associated earth sciences incorporated

Technical Memorandum

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		Principal in Charge:	Charles S. Lindsay, L.G., L.E.G., L.Hg.
		Project Name:	City of Ferndale Infiltration Feasibility Study
Attn:	Paul Knippel PaulKnippel@cityofferndale.org	Project No:	150676H003
Subject:	Task 3, Mapping Areas Feasible for Infiltration		

1.0 INTRODUCTION

The City of Ferndale has contracted Associated Earth Sciences, Inc. (AESI) to conduct an Infiltration Feasibility Assessment specific to stormwater infiltration limitations within the City of Ferndale (Figure 1). The Assessment includes GIS map products, documentation and additional support for infiltration infeasibility and feasibility assessment. The primary purpose of this contract is to develop a technical report that documents and maps:

- Infeasible areas for infiltration low impact development (LID) best management practices (BMPs), including rain gardens, bioretention facilities and permeable pavement, and
- Potentially feasible infiltration areas

This memorandum was completed as part of Task 3 "Mapping Feasible Infiltration Areas." Task 3 includes mapping infiltration feasibility in areas determined to be not infeasible in our larger Task 2 study: *Infiltration Infeasibility Analysis and Technical Report* (Infeasibility Technical Report) (AESI, 2017).

The scope of this effort, specifically Task 3, "Mapping Feasible Infiltration Areas," includes:

- Technical memorandum regarding methodology, assumptions and potential for shallow and deep stormwater infiltration.
- Infiltration feasibility maps.
- GIS file for stormwater infiltration feasibility in a file geodatabase format.

This infiltration potential assessment is a companion document to AESI's Infeasibility Technical Report. This technical memorandum specifically provides a summary of AESI's infiltration feasibility analysis and assessment of 'screening level' shallow and deep infiltration potential. Areas mapped as infeasible are subtracted (masked out) from the feasibility areas. This work was conducted to help the City understand infiltration best management practice (BMP) potential throughout the city limits and urban growth area.

The infiltration potential assessments provided in this technical memorandum are suitable for identification and evaluation of potential stormwater infiltration solutions. To determine the infiltration feasibility (or feasibility of a particular infiltration technique) at a specific location, site-specific hydrogeologic and geotechnical assessments would be required.

1.1 Objective and Scope

Infiltration facilities reduce peak stormwater runoff rates by allowing stormwater to soak into the ground, increasing ground water recharge, and maintaining baseflows to streams. This reduction in peak stormwater runoff can reduce streambank erosion and sediment discharge. Additional benefits can include improved water quality due to soil zone treatment.

The feasibility of infiltration techniques is primarily dependent on sediment permeability, the vertical and lateral extent of the unsaturated material, depth to ground water or low-permeability sediments, the rate and quantity of runoff to be infiltrated, and proximity to geologic hazards. Other criteria which affect infiltration feasibility, including horizontal setbacks and vertical separation criteria for siting infiltration BMPs, are described in the *2012 Stormwater Management Manual for Western Washington, as Amended in 2014* (Ecology Manual) adopted by the City of Ferndale as the reference document for the planning, design, and construction of stormwater facilities in Ferndale.

Infiltration facilities may be either shallow or deep or a combination of both techniques. Shallow and deep infiltration facilities for this document are generally described below, and discussed in more detail in Section 3.0.

- Shallow infiltration facilities may include permeable pavement or bioretention/raingardens (BMPs described in the 2014 Ecology Manual) or conventional infiltration ponds, vaults, or other infiltrating basins. Shallow infiltration facilities are best suited in settings where moderate- to high-permeability sediments are present near the ground surface in sufficient unsaturated thickness and lateral extent to allow the stormwater to spread-out, disperse, and avoid re-emergence. Moderate- to high-permeability sediments include outwash sediments.
- Deep infiltration facilities may include infiltration trenches and drywells, both of which can also be referred to as Class V underground injection control (UIC) wells. Some types of deeper drywells are referred to as 'drilled drains' or 'pit drains.' Deep infiltration facilities are designed to penetrate low-permeability sediments and allow infiltration into the more

permeable underlying sediments. Deep infiltration facilities could be considered in settings where surficial low-permeability geologic units (such as glaciomarine drift) are present at the surface and more permeable sediments (such as Vashon advance outwash) are present below in sufficient unsaturated thickness. Deep infiltration facilities may be more costly to install and maintain than shallow infiltration facilities.

This technical memorandum discusses the feasibility of both types of infiltration systems in the City.

The purpose of our study was to conduct a City-wide assessment of stormwater infiltration characteristics. This task specifically excludes subsurface exploration. Work associated with this task evaluated four factors that influence infiltration potential:

- Infiltration potential as determined by geology, geomorphology, and soil type: This information was based on available geologic and hydrogeologic reports and maps, internal AESI files/information, and water well information on file with the Washington State Department of Ecology (Ecology).
- Topography/slope: Based on analysis of Light Detection and Ranging (LiDAR) and United States Geological Survey (USGS) topographic data.
- Risk to environment: Based on maps of environmentally sensitive areas, including slopes, surface water, and well head protection areas.
- Thickness of unsaturated permeable horizon and depth to ground water/seasonal high water table: This information was based on geology, well data, available hydrogeologic studies, and surface water elevations. The information is generally of poor quality for any given site but it should be useful for a screening level analysis.

1.2 Approach

AESI completed the following tasks to develop an understanding of the general hydrogeologic opportunities and constraints to evaluate both shallow and deep infiltration potential throughout the City:

- Review existing literature regarding the geologic/hydrogeologic conditions within the City. The literature review is listed in the references and included:
    - Regional geology and soils maps/reports available from the USGS, the Washington State Department of Natural Resources (DNR), and United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS);
    - Whatcom County LiDAR mapping;
    - City and County sensitive area maps;
    - Water well reports on file with Ecology for wells located within the City;
    - Water supply system information on file with the Washington State Health Department (DOH) Office of Drinking Water (ODW) and Source Water Assessment Program (SWAP);

- Conduct a qualitative evaluation of infiltration potential.
- Delineate areas potentially suitable for shallow and deep infiltration.
- Subtract previously delineated areas in AESI's Infiltration Infeasibility Report not suitable for infiltration due to proximity to steep slopes, water wells, and other regional features that might be impacted by increased infiltration.
- Create Geographic information System (GIS) layers to represent shallow and deep infiltration potential.
- This technical memorandum summarizes the results of the site characteristics assessment, infiltration feasibility approach, GIS maps for all the layers defined above, and a summary of the results.

2.0 FACTORS CONSIDERED FOR INFILTRATION POTENTIAL

The potential for infiltration in an area is primarily dependent on permeability of the infiltration receptor horizon, the vertical and lateral extent of the unsaturated material, depth to ground water or perching layers, and proximity to geologic hazards. As discussed in AESI's Infeasibility Technical Report, in order to receive water and transmit it away from the infiltration facility, the subsurface must be both sufficiently permeable and unsaturated. The primary factor addressed in this assessment of shallow infiltration potential is permeability. Information regarding the permeability of geologic units and soils is discussed in Sections 2.1 and 2.2, and its application in mapping is discussed in Section 3.

The presence of ground water and geologic hazards limit and constrain infiltration feasibility, and were criteria addressed in AESI's Infeasibility Technical Report. Areas of slopes in excess of 20 percent were mapped as infeasible. For constraints on deep infiltration potential, information regarding deeper ground water and overburden is discussed in Section 2.3. For both shallow and deep infiltration potential, additional ground water and geologic hazards should be expected in some areas mapped as feasible, particularly near the designated infeasible areas. This document does not replace site specific studies. For all infiltration projects, site-specific studies will be required to validate the data used as a basis for the City-wide assessments.

2.1 Geologic Units and Permeability

Geologic studies in the area include the *Geologic Map of Western Whatcom County, Washington* (Easterbrook, 1976) and the *Geologic Map of the Bellingham Quadrangle (Lapen, 2000)*. AESI generally based infiltration potential of geologic units on the geologic mapping in GIS format from the Washington State Department of Natural Resources, which represents a digitized form of the *Geologic Map of the Bellingham Quadrangle (Lapen, 2000)*. Geologic units within the project area are shown on Figure 2. A regional cross-section illustrating geologic conditions is presented on Figure 3.

AESI categorized eight geologic units for infiltration potential. Details of specific geologic units are discussed in AESI's Infeasibility Technical Report. Based on their typical properties, geologic units were considered to be either moderate to highly permeable or to have low permeability for purposes of mapping infiltration potential. Table 1 (attached at the end of this document) summarizes the geologic units in the study area, and AESI's assignment of infiltration potential categories.

Permeability is one of the key components of infiltration potential. This applies to both shallow and deep infiltration systems. Factors considered during the assignment of permeability to geologic units include degree of compaction, grain size and age, and are discussed below:

2.1.1 Degree of Compaction

The project area is generally covered by several hundred feet of Quaternary sediments that were deposited during several glacial and nonglacial intervals that occurred repeatedly during the past 1.8 to 2.4 million years. During glacial periods, the southwestern margin of the Cordilleran Ice Sheet flowed south from British Columbia into and through the Fraser-Whatcom Lowlands (Blunt, et al., 1987; Easterbrook, 1963, 1994). The weight of this ice, which comprised an ice sheet up to approximately 5,000 feet thick in the region, compressed the geologic units beneath it, compacting them and greatly decreasing their permeability. Sediments deposited since this time, which have not been glacially consolidated, include all Holocene deposits (Alluvium, fan, lake, wetland and peat deposits), and recessional outwash deposits from the most recent period of glacial retreat (the Sumas glaciation). All older geologic units in the area have been glacially overridden by one or more glaciers, and are glacially consolidated.

