

Evaluation of the Fennel Weyerhaeuser Mine within the Fennel Creek Delta;  
McMillian, WA

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## EXECUTIVE SUMMARY

This report is an evaluation of aggregate resources for the 60 acre Fennel Weyerhaeuser active sand and gravel mine located in McMillian, Washington. The Fennel Weyerhaeuser mine is one of two sand and gravel mines located within the 900 acre Fennel Creek delta complex and has been active since 2015. The Fennel Creek delta complex is a series of four nested Gilbert-type deltas. Gilbert-type deltas are coarse grained deltas that form when a high energy drainage intersects a low energy marine or lacustrine environment. Thirty-eight borings have been completed within the delta complex. The USCS soil classification scheme was used to describe the materials encountered in each boring. The regional stratigraphy was developed from open pit exposures and from the information obtained from each bore log. Groundwater data was collected for seventeen of the borings. The USCS and groundwater data were entered into Rockworks 16 software to create a three dimensional model of the Fennel Weyerhaeuser mine. Gradation data from samples taken from the borings was compiled for each of the three major stratigraphic units within the study area.

The 3D model generated from Rockworks 16 utilized a 2H:1V final mine perimeter slope and a 5-foot vertical groundwater buffer. A maximum volume of 14.5 million cubic yards (about 26 million tons) of sand and gravel is available with a 2H:1V final mine slope. Including the groundwater buffer in the Rockworks model reduces the total possible extractable sand and gravel to 8.8 million cubic yards (15.8 million tons).

The extraction plan for the mine will be guided by two equally important aspects, 1) the aggregate products that will be produced, and 2) the infrastructure to support aggregate production. The Fennel Weyerhaeuser mine primarily produces "gravel borrow," a multiuse, free draining, fill material consisting of sand and gravel typically mixed in the proportion of native occurrence, i.e without deliberate mechanical prescriptive blending. In order to produce gravel borrow, the topset and foreset beds will be combined at a ratio of 2:5 respectively. To accomplish the material mixing a 1H:1V mine face will be exposed extending from the upper surrounding land surface to the bottom of the mine. In addition, the mine face will be roughly perpendicular to the front slope of the delta. The foreset beds have alternating debris flow and turbidite facies which have different gradations. By mining perpendicular to the delta face the two facies are combined, resulting in a more consistent feed material.

Mining and conveying infrastructure in place as of March 2017 will be expanded. The mining plan calls for five mining phases lasting a total of 15-20 years. The first mining phase will expose the 1H: 1V face toward the center of the mine and will include the installation of a 900ft conveyor. The second phase will extract the material in the northwest area comprising 10 acres and an additional 200ft of conveyor. Phase three calls for the extraction of 21 acres to the southwest and 900ft of conveyor. Material extraction of phases four and five will vary as mine conveyors will need to be removed from the site.

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## INTRODUCTION

The purpose of this investigation is to develop guidelines for a mining plan for sand and gravel extraction. The mining plan will be for the currently active Fennel Weyerhaeuser sand and gravel mine. The mining plan is based on the geomorphic and stratigraphic structure of the Quaternary age Fennel Creek delta system.

Information derived from direct observation of existing geologic exposures, existing geologic maps, on-site exploratory borings, laboratory test data, and relevant mine regulations were used to construct a 3D stratigraphic model of the Fennel Creek delta area. The model is to be used to help guide mining within the currently active sand and gravel mine. From the model, the total amount of sand and gravel mineral resources can be calculated along with an estimate of total waste products for the Fennel Weyerhaeuser mine. Waste products consist of material that cannot be sold as a portion of a commercial product, but could potentially be used for reclamation of the mine area. Finally, this information will be used to direct mining efforts to minimize variances in sand and gravel gradation and maximize mineral recovery by reducing waste material in the mined aggregate.

The study area is located in Pierce County Washington about thirty-two miles south of the City of Seattle (Figure 1). The Fennel Creek delta complex occupies approximately 900 acres on the eastern edge of the Puyallup River valley (Crandell, 1963; Figure 2). Within the study area there are two major drainages: Canyon Falls Creek in the center of the study area and Fennel Creek at the north edge of the study area. Also within the study area there are two active sand and gravel mines, along with the Tehaleh master plan community, and a trout and salmon hatchery. The focus of this study is the Fennel Weyerhaeuser sand and gravel mine. The Fennel Weyerhaeuser mine is approximately 62 acres and has an average top surface elevation of 460ft. The final extent of the mine will be a large depression in the ground.

## SAND AND GRAVEL NEEDS

Construction aggregates are needed for nearly every construction project. Construction aggregates have a near infinite number of uses; some of the most frequent include, concrete, asphalt, general foundation fill material for roads and buildings, controlled density fill, levees, drainage, erosion control, habitat restoration and a myriad of other construction applications. Sand and gravel deposits in the Puget Sound area are a result of repeated episodes of continental glaciations paired with the erosion of bedrock by high-energy rivers and streams. These rivers and streams originate in the nearby mountains and discharge into the Puget Sound Basin. Construction aggregates are common in the glaciated areas of the Puget Lowlands which extend from Chehalis to the Canadian border, making the relative cost per weight inexpensive compared to other construction aggregate sources like quarried stone or recycled aggregate (Finnie and Peet, 2003). Although plentiful, access to construction aggregates quickly becomes more expensive as sources near major urban areas are exhausted and competing land

development limits additional sources or expansion (Finnie and Peet, 2003). Price for construction aggregates double approximately every 25 miles away from the source (Finnie and Peet, 2003).

The most desirable aggregate sources are concentrated in deposits that are fluvial in nature. The process of fluvial transport sorts the sand and gravel from the fine grained silt and clay which results in a material that requires less processing in order to be marketable. As a result of the environmental regulations in place today, aggregate deposits in or connected to modern streams are generally inaccessible. The modern streams and rivers are considered extremely sensitive in an environmental context due to support of fish resources and for clean water standards. Therefore the preferred source of aggregates are in deposits from ancient glacial streams independent of current topography and surface water.

Demand for construction aggregate in the State of Washington reached an estimated 13.5 tons per person annually in 2000, which equates to roughly 55 million tons annually in total for the state (Finnie and Peet, 2003). Demand for construction aggregates is projected to reach 66 million tons annually by 2020 (Finnie and Peet, 2003). In order to meet the demand, new mines are required, and existing mines need to maximize aggregate removal. The biggest product demand is for gravel borrow.

Gravel borrow is a sand and gravel base building material used as a general engineered fill. The product is described in the Washington State Department of Transportation (WSDOT) Standard Specifications for Road, Bridges, and Municipal Construction Manual as aggregate with a specified grain-size distribution and certain other physical properties; the grain-size distribution is indicated below in Table 1.

Table 1: WSDOT Gravel Borrow Specifications 9-03.14(1)

Sieve		Percent Passing
Opening (inch)	Mesh	
4	4 inch	99-100
2	2 inch	75-100
0.187	No. 4	50-80
0.0165	No. 40	30 max.
0.0029	No. 200	7.0 max
Sand Equivalent		50 min.

All percentages are by weight

Several basic steps are required to produce gravel borrow. Gravel larger than two inches is separated by screening the material. The gravel larger than two inches is typically crushed and sold as other aggregate products. The remaining material is used for gravel borrow. The most difficult requirement of the WSDOT gravel borrow specification is the requirement for 50% of the material to pass the No. 4 (0.187 inch) sieve and have a 50 or greater Sand Equivalent (SE). SE is the relative amount of sand vs silt and clay in a material. A higher numerical SE value

means there is smaller amount of silt and clay relative to sand. In order to meet the gravel borrow specification with minimal processing, the source material needs to consist of a clean, well-graded sand. In most cases, the aggregate will require an amendment of washed sand to meet the gravel borrow specification. There is substantial financial savings by mining in a way that will not require amending gravel borrow with washed sand.

## MINERAL EXPLORATION

Sand and gravel is a quantity-based product, requiring large deposits in order to support market demand. Exploration is undertaken to determine the distribution and extent along with the characteristics of a potential aggregate source. Due to the high initial cost, explorations of aggregate reserves are often limited to simply identifying extent of a deposit, rather than developing a well-supported description of the materials. A typical 100-acre site will have just a handful of boreholes spaced every few thousand feet, along with several dozen test pits.

This type of limited exploration has significant drawbacks. Boreholes spaced far apart require substantial interpretation to evaluate the resource, and may result in significant inaccuracy regarding the nature of the deposit. Test pits are limited to a maximum depth of about 30ft, and so cannot fully compensate for sparse borehole data. This leaves much to chance for the operations planning and capital investment for an aggregate source.

The benefits of a robust understanding of an aggregate deposit are substantial. The principal benefit is the ability to determine the total volume of saleable material at the site. This information will be used in nearly every development decision of the mine. The total volume will allow sizing and design of the processing equipment along with the equipment location and layout. Production planning is based on material description and gradations. Development of a waste materials management plan begins by estimating the waste material volume.

The inclusion of mining related infrastructure also needs to be addressed. Mining related infrastructure includes haul roads, service roads, conveyors, utilities, mineral processing, stockpiles, wash plants, wash water storage ponds, and accessory use facilities like asphalt and concrete batch plants. Ideally the placement of mine infrastructure will optimize mineral extraction and minimize the need for modification during the course of mining.

A 3D model utilizing USCS soil classification and gradation data can be used to evaluate and classify the aggregate resource along with enabling the quantitative estimate of various components and the location of same. The model is also an excellent tool to facilitate explaining the aggregate deposit to others. Rockworks 16 allows for the inclusion of mining limitations such as groundwater buffers, slope stability, and unsuitable material to create an accurate assessment of extractable aggregate. Once the model is constructed, cross sections and other visuals can be created to describe the important changes in an easily understandable way.

Risks for not having an accurate mining plan are extensive. Examples include poor utilization of resource material, creation of material that does not meet required specifications, poor stormwater management, slope stability issues, and potential adverse environmental impacts. Most sand and gravel mines in the Puget lowlands are limited to a depth of about 50ft or involve mining into an existing slope. These common mining parameters result in a mining plan limited by the modes of mineral extraction. The shallow deposits can be mined wherever there is ingress and egress for front end loaders. Mining of existing slopes is limited to bulldozing the face to a conveyor or front end loader. However, for this study a more robust extraction plan is needed due to the high relief of the site, groundwater elevation, variable stratigraphy, and location of fixed mining related infrastructure.

## BACKGROUND

### STUDY AREA LAND USE

The study areas currently contains two active mine sites, a hatchery, and a master plan community. The two mines are operated by Miles Sand & Gravel Company. The first mine, named Fennel Resources, is located at the northern end of the study areas. The second mine and the focus of this study, Fennel Weyerhaeuser, is located near the center (Figure 2). The two mines are divided by Canyon Falls Creek. The processing of material from the mines was designed to work in tandem. The processing of all material is to occur on the northern mine, Fennel Resources, with material mined and conveyed from Fennel Weyerhaeuser via a 1 mile long conveyor.

Intersecting Canyon Falls Creek is a hatchery, owned by Troutlodge. To the south and east is the Tehaleh master plan community. The community is 4,200 acres and has approximately 2,000 residences (Pierce County, 2017). The development of the area is ongoing with an expansion of state highway 162 at the southern end of the study area, which will impact the final mining grade of the Fennel Weyerhaeuser mine.

### ENVIRONMENTAL CONCERNS

#### GROUNDWATER & SURFACE WATER

With any mining operation, it is essential to understand environmental regulations, environmentally critical areas near the mine, and possible environmental impacts. Surface mining in the State of Washington has stringent water impact restrictions. Washington State Department of Ecology regulates water quality for mining operations under the National Pollution Discharge Elimination System (NPDES) Sand and Gravel General Permit. This is the State managed implementation of the Clean Water Act. The Fennel Resources mine crushes aggregate supplied by the Fennel Weyerhaeuser mine. Stormwater is managed on site via groundwater infiltration and is monitored for oil sheen only. If surface water discharges

beyond the mine boundary were to occur then additional monitoring for volume, flow rate, and turbidity would be required. In addition to added water quality restrictions, surface water discharges also bring added oversight from third party groups and a larger chance of environmental impact. Managing stormwater onsite greatly reduces the likelihood of environmental impact.

Mining for both Fennel sites is also restricted by groundwater elevation. The Washington State Department of Natural Resources (DNR) typically requires all aggregate mining operations to leave an unexcavated zone (buffer) a minimum of five feet above the normal high groundwater level. In-water mining (extracting material below the water table) is allowed only with explicit permission from DNR (RCW 78.44). Both Fennel mine sites currently adhere to the groundwater buffers to meet DNR legally mandated reclamation requirements. Due to the DNR groundwater requirements, an accurate assessment of groundwater elevation will be needed to estimate extractable quantities.

## PREVIOUS EXPLORATION

The Fennel Creek Delta complex has been studied the past 30 years by Miles Sand & Gravel Company (2004) and several geotechnical consulting firms. Standard subsurface exploration was performed and material was classified using ASTM Soil classification system, with the exception of Miles (2004), which used a mining specific description. Exploration for mineral resources began in 1988 with GeoEngineers, followed by GeoResources (1997, 2000); Miles (2004) and AESI (2009, 2010). Separate subsurface explorations were performed for development of the Tehaleh wastewater treatment facility by Terra Associates (2006) and state route 162 expansion by AESI (2013, 2015). With exception of AESI reports, the prior data gathered was not included in subsequent reports, because subsequent investigation areas did not overlap or data were not available. In addition, most of the explorations were limited to bore logs and a cross section. For this study the bore logs from all of the aforementioned reports were compiled, representing data collected 1988-2015.

## GEOLOGY

### GILBERT DELTA SEDIMENTOLOGY

Coarse sediment deltas were first described by Grove Karl Gilbert in 1885 at Lake Bonneville, Utah. A Gilbert-type delta forms when a sediment-laden river discharges into a lacustrine or low energy marine environment (Gilbert, 1885; Gobo, 2014). The confluence of the high-transport-energy fluvial system with the low-energy (or static) marine or lacustrine system causes the river-borne sediment to deposit quite rapidly in the form of a depositional delta. Within a typical delta there are three distinct depositional zones called the topset, foreset, and

bottomset beds (Figure 3). The three zones can be distinguished by the distinct stratigraphic and gradation changes in each unit (Barell, 1912).

