21	11	21	E	Yakima	Mcg		0	8						820	Y	
21390008	11				Miles Van Leuven		NW	NW	22	11	21	E	Yakima	Mcg		0	72						855	Y	
21390009	11				Houghton Farms		SW	NW	22	11	21	E	Yakima	Mcg		0	72						855	Y	
21390010	11	W092363			Mike Argo		SW	SW	22	11	21	E	Yakima	Mc		5	22	87	24				405	Y	
21390012	11				Peter Best		NW	SE	22	11	21	E	Yakima	Mc		1	99						1087	Y	
21390013	11			2	Sandlin Farms, Inc.		SW	NE	22	11	21	E	Yakima	Mcg		5	76						1808	Y	
21390014	11	W093632			Elizabeth Fletcher	Parcel #211122-12403	NW	NE	22	11	21	E	Yakima	Mcg		3	8						444	Y	
21390015	11				Pete Best		SE	SE	22	11	21	E	Yakima	Mc		3	22	50	37				978	Y	
21390016	11	W36980		1	Russell Elliott		SE	NE	22	11	21	E	Yakima	Mcg		1	101						965	Y	
21390003	11	86473			Bill Swank	470 Lucy Lane	NE	SE	31	11	21	E	Yakima	Qfs	>	63	60					100	123	N	
21400004	11				Arvid Monson		SW	SW	19	11	22	E	Yakima	Ql		2	11	19	82				846	Y	
21400002	11	W109690			Peter Plath	780 Chaffee Road	NW	NW	33	11	22	E	Yakima	Ql		3	43	149	108				498	Y	
21370100	12		Y	8	WSDOT	I-82; SR-12, Burlington Northern & Union Pacific overcrossing	NW	SW	27	12	19	E	Yakima	Qa		4	15						55	N	WSDOT
21370086	12		Y	H-2	WSDOT	I-82; Mellis Road overcrossing	NW	NE	34	12	19	E	Yakima	Qa		0	38					8	52	N	WSDOT
21370088	11	86489			Marley Orchards		NE	SE	34	12	19	E	Yakima	Qa	>	1	79						80	N	
21370091	11			1	Terry Baker		NE	NE	34	12	19	E	Yakima	Qfs	>	13	17						30	N	
21370090	11	W044991			Ruth Kure		SW	NW	35	12	19	E	Yakima	Qa		3	63						141	Y	
21370092	11	W109369			Allen Mercer	3100 Yakima Valley Hwy	NW	SE	35	12	19	E	Yakima	Qa	>	0	57						57	N	

Appendix 6. Geologic description of significant and (or) historically mined units

This appendix includes unit descriptions for geologic units that have been mined for construction aggregates and (or) that have potential to produce gravel or bedrock meeting the threshold criteria of this study. These definitions are intended for geologists and engineers and contain a number of terms that are not included in the glossary (Appendix 1). For complete descriptions of all geologic units in the Toppenish quadrangle, the reader is referred to Walsh (1986) and Schuster (1994).

SAND AND GRAVEL UNITS

Qa **Alluvium (Holocene)**—Unconsolidated deposits of gravel, sand, and silt in flood plains of rivers and creeks and in valley bottoms. Mainstream facies were directly deposited by the Yakima River and include a variety of clast types, while sidestream facies were deposited by tributary creeks and consist almost entirely of locally derived basalt clasts. Mainstream facies gravel and sand deposits dominate along the Yakima River upstream of Emerald. Sand and silt from reworking of glacial flood deposits dominate all alluvium deposits southeast of Emerald. (Descriptions compiled from Bentley and others, 1980; Schuster, 1994.) Gravel deposits of the mainstream facies of this unit are of very high quality and are considered a significant resource.

Qt **Terrace deposits (Holocene to Pleistocene)**—Two ages of terrace deposits are present in the Toppenish quadrangle. The lower (younger) terrace was deposited solely by the Yakima River and is the only terrace that is found of off the Yakama Indian Reservation. The terrace deposits closely resemble the alluvial deposits of the present Yakima River, but are slightly more weathered and contain a higher percentage of fine-grained material. (Description compiled from Bentley and others, 1980, 1993; Newell P. Campbell, oral commun., 2001.) Gravel deposits of the lower terrace within this unit are of high quality and are considered a significant resource.