2.1.2 Grain Size

Sediment grains, when packed together, have small gaps between them. These gaps are referred to as pore spaces, and they comprise the space which is available for water to flow through and occupy within the geologic unit. In coarse grained geologic units such as gravel, these pore spaces are relatively large, and water can flow through them rapidly. In a fine grained geologic unit such as a silt or a clay, or a coarse grained unit with a significant quantity of fine grained material, the small particles occupy the gaps between the larger grains, where present. This greatly reduces the rate at which water can flow through the pore spaces, resulting in low permeability.

2.1.3 Age

The age of a geologic unit affects many of its properties, including lithification and diagenesis – the process of sediment becoming a sedimentary rock; over time, as sediment is subjected to pressure and moisture, minerals form. Eventually these minerals can bond the sediment grains together, forming rock. As this process occurs, permeability of the unit decreases. Thus, geologic units of greater age typically have lower permeability than otherwise similar but relatively younger geologic units.

2.2 Soil Units and Permeability

Information on soils was collected by the USDA NRCS and published in the *Soil Survey of Whatcom County Area, Washington* (NRCS, 1992). This information has been digitized by the NRCS and was downloaded by AESI in GIS format from the NRCS web portal. The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils of the City formed primarily from young glacial deposits and have not had sufficient time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation. As shown on Figure 4, "Soils," about half of the City soils are comprised of soil map units with glaciomarine drift parent materials. These glaciomarine drift-derived soil units include Birchbay, Hallenton, Labounty, Whatcom, and Whitehorn Soil series. Table 2 (attached at the end of this document) summarizes the soil units in the study area, and AESI's assignment of infiltration potential categories.

NRCS classifies soils into hydrologic soil groups A through D based on the minimum rate of infiltration obtained for bare soil after prolonged wetting. Group A soils have a high infiltration rate, Group B soils have a moderate infiltration rate, Group C soils have a slow infiltration rate, and Group D soils have a very slow infiltration rate. Some soils are classified into two groups, such as A/D or B/D. For a soil classified as A/D, this indicates that the soil is classified into Group D due to the presence of shallow ground water preventing infiltration, but would be in Group A if drained.

For soils derived from deposits of glaciomarine drift, capacity of the most limiting layer to transmit water (Ksat) is described as low (on the order of 0.06 inches per hour [iph]). These glaciomarine drift soils are typically Hydrologic Group C. For soils derived from deposits of outwash, the infiltration capacity typically increases with depth if not saturated. These outwash soils are typically Hydrologic Group A or B. The soils mapping is generally consistent with the regional geology mapping though variations exist.

In general, hydrologic soil group A and B are classified as "medium" infiltration potential, and soils in hydrologic soil groups C, D, or A/D, B/D, or C/D are classified as "low" infiltration potential. Exceptions include the Hale, Laxton, Yelm and Tromp soils groups, which are formed on glacial outwash, but classified as hydrologic group C by NRCS. These soils all have surficial permeability as low as 0.6 inches per hour, but have increasing permeability at depths of 3 to 6 feet. AESI therefore classified these soil groups as having "medium" infiltration potential. Another exception includes the Edmonds-Woodlyn loams, classified as hydrologic group B/D, indicating that the soil unit has moderate permeability but can contain shallow ground water. This map unit covers approximately 9 percent of the urban growth area. Based on review of the mapped area relative to LiDAR topography data at a scale of 1:6,000, and geologic mapping, AESI interpreted that some portions of this mapped area may be unsaturated, and classified the infiltration potential of this soil unit mixed in Table 2 and mapped it with the soils with "medium" infiltration potential.

AESI reviewed geotechnical explorations in the project area and found them to be generally consistent with soils mapping and with the assigned shallow infiltration potential for soil map units. Some inconsistencies were observed in the immediate area of the contact between typically "medium" shallow infiltration potential soils to the east of the northern uplands, and "low" mapped shallow infiltration potential units on the uplands. Because soils mapping was done at a scale of 1:24,000, inconsistencies in the immediate vicinity of the boundaries of mapped soils units are expected when viewing the map units at scales greater than 1:24,000.

2.3 Special Considerations for Deep Infiltration

The primary potential deep infiltration receptor horizon within the City of Ferndale is the Vashon advance outwash which is present beneath portions of the northwest upland area (Mountain View Upland) of the city. Across most of the Mountain View Upland, the low permeability units of Everson glaciomarine drift and Vashon lodgement till overlie the more permeable advance outwash. AESI assessed the extent of the Vashon advance outwash deposits based on existing data and developed a cross section (Figure 3) showing a generalized interpretation of the geologic units underlying the Mountain View upland. The low permeability units behave together as a collective overburden unit, constraining deep infiltration potential. In areas where the advance outwash is unsaturated beneath the overburden, there is moderate to good potential for deep infiltration systems. Conversely, in areas where the advance outwash is saturated up to the base of the overburden, there is low potential for deep infiltration. As such, the primary controls on the potential of deep infiltration systems are the thickness of unsaturated advance outwash, and overburden thickness.

AESI reviewed previous ground water modeling (AESI, 2015) and new data that has become available as a result of ongoing exploration in the area (Thornton Road Well, AESI, Shop well #3, installation in progress) to estimate overburden thickness and depth to ground water. Ground water beneath the upland generally flows to the south and east, and aquifer elevation beneath the upland area are generally in the range of 55 to 65 feet above sea level. Deep infiltration potential occurs where a sufficient thickness of unsaturated outwash is present below the overburden, but above the aquifer elevation.

Information on overburden thickness and depth to ground water is generally widely-spaced and based on interpretation from limited available data (AESI, 2015). Water levels shown in the cross section (Figure 3) are static water levels listed on available well logs. Water levels in specific wells may have been affected over time by pumping. Actual overburden thickness and depth to ground water may differ at a site specific location.

3.0 INFILTRATION POTENTIAL

3.1 Conceptual Infiltration Strategies

Infiltration feasibility is dependent on the permeability of the infiltration receptor horizon, the vertical and lateral extent of the unsaturated material, the depth to ground water for perched water, the transmissivity of the underlying aquifer, proximity to geologic hazards, and considerations for other nearby water users such as water wells, springs, and streams. Conceptual geologic conditions of the Mountain View Upland are illustrated on Figure 3 “Geologic Cross-Section A-A’.” The unsaturated portion of the Vashon advance outwash layer shown in the Figure 3 concept would be the receptor for deep infiltration beneath the Mountain View Upland.

Infiltration facilities may be either shallow or deep. Shallow infiltration facilities could be considered in settings where high-permeability sediments (such as recessional outwash) are present in sufficient unsaturated thickness and lateral extent to allow the stormwater to spread out, disperse, and avoid re-emergence. Deep infiltration facilities could be considered in settings where low-permeability geologic units (such as glaciomarine drift) are present at the surface and more permeable sediments (such as advance outwash) are present below. Deep infiltration facility strategies would be dependent on the thickness of the low-permeability unit(s) at the surface and the depth to ground water in the infiltration receptor horizon.

Shallow infiltration strategies include:

- Long or linear infiltration systems that spread out recharge such as infiltration trenches, bioretention swales, or permeable pavements.
- Concentrated infiltration facilities may be considered, such as a series of basins, ponds, or bioretention cells if the infiltration receptor horizon has sufficient unsaturated thickness and lateral extent.

Deep infiltration strategies include:

- Conventional large infiltration ponds, trenches, or vaults that are excavated through the surficial glaciomarine drift (or surficial fill and fine-grained sediments) and into underlying higher permeability units (such as Vashon advance outwash). If the infiltration receptor horizon is present within 10 to 15 feet of the ground surface, this type of deep infiltration facility could be considered. In our experience, large conventional infiltration ponds, trenches, or vaults situated in Vashon advance outwash have long-term design infiltration rates on the order of 0.5 to 5 iph.
- Combination large infiltration pond, trench, or vault modified with a series of pit drains (short infiltration trenches) to increase the effective infiltration rate. In our experience, including pit drains increases the effective infiltration rate on the order of 4 to 10 times, resulting in facilities with long-term design infiltration rates typically ranging from 2 to 5 iph. Some facilities have achieved full-scale performance rates of 20 iph using this approach.
- UIC Well Systems. UIC wells could be considered if the infiltration receptor horizon is too deep to make conventional infiltration ponds, trenches, or vaults feasible. UIC well systems for this setting would be drilled through the surficial low-permeability unit and into the underlying higher permeability unit (such as Vashon advance outwash). In practice, our projects have had UIC design flow rates that ranged from 50 gallons per minute (gpm) per

UIC well using shorter screens or in more sandy deposits to greater than 350 gpm per UIC well using longer screens or in more gravelly sands or gravel deposits.

3.2 Infiltration Potential Assessment

3.2.1 Shallow Infiltration Potential

For the shallow infiltration potential assessment, AESI assigned infiltration potential ratings to soil and geologic units based primarily on permeability. Areas mapped as infeasible due to slope or other constraints in AESI's Infeasibility Technical Report are included as infeasible. These Infiltration Potential Maps are presented as Figure 5, and Figure 5A through Figure 5F. The data were organized into a GIS database. Infiltration potential ratings are summarized in Table 1 and Table 2 (attached). In some areas where geotechnical data was available and supported classification as a different category of infiltration feasibility than regional mapping, AESI mapped shallow infiltration potential based on the geotechnical data. The resulting ratings include three shallow infiltration potential categories and an infeasible category, summarized below.