#### TOPSET

The topset beds are comprised of nearly horizontal coarse gravel sediment related to normal alluvial and fluvial deposition. As the high energy river channel intersects the low energy lacustrine or marine environment, the largest sediment is deposited and the finer sediment is carried out. This results in a coarse sediment deposit with a low fines content. The size of the sediment is dictated by the force of the flow. Shallow crossbedding is formed during deposition of the coarse non-cohesive sediment. Topset beds form at the water surface elevation of the receiving waterbody. As such, topset beds provide an excellent record of base level changes for the receiving waterbody level (Gobo and Ghinassi, 2014). The topset beds transition to foreset beds with the intersection of the fluvial and lacustrine depositional environments (Gilbert 1885).

#### FORESET

Foreset beds form when the receiving water body is significantly deeper than the stream that transported the sediment. Foreset beds consist of sand and gravel layers deposited on a slope, i.e. with an initial "dip". The dip of the beds can range between 10 and 25 degrees (Barell, 1912). The angularity of the sand and gravel along with the total sand content present, impacts the final angle of repose. The foreset layer of a Gilbert type delta is the thickest and can have high variability in vertical thickness depending on the variation in base level. The foreset beds were initially thought to be massive, fairly homogenous units with downward fining as Figure 3 shows (Gilbert 1885; Gobo 2014). Figure 4 shows additional stratigraphic variations contained within foreset beds. Foreset beds have since been determined to have two significant facies; debris flow-dominant and turbidite-dominant.

The variation between the standard depositional facies and turbidite dominate facies corresponds to base level elevation (Gobo and Ghinassi, 2014). As base level decreases the foreset beds transition from depositional facies to turbidite facies. As base level decreases sediment that was below base level is now above base level. The lower water level triggers slope failure, largely as turbidite sequences. The turbidite facies lacks the normal transition from coarser sediment to finer sediment as would be expected in the foreset bed. The turbidites are typically high density flows, which form graded beds upon settling (Bauma, 1962). The changes in deposition result in interbedded layers, as shown in figure 5. At constant base level, normal depositional facies dominates. (Gobo and Ghinassi, 2014). The foreset beds will compose the largest portion of the mine face.

#### BOTTOMSET

The bottomset beds form as the tail end of the delta sediment is deposited in front of (offshore of) the foreset beds. The transition from foreset to the bottomset beds can vary between a gradual transition and a more abrupt transition (Gobo, 2014). The transition will also be

impacted by the depositional vs turbidite facies like the foreset beds and by the energy level present in the receiving water body. For example, in a static water lacustrine environment the transition may be quite different from that in a tidal, or marine current situation. The presence of the turbidite facies will increase coarse sediment content and contribute to a more abrupt transition. The low energy depositional facies will contribute to a gentle transition (Gobo, 2014). The fining of material is also influenced by the sediment plume from the river into the receiving water body. The different densities, due to temperature of the basin vs the temperature of the river, of the receiving water and the incoming water causes finer sediment to stay suspended longer, thusly depositing further away (Nemec, 1995). Due to the thickness of the foreset beds, bottom set beds are not encountered in the Fennel Weyerhaeuser Mine.

## REGIONAL GEOLOGY

The study area is located in the Puget Lowlands in western Washington. The Puget Lowlands have been repeatedly glaciated. Each period of glacial advance and recession altered the landscape and surface geology (Booth et al., 2003). The Cordilleran Ice Sheet last advanced through western Washington during the Vashon Stade of the Fraser glaciation during the late Pleistocene, approximately 25,000 to 13,500 years before present (Porter and Swanson, 1998). The resulting geology is glacially derived and generally varies between outwash, till, and lacustrine deposits. The target deposits for aggregate are typically related to the most recent glacial transgressing or regression. Older deposits are mined when the aggregate is accessible and not covered by more recent drift. The scale and location of such deposits varies widely depending on location and depositional influences (Booth et al., 2003).

## LOCAL GEOLOGY

Surface geology in the study area is described as a Quaternary glacial delta overlaying several mudflow deposits and is confined by the Puyallup River Valley (Crandell, 1963). The Fennel Creek deltaic deposit was formed during the late stages of glacial Lake Puyallup (Crandell, 1963), as ancient Fennel Creek deposited glacially derived sediment into the lake.

Prior mapping at 1:24,000 identified just two major units in the study area: 1) proglacial stratified drift (Qpa) and 2) ice-contact stratified drift (Qit) (Crandell, 1965; Figure 6). Qpa is described as valley-train and delta deposits, indicating clean sand and gravel. Ice contact drift is typically much more variable, with some areas resembling till and others outwash. The geologic map (Figure 6) shows the undifferentiated stream deposit (Qpa) limited to the north and south of the drift plateau, labeled Qit. However, the current LIDAR imagery shows the Qit plateau is instead likely the oldest delta deposit for the Fennel Creek delta system with stream deposit (Qpa) (PSLC, 2011).

Within the study area there are four distinct deltaic terraces, delineated by elevation (Figure 7). The terrace elevations record the base level elevation of glacial Lake Puyallup and associated with the recession of Puget Lobe of the Cordilleran Ice sheet and related glacial outburst floods (Crandell, 1963; Troost, 2007). With the recession of the ice sheet, new outflow channels were formed. The Ohop Valley was the original drainage for Glacial Lake Puyallup, followed by lower drainages through the Bradley, Kirby, and Muck creek channels resulting in abrupt lowering of lake level (Troost, 2007). With each water level change, Fennel Creek incised into pre-existing delta deposits, building a new delta at lower elevation. The result is a nested sequence of delta deposits, with older delta surfaces at higher elevation, and younger surfaces lower (Figure 7).

#### CURRENT MINING OF FENNEL WEYERHAEUSER

The Fennel Weyerhaeuser mine had been extracting construction aggregate since August 2015. Mining began in the northeast corner, moving the active mine face to the west before moving south. As the active mine face moved south toward the center of the mine, the percentage of sand decreased. To supplement sand, a second active face was started at the far southern extent of the mining boundary where prior exploration had shown a deposit of clean sand. As of February 2017, mining is now focused on the southern extent of the mine.

## METHODS

#### MAPPING AND GEOLOGIC DESCRIPTION

Observations were made of the exposed mine face during two site visits in July 2016 and January 2017 at the Fennel Weyerhaeuser mine. The exposed outcrops were described and paired with available bore log data for the site. During July 2016, mining was confined to the northern quarter of the site. The depth of mining was 20ft below original grade. By January 2017, mining had expanded extensively, with the pit floor an average 30ft below original elevation. As of February 2017, the deepest area of the mine was approximately 60ft below original elevation. Four samples were taken to determine gradation of the topset and foreset beds. Two samples were taken in the top 15ft for the topset beds and two samples at approximately 50ft for the foreset beds. Figure 2 shows the locations of the four samples.

#### BOREHOLE DATA AND MODELING

The first portion of the investigation began by compiling all the available geologic data for the site. 38 borings have been conducted within the 900 acre Fennel Creek delta (Figure 2). The borings were completed for resource evaluation or for geotechnical needs for future county infrastructure. Borehole data was described generally using the Unified Soils Classification System (USCS) in both exploration types, with the exception of borings done by Miles. Miles

used a mining specific description system. Samples were taken during borings at spot intervals determined to be representative of the unit by the geologist logging the cores. The locations, USCS classification, and unit thicknesses were input into a Rockworks 16 3D modeling software for all 38 borings. Groundwater elevations were also added when available. Elevation raster from the Puget Sound Lidar Consortium data was then added to give accurate topography. Gradation data were compiled for topset, foreset, and bottomset beds to distinguish each unit by gradation.

Rockworks 16 is a geologic modeling software that allows for the creation of subsurface block diagrams based on classification characteristics e.g. color, geologic or other scientific data or other properties imported into the software (Rockware, Inc.). To create the model framework for this study the input data included the boring locations (northing and easting), the ground surface elevation, and depth of the borehole. The resulting block model displays one selected variable. Multiple block models can be input to create a single output. The nature of the mining requires multiple variables to be met in order to describe the material accurately.

The model was constructed to incorporate all the data available for all of the Fennel Creek Delta complex. Once the data was entered, the areas out of the Fennel Weyerhaeuser mine boundary were clipped. The model was then constructed with the 2 (Horizontal) to 1 (Vertical) mine face limit included to get a total possible extraction amount.

A second model was then constructed to show ground water elevation. Groundwater data from 17 different wells were input into the Rockworks 16. The groundwater elevations were altered with data from a 2015 AESI study. Groundwater contours produced from the Rockworks analysis were modified to match the AESI values on the southern end of the Fennel Weyerhaeuser mine. This model was then combined with the 2H:1V finished slope and the 5ft groundwater buffer to determine the total extractable volume. Elevation contours from this model were then extracted and overlaid on the DNR approved mine reclamation plan. The resulting model gives the total extractable volume.

## GRADATION

Gradation data was available for 74 samples representing portions of 18 boreholes. Gradation data were compiled and categorized based on the vertical position in the Gilbert Delta, i.e. topset, foreset, and bottomset bed. The thickness of the topset beds were determined to be 20-30ft thick in the two active mines from observations during site visits along with a natural break in gradation data from courser gravel to finer gravel. The sample from the different boreholes were then segregated into one of the four deltas in the study area. The gradation data was then compared between each delta. Based on the available gradation data, an average gradation was determined. The compiled gradation data was then compared to the four samples taken from January 2017 at the active mine face. This was done to validate the results of the compiled gradations to the onsite samples.

# RESULTS

## STRATIGRAPHY

Four cross sections were constructed to show the stratigraphy of the overall study area as well as individual deltas (Lines in Figure 7). The first cross section extends from the north to the south of the study area (Figure 8, blue line in Figure 7). In that cross section, the Fennel Resources and Fennel Weyerhaeuser mines are highlighted along with another delta located in the Tehaleh owned area. Figure 9 (Yellow line in Figure 7) shows the northwest to southeast cross section for the Fennel Resources mine. Figure 10 (Red line in Figure 7) shows the west to east cross section for the Fennel Weyerhaeuser mine. The horizontal changes in USCS soil classification shown in the cross sections are minimal within the Fennel Resources, Fennel Weyerhaeuser, and the Tehaleh deltas. For both mines, the stratigraphy becomes more variable in gradation and USCS soil classification closer to the active creek channels. Both mines have a homogenous central portion (denoted in green on the figures) which is described as a well-graded gravel with sand or a poorly-graded gravel with sand. These areas are interpreted to be the topset and foreset beds of the delta complexes, and have an underlying silty unit (shown in red), interpreted to be the bottomset beds. The Tehaleh delta (Figure 11, light blue in Figure 7) has a much more homogenous and thinner delta system.

Summarizing from the borehole data and stratigraphic modeling: The Fennel Weyerhaeuser site has three units with significant gradational changes that will impact material for processing. These areas follow the stratigraphy of a classic Gilbert Delta: topset, foreset and bottomset beds. Samples taken from different elevations within the delta complex show distinct gradations (Figure 12). Table 2 shows the diameter values.

Table 2: Gradation comparison between topset foreset and bottomset beds for all deltas

Percent Passing Diameter	Grain Size (inch)		
	Topset	Foreset	Bottomset
D86	2.2	1	0.6
D50	0.65	0.19	0.033
D10	0.02	0.009	--

The topset beds were interpreted to extend down 20-30ft below the original top surface at all four delta sequences. The bore logs did not denote the change in topset and foreset beds based on the Unified Soils Classification System designation that was used to describe the material. However, a difference in foreset and topset beds was determined with gradation data along with direct observations of the Fennel Weyerhaeuser mine face and Fennel Resource former mine face. Table 2 describes the beds by the D86, D50, and D10. As Table 2

and Figure 12 show the topset beds are the coarsest material. The topset beds were visually delineated in the Fennel Weyerhaeuser active mine face by an undulating layer of 18-36 inch boulders along with a change in depositional slope angle from 2-5 degrees in the topset beds to 15-25 degrees in the foreset beds (Figure 13). As of January 2017, the majority of the topset bed material has been mined out and the only remaining portion is eight acres to the southwest and ten acres in the northwest corner.

The second major layer, and largest by volume, are the foreset beds. The foreset beds extended from the undulating boulder layer at 20-30ft depth to approximately elevation 225ft. The foreset beds, as described by Gilbert, increase sand and fines content with depth (Gilbert, 1885). Cross section shown in Figure 10 shows a change in material at approximately elevation 370ft from well-graded sand and gravel (SW-GW), to gravel with silt (GM). Three gradation samples were taken of the foreset beds within the active mine faces. The gradation data shown shows downward fining of the three samples (Figure 14). Within the mining area, average grain size and SE both decrease with depth.

The third significant unit is a fines-dominant layer below the topset and bottomset beds. This is identified as the red ML layer in figure 10. This layer occurs at elevation 285ft and contains interbedded layers of fines, sand, and gravel. Since the groundwater follows this boundary it will not be mined.

One other unit within the site boundary is described as a mud flow (Crandell, 1963). This unit is only shown within the Fennel Creek valley and Fennel Weyerhaeuser mine. The 1:24,000 geologic map shows it is overlain with Quaternary sediment. The unit is described as the Alderton Formation, which contain highly consolidated mudflow deposits, originating from Mt. Rainer (Crandall, 1963). The Alderton Formation is exposed in the Fennel Resources mine (Figure 6). The exposed face of the Alderton Formation is steep, with a slope of .5H:1V. The steep face of the Alderton formation runs roughly north and south through the eastern portion of both mines. Groundwater is confined by this layer resulting in a rapid change in groundwater elevation as the groundwater moves from east to west.

