Technical Memorandum

Date:	Original Issue; August 25, 2020. Updated January 4, 2021
Project:	Chehalis River Basin Flood Damage Reduction Project
To:	Chehalis Basin Flood Control Zone District
From:	HDR
Subject:	Ranking of Potential Quarry Sites for Proposed Flood Retention Structure on the Chehalis River

1.0 Introduction and Purpose

As part of a strategy to reduce flood damage along the Chehalis River, the Chehalis River Basin Flood Control Zone District (District) is proposing to construct a flood retention structure (the proposed project) near the town of Pe Ell on the mainstem of the Chehalis River. Construction of this facility will require acquisition of large quantities of concrete aggregate, road base, and riprap material. Contained within the Draft Environmental Impact Statements (EISs) prepared by the Washington Depart of Ecology (SEPA EIS) and the U.S. Army Corps of Engineers (NEPA EIS) is an evaluation of the technical suitability and environmental impacts associated with three candidate quarry sites located in close proximity to the proposed facility. In response to the potential environmental impacts identified in the EISs, the District has undertaken additional evaluation of the candidate quarry sites to avoid and/or minimize potential project impacts.

Four quarry sites were previously identified and evaluated for this project: Rock Creek, Huckleberry Ridge, and the North and South sites within the proposed reservoir footprint. The Rock Creek Quarry site was previously eliminated due to 1) its location, transport route considerations, and overall distance from proposed site, and 2) the limited quantity of suitable quality construction materials available. The District requested HDR evaluate and rank the three remaining potential quarry sites to serve as the basis for continuing to include or eliminating one or more of the potential quarry sites within the overall project configuration and description. The location of the North and South quarries within the reservoir footprint and the Huckleberry Ridge quarry are shown on Figure 1 (all figures provided in Attachment A). Brief summaries of each of these sites are presented in the following section.

2.0 Quarry Descriptions

Potential quarry sites for obtaining construction materials for the proposed flood retention structure were first identified through a regional geologic mapping and assessment process. Following identification of a candidate quarry site, a sequence of site investigations, laboratory testing, and engineering assessments were performed.

The following quarry descriptions provide the quarry locations and a summary of the field investigations that have been completed including geotechnical borings, and seismic refraction survey lines. Laboratory testing results used to qualify materials that would be obtained from the quarries are summarized later in this memorandum. For site investigation methodology details and results refer to the Phase 2 Site Characterization TM (HDR and Shannon & Wilson, Inc. 2016) and the Phase 3 Geotechnical Data Report (Shannon & Wilson, Inc. 2019b).

North Quarry: The North Quarry is located about 1.2 miles directly southeast (2.14 miles by road) of the proposed flood retention structure site and within the limits of the detention pool. The site is accessed off the main Road 1000 by the 1000F Road (Figure 2, page 1 of 4). One seismic refraction survey line and four borings (one in 2016 and three in 2018) have been completed at this potential quarry site.

South Quarry: The South Quarry is located about 2.5 miles directly south (4.3 miles by road) of the proposed flood retention structure site and is also within the limits of the detention pool. The site is accessed off the main Road 1000 by the 1020 Road southwest of the site as it rises to the northeast and exposes a basalt outcrop along the southeastern margin of the site (Figure 2, page 2 of 4). This quarry site was added following the Phase 2 investigation when a Weyerhaeuser contractor improved the grade of the 1020 Road, west of the mainstem Chehalis River, exposing basalt that had not been visible previously. A grab sample of the rock from that road cut was tested in early 2018 and tests indicated that the rock may be promising as aggregate. Consequently, a boring was included in the Phase 3 investigation, but no seismic refraction survey has been performed.

Huckleberry Ridge Quarry: The Huckleberry Ridge Quarry was previously called Quarry 2 in the Phase 2 Site Characterization TM (HDR and Shannon & Wilson, Inc. 2016). It is located about 7.0 miles directly southwest (8.4 miles by road) of the proposed flood retention structure site. The site is accessed via the Huckleberry Ridge Road (1000D2 Road) and would fall outside the inundation pool limits (Figure 1). An unnamed logging road flanks the eastern side of the quarry (Figure 2, page 4 of 4) and exposes high-quality basalt in outcrop. One seismic refraction survey line and one boring were completed at this potential quarry site in 2016.

3.0 Screening Criteria

Five separate criteria were identified and used in this quarry evaluation. The focus of this evaluation is construction costs and material suitability. Some desktop studies have been performed associated with wetlands and endangered species, with no significant differentiators between the quarries with the exception of additional tree removal and potential noise associated with the Huckleberry Ridge site. Additional studies and permitting will be required prior to final decisions regarding final quarry selection. While other criteria are possible, these five were judged as the most important for screening and selecting a preferred quarry for inclusion in the project description and requirements.