- **High Potential:** areas where multiple data sources map moderate and high permeability sediments such as outwash and corresponding moderate and high permeability soil units.
- **Medium Potential:** typically areas where data sources map varying units with variable permeability or areas where mapping is not consistent, for example permeable geologic units are mapped in areas in which soils with low infiltration potential are mapped, or low permeability geologic units are mapped in areas in which soils with moderate infiltration potential are mapped.
- **Low Potential:** areas where multiple data sources map lower permeability sediments such as glaciomarine drift.
- **Infeasible Areas:** Mapping of areas infeasible for infiltration is discussed in AESI's Infeasibility Technical Report. AESI did not map infiltration potential within these mapped infeasible areas.

High infiltration potential areas generally encompass areas near I-5, east of the uplands in the northern portion of the urban growth area, on terraces within the Nooksack river valley (where outside of the floodway), and several small portions of the upland on the southern edge of the urban growth area. Medium infiltration potential areas are generally present along the margins of high infiltration potential areas, where the soils and geology mapping differ in the extent of mapped units. Low infiltration potential areas generally occur on glaciomarine drift-mantled uplands.

3.2.2 Deep Infiltration Potential

Because unsaturated Vashon advance outwash is the primary deep infiltration receptor layer in Ferndale, AESI reviewed the extent of mapped Vashon advance outwash as a first step in assessing deep infiltration potential. Depth to ground water is also a critical element for deep infiltration.

AESI incorporated information from ground water modeling of the advance aquifer (AESI, 2015) and delineated a deep infiltration potential area beneath the Mountain View Upland illustrated on Figure 6.

Deep infiltration potential assumptions were based on a minimum of 5 feet of separation above the water table, and an additional 20 feet of unsaturated receptor horizon. Further, we assumed an overburden thickness of 50 feet. AESI used 1,000-foot rasters for the elevation of the top of the advance outwash and the aquifer elevation within the advance outwash, and calculated areas where the above described relationship was true. AESI defined an approximate area of deep infiltration potential based on estimated aquifer elevation and an assumed overburden thickness of 50 feet. As shown in the cross section (Figure 3), AESI interprets that the overburden can be greater than 50 feet in thickness, however the thickness may vary laterally.

There is another more subdued upland in the southern portion of the City; however, the southern upland is at lower elevation than the Mountain View upland (approximately 100 feet, and approximately 360 feet, respectively). The lower ground surface elevation limits the possibility of the presence of an unsaturated receptor horizon which could be accessed by deep infiltration systems. For this reason, AESI interprets there to be little potential for deep infiltration in the southern upland, and mapped it as outside of the deep infiltration potential area.

4.0 SUMMARY OF RESULTS

This section presents the results of the infiltration feasibility assessment for the City of Ferndale. Maps of infiltration feasibility were created and the results are summarized below:

Shallow Infiltration Feasibility: As shown on Figure 5 and Figure 5A through Figure 5F, most of the City's possibly feasible infiltration areas in the upland have a low potential for shallow infiltration due to the presence of low-permeability glaciomarine drift sediments. Areas of medium to high infiltration potential are present on the margins of the upland or on the valley bottom. However, these areas are, in many cases, in close proximity to potential wetland areas.

Deep Infiltration Feasibility: As shown on Figure 6, deep infiltration potential exists on the Mountain View Upland where it is possible that a deep infiltration facility could penetrate through the glaciomarine drift into unsaturated glacial outwash, typically a suitable receptor horizon for stormwater infiltration. As discussed previously, the area with potential for deep infiltration is based on an assumed overburden thickness of 50 feet. Additional explorations which penetrate the glaciomarine drift and provide information on depth to glacial outwash would better define deep infiltration potential. In general, deep infiltration potential increases at higher elevations.

AESI notes that the City currently draws drinking water from the Vashon Advance outwash aquifer. Deep infiltration is an opportunity to provide recharge to the aquifer in conjunction with appropriate water quality treatment considerations to protect the source aquifer.

5.0 LIMITATIONS

The infiltration potential mapping provided in this technical memorandum is suitable for identification and evaluation of planning-level or conceptual infiltration solutions. For infiltration feasibility and design projects, additional subsurface explorations, infiltration testing, and analysis will be required by the City of Ferndale stormwater management code and Critical Areas Code. For site-specific infiltration target areas of interest, site-specific information is recommended to verify the information that provides the basis for the assessments included in this technical memorandum and to refine the analysis.

We have prepared this technical memorandum for use by the City of Ferndale. The conclusions and interpretations presented in this technical memorandum should not be construed as a warranty of the subsurface conditions. Our conclusions and recommendations are based on information provided by others and our experience in the area. Our experience has shown that soil and ground water conditions can vary significantly over small distances.

Within the limitations of scope, schedule, and budget, AESI attempted to execute these services in accordance with generally accepted professional principles in the fields of geology and hydrogeology at the time this memorandum was prepared. No warranty, express or implied, is made. If you should have any questions, or require further assistance, please do not hesitate to call.

Attachments:

Tables

Figures

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Table 1: Permeability Rating of Geologic Units

Geologic Unit	Grain Size	Density	Permeability	Typical Range of Vertical Infiltration Rates*	Comment
Qpv*: Pre-Fraser-Age Undifferentiated Glacial and Nonglacial Deposits	Varies	Typically dense to very dense	Varies, but typically lower because of consolidation and mild diagenesis	Varied <0.1-1 inches per hour	Varied properties; present in subsurface, not at ground surface
Qva*: Vashon Advance Outwash	Sand, gravel, variable silt	Dense to very dense	Moderate to High; Low where silt content exceeds ~15%	0.5 to 10 inches per hour	Can contain regional aquifer
Qvt*: Vashon Glacial Till	Silt/clay, sand, gravel, cobbles	Dense to very dense	Low	<0.1 inches per hour:	Aquitard
Qgdm(e): Everson Glaciomarine drift (includes Kulshan and Bellingham Drift Units)	Silt, clay, sandy in places	Medium dense to dense	Low	<0.1 inches per hour.	Aquitard
Qgdm(ee): Everson Emergence (beach) Deposits	Sand and gravel	Loose to medium dense	Moderate to high	1 to 10 inches per hour.	Typically less than 25 feet thick; can contain aquifer,
Qgo(s): Sumas Outwash	Sand, gravel, variable silt	Loose to medium dense	Moderate to High	1 to 100 inches per hour.	Contains shallow aquifer in places
Qa: Recent Sediments	Variable	Very loose to loose, or very soft to medium stiff	Variable. AESI assigned "moderate to mixed" permeability	<0.1 to 10 inches per hour	Contains shallow aquifer in places
Qp: Peat	N/A (organic)	Soft	High. Considered low for infiltration potential.	Not typically recommend ed for infiltration.	Often saturated

*Permeability ratings are included for reference for units which are not mapped on the surface within the project area.

Table 2: Permeability Rating of Soil Units

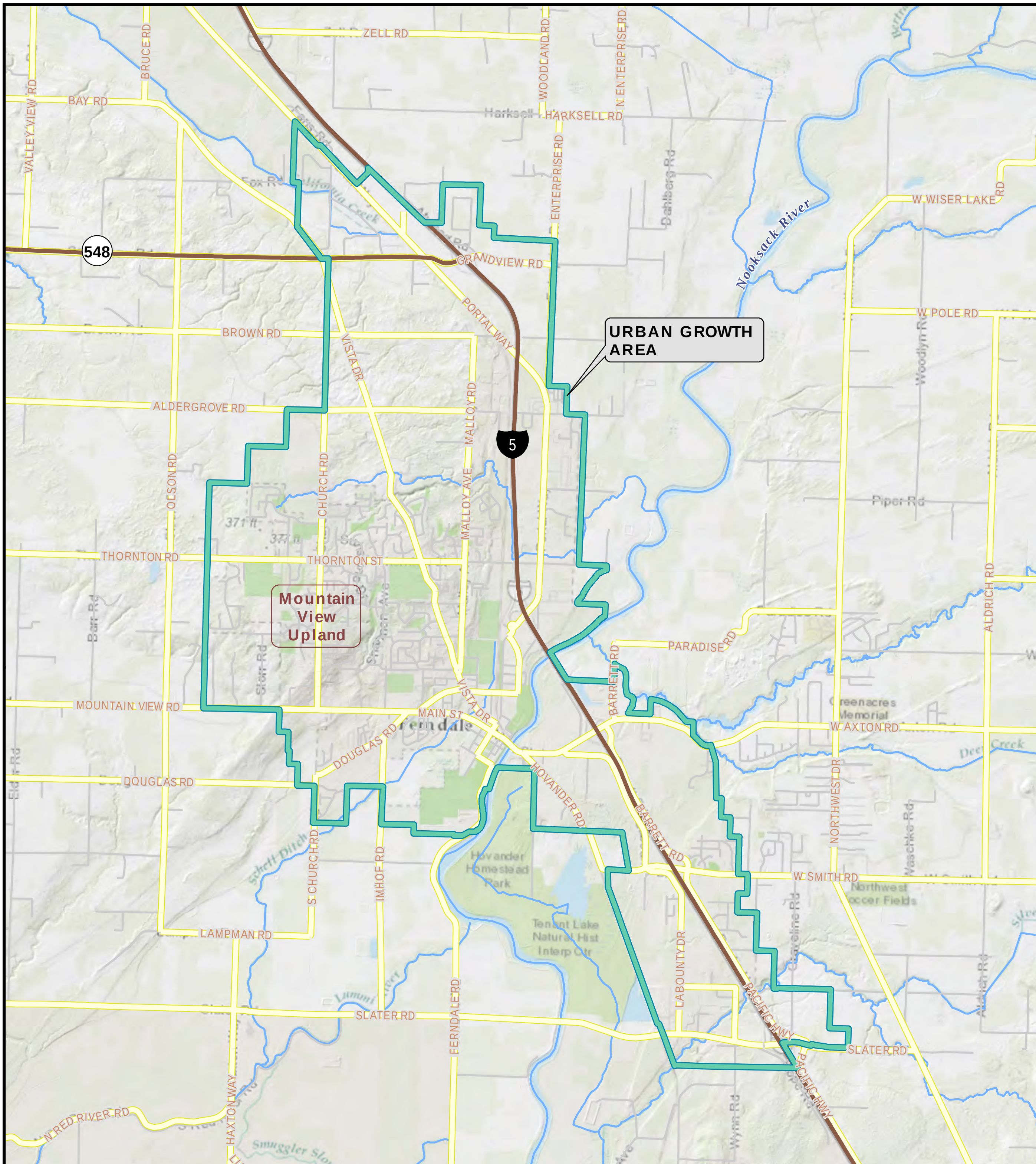
Soil Source	Soil Categories	USDA Texture	Hydro-logic Soil Group	Shallow Infiltration Potential**	Surficial permeability (depth range, inches: inches/hour)	Symbol	Area (% of Urban Growth Area)	Slope category	Erosion Hazard	Runoff Rate
Alluvium	Mt. Vernon	Fine sandy loam	C	Low	0-7: 0.6-2, 7-60; 0.6-2	107	2.6	0-2%	None	Very slow or ponded
	Oridia	Silt loam, drained	C	Low	0-12: 0.6-2, 12-60; 0.6-2	115	0.1	0-2%	None	Very slow or ponded
	Puget	Silt loam, drained	C	Low	0-9: 0.6-2, 9-60: 0.2-0.6	123	0.1	0-2%	None	Very slow or ponded
	Eliza	Silt loam, drained	B/D	Low	0-11: 0.6-2.0, 11-24: 0.6-2.0, 24-52: 0.6-2.0, 52-60: 0.6-2.0	46	0.6	0-1%	None	Very slow
	Sumas	Silt loam, drained	C	Low	0-8: 0.6-2, 8-26: 0.2-0.6, 26-60: 6-20	162	0.1	0-2%	None	Very slow
	Tacoma	Silt loam	C/D	Low	0-11: 0.6-2, 11-60: 0.2-0.6	163	0.6	0-1%	None	Very slow
Alluvium and Glacio-lacustrine deposits	Bellingham	Silty clay loam	C/D	Low	0-10: 0.6-2, 10-60; 0.06-.2	11	3	0-2%	None	Very slow or ponded
Glacio-lacustrine deposits	Skipopa	Silt loam	D	Low	0-8: 0.6-2, 8-20: 0.6-2, 20-60: <0.06	148	4.1	0-8%	Slight	Slow
Glacio-marine deposits	Labounty	Silt loam, drained	C	Low	0-10: 0.6-2, 10-16: 0.6-2, 16-35: 0.2-0.6, 35-60: 0.2-0.6	94	3.3	0-2%	None	Very slow