## GROUNDWATER

The largest impact to mining comes from the elevation of groundwater. Groundwater for the site flows from east to west through the fluvial and delta sediment. The western portion of the Fennel Weyerhaeuser mine has relatively thin veneer of fluvial sediment, 20-30ft thick, over the Alderton formation. The groundwater for the site travels through this layer before rapidly reducing in elevation once entering the delta sediment. 17 borings had groundwater elevation data, but none had hydraulic conductivity data. Since there was no hydraulic conductivity data, the groundwater elevation data entered into Rockworks provided a linear interpretation of groundwater. AESI created groundwater model for the Rhodes Lake road expansion, utilizing hydraulic conductivity data (AESI, 2015). Figure 15 shows a comparison of the groundwater

elevation between the Rhodes Lake road study, and the groundwater elevation for this investigation. Since the AESI groundwater elevations were imported into Rockworks to determine the extractable material volumes. Figure 16, shows the groundwater elevation and final mine grade overlaid on cross section C-C'. The slope of the eastern side of the mine is reduced from 2H:1V to 4H:1V. There will be seasonal variation in groundwater elevation, DNR however requires 5ft above normal seasonal high water. This will be measured with two existing wells along with possible future installation of additional monitoring wells as mining occurs. The reduced slope also reduces the maximum depth of the mine from. The groundwater buffer requirements reduced the mine depth by 80ft to an elevation of 295ft. In addition, the angle of the eastern slope was reduced to match the slope of the groundwater plus 5ft

### VOLUMETRICS

The total volumes were calculated exclusively based off the property boundary and the 2H to 1V perimeter slope required by DNR for final reclamation. The total depth of the deposit extends from an average elevation of 460ft to an elevation of 215ft. The total volume was then recalculated based on the DNR buffer requirements for groundwater, (mining must stay 5 ft. above water table). Figure 18 shows the total extent of the mining area based on the groundwater restrictions. Table 3 gives extractable material volumes for the site incorporating groundwater elevation. The groundwater elevation reduces the total extractable material by 40%.

Table 3: Material Volumes

	Volume (yrd <sup>3</sup> )	Weight (Tons)
Total Aggregate Reserves	14,518,519	26,133,333
Extractable Aggregate Reserves	8,792,667	15,826,800
Waste material	8,792	15,826

Waste material volume was calculated based on the total fines content of the processed material. Currently all of the material extracted is being incorporated into a product resulting in no waste material. However, an aggregate wash plant is currently being constructed and it will generate nearly all of the waste product, as fines are washed from sand and gravel to meet SE requirements. The waste volume estimates were made calculating by assuming 1% of the total material volume will be waste material. This is an estimation based on the expected split of washed and unwashed material. However, the inclusion of wash water in the removal of the silt and clay will cause the volume to vary enormously. The usefulness of the waste material volume and weight estimates is low as there is high variability for the percentage of washed and unwashed material along with the amount of water used in the washing process.

## MINING PLAN

The contours of the existing mining plan were overlaid with the final contours derived from the Rockworks model, Rockworks groundwater model, and revised groundwater information from AESI 2015. Figure 18 shows the proposed final mining grade. Due to groundwater elevation, the total depth is reduced 80ft from the total possible depth and the eastern slope is much more gradual compared to the expected 2H:1V slope. The current locations of the material feed belts are shown along with the proposed location of the conveyors needed to reach the extent of the mining area.

Based on the cross section and gradation data, mining should occur in five phases. Excavation for the location of the conveyor needs to occur first. Figure 18 shows the proposed mining stages along with proposed locations for conveyors. The conveyor excavation will extend to the bottom elevation of the mining area and will cut perpendicular to the depositional front of the delta sequence. Conveyors have a maximum angle of 9 degrees in order to service them with standard equipment. This allows for a mine face that exposes the alternating debris flows and turbidity current allowing for mixing of the two units. Inversely, mining parallel to the depositional front would expose either debris flow layers or turbidity current layers resulting in a less consistent feed material.

Phase two will mine the vertical face north of the end of the conveyor from phase one. This will allow for the mixing of the two facies of the foreset bed and the inclusion of the topset bed. Figure 19 shows the mining phases along with the areas of topset beds remaining. An additional 100ft of conveyor will need to be added during mining. Phase three will replicate phase two, but will require approximately 900ft of conveyor and will have a smaller volume of topset bed, as mining the topset bed in the south to supplement the material removed during phase one.

Phase four and five will be the final mining phases. The life of the mine along with the final use will impact if and how the material will be removed. As urban expansion occurs, it could make more financial sense to use this material create level areas for housing or commercial space. If extraction of the material does occur, it will require the removal of conveyors from phases one, two, and three. Phase 5 will require the existing conveyor to be removed as the mine face moves from south to north. There is a high likelihood the mining of phases four and five will deviate from the expected extraction plan due to surrounding land use.

## DISCUSSION

The Fennel Weyerhaeuser mine area is located within a very complex depositional system. The complexity of the system impacts resource assessment in several ways and therefore the

extraction plan. The focus of aggregate production is on gravel borrow which requires the material to meet the gravel borrow specification stipulated by the WSDOT. The sand and gravel currently being mined does not meet the specification. In order to meet the gravel borrow specification without amending the mined material with washed sand, a mining plan that mixes different parts of the deltaic units is needed.

The two mineable units present in the Fennel Weyerhaeuser delta are the topset and foreset beds. The bottomset beds are below the maximum depth of the mine. The topset bed shows little change in gradation or thickness over the extent of the site. The foreset beds show more variation vertically, as well as east to west horizontal variation as delta deposition altered from the standard depositional facies to turbidity facies.

A vertical mine face will allow for mixing of cleaner coarser material present in the topset and upper foreset beds with finer material present in the lower foreset beds. The gravel borrow SE 50 requirement can be met by increasing the sand fraction more than the fines fraction of the material. As depth is increased the fines content will also increase. Aggregate feed material at a ratio of 5 units of foreset to 2 units of topset and upper foreset beds will be very close to the WSDOT Gravel Borrow specification. As of March 2017, topset beds remain only in an 8 acre section to the very south of the mine and a 10 acre section of at the northwest corner (Figure 19). The remaining topset beds have already been removed from the site. The southern 8 acres of the mine consists of a well graded sand (SW) with a high SE, which as of March 2017 is used to mix with other feed material in order to meet specifications. The top 30ft of the northwest corner consists of a sand matrix material (SW/SP) that transitions to the expected gravel matrix (GP/GW) material of the foreset beds. Mixing this with foreset beds will also raise the SE.

The preferred approach would have been to start at the eastern edge of the mine boundary and follow the groundwater to the west. The face of the mine slope during mining is stable at a 1:1 slope. By transecting the delta deposit perpendicular to the depositional face of the foreset beds, the interbedded normal depositional and turbidite facies would be exposed. The large exposed face would allow for the most consistent feed material possible. However, since mining is underway and infrastructure is already in place, a modified approach will be required.

To compensate for the lack of topset beds, a vertically phased mining approach will need to be undertaken. Figure 18 shows the phasing. In order to balance the material, the depth of the mine will need to be increased before expanding laterally. The sand area at the south will continue to be added until it is depleted. The northwest corner will then be mined to supplement clean sand. A conveyer will need to be added at a 9 degree angle, which equates to 1200ft of conveyors as shown in Figure 18. Mining will be done at a 1 to 1 slope until final contours are met to conform with the required 2H:1V slope. Once more vertical face is open, a more consistent material can be mixed by dozing material off the slope, mixing the cleaner material at the top with the dirty sandy material at the bottom.

The most unexpected issue that came from the analysis is the impact of groundwater to mining. The mining contours were adjusted match groundwater elevation from the 2013 AESI report and to include the 5ft groundwater buffer. Total mine depth has been reduced from elevation 220ft to elevation 300ft. In addition, the eastern slope of the mine has to match the groundwater slope. The limits in place from groundwater will reduce the total amount of material from 24 million to 15 million tons. The groundwater will limit the total extraction of material.

Finally, there are shortcoming to the modeling itself, on which these interpretations are based. The accuracy of the 3D model is predicated on the data that it has been given. The original groundwater elevations were calculated via equidistant linear distribution because no hydraulic conductivity data was available for the site. The resulting groundwater elevations were representative of a homogenous material. In reality the hydraulic conductivity changes significantly between the coarse grained delta material and the underlying Alderton formation. The groundwater elevations were changed to reflect the data present in the AESI 2015 report, to more accurately represent the known groundwater behavior.

## CONCLUSION

As noted above the purpose of this investigation was to develop a mining plan based on the geomorphic and stratigraphic structure of the Fennel Creek delta system using a 3D model. The total extractable amount of aggregate was estimated to be 8.8 million cubic yards (16 million tons) of aggregate, compared to the total possible amount of aggregate of 15 million cubic yards (26 million tons). The significantly reduced aggregate quantity is a direct result of higher than expected groundwater elevations caused by low permeability soils under the targeted mining material on the eastern extent of the mine and at depth.

Mining will need to occur as vertical as possible since the topset and foreset beds need to be mixed at a ratio of 2:5 in order to meet gradation and SE required by the gravel borrow specification. Presently only the southern 10 acres and northeastern 8 acres of the mine have topset beds remaining. The southern area can be used to amend as mining continues north and down in elevation. Once mining reaches the north central portion of the mine, the material from the topset beds in the northeast corner can be used to supplement for the needed clean sand.

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Figure 1: Location Map

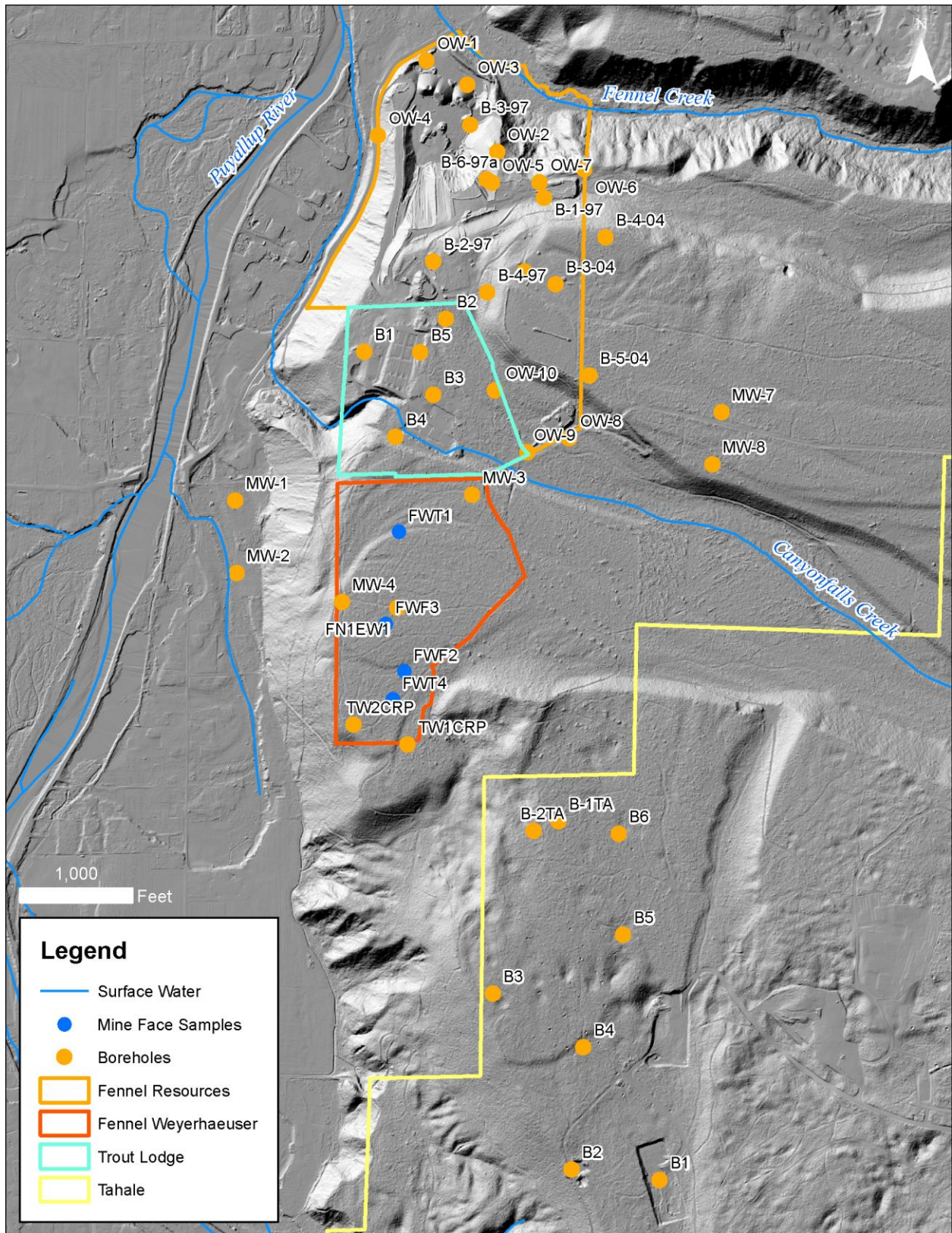


Figure 2: Study Area Map Hill shade base map showing surface water, mines, and other areas of interest (PSLC, 2011)