- **Rock quality:** Assesses the fundamental ability of a site to provide a material that meets generally accepted quality requirements for concrete aggregate, roadway, and riprap materials. The assessment is based on laboratory testing results (Table 1) and an assessment of the core photos and boring logs that consider the rock descriptions; strength index; weathering index; the presence of vesicles, siltstone, or breccia; and the overall ability to meet quality objectives.

- **Rock quantity:** Assesses the fundamental ability of a site to provide the required amount of suitable quality rock for the concrete aggregate, roadway, and riprap materials. The amount of waste material from within the specified quarry limits, processing, waste disposal requirements, and the overall impact that unacceptable materials would have on project quality objectives are considered under this rating criterion. This criterion also qualitatively considers the lateral and vertical distribution of rock quality along with the topography in an around each site that affects the ability to easily expand the quarry limits if needed.
- **Overburden removal:** Assesses the extent of overburden material that will need to be removed and wasted to access the specified limits for quarry materials. Under this criterion, the less overburden material there is to remove and dispose of, the more favorable the site will be ranked.
- **Haul distance:** During project construction, quarried materials will have to be transported in order to be crushed, screened, stockpiled and then used for production of concrete, or for placement as roadway or riprap protection. This criterion assesses the overall impact associated with material transportation by haul trucks and the round trips required to utilize the quarried materials at the proposed project site. Haul distances can significantly increase aggregate production costs, affect air quality, and increase the risks associated with construction equipment accidents and incidents. Quarry development and processing costs are expected to be relatively similar between the quarries and hence were not included in this, or as a separate evaluation criterion.
- **Road improvements and maintenance:** Assesses the relative differences in roadway improvement and maintenance that are expected between the alternate quarry sites. The main Road 1000 was built for timber-hauling trucks and assumed to be generally acceptable for aggregate-hauling trucks. Routine maintenance of Road 1000 will be required during construction. However, all three sites will be accessed via additional roads that will require improvement to support expected haul truck weight and traffic volume. The total distance of road improvements and expected maintenance was considered under this criterion including required clearing and erosion control measures.

Table 1. Aggregate Qualification Laboratory Testing

Quarry	Boring	Sample Depth (ft)	Specific Gravity	Absorption (percent)	LA Abrasion (percent)	ASR: 16-day (percent length change)
North Quarry	RNQ-16-301(QB-1)	38.0–50.0	2.6	**6.46**	27.1	0.08
		84.0–95.0	2.65	**4.69**	26.8	0.076
		127.0–140.0	2.49	**8.26**	27.5	**0.124**
	RNQ-18-301	80.0–100.0	**2.5**	**6.8**	19.8	-
		100.0–120.0	2.69	**4.8**	21.5	-
	RNQ-18-302	75.0–92.4	**2.51**	**8.85**	18.5	0.055
	RNQ-18-303	50.0–64.6	2.72	**5.08**	18.9	0.049
South Quarry	RSQ-18-301	50.2–70.0	2.71	**3.3**	20.5	0.042
		100.0–118.2	2.80	2.9	18.9	0.047
		149.8–171.2	2.63	**4.9**	20.4	0.042
	1020 Road Cut	GRAB	2.72	2.35	18.4	**0.254**
Huckleberry Ridge Quarry	QB-2	15.0–27.0	2.69	**4.04**	24.8	0.034
		45.0–55.0	2.71	**3.72**	24.1	0.036
WSDOT[a]/FHWA[b] criteria			2.55 min	3 max	35 max	See note c

Notes:
[a] WSDOT: Washington State Department of Transportation.
[b] FHWA: Federal Highway Administration.
[c] ASTM for alkali silica reactivity (ASR): 16-day test: a test value of 0 to 0.10 is innocuous, 0.11 to 0.20 is acceptable if supplemental testing confirms expansion is not due to ASR, and greater than
[d] 0.20 requires additional testing.
Bold numbers indicate test results that exceed the WSDOT/FHWA criteria.

4.0 Evaluation and Conclusions

Each of the three potential quarry sites was evaluated for the five criteria and ranked from best to worse for each criterion. The rankings for all criteria were then assembled into a summary ranking by site.

The ranking methodology used the pairwise evaluation system. The pairwise comparison is a method for evaluating options. It works like a round robin tournament in sports. Each candidate options are compared to the other candidates head-to-head for each criterion. Each candidate is awarded points for each head-to-head victory. The candidate with the most points wins.

4.1 Individual Criteria Evaluation of Quarry Site

Ranking scales were established with a range of 1 to 5 with 5 best and 1 worst. The rankings were based on a combination of quantitative evaluation and engineering judgement. If there is a numeric value for the criteria, such as haul distance, the integer value reflects the haul distance. If the criteria are a compilation of values or estimate based on limited data (such as rock quality and quantity) engineering judgement and the quantitative data were used to select the integer value.