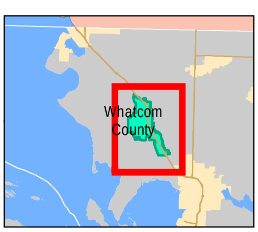
Soil Source	Soil Categories	USDA Texture	Hydro-logic Soil Group	Shallow Infiltration Potential**	Surficial permeability (depth range, inches: inches/hour)	Symbol	Area (% of Urban Growth Area)	Slope category	Erosion Hazard	Runoff Rate
Glacio-marine deposits	Hallenton	Silt loam	C/D	Low	0-11: 0.2-0.6, 11-19: 0.2-0.6, 19-60, 0.06-0.2	63	0	0-1%	None	Very slow
	Whatcom	Silt loam	C	Low	0-9: 0.6-2, 9-16: 0.6-2, 16-26: 0.2-0.6, 26-60: 0.06-0.2	178	17.5	0-3%	None	Very slow
						179		3-8%	Slight	Slow
					0-5: 0.6-2, 5-19: 0.6-2, 19-34: 0.2-0.6, 34-60: 0.06-0.2	180		8-15%	Moderate	Medium
						181		30-60%	Moderate	Medium
	Whatcom-Labounty	Silt loam	C	Low	See: Whatcom, Labounty	182, 183	26.9	0-8%	See others	See others
	Whitehorn	Silt loam	C/D	Low	0-10: 0.6-2, 10-18: 0.2-0.6, 18-26: 2-6, 26-60: 0.06-0.2	184	3.3	0-2%	None	Very slow
	Birchbay	Silt loam	C	Low	0-8: 0.6-2, 8-24: 0.6-2, 24-42: >20, 42-60: 0.06-0.2	12	0.4	0-3%	None	Very slow
						13		3-8%	Slight	Slow
Lacustrine/ Outwash, terraces	Everson	Silt loam	D	Low	0-7: 0.6-2, 7-19: 0.06-.2, 19-40: 6-20, 40-60: >20	53	1.6	0-2%	None	Very slow or ponded
Outwash (under herbaceous /woody deposits)	Fishtrap	Muck	C	Low	0-7: 0.6-2, 7-19: 0.6-2, 19-60: >20	54	0.2	0-2%	None	Very slow or ponded
	Salchar	Muck	B/D	Low	0-6: 0.4-0.6, 6-37: 0.3-0.5, 37-52: 1.2-1.35, 52-60: 1.5-1.65	143	0.1	0-2%	None	Very slow

Soil Source	Soil Categories	USDA Texture	Hydro-logic Soil Group	Shallow Infiltration Potential**	Surficial permeability (depth range, inches: inches/hour)	Symbol	Area (% of Urban Growth Area)	Slope category	Erosion Hazard	Runoff Rate
Outwash	Edmonds-Woodlyn	Loams	B/D	Moderate (mixed)	See: Edmonds, Woodlyn	45	9	0-2%	See others	See others
	Edmonds	(Included for reference by Edmonds-Woodlyn association)	Not present	Not present	0-11: 0.6-2, 11-18: 0.6-2, 18-37: 6-20, 37-60: >20	Not present	0	0-2%	None	Very slow
	Woodlyn	(Included for reference by Edmonds-Woodlyn association)	Not present	Not present	0-9: .6-2, 9-12: 0.6-2, 12-25: ----, 25-60: >20	Not present	0	0-2%	None	Very slow
	Hale	Silt loam, drained	C	Moderate	0-10: 0.6-2, 10-26: 0.6-2, 26-60: >20	62	2.4	0-2%	None	Very slow or ponded
	Kickerville	Silt loam	B	Moderate	0-9: .06-2, 9-22: .0.6-2, 22-32: 0.6-2, 32-60: >20	80	0.3	3-8%	Slight	Slow
					0-3: 0.6-2, 3-19: 0.6-2, 19-24: 0.6-2, 24-60: >20	81		8-15%	Moderate	Medium
	Laxton	Loam	C	Moderate	0-9: 0.6-2, 9-23: 0.6-2, 23-32: 6-20, 32-60: >20	96	4.2	0-3%	None	Very slow
						97		3-8%	Slight	Slow
					0-11: 0.6-2, 11-36: 0.6-2, 36-60: >20	98		8-15%	Moderate	Medium
	Lynden	Sandy loam	A	Moderate	0-8: 2-6, 8-18: 2-6, 18-30: >20, 30-60: >20	99	5.4	0-3%	None	Very slow
						100		3-8%	Slight	Slow

Soil Source	Soil Categories	USDA Texture	Hydro-logic Soil Group	Shallow Infiltration Potential**	Surficial permeability (depth range, inches: inches/hour)	Symbol	Area (% of Urban Growth Area)	Slope category	Erosion Hazard	Runoff Rate
Outwash	Lynnwood	Sandy loam	A	Moderate	0-4: 2-6, 4-36: 6-20, 36-60: 6-20	103	0.2	5-20%	Moderate	Medium
	Yelm	Loam	C	Moderate	0-8: 0.6-2, 8-36: 2-6, 36-60: 2-6	191	2.5	3-8%	Slight	Slow
	Tromp	Loam	C	Moderate	0-11: 0.6-2, 11-20: 0.6-2, 20-26: 2-6, 26-46: 6-20, 6-60: >20	165	7.2	0-2%	None	Very slow
Other	Histosols	--	B/D	Low	0-8: 0.6-2, 8-28: 0.6-2, 28-60: 0.2-20, 60-70: 0.6-20	72	0.1	0-1%	None	Ponded
	Pits, gravel	--	--	Moderate	0-6: >6, 6-60: >6	120	0.1	Varies	None to very severe	Very rapid to ponded
	Urban Land	--	--	Low	--	171	1	--	--	--
	Urban Land-Whatcom-Labounty complex	--	C	Low	--	172	1.8	--	--	--
	Lynden-Urban land complex	--	A	Low	--	101	0.5	--	--	--
	Water	--	--	N/A	--	193	0.5	--	--	--

Soil groups from NRCS Web Soil Survey. Other information from USDA (1992).
**Soils which are generally saturated but permeable were grouped with "low" infiltration potential soils for purposes of infiltration potential mapping.
-- Not applicable or not assigned.