Mc **Ellensburg Formation, undivided (upper and middle Miocene)**—Weakly to moderately indurated fluvial and laharic deposits consisting of gravel, sand, silt, and clay. These white to light red-brown deposits are dominated by pumiceous dacitic, andesitic, and basaltic clasts. The unit grades downward into thin units of fluvial sand, clay, and locally pebbly sand with mixed volcanic clasts and locally hyaloclastic units. The base of the Ellensburg Formation is defined as the top of the locally lowermost flow of the Columbia River Basalt Group, but the unit includes all conformably underlying sediments of similar lithology beyond the edge of lowermost basalt flow. The top of the unit is correlative with unit Mcg described below. To the east, this unit intertongues with flows of the Columbia River Basalt Group. (Description compiled from Walsh, 1986; Schuster, 1994.) Many small borrow pits are located within this unit, but because the clasts are highly weathered and weak, this deposit is not considered a gravel resource. However, some of the coarse sand layers within this unit may be useful as blending sand if combined with coarse aggregate from another unit.

Mcg **Ellensburg Formation, ancestral Columbia River gravels (upper Miocene)**—Also known as the conglomerate of Snipes Mountain (Bentley and others, 1980) and the Hood River conglomerate (Warren, 1939). Weakly to moderately indurated fluvial deposits consisting primarily of sand and gravel, with lesser amounts of silt and clay. The unit is characterized by well-rounded quartzite clasts that are stained yellow to reddish tan. This unit also includes granitic, gneissic, and andesitic clast types. These gravels interfinger with other fluvial and laharic deposits of the Ellensburg Formation. Cementation, when present, usually consists of calcite or hydrous iron oxide. This unit crops out in a northeast–southwest-trending band, which records the last known course of the Columbia River through the quadrangle. The largest deposits of this unit are on the Rattlesnake Hills, Snipes Mountain, and in the Horse Heaven Hills. (Description compiled from Warren, 1939; Bentley and others, 1980; Schuster, 1994.) Strength and durability testing indicates that this unit usually meets the criteria of this inventory, and it is considered a significant gravel resource.

BEDROCK UNITS

Columbia River Basalt Group

SADDLE MOUNTAINS BASALT

Mv_{sem} **Elephant Mountain Member (upper Miocene)**—Single fine-grained, normal to transitionally magnetized basalt flow that is aphyric to sparsely plagioclase-phyric. Black to blue-black on a fresh surface, the unit weathers gray. The flow is usually less than 50 feet thick and has a relatively short colonnade with many vesicle sheets. The unit crops out mainly on the east half of the quadrangle on the Rattlesnake Hills, Snipes Mountain, and Horse Heaven Hills, as well as in the canyons to the south. (Description compiled from Bentley and others, 1980; Schuster, 1994; Walsh, 1986.) This rock is extremely hard and durable and is considered a significant resource.

Mv_{sp} **Pomona Member (middle Miocene)**—Single fine- to medium-grained, reversely magnetized basalt flow with scattered plagioclase phenocrysts. Gray to blue-black on a fresh surface, the unit weathers gray. The flow is usually 180 feet thick and typically has small, fanning columns in the entablature. The unit crops out on the Rattlesnake Hills, Snipes Mountain, and Horse Heaven Hills, as well as in the canyons to the south. (Description compiled from Bentley and others, 1980; Schuster, 1994; Walsh, 1986.) This rock is extremely

hard and durable and is considered a significant resource.

Mv_{su} **Umatilla Member (middle Miocene)**—Single fine-grained or rarely medium-grained, normally magnetized basalt flow that is aphyric to very sparsely plagioclase-phyric. Black to blue-black on fresh surfaces, the unit weathers gray to red-orange. The flow is usually 100 feet thick and crops out mainly on the Horse Heaven Hills and in the canyons to the south, as well as on the Rattlesnake Hills. (Description compiled from Bentley and others, 1993; Schuster, 1994; Walsh, 1986.) This rock is extremely hard and durable and is considered a significant resource.

WANAPUM BASALT

Mv_{wpr} **Priest Rapids Member (middle Miocene)**—One to three medium- to coarse-grained, reversely magnetized basalt flows that are diktytaxitic and aphyric with rare plagioclase and olivine phenocrysts. Gray-black on fresh surfaces, the unit weathers rusty brown. The member is usually 200 feet thick and the flows have well-developed colonnades with 1.5- to 5-foot diameter columns. This unit crops out mainly on the Horse Heaven Hills and in the canyons to the south, as well as on the Rattlesnake Hills. (Description compiled from Bentley and others, 1980, 1993; Schuster, 1994; Walsh, 1986.) This rock is extremely hard and durable and is considered a significant resource.