Rock Quality: Nearly all of the laboratory tests from the quarry sites show that suitable materials for roller-compacted concrete (RCC) and conventional concrete aggregate along with riprap and road base can be obtained. The durability of materials from each source indicated by the LA Abrasion test (which relates to how the rock will break down during crushing, processing and construction) results were all good. The primary concerns indicated by the laboratory test results are related to the amount of moisture absorption that would occur for materials from each source (which is an indication of porosity that can negatively influence suitability of an aggregate). The most favorable absorption characteristics were found in the South Quarry materials. Aggregate absorption in excess of 3 percent suggests potential impacts to the workability of RCC mixes that ultimately increase cementitious material requirements and cause wider variations in strength of the in-place materials. Materials from the North Quarry have the least favorable absorption characteristics.

Other properties found outside the limits of normal acceptance criteria include specific gravity and alkali silica reaction (ASR). In both cases, mix design strategies are available to address these issues. In all cases, additional explorations, lab testing, and mix design testing are indicated to identify mix requirements affecting construction costs, schedule, and quality control requirements during construction.

The basalt in the North Quarry basalt was described as medium strong to strong, slightly weathered, and slightly vesicular with zones of moderately vesicular. There were two layers of quality basalt in the South Quarry. The upper layer was from 35 to 133 feet deep and moderately strong to very strong with very weak zones, fresh to slightly weathered, with moderately weathered zones. The lower layer was from 146 to 180 feet below a zone of breccia and siltstone and similar to the upper layer of basalt with the exception that it contained siltstone interbeds throughout and was moderately vesicular from a depth of 176 feet to the bottom of the boring at 180 feet. The Huckleberry Ridge Quarry also had two layers of basalt from 0 to 94 feet and 133 to 150 feet with interbedded claystone/siltstone, basalt, and breccia between 94 and 133 feet. Both the upper and lower zones of basalt were moderately strong to very strong, fresh to slightly weathered, with no vesicles.

Table 2 shows the rankings given based on applying engineering judgement after review of the testing data for each site and a summary of the criteria discussed above. It was determined that the difference in the rock quality between sites was fairly tight, however there were differences between the quarry sites that would affect the construction process and associated costs.

Table 2. Rock Quality Criteria

Quarry Site	Rank	Discussion
North Quarry	2	Absorption of aggregate would decrease workability of RCC mixes prepared with this aggregate. This may increase the cement and admixture requirements for the mixes. Least favorable laboratory test results. Relatively high amounts of vesicles.
South Quarry	4	Most favorable laboratory test results. Most workable and lowest cement content mixes can be produced from these materials. Both upper and lower basalt layers contained very weak zones and moderately weathered zones but relatively low amounts of vesicles. Lower basalt layer contained siltstone interbeds.
Huckleberry Ridge	3	Absorption of aggregate would decrease workability of RCC mixes prepared with this aggregate. This may increase the cement and admixture requirements for the mixes. No major zones of weak rock or moderate weathering. No vesicles.

Rock Quantity: The North Quarry has a prominent north–south ridge but the topography falls off on both sides of the ridge and one boring shows there may be a lower limit to the depth of accessible basalt. To obtain an adequate volume, the quarry footprint would likely need to be extended to the minor ridge to the northwest. The depth of the South Quarry may be limited to the upper layer of basalt if further investigation determines that the lower basalt layer that contains siltstone interbeds is not worth removing the siltstone breccia layer in between. However, the topography at the South Quarry would allow for lateral advancement of the footprint into the hillslope to the north to continue to mine the upper, higher-quality basalt layer. At the Huckleberry Ridge Quarry the depth of quality basalt has not been encountered with borings and similarly high-quality basalt has been seen along road cuts to the south. It is conceivable that this site could provide the smallest footprint for the highest quantity of high-quality basalt.

Table 3 shows the rankings based on applying engineering judgement after review of the depth and character of rock from borehole data for each site and a summary of the criteria discussed above.

Table 3. Rock Quantity Criteria

Quarry Site	Rank	Discussion
North Quarry	2	Depth of quality basalt limited Adverse topography would require a large footprint to obtain adequate volume
South Quarry	4	Depth of quality basalt may be limited; further investigation is required Favorable topography allows for limited footprint expansion to obtain adequate volume
Huckleberry Ridge	5	No apparent limit to depth of high quality basalt Potential for the smallest footprint and highest volume

Overburden Removal: The North Quarry has overburden thickness according to the borings ranging from 38 to 75 feet, with an average of 52 feet. The seismic refraction survey line (HDR and Shannon & Wilson, Inc. 2016) shows the primary wave velocity to be about 3,000 feet per second (fps) at the average 52-foot depth. Typically, sound rock has a primary wave velocity in excess of 9,000 fps, which is shown at depths ranging from 60 to 120 feet. This creates some uncertainty regarding the depth of overburden at the North Quarry but at best it will be an average of 52 feet deep. Only one boring in the South Quarry shows an overburden depth of 35 feet. While a single data point also leaves significant uncertainty, the steep topography suggests that the average overburden would be much less than at the North Quarry. A single boring at the Huckleberry Ridge Quarry that shows no overburden and the seismic refraction line (HDR and Shannon & Wilson, Inc. 2016) corroborates this but shows the overburden increasing drastically to a depth of about 50 feet to the northeast. However, the topography to the south is steep and the quarry would be advanced in that direction where there is likely to be almost no overburden.