DATA SOURCES / REFERENCES:
ESRI OPENSTREETMAP
CITY OF FERNDALE UGA BOUNDARY12/16

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 2500 5000

FEET

NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

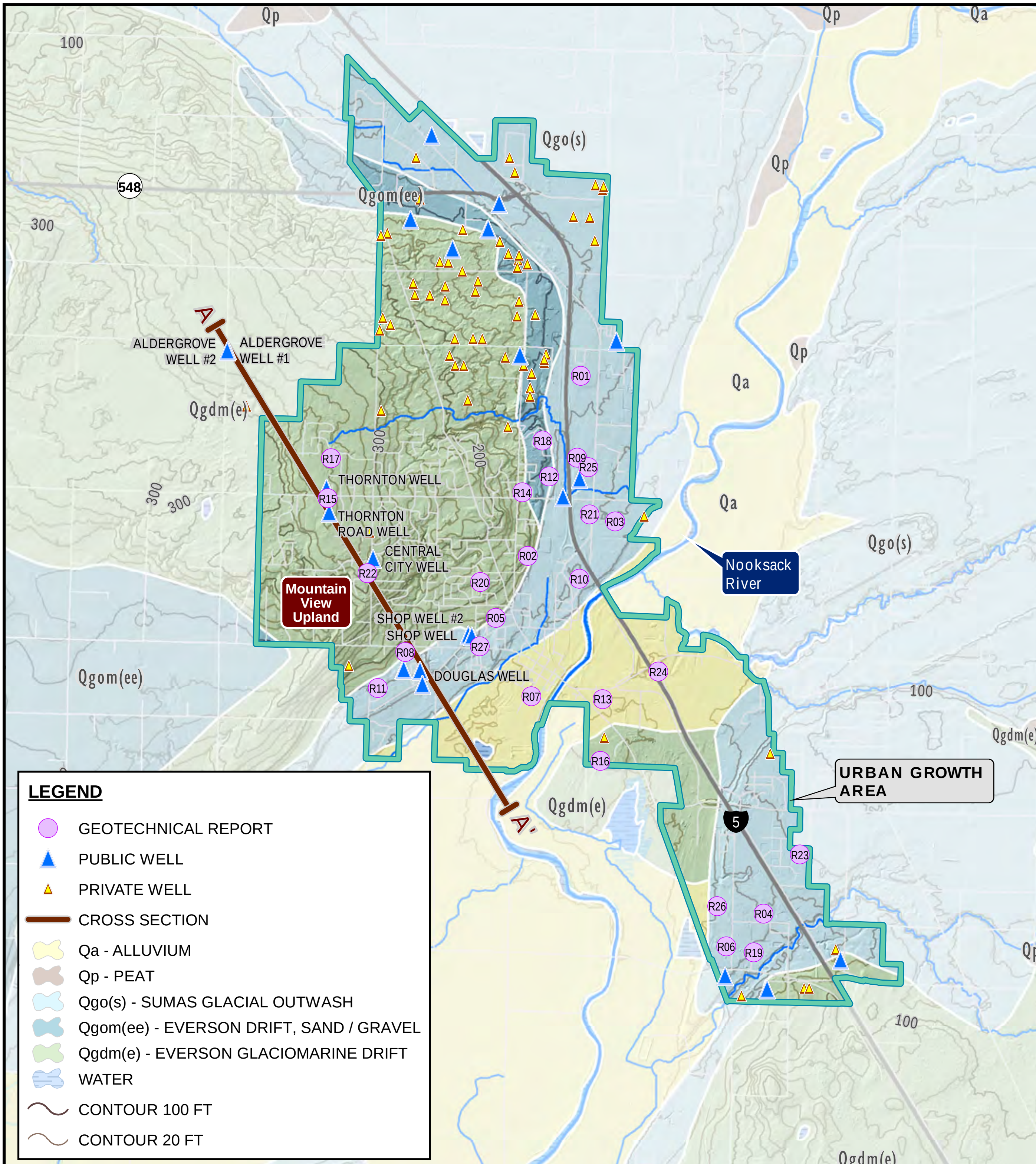
associated earth sciences incorporated

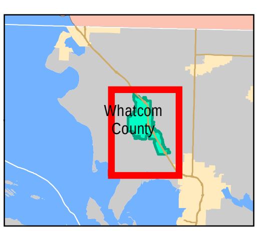
VICINITY MAP

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

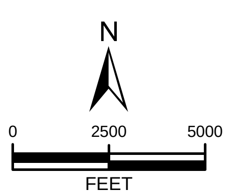
PROJ NO.	DATE:	FIGURE:
150676H004	9/17	1

Document Path: G:\GIS_Projects\aY15post0716\150676 Ferndale Infiltration\mxd\H004\150676H004 F1 VM_Fern.mxd





DATA SOURCES / REFERENCES:
PSLC LIDAR 2005, CONTOURS FROM LIDAR
CITY OF FERNDALE UGA BOUNDARY12/16
CITY OF BELLINGHAM ROADS 3/17
DNR 100K GEO, EASTERBROOK 1976, MAP I-854-B
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE



NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

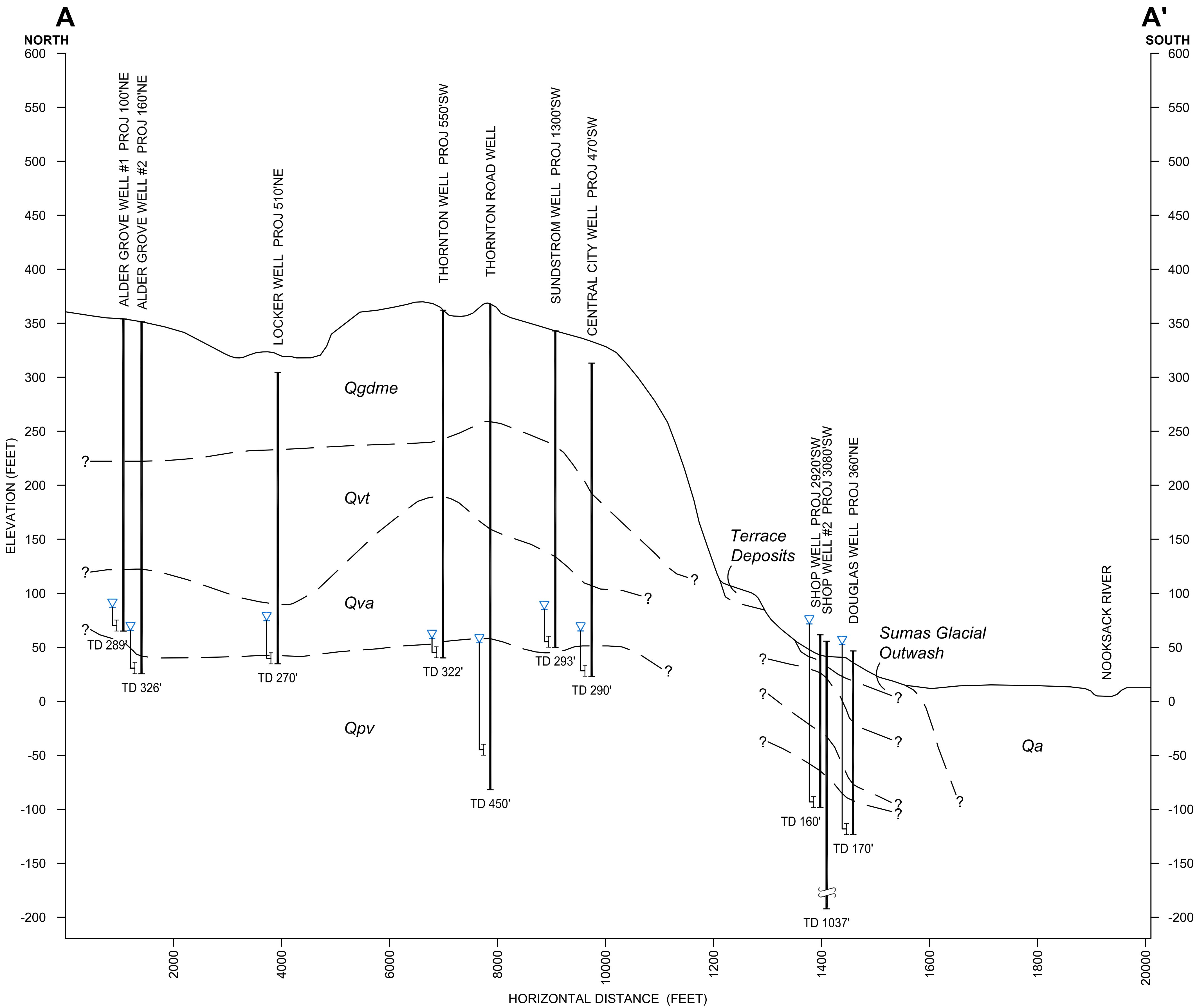
associated earth sciences incorporated

GEOLOGIC MAP

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	2

Document Path: G:\GIS_Projects\aY15post0716\150676 Ferndale Infiltration\mxd\H004\150676H004 F2 Geo_Fern_L.mxd



LEGEND:

Qgdme	EVERSON GLACIOMARINE DRIFT
Qvt	VASHON LODGEMENT TILL
Qva	VASHON ADVANCE OUTWASH
Qpv	OLDER UNDIFFERENTIATED GLACIAL AND NONGLACIAL SEDIMENTS
Qa	ALLUVIUM
	WELL
	STATIC WATER LEVEL
	SCREENED INTERVAL
TD	TOTAL DEPTH OF BORING
	GEOLOGIC CONTACT

VERTICAL EXAGGERATION = 20X

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE

NOTES:
1. THE SUBSURFACE CONDITIONS PRESENTED IN THIS GEOLOGIC CROSS-SECTION ARE BASED ON AN INTERPRETATION OF CONDITIONS ENCOUNTERED IN WIDELY SPACED EXPLORATIONS COMPLETED AT THE SUBJECT SITE AND RELEVANT SITE INFORMATION DEVELOPED AND PROVIDED BY OTHERS. THE SUBSURFACE INTERPRETATIONS PRESENTED IN THIS GEOLOGIC CROSS-SECTION SHOULD NOT BE CONSTRUED AS A WARRANTY OF ACTUAL SUBSURFACE CONDITIONS AT THE SITE. OUR EXPERIENCE HAS SHOWN THAT SOIL AND GROUND WATER CONDITIONS CAN VARY SIGNIFICANTLY OVER SMALL DISTANCES.

NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

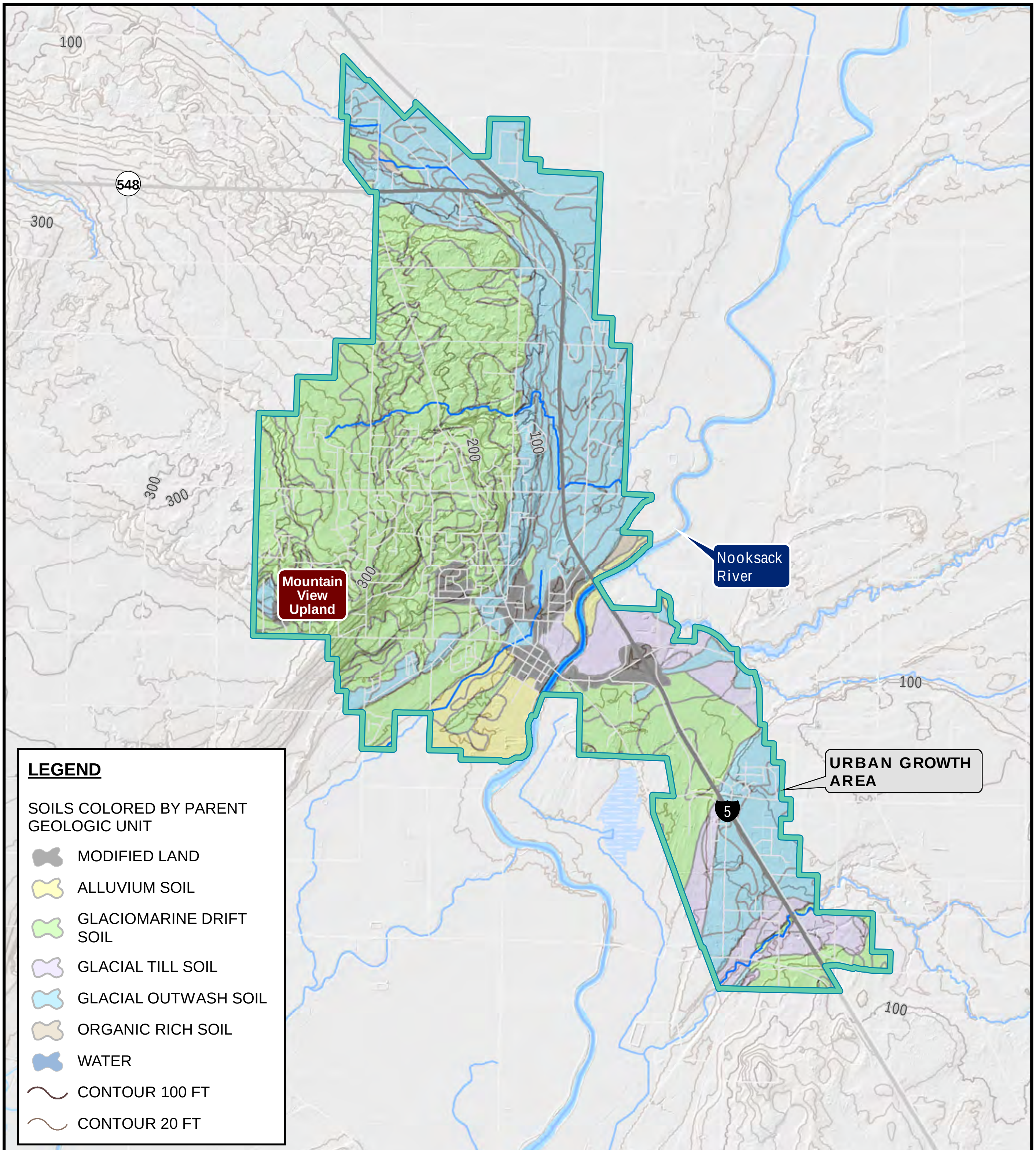
associated earth sciences incorporated

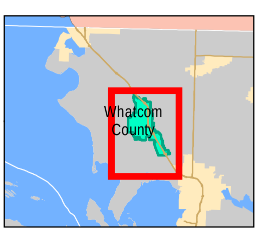
GEOLOGIC CROSS-SECTION A-A'

CITY OF FERNDALE INFILTRATION FEASIBILITY ASSESMENT
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	3

150676 Ferndale \ 150676H004 GeoSect.dwg LAYOUT: F3 Sect A-A





N

0 2500 5000

FEET

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005, CONTOURS FROM LIDAR
CITY OF FERNDALE UGA BOUNDARY12/16, USDA\NRCS SOIL DATA
CITY OF BELLINGHAM ROADS 3/17
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

SOILS MAP

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	4

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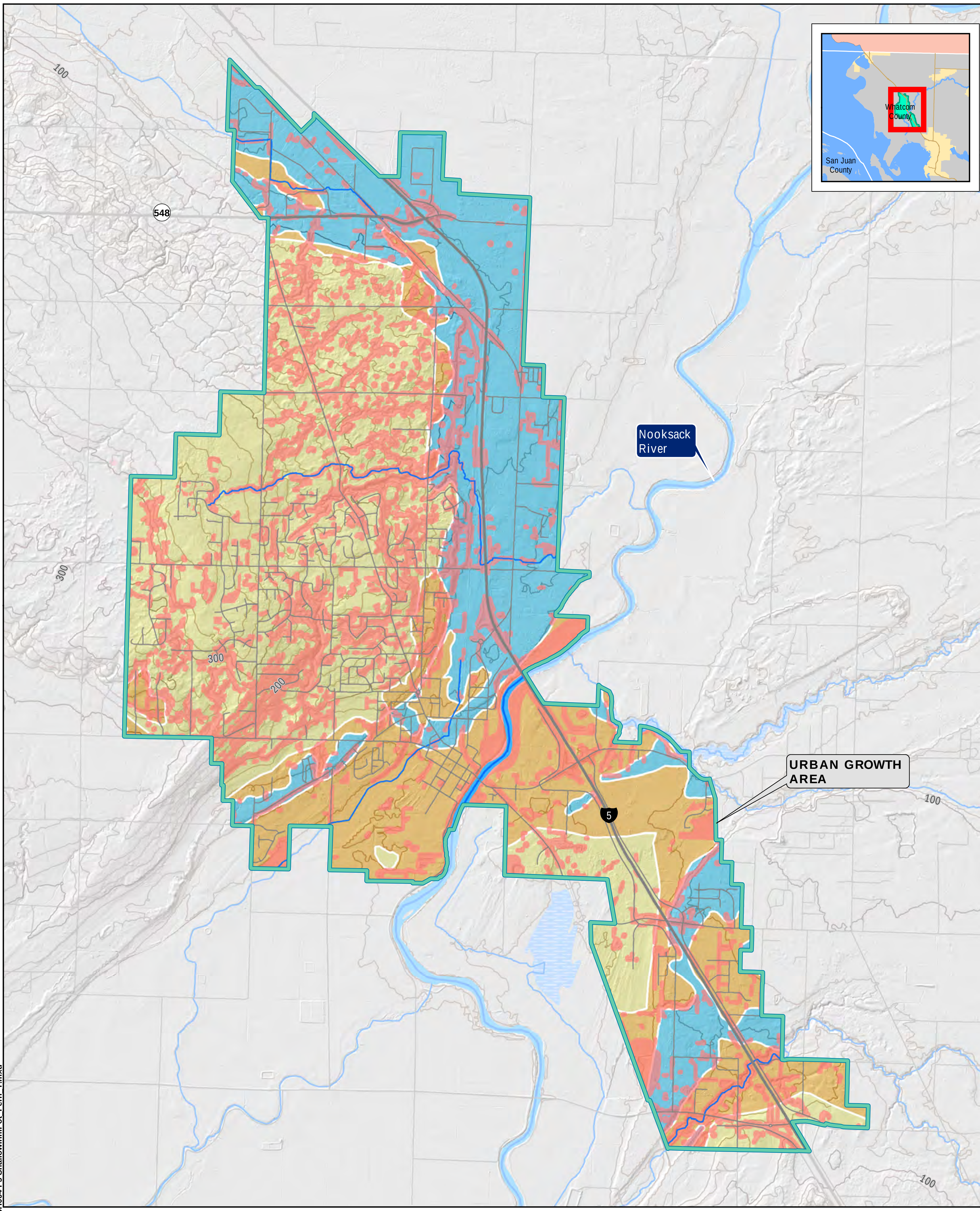

LEGEND:

SHALLOW INFILTRATION POTENTIAL

- HIGH
- MEDIUM
- LOW
- INFEASIBLE AREA (AESI, 2017)

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005. GRID CELL SIZE IS 6'.
WA STATE PLANE NORTH (FIPS 4601), NAD83(HARN)
NAVD88 GEOID03, US SURVEY FEET. CONTOURS FROM LIDAR
WHATCOM CO: PARCELS 4/17, HYDRO, CITY BOUNDARY
WSDOT: STATE ROUTES
CITY OF BELLINGHAM: ROADS 3/17
CITY OF FERNDALE UGA