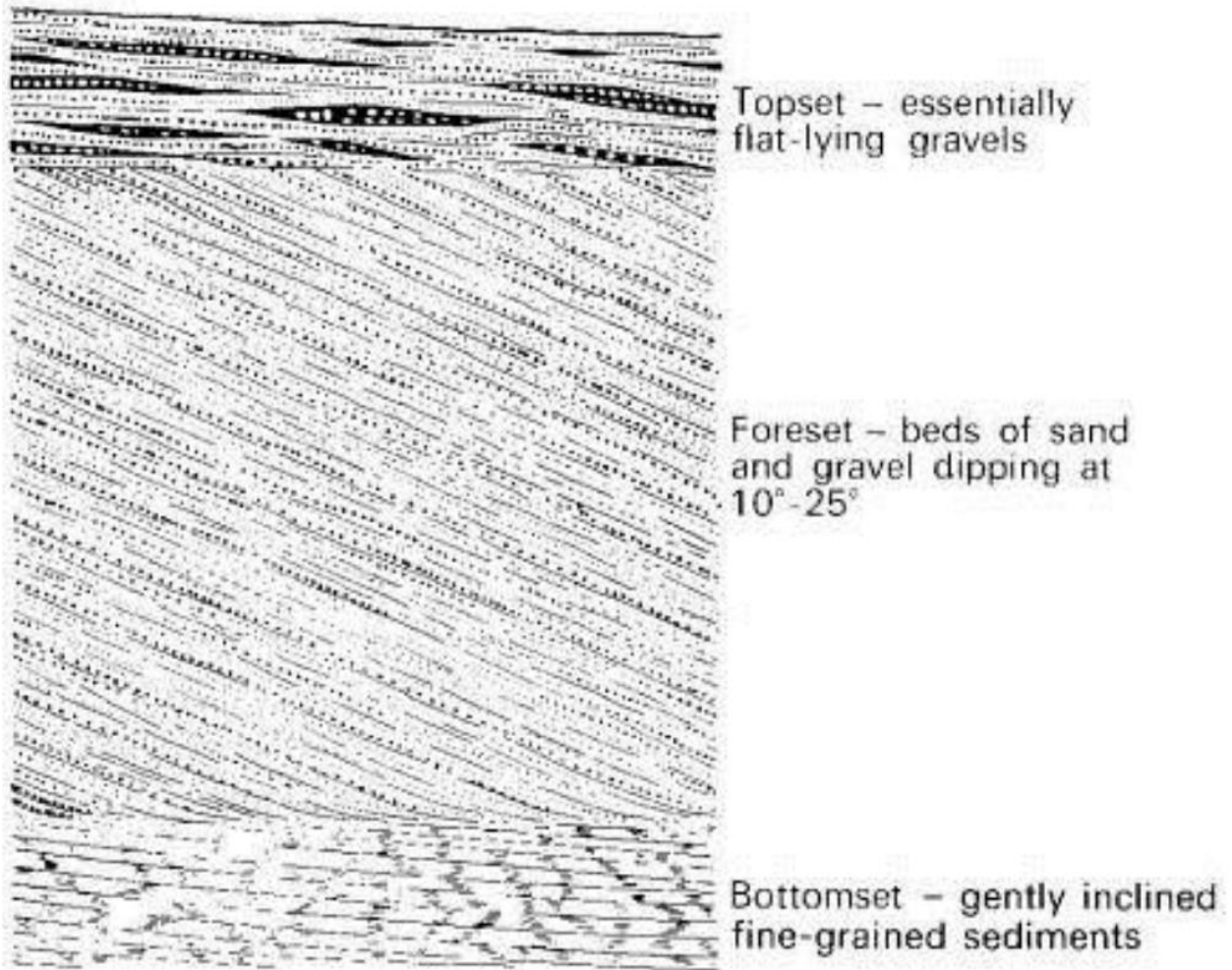


Figure 3: Basic cross section of a Gilbert-type delta (Gilbert, 1885; Gobo, 2014)

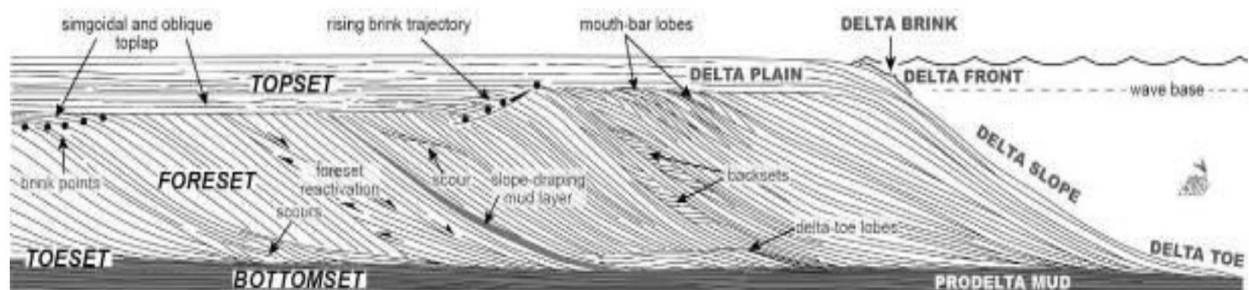


Figure 4: Complex cross section for a Gilbert-type delta (Nemec, 2007; Gobo, 2014).

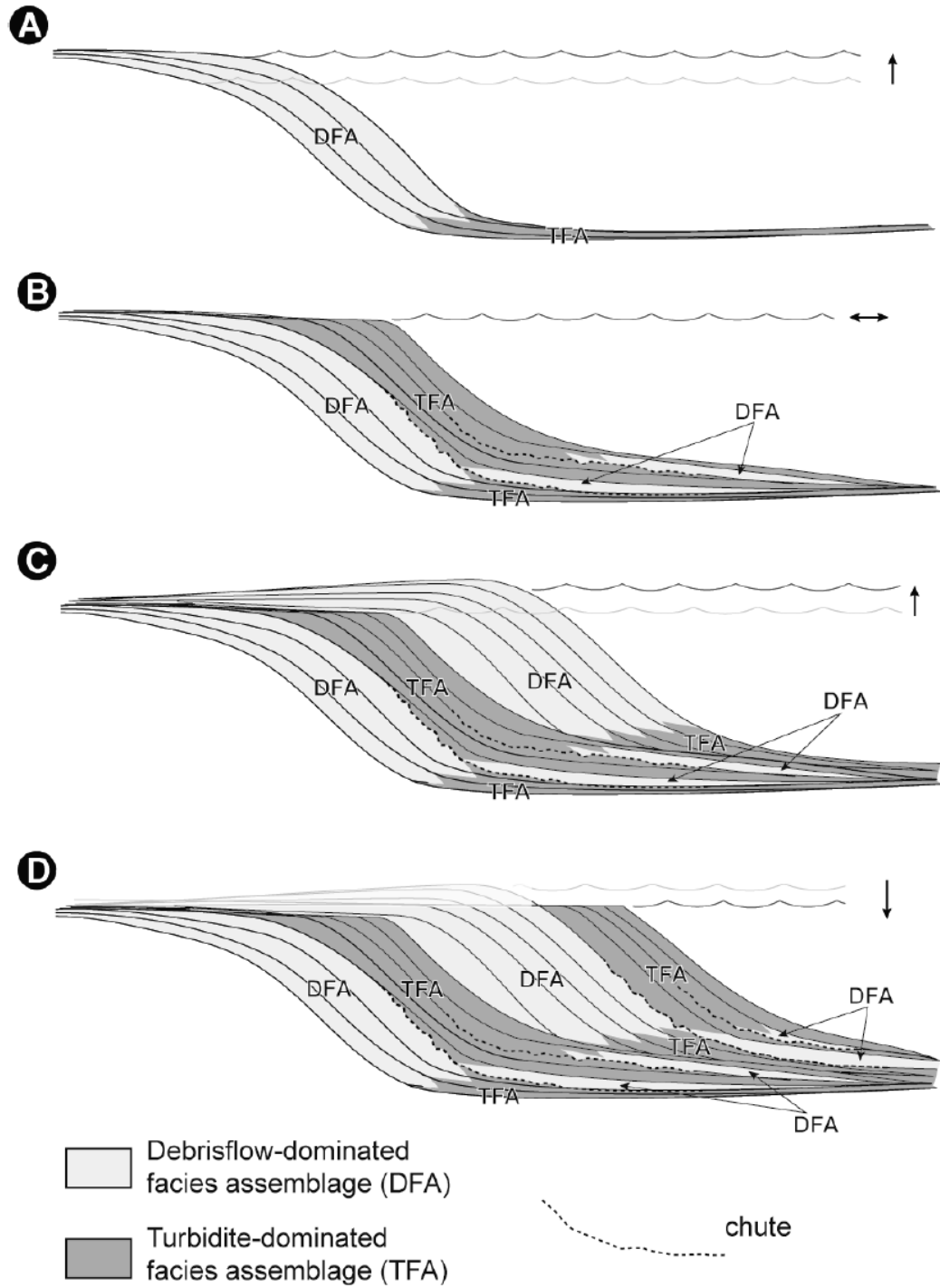


Figure 5: Foreset bed facies (Gobo, 2014)

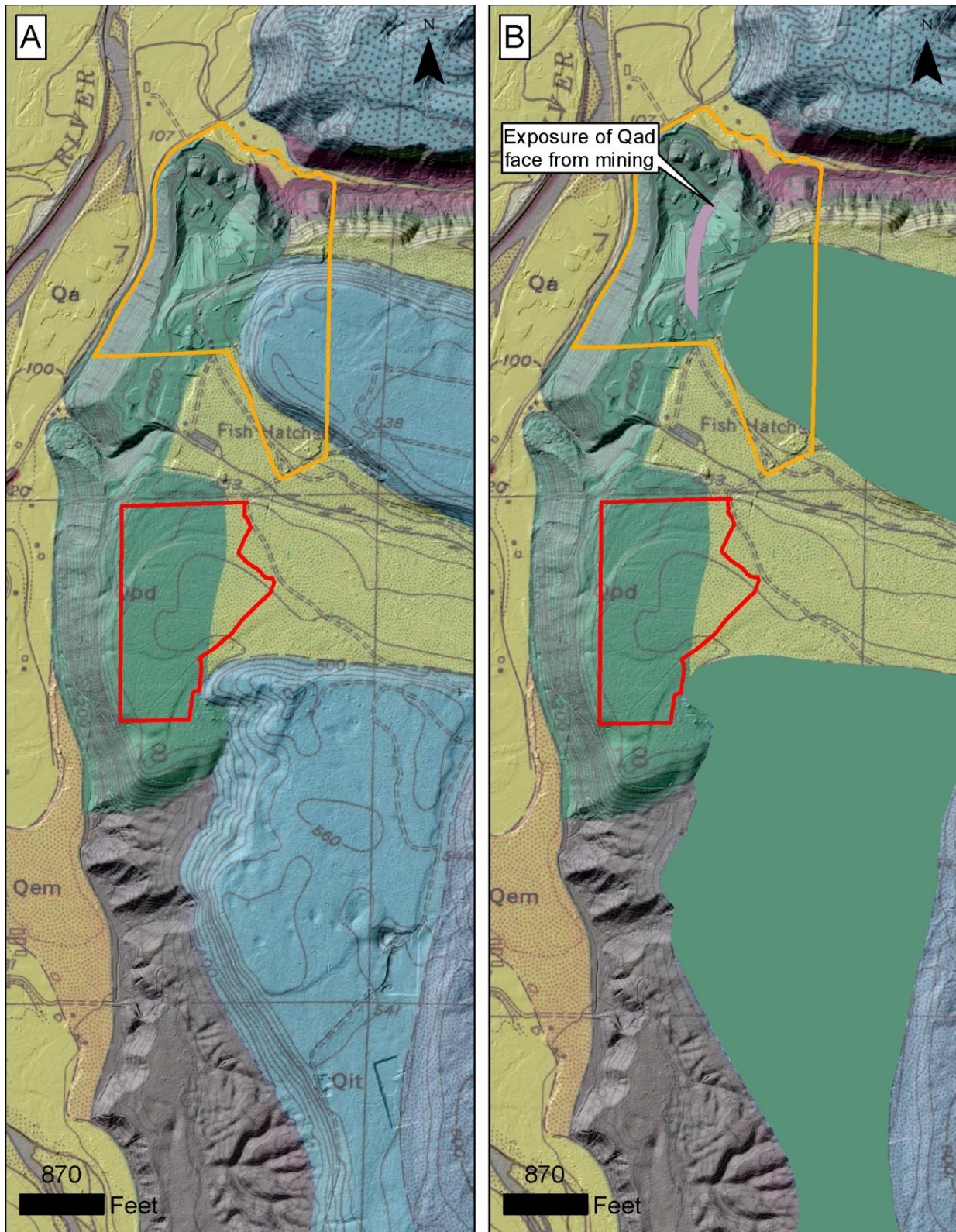


Figure 6: A- Geologic Map of the Study Area (Crandell, 1963) B – Updated Geologic Map shows ice contact stratified drift (Qit) remapped as delta deposit (Qpd). In addition, the exposed Alderton formation (Qad) is shown as it has been exposed from mining.

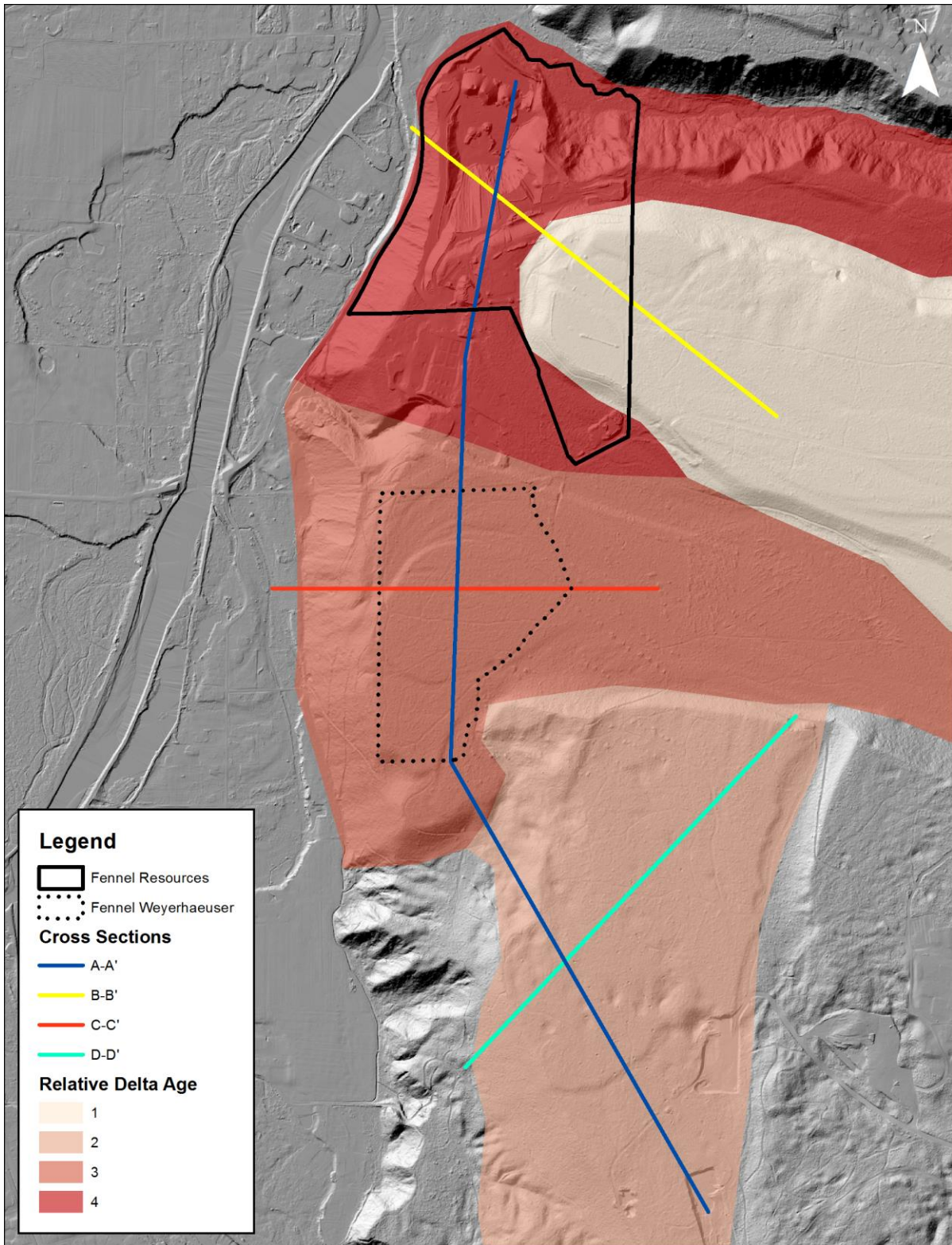


Figure 7: Relative Delta Ages. The four delta deposits for the study area along with lines showing the locations of cross sections showing USCS soil classification generated from Rockworks.