Table 4 shows the ranks given based on applying engineering judgement after review of the depth of overburden from borehole and geophysical data for each site and summary of the criteria discussed above. It was determined that the difference in the overburden removal criteria between sites was great enough to rank them with more than a single value between the rankings.

Table 4. Overburden Removal Criteria

Quarry Site	Rank	Discussion
North Quarry	1	Significant uncertainty even with several data points Average overburden depth likely to exceed 52 feet
South Quarry	3	Uncertainty because of a single data point Overburden not likely to exceed 35 feet based on topography
Huckleberry Ridge	5	Seismic refraction corroborates the single boring with 0 feet overburden Steep topography in the direction of quarry development suggests that minimal overburden exists

Haul Distance: The haul distance criteria ranked the closest quarry site (North Quarry) at 5 (best) and the furthest (Huckleberry Ridge) at 1 (worst). South Quarry is about twice as far as the North Quarry and Huckleberry Ridge is about four times the distance as the North Quarry therefore receiving a ranking of 3.5, based on the proportional distance between the quarry site from the proposed project site. This distance was used as a surrogate for the cost of transporting aggregate to the construction site. Table 5 shows the rankings given for each site based solely on road miles.

Table 5. Haul Distance Criteria

Quarry Site	Rank	Discussion
North Quarry	5	2.14 miles Closest to the site relatively
South Quarry	3.5	4.3 miles Twice the distance as the North Quarry but half that of the Huckleberry Ridge
Huckleberry Ridge	1	8.4 miles Nearly four times the distance as the North Quarry

Road Improvements and Maintenance: It is assumed that the main 1000 Road is suitable for haul truck traffic so this criterion evaluates only the portion of the smaller roads that would need to be improved for haul trucks to access the quarry site. The total haul road distance for maintenance is also considered in the ranking. The distance of smaller road improvement for the North Quarry and South Quarry is about the same from the main road, whereas for the Huckleberry Ridge Quarry almost the entire length of Huckleberry Ridge Road (Figure 1) with the exception of the last mile would need improvements, thus a large disparity in scoring shown in Table 6.

Table 6. Road Improvement and Maintenance Criteria

Quarry Site	Rank	Discussion
North Quarry	4	About 0.5 mile of improvement
South Quarry	3	About 0.5 mile of improvement
Huckleberry Ridge	1	About 7.5 miles of improvement

Summary Ranking of Quarry Sites

A pairwise comparison process was used to develop weighting factors for each criterion (Table 7). The pairwise comparisons are qualitative based on the range of characteristics of each quarry and experience evaluating quarry sources for similar projects. Table 7 shows a section in yellow with input numbers that provide the basis for calculating the criteria weighting factors. The row heading criteria are compared to the column heading criteria. If the row heading is much less important than the column heading the input value is 1, less important the input value is 2, the same importance the input value is 3, of higher importance 4, and much higher importance 5. Based on the ranking in yellow, the criteria weighting factor is developed. The results of the criteria ranking are summarized in the last two columns of Table 7 and show that the haul distance and rock quality criteria are the most important factors while rock quantity is in the middle and road improvements and overburden removal are the lowest rated.

The final step is to rate each quarry site on a scale from 1 to 5 with 1 representing the least favorable condition and 5 being the most favorable condition. Each rating is then multiplied by the weighting factor and a weighted average score is developed. The quarry rating results are presented in Table 8.

Table 7. Pairwise Criteria Ranking

	Rock Quality	Rock Quantity	Overburden Removal	Haul Distance	Road Improvements	Weighting Factor (Percent)	Rank
Rock quality		**3**	**5**	**1**	**4**	**22**	**2.00**
Rock quantity	**3**		**4**	**1**	**4**	**20**	**3.00**
Overburden removal	**1**	**2**		**1**	**2**	**10**	**5.00**
Haul distance	**5**	**5**	**5**		**3**	**30**	**1.00**
Road improvements	**2**	**2**	**4**	**3**		**18**	**4.00**

Scale:
Importance of the activity in the row to activity in the column where they intersect
1: If the row is much less important than the column
2: If the row is less important than the column
3: If the row has the same importance as the column
4: If the row is more important than the column
5: If the row is much more important than the column

Table 8. Quarry Site Ranking

Project Description\ Weighting Factor	Rock Quality	Rock Quantity	Overburden Removal	Haul Distance	Road Improvements	Weighted Average Score	Rank
	0.22	0.20	0.10	0.30	0.18		
North Quarry	2	2	1	5	4	3.17	Middle
South Quarry	4	4	3	3.5	3	3.57	Best
Huckleberry Ridge	3	5	5	1	1	2.63	Worst

Key: scale 1 to 5; 1 = least favorable, 5 = most favorable.