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N
0 1500 3000
FEET

BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

SHALLOW INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	5

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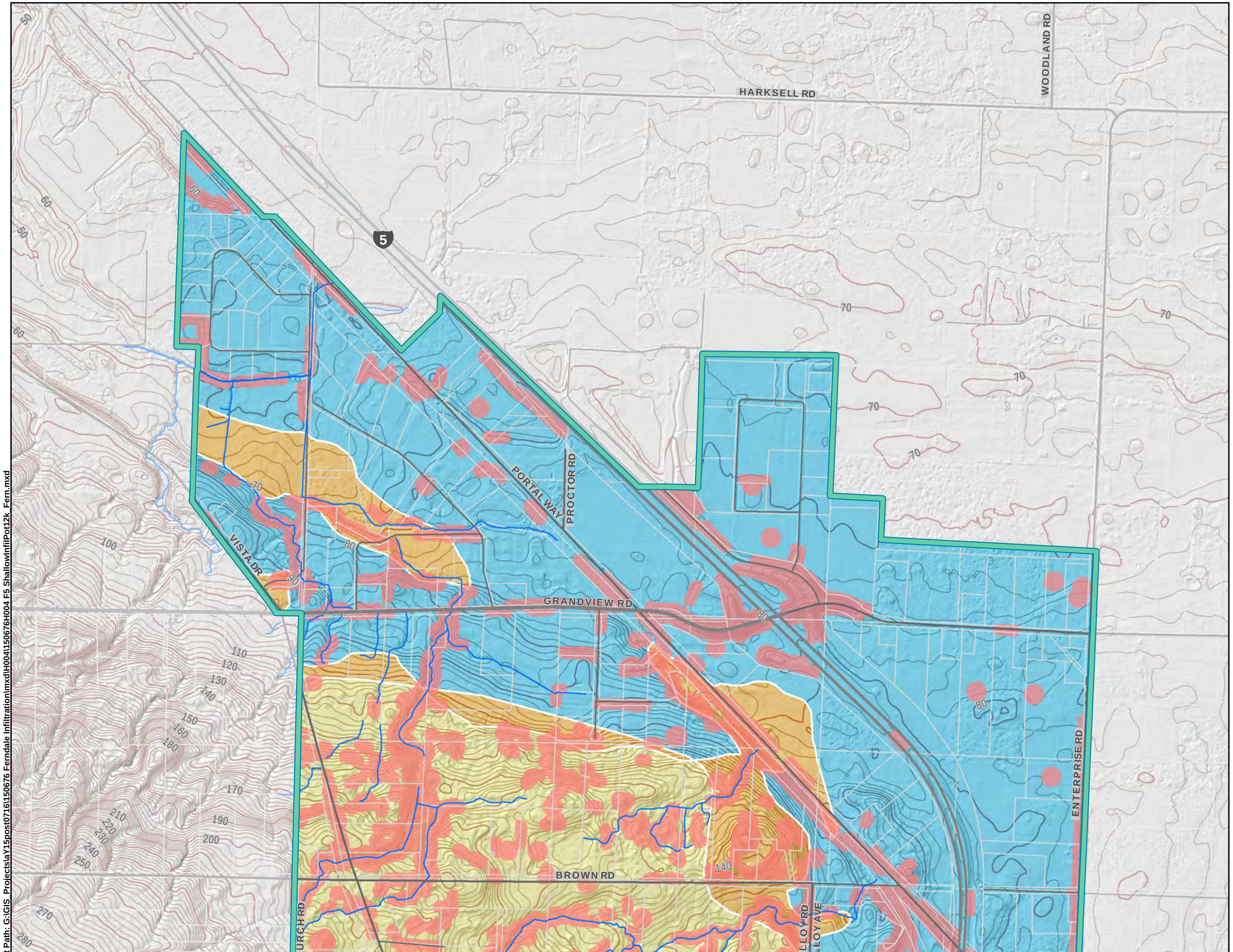


LEGEND:

PROJECT BOUNDARY

INFEASIBLE AREA

SHALLOW INFILTRATION POTENTIAL

HIGH

MEDIUM

LOW

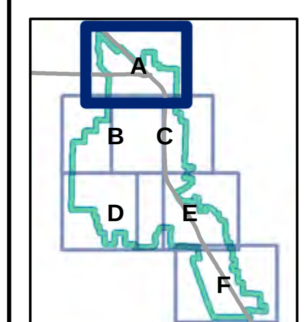
CONTOUR 10 FT

CONTOUR 2 FT

PARCEL

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005. GRID CELL SIZE IS 6'.
WA STATE PLANE NORTH (FIPS 4601), NAD83(HARN)
NAVD88 GEOID03, US SURVEY FEET. CONTOURS FROM LIDAR
CONTOURS SMOOTHED FOR DISPLAY
WHATCOM CO: PARCELS 4/17, HYDRO, CITY BOUNDARY
WSDOT: STATE ROUTES
CITY OF BELLINGHAM: ROADS 3/17
CITY OF FERNDALE UGA

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE



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FEET

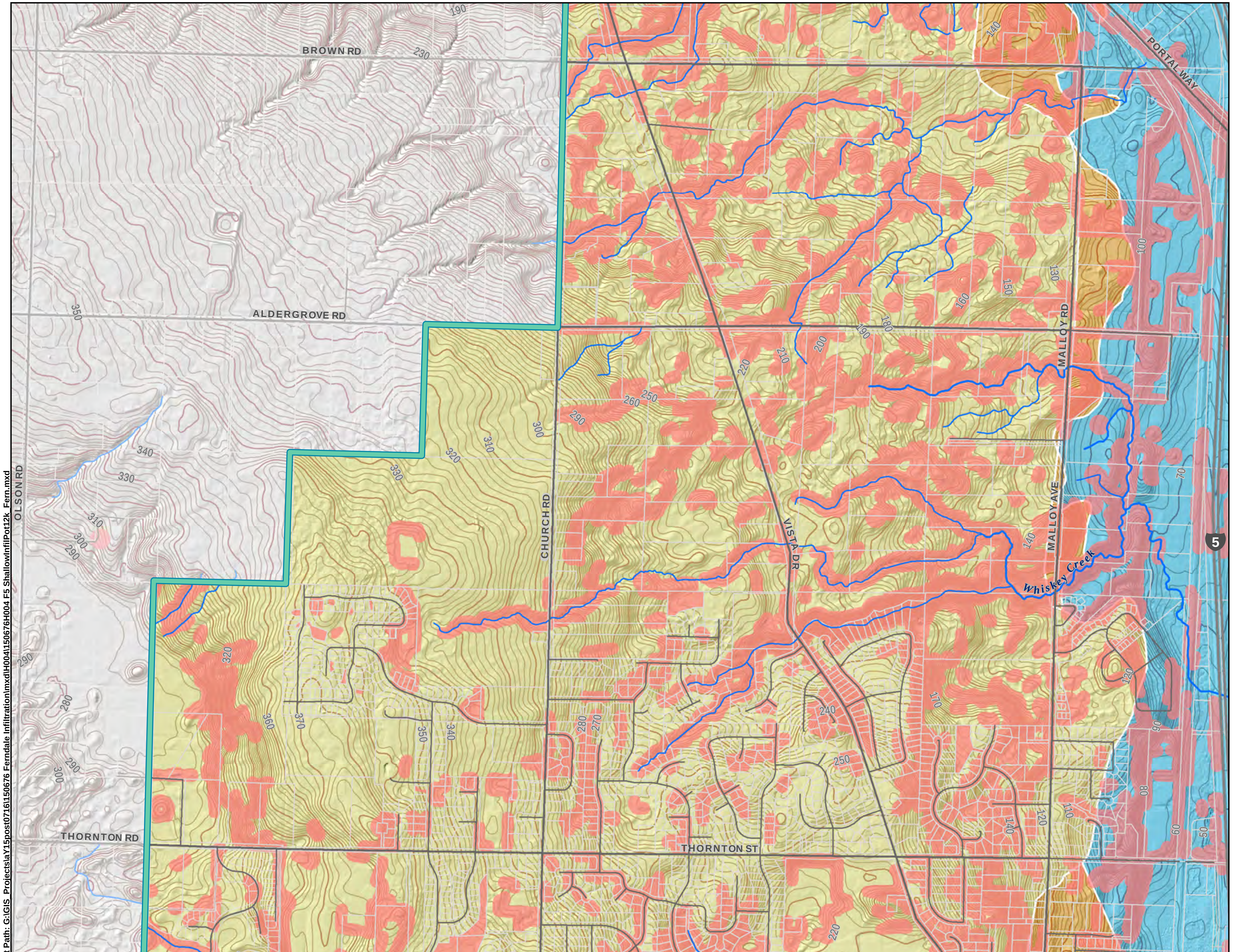
BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

SHALLOW INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	5-A



LEGEND:

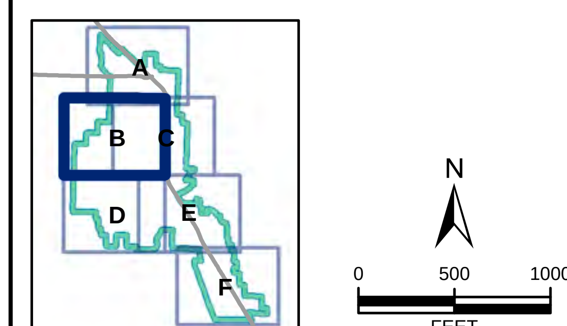
- PROJECT BOUNDARY
- INFEASIBLE AREA

SHALLOW INFILTRATION POTENTIAL

- HIGH
- MEDIUM
- LOW
- CONTOUR 10 FT
- CONTOUR 2 FT
- PARCEL

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005. GRID CELL SIZE IS 6'.
WA STATE PLANE NORTH (FIPS 4601), NAD83(HARN)
NAVD88 GEOID03, US SURVEY FEET. CONTOURS FROM LIDAR
CONTOURS SMOOTHED FOR DISPLAY
WHATCOM CO: PARCELS 4/17, HYDRO, CITY BOUNDARY
WSDOT: STATE ROUTES
CITY OF BELLINGHAM: ROADS 3/17
CITY OF FERNDALE UGA