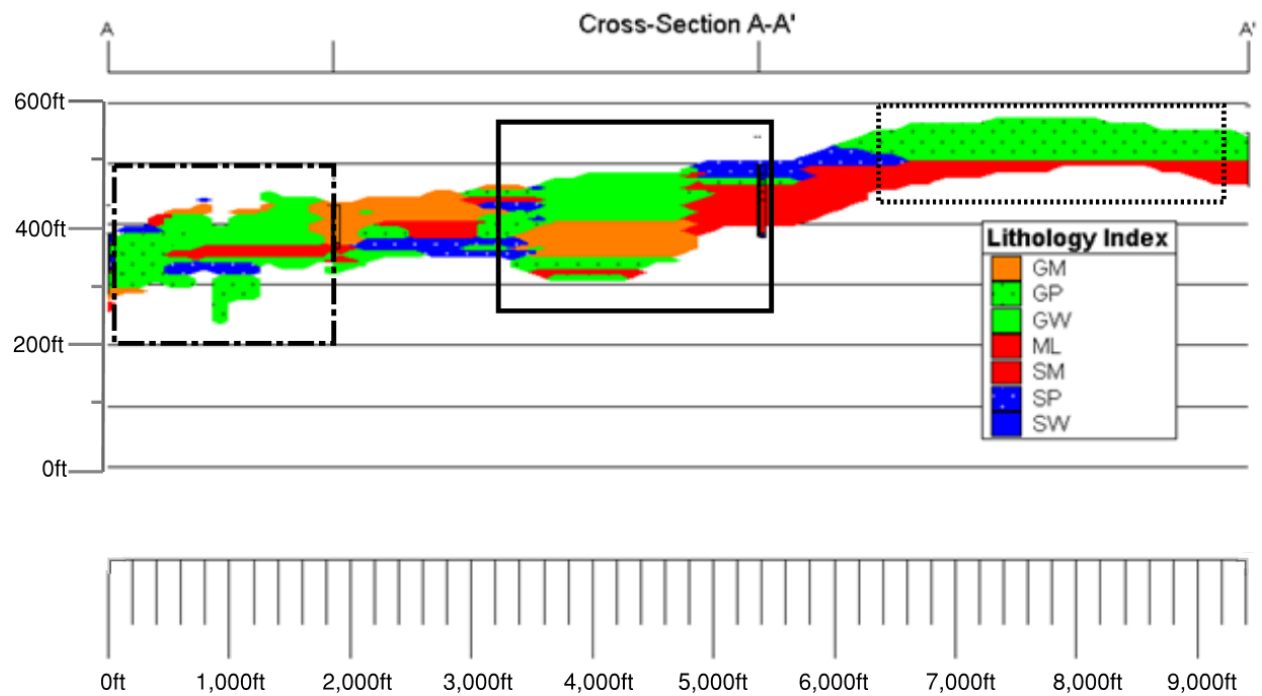


Figure 8: North-south cross section. The fennel Resources mine limits are shown with the dashed line. The Fennel Weyerhaeuser mine is outlined by the black line. The Tehaleh delta is outlined with the dotted line.

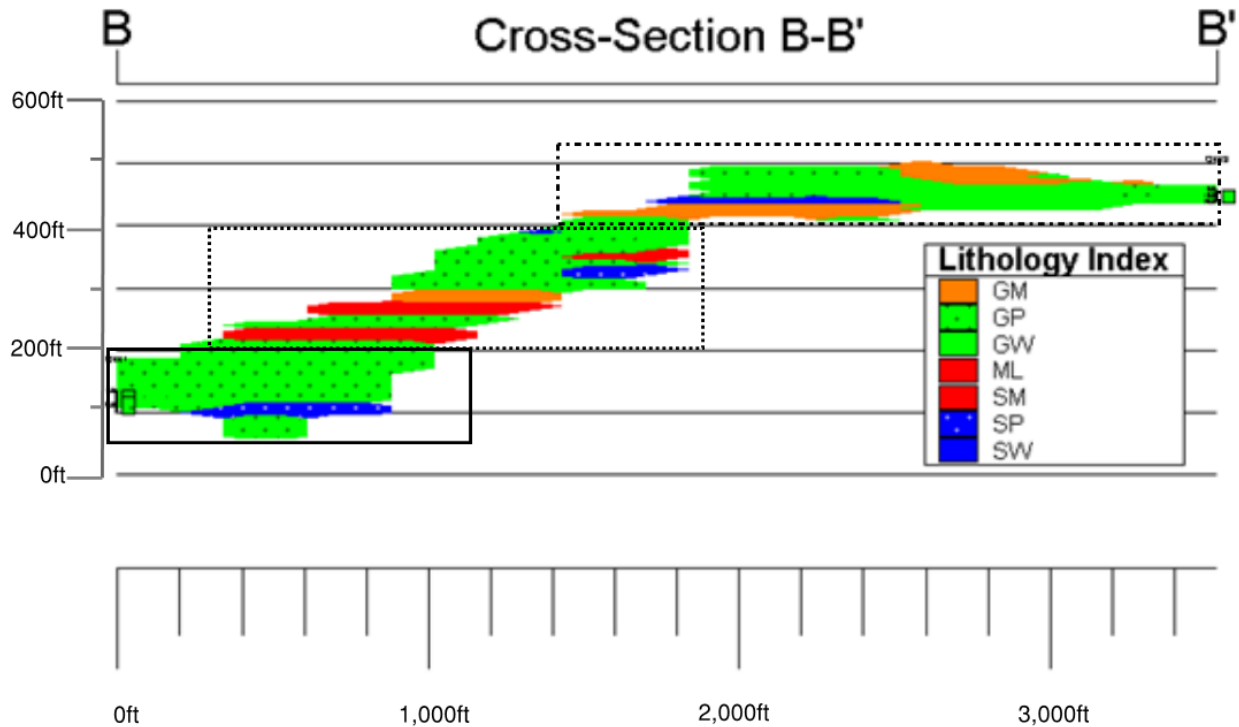


Figure 9: Fennel Resources cross section the upper box highlights the oldest delta shown in Figure 7. The lack of deep boreholes limits the interpretation of the upper delta. The middle box shows the current Fennel Resources mine. The Fennel Resources mines shows the cleaner courser forset and topset beds form elevation 400ft to 250ft with a transition to the bottomset beds from elevation 250ft to 200ft. The lower box is possibly older alluvial or fluvial deposition.

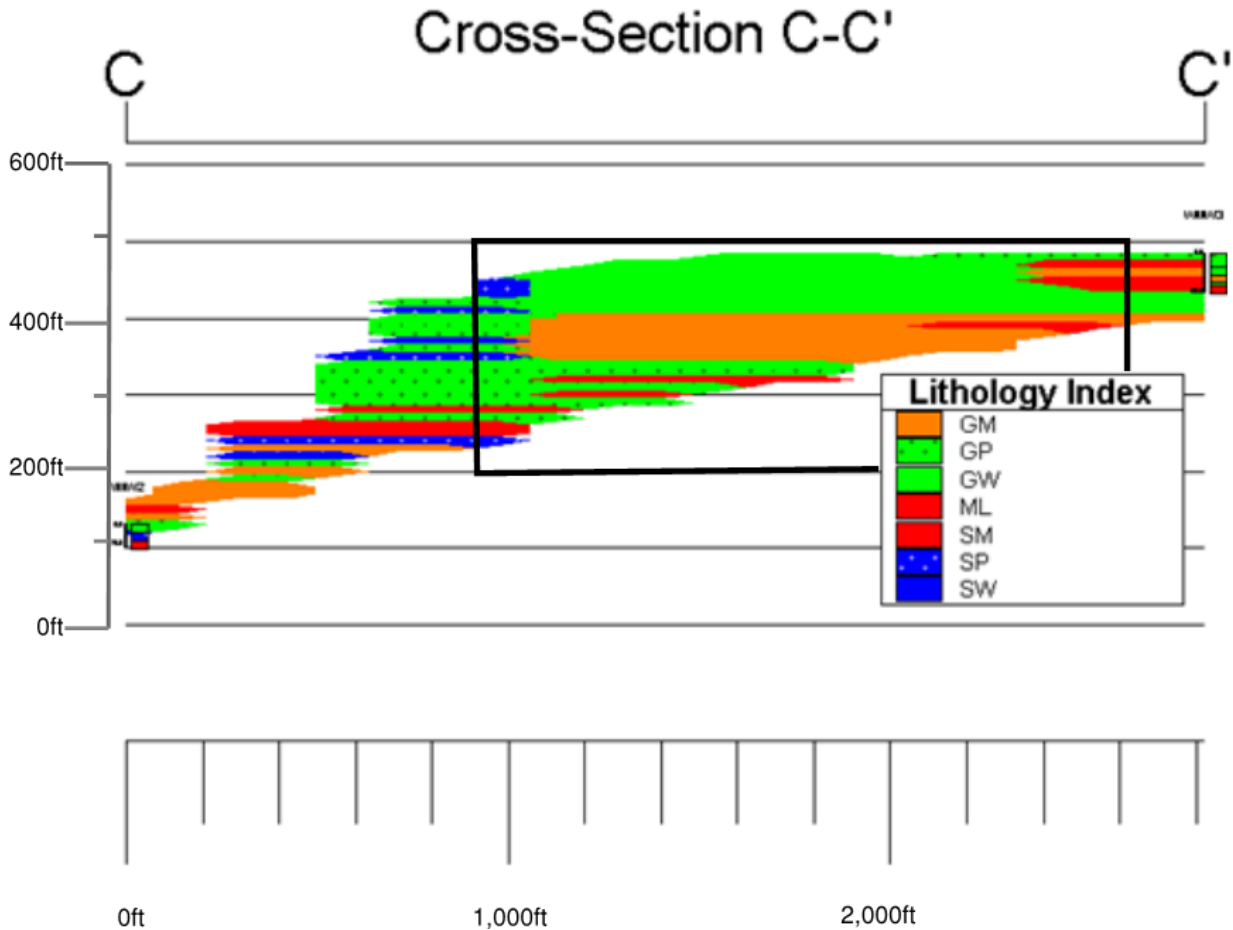


Figure 10: Fennel Weyerhaeuser mine cross section. From field observations the topset beds extend from elevation 460ft to elevation 380ft and are described in the figure as well graded gravel. The foreset beds transition to a gravel with silt at elevation 380ft to elevation 300ft. At elevation 300ft we see what appears to be the beginning of bottomset transition. The alternating layers of poorly graded gravel and silt could represent the debris flow and turbidite facies of the foreset beds along with the transition from foreset beds to bottomset beds.

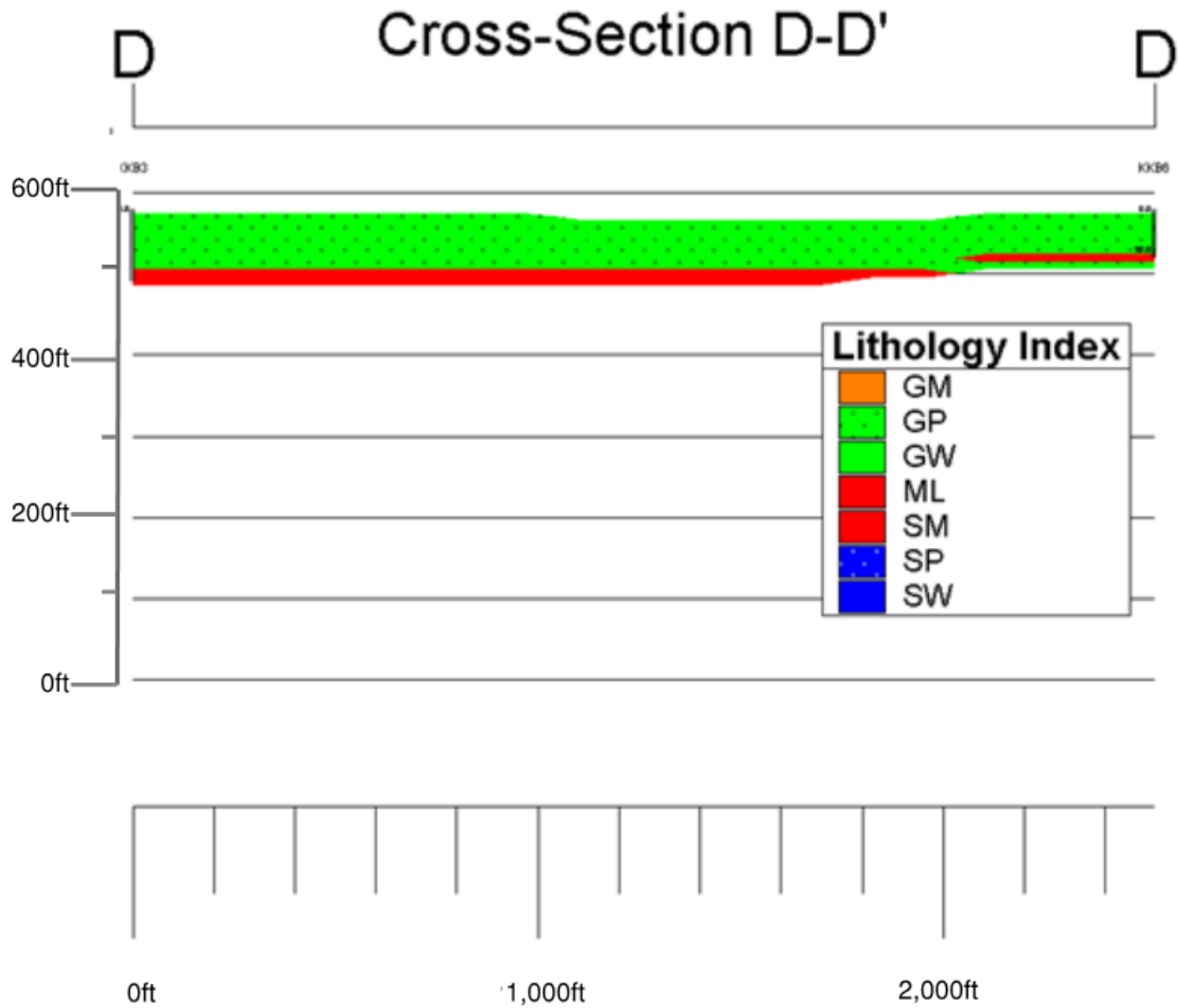


Figure 11: Tehaleh delta cross section shows a more consistent topset layer from elevation 550ft to elevation 500ft. However, boring depth reduces the ability to interpret the delta stratigraphy.