5.0 Summary

According to the weighting of the criteria presented in Table 7 and the ranking of each site based on those weighted criterion presented in Table 8, the South Quarry is the highest ranked with a weighted average score of 3.57 while the North Quarry has a score of 3.17, and Huckleberry Ridge Quarry has a score of 2.63. Based on these scores of the criteria and weighting factors, the South Quarry is preferred for incorporation into the project configuration and description. The North Quarry is the second rated source and should be retained as a supplemental, and/or backup source for project use. This secondary project source becomes technically and commercially important if further investigations and testing of materials from the South Quarry indicate less favorable quantities or conditions, thus forcing the project into full or partial commercial supply.

6.0 Literature Cited

HDR Engineering and Shannon & Wilson, Inc.

2016 Phase 2 Site Characterization Technical Memorandum, prepared for State of Washington Office of Financial Management and Chehalis Basin Work Group, 39 p.

Shannon & Wilson, Inc.

2019a Rock Quarry Characterization, Potential Aggregate Sources for Chehalis Dam, Chehalis Basin Work Group, Pe Ell, Washington.

2019b Phase 3 Chehalis Dam Geotechnical Data Report, Chehalis Basin Work Group, Pe Ell, Washington.

7.0 Abbreviations list

ASR	alkali silica reaction
District	Chehalis River Basin Flood Control Zone District
Ecology	Washington Department of Ecology
EIS	environmental impact statement
fps	foot/feet per second
HDR	HDR Engineering, Inc.
NEPA	National Environmental Policy Act
proposed project	proposed Chehalis River Basin Flood Damage Reduction Project
RCC	roller-compacted concrete
SEPA	State Environmental Policy Act
Strategy	Chehalis Basin Strategy
TM	technical memorandum
USACE	United States Army Corps of Engineers

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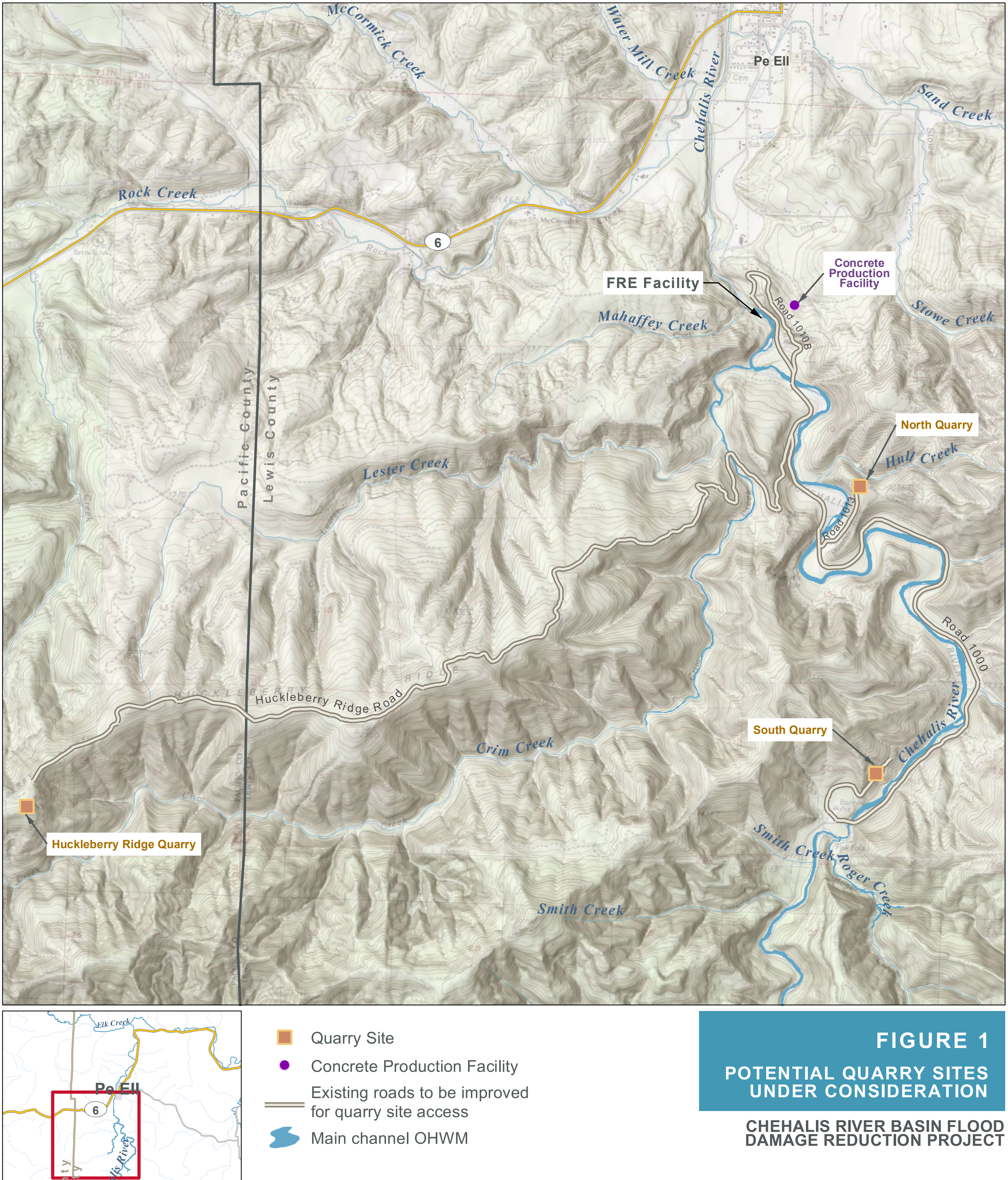
Attachment A. Figures