Mv_{wr} **Roza Member (middle Miocene)**—One or two fine- to medium-grained, normally magnetized basalt flows that have abundant plagioclase phenocrysts and glomerocrysts and are locally diktytaxitic. Gray-black on fresh surfaces, the unit weathers reddish brown. The member is usually 85 feet thick, and the flows usually have a well-developed colonnade with columns up to 3 feet in diameter. This unit crops out mainly on the Horse Heaven Hills, as well as on the Rattlesnake Hills. (Description compiled from Bentley and others, 1980, 1993; Schuster, 1994; Walsh, 1986.) This rock is extremely hard and durable and is considered a significant resource.

Mv_{wfs} **Frenchman Springs Member (middle Miocene)**—Multiple fine- to medium-grained, normally magnetized basalt flows, usually with moderate to abundant plagioclase phenocrysts, but some flows are aphyric or sparsely phyric. Gray to black on fresh surfaces, the unit weathers from gray to reddish brown. This unit crops out in the southwest corner of the quadrangle and also on the Horse Heaven Hills. (Description compiled from Bentley and others, 1980, 1993; Schuster, 1994; Schuster and others, 1997; Walsh, 1986.) This rock is extremely hard and durable and is considered a significant resource.

GRANDE RONDE BASALT

Mv_{gN2} **Grande Ronde Basalt, upper flows, normal polarity (middle Miocene)**—Four or five, mostly fine-grained, normally magnetized basalt flows that are aphyric. Dark-gray to black on fresh surfaces, the unit weathers reddish brown or gray. This unit crops out in the northwest and southwest corners of the quadrangle. (Description compiled from Bentley and others, 1980, 1993; Walsh, 1986.) This rock is extremely hard and durable and is considered a significant resource.

Mv_{gR2} **Grande Ronde Basalt, upper flows, reversed polarity (middle Miocene)**—Three to six usually fine-grained with some medium- and coarse-grained, reversely magnetized basalt flows that are aphyric. Black to gray-black on fresh surfaces, the unit weathers reddish gray to grayish black. Each flow averages approximately 85 feet thick and contains poorly developed colonnade and entablature zones. This unit crops out in the northwest corner of the quadrangle. (Description compiled from Bentley and others, 1980, 1993; Walsh, 1986; Campbell and Gusey, 1992.) This rock is extremely hard and durable and is considered a significant resource.

Washington Division of Geology and Earth Resources
Ron Teissere, Acting State Geologist
Information Circular 93
August 2001