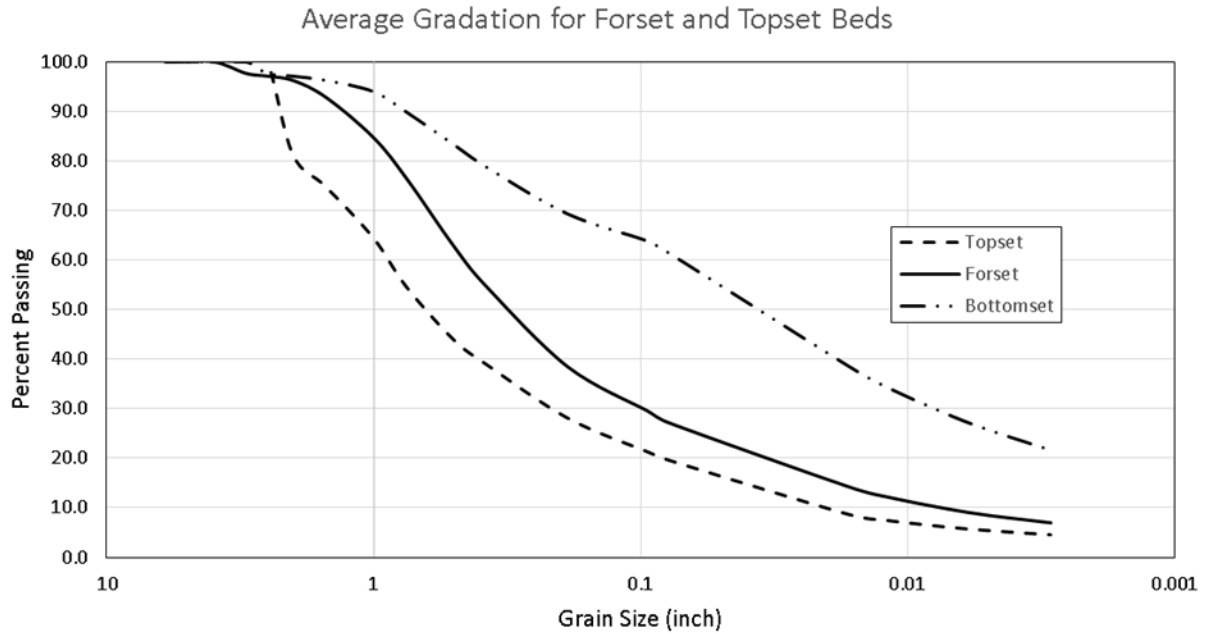


Figure 12: Gradations for topset, foreset, and bottomset beds. The 72 gradation samples from Appendix B were compiled by bed type. The gradations were separated based on gradation breaks for the topset and foreset beds along with using depth based off observations from site visits. The topset and foreset beds show a D50 within gravel sized clasts. The bottomset beds D50 reduces to fine sand.

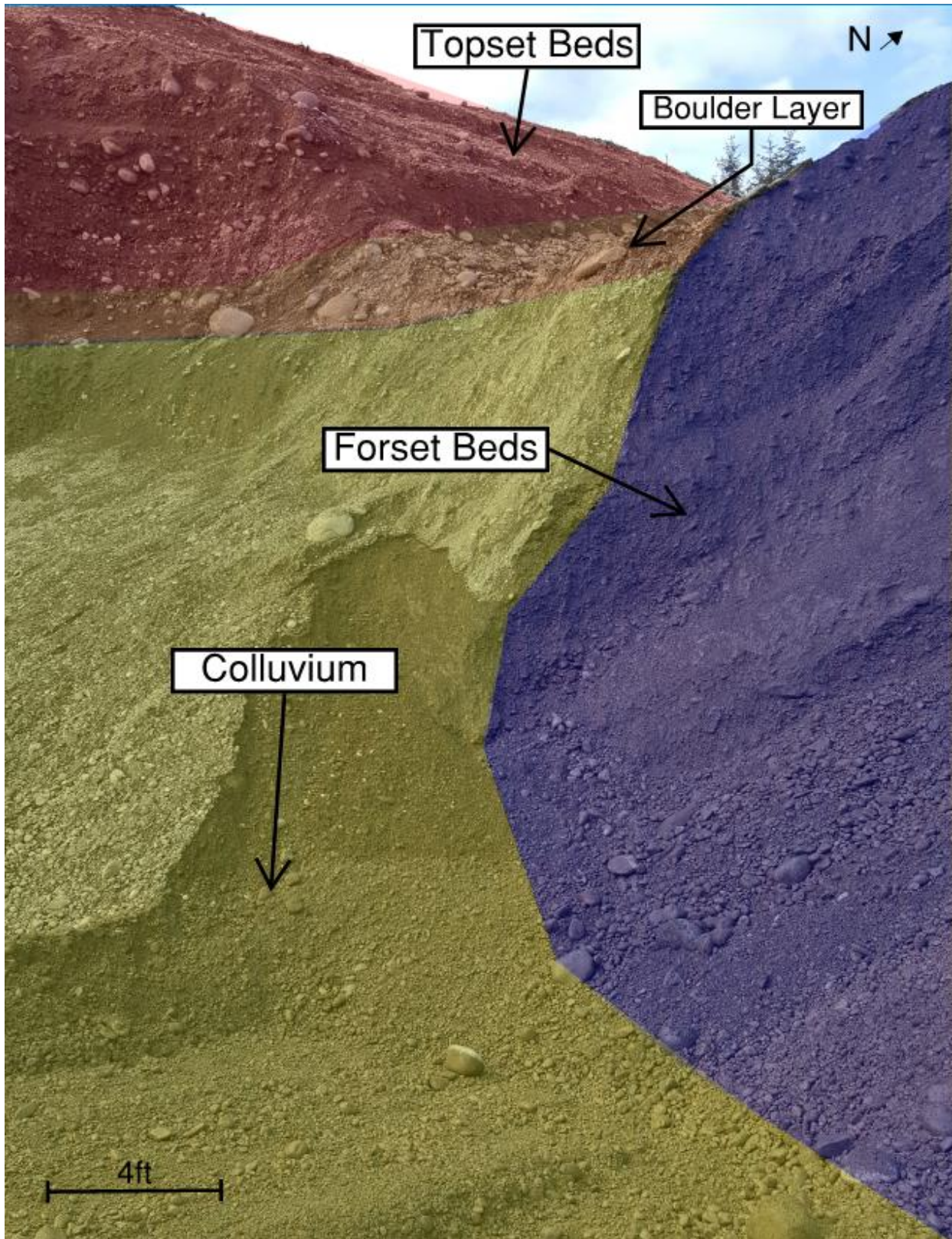


Figure 13: Photo of the Fennel Weyerhaeuser mine face at location FWF3 from figure 2 looking west.

February 2017 Foreset Gradation Samples

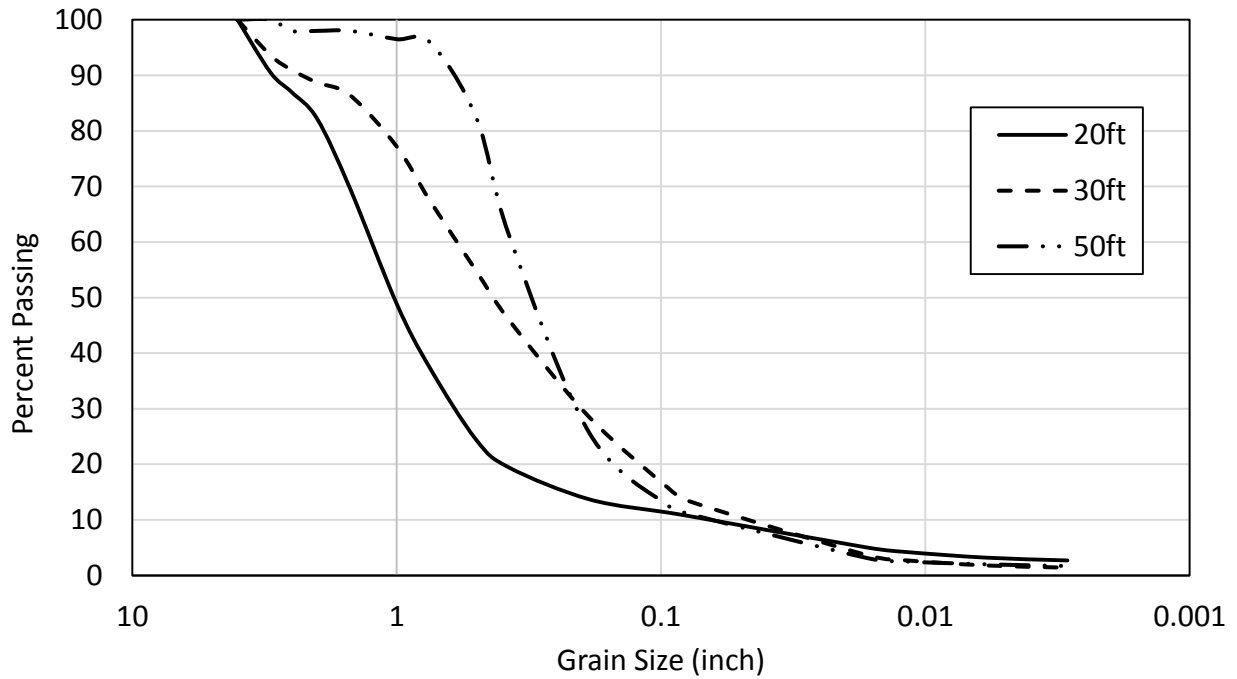


Figure 14: Foreset Gradation Change with Depth. The gradations shows three samples from the Foreset beds at three different depths. The D50 reduces with depth but the D10 is nearly the same for all three.

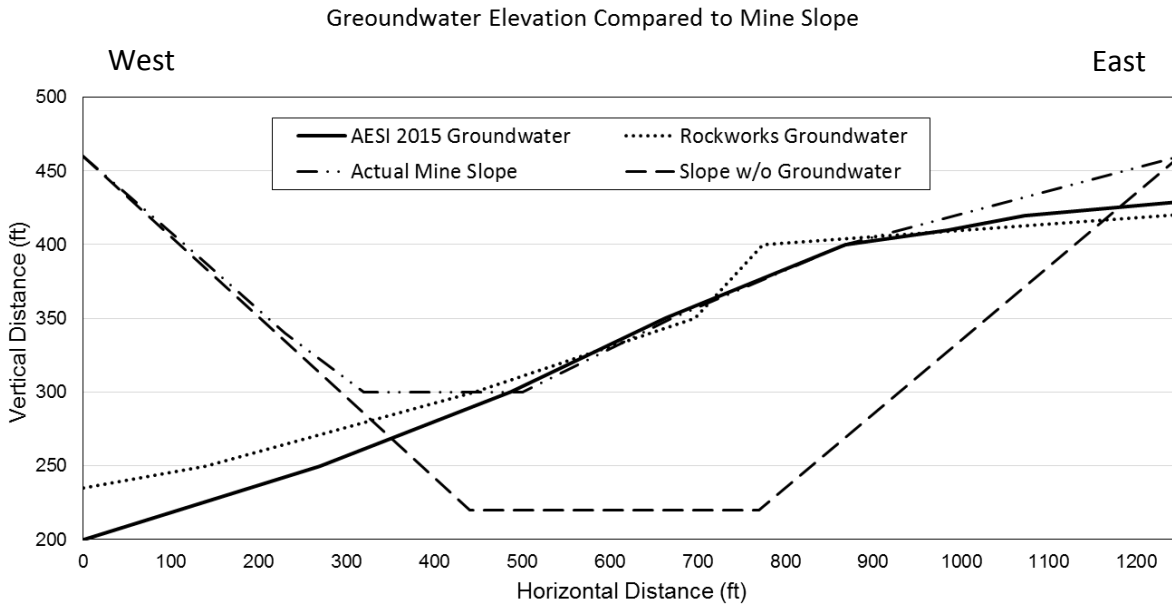


Figure 15: Groundwater and Mine Elevation. This is a representative cross section for the Fennel Weyerhaeuser mine. There is odd groundwater behavior from the Rockworks generated groundwater elevations due to the lack of hydraulic conductivity data. The difference in mineable material is shown between the slope only mining boundary and the boundary limited by groundwater.