Annotations added to Figure 2 (pages 1-4) from Shannon & Wilson (2019a).



Quarry Site

Concrete Production Facility

Existing roads to be improved for quarry site access

Main channel OHWM

0 2,500 5,000
Feet

NAD 1983 STATE PLANE WASHINGTON SOUTH FT (FIPS 4602)

FIGURE 1

POTENTIAL QUARRY SITES UNDER CONSIDERATION

CHEHALIS RIVER BASIN FLOOD DAMAGE REDUCTION PROJECT

12/30/2020

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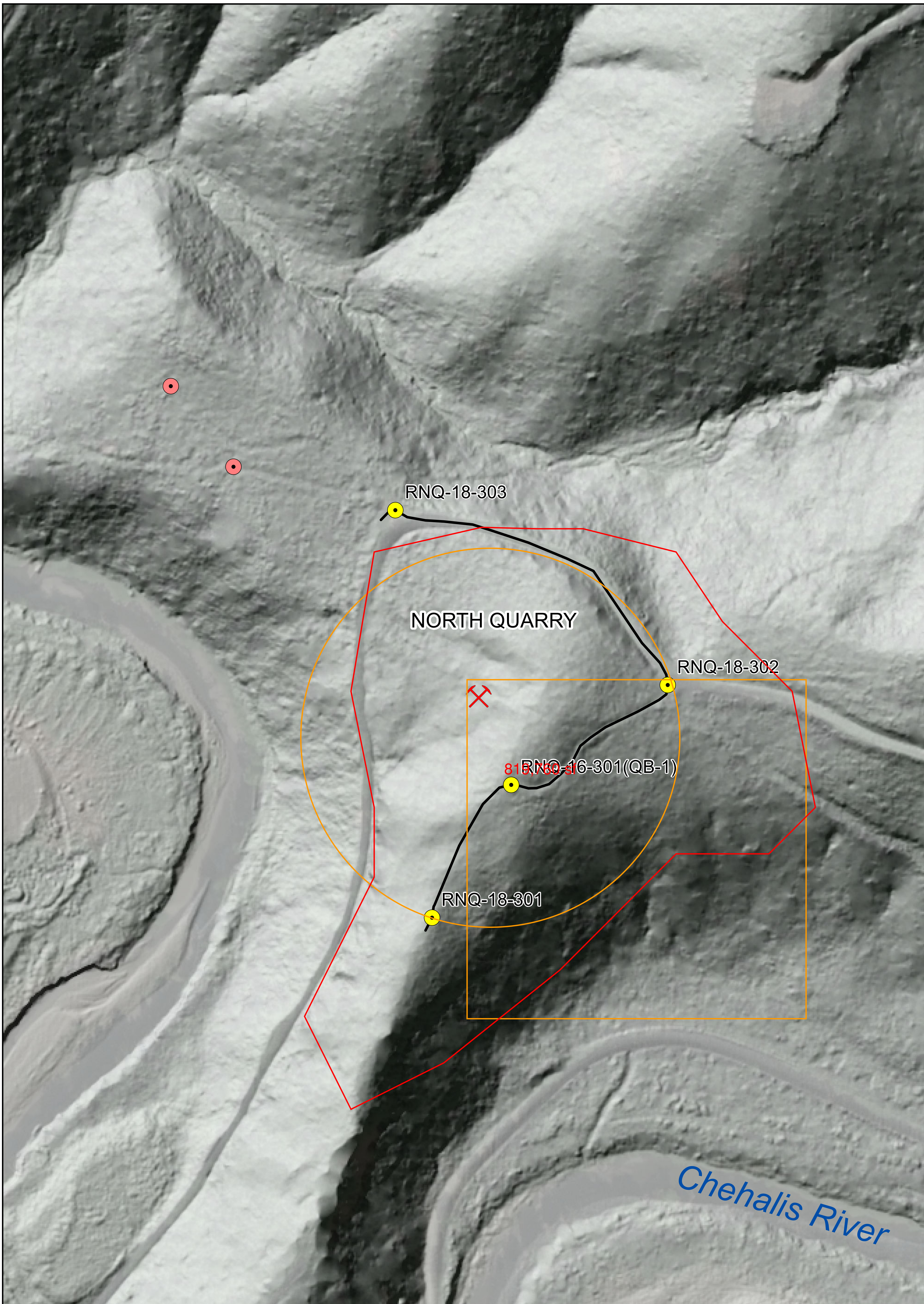