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

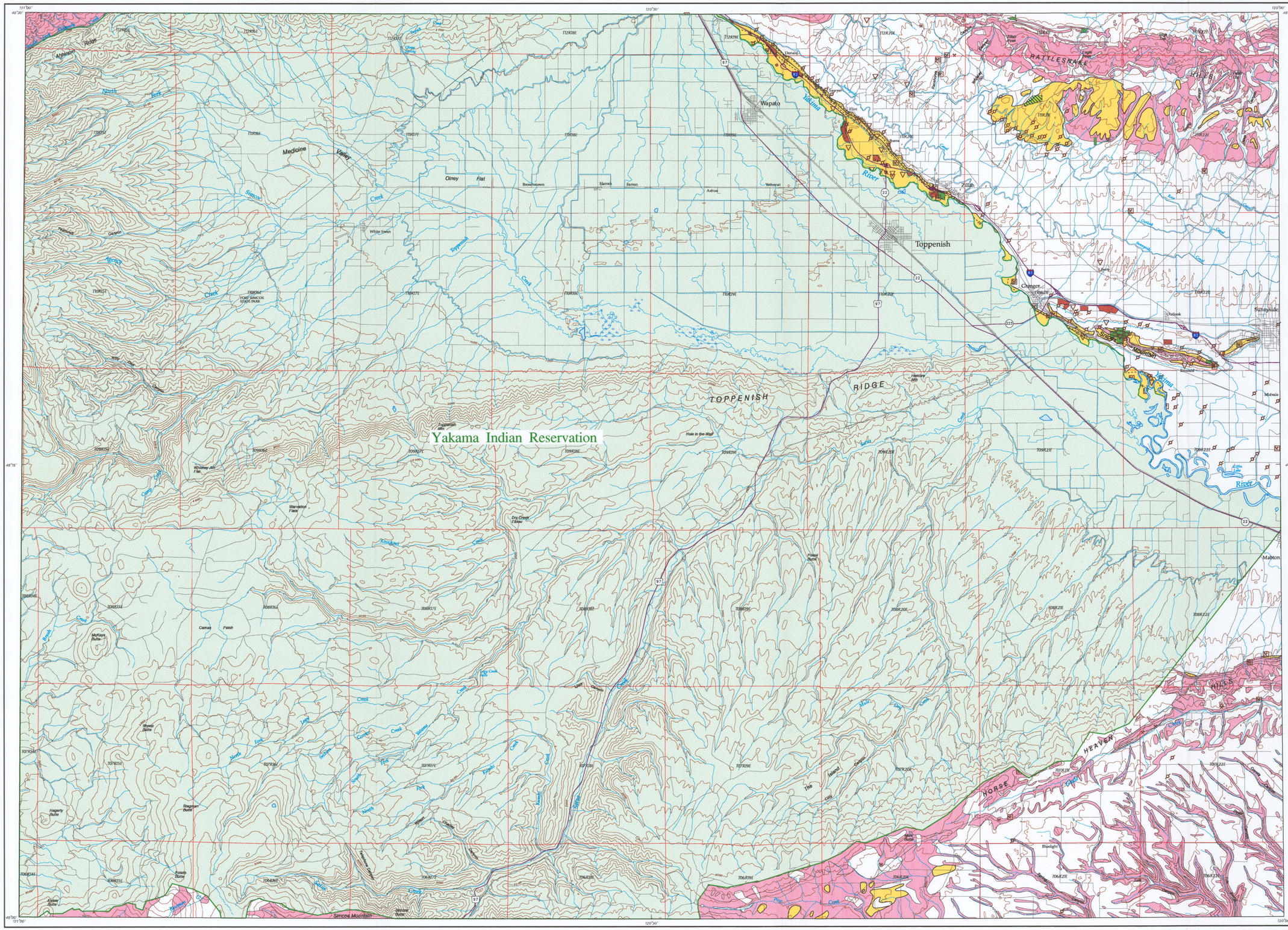

PLATE 1

RECONNAISSANCE INVESTIGATION OF SAND, GRAVEL, AND QUARRIED BEDROCK RESOURCES IN THE TOPPENISH 1:100,000 QUADRANGLE, WASHINGTON

Andrew B. Dunn

with additional digital cartography by
Phung Ho and Charles G. Caruthers

EXPLANATION

- Location of water well used in this study for subsurface information
- Location of geotechnical or other borehole used in this study
- Sampling site for laboratory test of strength and durability of gravel or rock. (Does not include analyses from most mines. These are described in Appendix 4)
- Small gravel pit, borrow pit, or quarry. Most of these mines are used for forest road maintenance or construction and/or do not significantly influence the market at this time
- Depleted or abandoned small gravel pit, borrow pit, or quarry. Includes mines with terminated state reclamation permits, reclaimed sites, and mines that cannot be operated owing to changes in land use (for example, if the site has been flooded by a reservoir)
- Large active mine. Includes intermittently operated sites and a few sites that may have been abandoned, but not reported as such
- Large depleted or abandoned mine
- Large proposed mine
- Potential extent of 'hypothetical undiscovered' sand and gravel reserves, most of which meet threshold criteria for strength, durability, thickness, areal extent, and clast-size distribution, and are not buried under thick layers of overburden. (See text for further explanation)
- Potential extent of 'speculative undiscovered' bedrock reserves, most of which meet threshold criteria for strength, durability, thickness, and areal extent, and are not buried under thick layers of overburden. (See text for further explanation)
- Contour showing possible thickness of some hypothetical gravel deposits meeting the threshold criteria (50-ft interval, half contours dashed)

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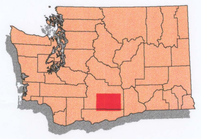

0 1 2 3 4 5
MILES

Scale 1:100,000
TOPOGRAPHIC CONTOUR INTERVAL 200 FEET

Lambert Conformal Conic Projection
1927 North American Datum
Washington State Plane Coordinate System, South Zone
Other base map information from the Washington Department of Natural Resources, Geographic Information System Database - 2000
Washington Division of Geology and Earth Resources