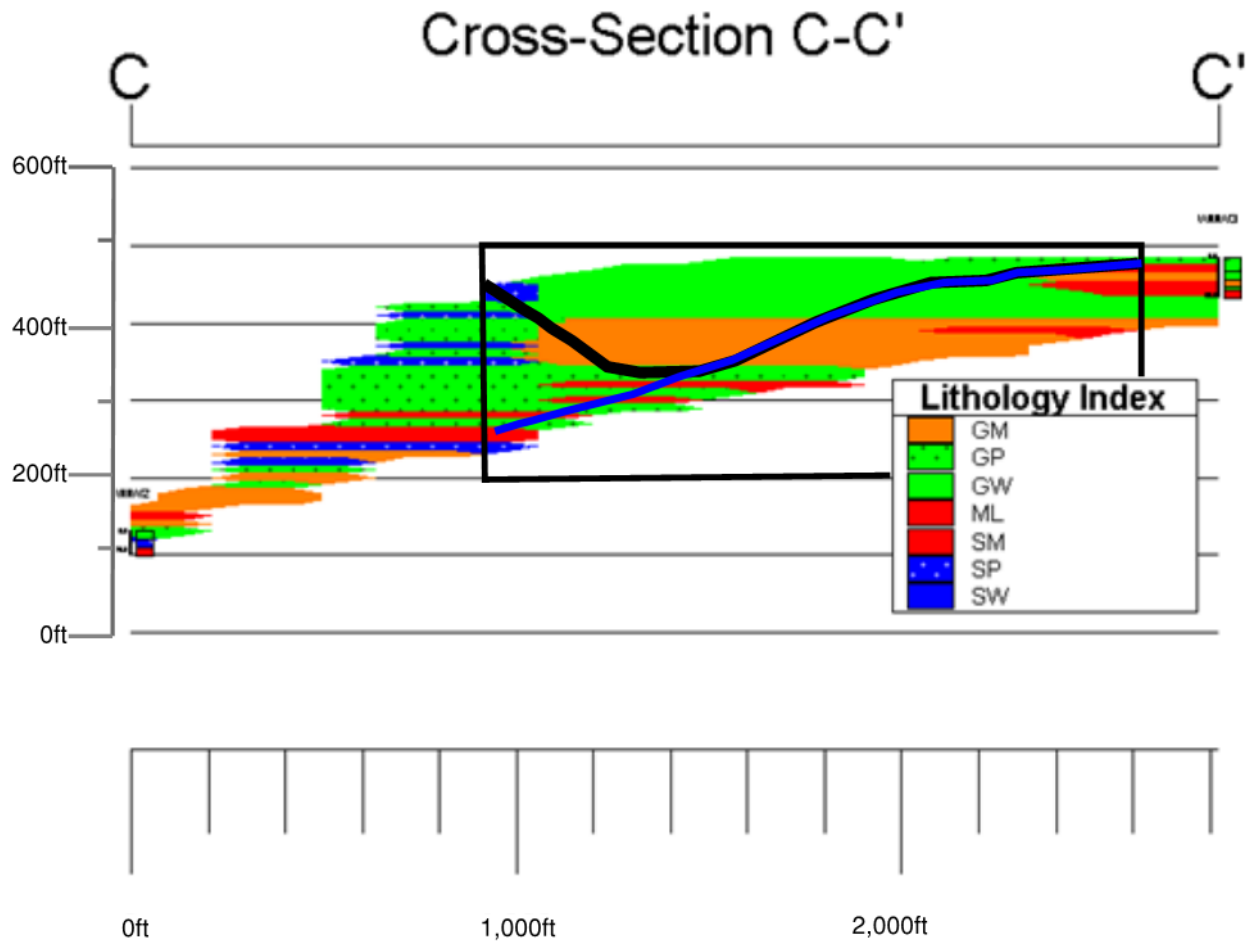


Figure 16: Groundwater Compared to USCS Soil Classification. The groundwater elevations for the C-C' cross section is shown in blue and the updated mining grade is shown in black.



Figure 17: Final Mine Contours. The contours are based on the 2H:1V DNR slope requirements and AESI 2015 groundwater elevation along with the required groundwater buffer of 5ft.

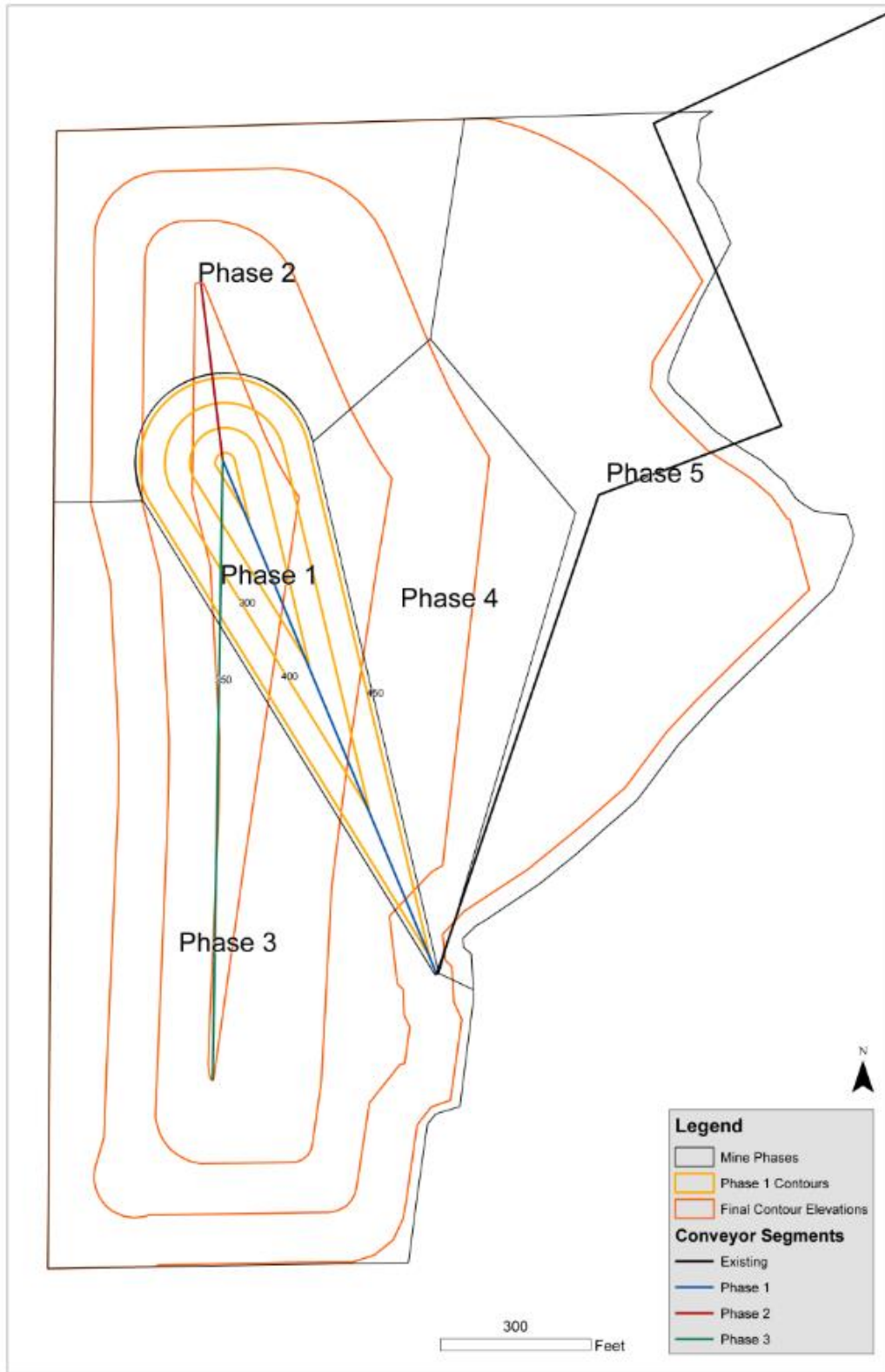


Figure 18: Final Mining Plan. The five phases will occur in order and will be mined to maximum depth.

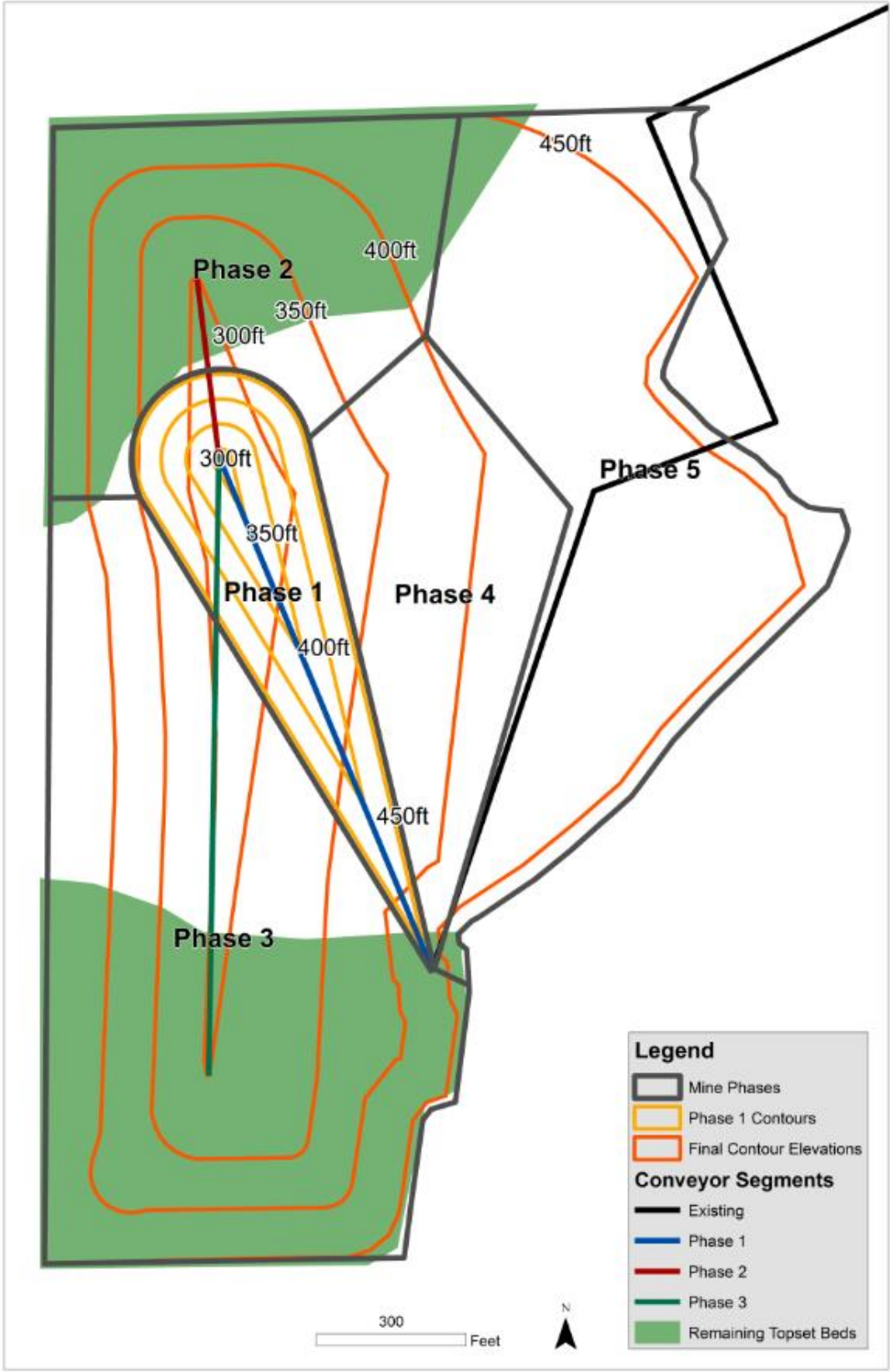


Figure 19: Mining Phases with Remaining Topset Beds. The Five phases will occur in order. The Green area shows the remaining topset beds for the site. Current mining is located south of the phase one and current conveyor location. Phase one is first in order to expose the required vertical face and install the conveyor. This will also allow the addition of material from the southern topset beds to the foreset material mined out during phase one. Phase two will allow for the incorporation of topset beds in the northwest along foreset material. Phase three will use the remaining topset material in the southern end. Phase four and five will be much more variable depending on the final site use.