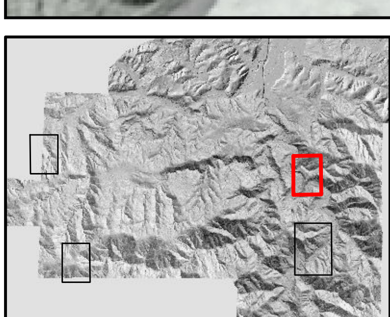

LEGEND

Landslide Location and Designation
LS-26

Quarry Site Location

Profile Location

Potential Dam Site Location

Completed Boring Locations

Recommended Boring Locations

NOTE:
Hillshade generated using ESRI 3D Analyst from LiDAR data provided by HDR. NAVD 88, Illumination 315

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Chehalis Dam
Rock Quarry Characterization
Pe Ell, Washington

SITE PLAN

March 2019

21-1-21897-025

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FIG. 2
Page 1 of 4

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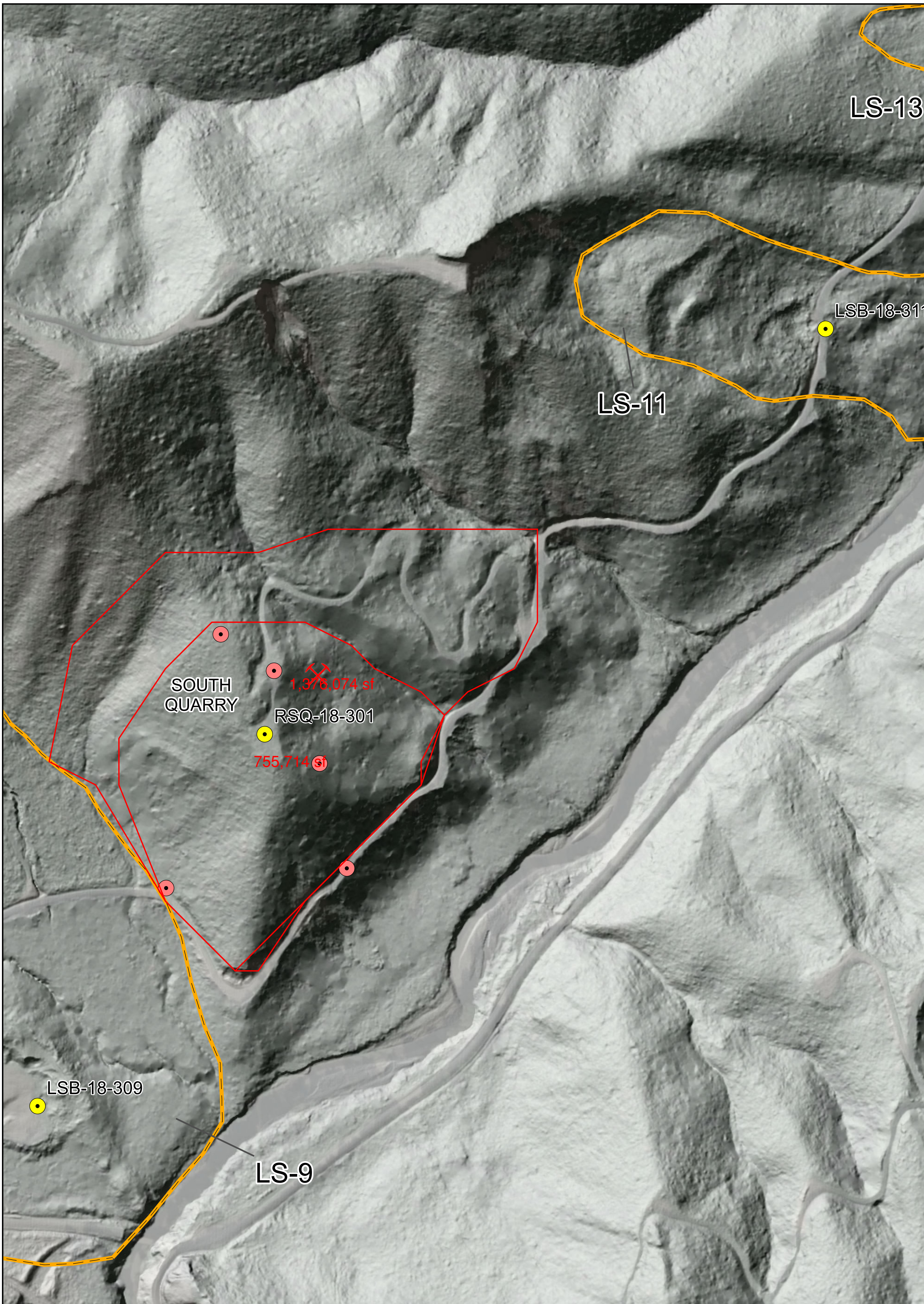

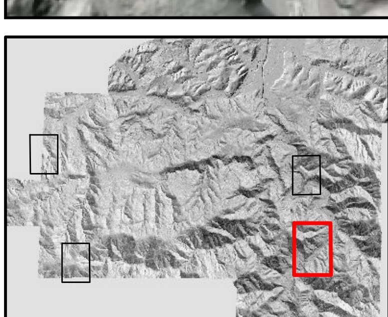

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FIG. 2
Page 2 of 4

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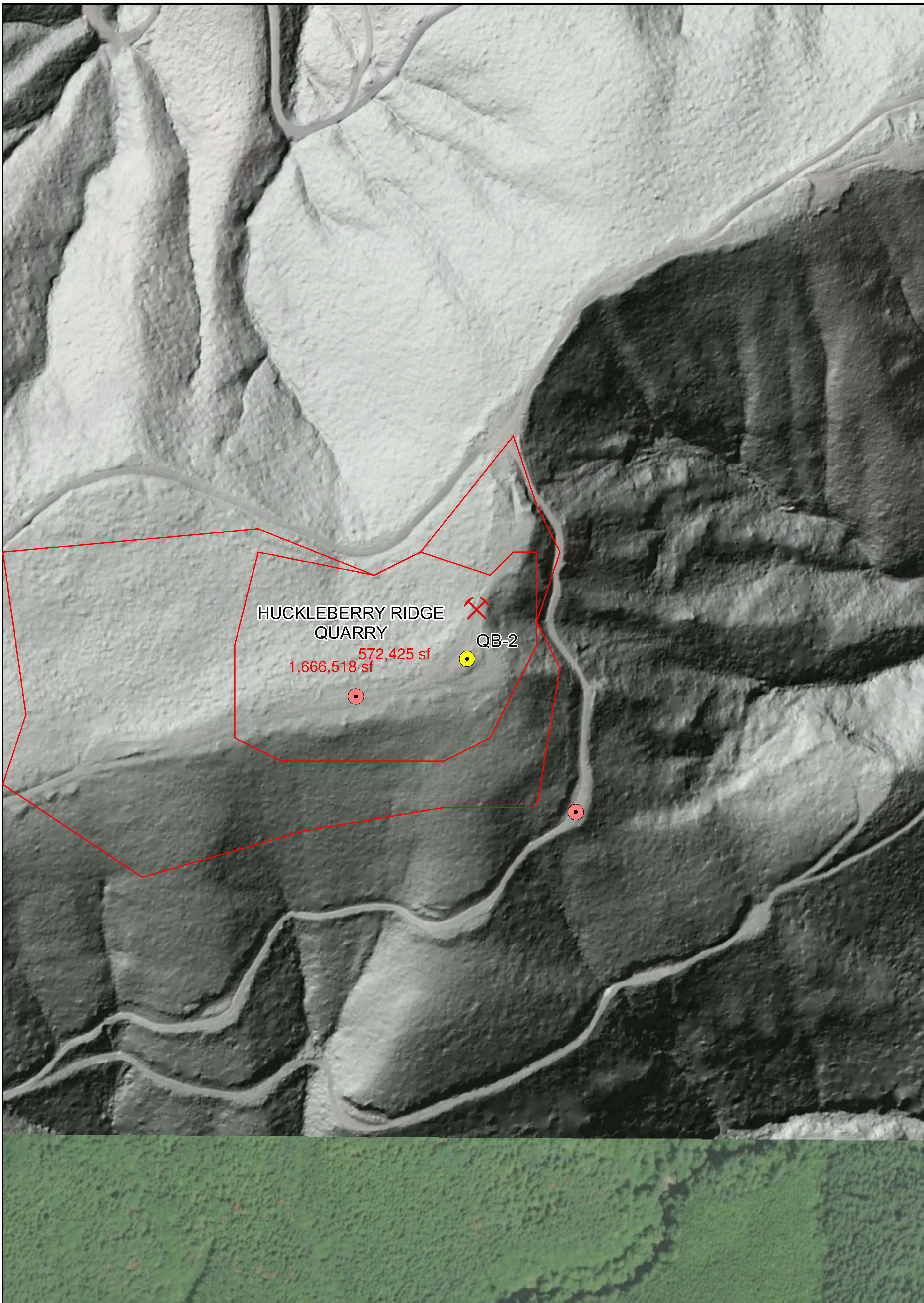

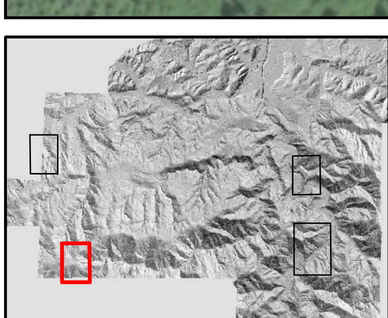

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FIG. 2