# APPENDIX A: BORING DATA

New ID	Name	Property	Date	GE ELE	ELE	Total Depth	Depth to GW	GW Elevaton	Lat	Long
WMW1	MW-1	Weyerhaeuser	1988	110		37	12.8	97.2	47.139571	-122.223936
WMW2	MW-2	Weyerhaeuser	1988	110		32	6.27	103.73	47.137801	-122.223837
WMW3	MW-3	Weyerhaeuser	1988	465			37.5	427.5	47.1398520	-122.2152660
WMW4	MW-4	Weyerhaeuser	1988	458			226	232	47.1383770	-122.2199810
FN1	FN1EW1	Weyerhaeuser	1983	475		200	159.4	315.6	47.1371550	-122.2181100
TW1CRP	TW1CRP	Weyerhaeuser	2015	478		120	83	395	47.1337240	-122.2176470
TW2CRP	TW2CRP	Weyerhaeuser	2015	503					47.1341740	-122.2195560
	MW-7	FallingWater	1999	578					47.141986	-122.206698
	MW-8	FallingWater	1999	548					47.140706	-122.206978
TLB1	B1	Troutlodge	2010		392	290			47.143114	-122.219603
TLB2	B2	Troutlodge	2010		439	110			47.144163	-122.216643
TLB3	B3	Troutlodge	2010		429	78			47.142339	-122.216962
TLB4	B4	Troutlodge	2010		428	115			47.141296	-122.218303
TLB5	B5	Troutlodge	2010		410	95			47.143231	-122.217493
OW-1	OW-1	Fennel Resources	2004	115					47.150553	-122.217247
OW-2	OW-2	Fennel Resources	2004	347					47.147986	-122.214383
OW-3	OW-3	Fennel Resources	2004	113						
OW-4	OW-4	Fennel Resources	2004	180					47.148525	-122.219136
OW-5	OW-5	Fennel Resources	2004	377					47.147505	-122.214717
OW-6	OW-6	Fennel Resources	2004	392			16	376	47.147849	-122.212015
OW-7	OW-7	Fennel Resources	2004	388			41	347	47.147531	-122.213366
OW-8	OW-8	Fennel Resources	2004	446			10	436	47.141552	-122.212041
OW-9	OW-9	Fennel Resources	2004	438			5	433	47.141198	-122.213033
OW-10	OW-10	Fennel Resources	2004	444			25	419	47.142668	-122.215025
97B1	B-1-97	Fennel Resources	1997	443		110			47.147123	-122.213176
97B2	B-2-97	Fennel Resources	1997	306		250			47.145506	-122.217085
97B3	B-3-97	Fennel Resources	1997	174		260			47.148868	-122.215866
97B4	B-4-97	Fennel Resources	1997	471		70			47.144785	-122.215125
97B6	B-6-97a6	Fennel Resources	1997	360		160			47.147545	-122.215231
97B5	B-6-97b5	Fennel Resources	1997	527		70			47.145316	-122.213816
-	B-1-04	Fennel Resources	2004							
-	B-2-04	Fennel Resources	2004							
04B3	B-3-04	Fennel Resources	2004	528		110			47.145023	-122.212708
04B4	B-4-04	Fennel Resources	2004	578		145			47.146192	-122.210966
04B5	B-5-04	Fennel Resources	2004	563		130	115	448	47.142807	-122.211427
	B-6-04	Fennel Resources	2004		440		9.9	430.1		
	B-7-04	Fennel Resources	2004		432		2.6	429.4		
	B-8-04	Fennel Resources	2004		440		20.7	419.3		
KKB1	B1	KK	2009	537			40	497	47.123195	-122.208302
KKB2	B2	KK	2009	533					47.123406	-122.211448
KKB3	B3	KK	2009	577					47.127662	-122.214388
KKB4	B4	KK	2009	557					47.126396	-122.211124
KKB5	B5	KK	2009	555					47.129172	-122.20979
KKB6	B6	KK	2009	555			56	499	47.131633	-122.210035
KKTB1	B1(TA)	KK	2008	568					47.131909	-122.212176
KKTB2	B2(TA)	KK	2008	557					47.131663	-122.213054

# APPENDIX B: GRADATION DATA

Location	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR	FR
Bore Log	04B1	04B2	04B2	04B3	04B3	04B3	04B3	04B3	04B3	04B4	04B4	04B4	04B4	04B4	04B5
Depth	0-15	0-20	20-40	0-35	35-65	65-85	85-110	10-35	35-80	80-110	110-145	5-30			
% Passing															
6															
4															
3															
2.5															
2	95.1	98.1	93.8	95.3	92.9	100	94.3	100	100	100	100	97.5	99		
1.5	81.5	95.3	90.3	86.1	87.9	90.4	88	95.6	98.1	93.2	92	90.3			
1	71.3	87	82.4	70.5	80.8	83.4	81.3	83.6	92.5	79.3	87.1	77			
0.75	63.1	78.7	75.1	49.4	72.9	78.1	71.9	66.4	82.6	63.8	80.7	63.4			
0.5	54.1	68.4	64.5	30.8	65.9	73.4	58.9	49.1	66.2	50.6	74.1	49.8			
0.375	49.2	62.6	58.9	24.8	62.1	70.9	51.6	39.9	55.8	43.5	70.4	43.1			
0.187	37.9	49.5	47.3	17.3	51.5	65.7	37	24.6	29.9	27.8	62.4	30			
0.0937	28.6	40.5	40.4	13.8	44.2	63.1	28.3	17.1	12.1	17.4	57.3	22.2			
0.0787	25.8	38.6	38.9	13.2	41.5	62.6	26.3	15.6	9.4	15.3	56.2	20.5			
0.0165	6.6	21.1	14.9	8.5	12.8	53.5	10.2	7	2.2	5	33.8	10.6			
0.0117	5.1	18.2	11.6	7.6	9.7	47.6	7.9	5.9	2	4.1	24.6	9.4			
0.0059	3.4	13.9	8.1	6.2	6	32.7	5.3	5	1.8	3	12.4	7.5			
0.0029	2.6	10.9	6.2	5.1	4.1	23.3	3.9	4.2	1.5	2.3	7.8	6.1			
SE	39	21	31	19	37	16	47	38	80	66	50	29			





Location	KK	KK	KK	KK	KK	TL	TL	TL	TL	TL	TL	TL	TL
Bore Log	B5	B5	B6	B6	B6	B1	B1	B1	B1	B1	B1	B1	B1
Depth	45-50	57-60	20-25	35-37	57-60	53-55	80-85	100-103	125-127	150-152	175-178		
% Passing													
6								100				100	
4								89.3				92.6	
3								100		100		83.3	
2.5								94.7		100			
2								100		94.7			
1.5								94.1		100			
1								100		97.7			
0.75								100		94.1			
0.5								100		97.7			
0.375								94.1		97.7			
0.187								94.1		97.7			
0.0937								94.1		97.7			
0.0787								94.1		97.7			
0.0165								94.1		97.7			
0.0117								94.1		97.7			
0.0059								94.1		97.7			
0.0029								94.1		97.7			
SE													

Location	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL
Bore Log	B1	B1	B1	B1	B2	B2	B2	B2	B2	B2	B3	B3	B3	B3
Depth	199-202	225-227	250-253	275-128	11-14	25-28	48-53	67-69	43021	20-23	40-43			
% Passing														
6														
4		100				100				100			100	
3	100	93.6	100	100		93.3				93.2	100	100	92.8	100
2.5														
2	96.1	84.5	98.9	95.9	100	93.3	100	84.7	81.7	77.9	94.4			
1.5	92	79.5	90.9	93.4	96.5	92.7	96.6	81.1	61.4	60.9	91.3			
1	81.2	73.3	84.3	87.9	92.3	88.7	84.8	77.8	29.4	39	78.4			
0.75	71.2	67.3	78	83.1	86.9	83.9	73.3	73.1	20	31.1	69.7			
0.5	57	59.1	64.7	74	71.5	70.7	58.6	62.3	12.2	23.1	53.1			
0.375	49.1	53.2	56.5	67.4	60.7	60.5	51.8	55.4	10.5	18.7	44.6			
0.187	37	40.4	42.7	55.4	44.8	47.3	41.4	45.8	8.7	12.3	36.9			
0.0937	29.4	30.2	30.7	46.1	31.5	34.1	34.6	39.1	7.6	10.8	30.1			
0.0787	27.1	27.3	27.3	43.3	27.3	29.8	32.3	36.7	7.4	10.2	27.5			
0.0165	13.8	13.4	10.3	27	10.1	12.2	17.7	17.8	5.6	6.9	11.2			
0.0117	12.3	12	9	26.1	8.9	10.9	15.7	12.5	5.2	6.3	9.9			
0.0059	9.9	10	7.2	22	7.3	9.2	12.9	6.3	4.5	5.3	8.2			
0.0029	8.1	8.4	5.9	18.3	6.1	7.8	10.6	4.1	3.9	4.4	6.7			
SE														

Location	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	TL	FW
Bore Log	B4	B4	B4	B4	B4	B5	B5	B5	B5	B5	B5	B5	B5	B5	FWF2
Depth	"8-10	33-35	53-55	73-75	93-95	5-9	23-25	40-43	58-60	73-75					15
% Passing															
6															
4				100		100									100
3	100	100	100	100	100	95.7	100	100	100	100	100	100	100	100	100
2.5															98
2	96.3	94.6	84.3	91.7	83.2	93.3	98.1	93.4	100	96.8					98
1.5	90	89.7	74.6	86.2	68.2	89.7	96.6	90.6	99.4	95.3					98
1	70.8	85.2	63.6	72.2	48	82.4	91	79.7	89	89.9					96.5
0.75	58	79.7	57.4	62.8	34.1	75.1	84.5	68	70.4	83.7					96
0.5	42.5	65.2	45.9	46	22.1	59	68.3	46.1	34.3	74.6					82.4
0.375	36.3	54.8	37.2	34.4	17.6	48.3	52.7	31.7	23.8	68.8					61.1
0.187	28	45.9	16.1	19.8	14	32.7	36.7	20.6	11.1	57.9					25.7
0.0937	21.9	37.8	12.5	9.5	11.3	21.1	24.6	12.3	8.6	49					12.5
0.0787	19.9	35.1	10.6	7.5	10.7	17.9	21.3	10.5	7.9	46.2					11.1
0.0165	10.6	21	4.3	3.2	7.1	7.3	9.2	4.8	5.3	15.1					3.1
0.0117	9.7	18.4	3.7	3	6.2	6.6	8.3	4.4	5	8.6					2.5
0.0059	8.2	14.1	2.9	2.5	4.9	5.7	7	3.8	4.1	4.7					2
0.0029	6.9	11.2	2.3	2.1	3.9	4.8	6	3.3	2.9	3.2					1.7
SE															

Location	FW	FW	FW
Bore Log	FWF3	FWT1	FWT4
Depth			
% Passing			
6			
4	100	100	100
3	93.6	90.5	100
2.5	88.7	82.2	100
2			
1.5	86.4	69.6	100
1	77.2	48.9	95.3
0.75	67.5	37.4	88.1
0.5	54.8	24.4	78
0.375	45.9	19.4	71.8
0.187	28.5	13.7	60.8
0.0937	15.7	11.3	52
0.0787	13.4	10.7	49.9
0.0165	3.6	5	17.1
0.0117	2.7	4.2	8.9
0.0059	1.8	3.2	3.2
0.0029	1.4	2.7	2.1
SE			

# APPENDIX C: VOLUMETRIC DATA

Total

Maximum Elevation LINEAR_FEET	Minimum Elevation LINEAR_FEET	GM	GP	GW	ML	SM	SP
585	575	0	0	0	0	0	0
575	565	0	0	0	0	0	0
565	555	0	0	0	0	0	0
555	545	0	0	0	0	0	0
545	535	0	0	0	0	0	0
535	525	0	0	0	0	0	0
525	515	0	0	0	0	0	0
515	505	0	0	0	0	0	0
505	495	0	0	0	0	0	0
495	485	0	0	0	0	0	800,000
485	475	0	0	0	0	0	3,200,000
475	465	0	1,600,000	1,600,000	0	0	1,600,000
465	455	0	800,000	9,600,000	0	0	0
455	445	0	4,000,000	14,800,000	0	0	0
445	435	5,600,000	2,800,000	8,800,000	1,600,000	1,600,000	1,200,000
435	425	0	8,800,000	12,000,000	0	1,600,000	2,000,000
425	415	400,000	2,400,000	13,200,000	0	7,200,000	2,800,000
415	405	400,000	0	16,000,000	0	1,600,000	8,800,000
405	395	800,000	6,000,000	16,400,000	0	3,600,000	0
395	385	1,200,000	0	17,200,000	0	2,800,000	4,800,000
385	375	18,000,000	4,000,000	0	0	3,200,000	0
375	365	10,800,000	5,600,000	0	0	6,400,000	0
365	355	16,000,000	4,400,000	0	0	1,200,000	0
355	345	11,600,000	0	0	0	0	8,000,000
345	335	15,200,000	3,600,000	0	0	0	0
335	325	11,200,000	0	0	0	0	5,200,000
325	315	0	14,400,000	0	0	0	0
315	305	0	13,200,000	0	0	0	0
305	295	0	4,000,000	0	0	7,200,000	0
295	285	0	9,600,000	0	0	0	0
285	275	0	5,200,000	0	0	2,400,000	0
275	265	0	6,400,000	0	0	0	0
265	255	0	0	0	0	5,200,000	0
255	245	0	3,600,000	0	0	0	0
245	235	0	0	0	0	3,200,000	0
235	225	0	0	0	0	2,000,000	0
225	215	0	0	0	0	0	1,200,000
215	205	400,000	0	0	0	0	0

Groundwater limited

Maximum Elevation LINEAR_FEET	Minimum Elevation LINEAR_FEET	GM	GP	GW	ML	SM	SP	SW
585	575	0	0	0	0	0	0	0
575	565	0	0	0	0	0	0	0
565	555	0	0	0	0	0	0	0
555	545	0	0	0	0	0	0	0
545	535	0	0	0	0	0	0	0
535	525	0	0	0	0	0	0	0
525	515	0	0	0	0	0	0	0
515	505	0	0	0	0	0	0	0
505	495	0	0	0	0	0	0	0
495	485	0	0	0	0	0	0	0
485	475	0	0	0	0	0	3,200,000	0
475	465	0	1,600,000	1,600,000	0	0	1,600,000	0
465	455	0	800,000	9,600,000	0	0	0	1,200,000
455	445	0	4,000,000	14,800,000	0	0	0	0
445	435	500,000	2,000,000	8,000,000	1,600,000	1,600,000	1,200,000	0
435	425	0	8,800,000	10,000,000	0	1,600,000	2,000,000	0
425	415	400,000	2,400,000	11,200,000	0	5,200,000	2,800,000	0
415	405	400,000	0	8,000,000	0	1,600,000	600,000	0
405	395	800,000	6,000,000	10,400,000	0	3,600,000	0	0
395	385	1,200,000	0	12,200,000	0	2,800,000	4,800,000	0
385	375	10,000,000	4,000,000	0	0	3,200,000	0	0
375	365	5,800,000	5,600,000	0	0	2,400,000	0	0
365	355	11,000,000	4,400,000	0	0	1,200,000	0	0
355	345	6,600,000	0	0	0	0	4,000,000	0
345	335	10,200,000	3,600,000	0	0	0	0	0
335	325	6,200,000	0	0	0	0	4,200,000	0
325	315	0	2,400,000	0	0	0	0	0
315	305	0	1,200,000	0	0	0	0	0
305	295	0	0	0	0	0	0	0
295	285	0	0	0	0	0	0	0
285	275	0	0	0	0	0	0	0
275	265	0	0	0	0	0	0	0
265	255	0	0	0	0	0	0	0
255	245	0	0	0	0	0	0	0
245	235	0	0	0	0	0	0	0
235	225	0	0	0	0	0	0	0
225	215	0	0	0	0	0	0	0