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE



BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

SHALLOW INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	5-B

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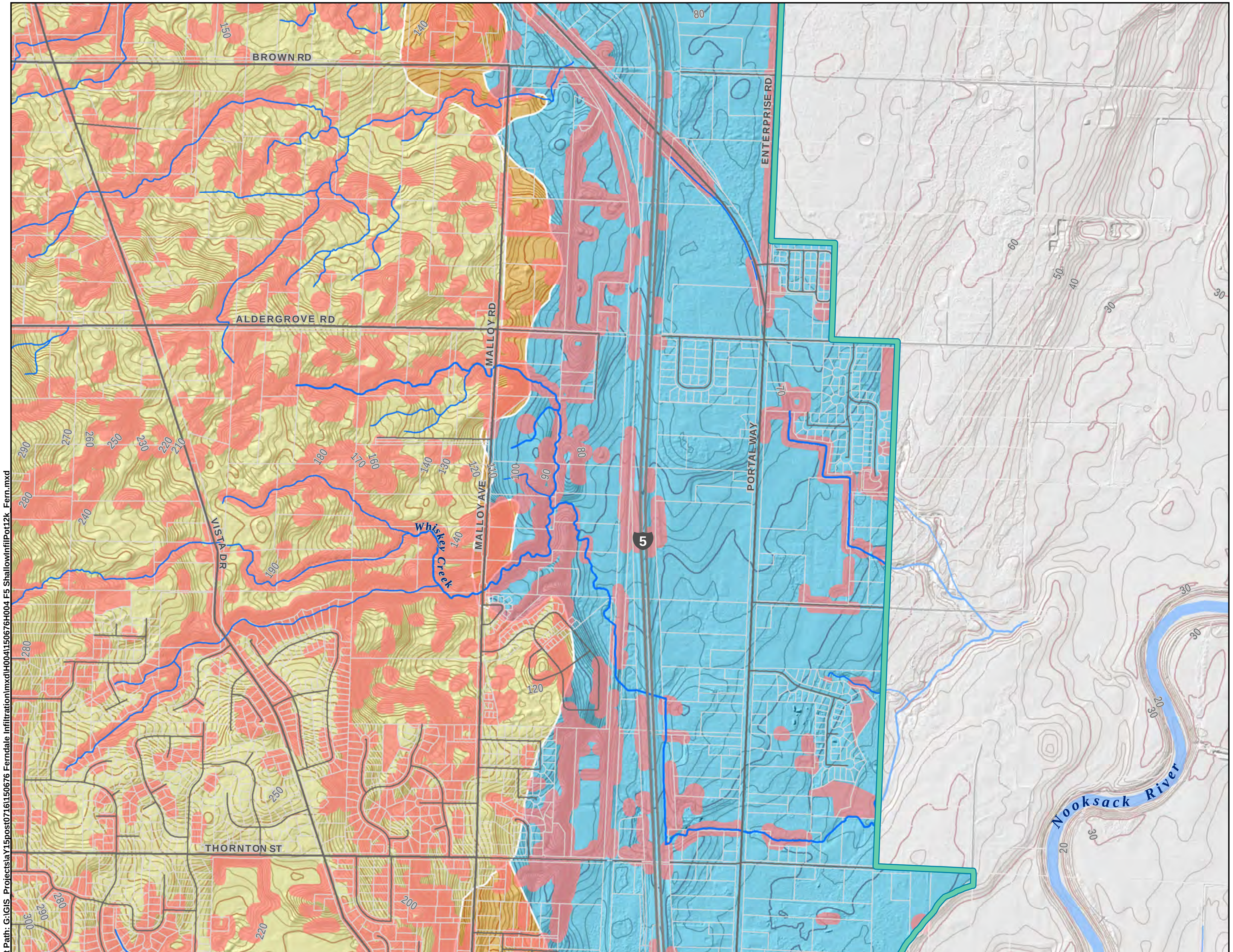


LEGEND:

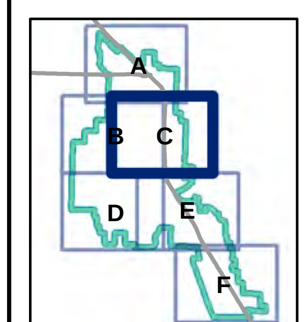
- PROJECT BOUNDARY
- INFEASIBLE AREA

SHALLOW INFILTRATION POTENTIAL

- HIGH
- MEDIUM
- LOW
- CONTOUR 10 FT
- CONTOUR 2 FT
- PARCEL

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005. GRID CELL SIZE IS 6'.
WA STATE PLANE NORTH (FIPS 4601), NAD83(HARN)
NAVD88 GEOID03, US SURVEY FEET. CONTOURS FROM LIDAR
CONTOURS SMOOTHED FOR DISPLAY
WHATCOM CO: PARCELS 4/17, HYDRO, CITY BOUNDARY
WSDOT: STATE ROUTES
CITY OF BELLINGHAM: ROADS 3/17
CITY OF FERNDALE UGA

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE



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0 500 1000
FEET

BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

SHALLOW INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	5-C

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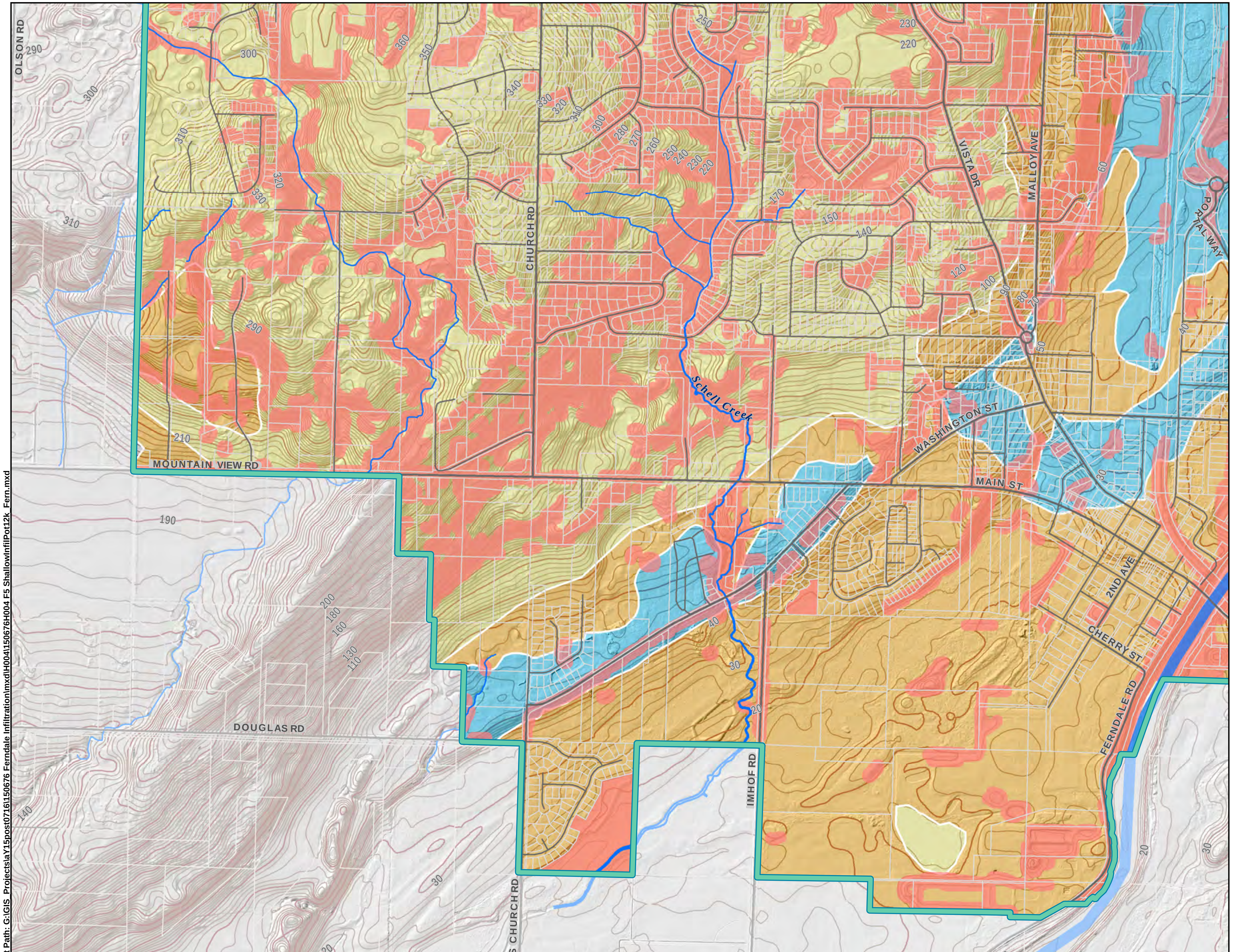

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LEGEND:

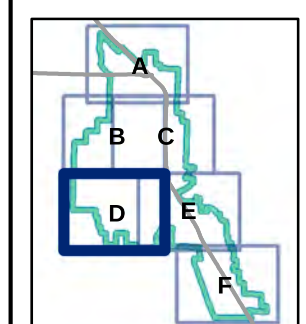
- PROJECT BOUNDARY
- INFEASIBLE AREA

SHALLOW INFILTRATION POTENTIAL

- HIGH
- MEDIUM
- LOW
- CONTOUR 10 FT
- CONTOUR 2 FT
- PARCEL

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005. GRID CELL SIZE IS 6'.
WA STATE PLANE NORTH (FIPS 4601), NAD83(HARN)
NAVD88 GEOID03, US SURVEY FEET. CONTOURS FROM LIDAR
CONTOURS SMOOTHED FOR DISPLAY
WHATCOM CO: PARCELS 4/17, HYDRO, CITY BOUNDARY
WSDOT: STATE ROUTES
CITY OF BELLINGHAM: ROADS 3/17
CITY OF FERNDALE UGA

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE



N

0 500 1000
FEET

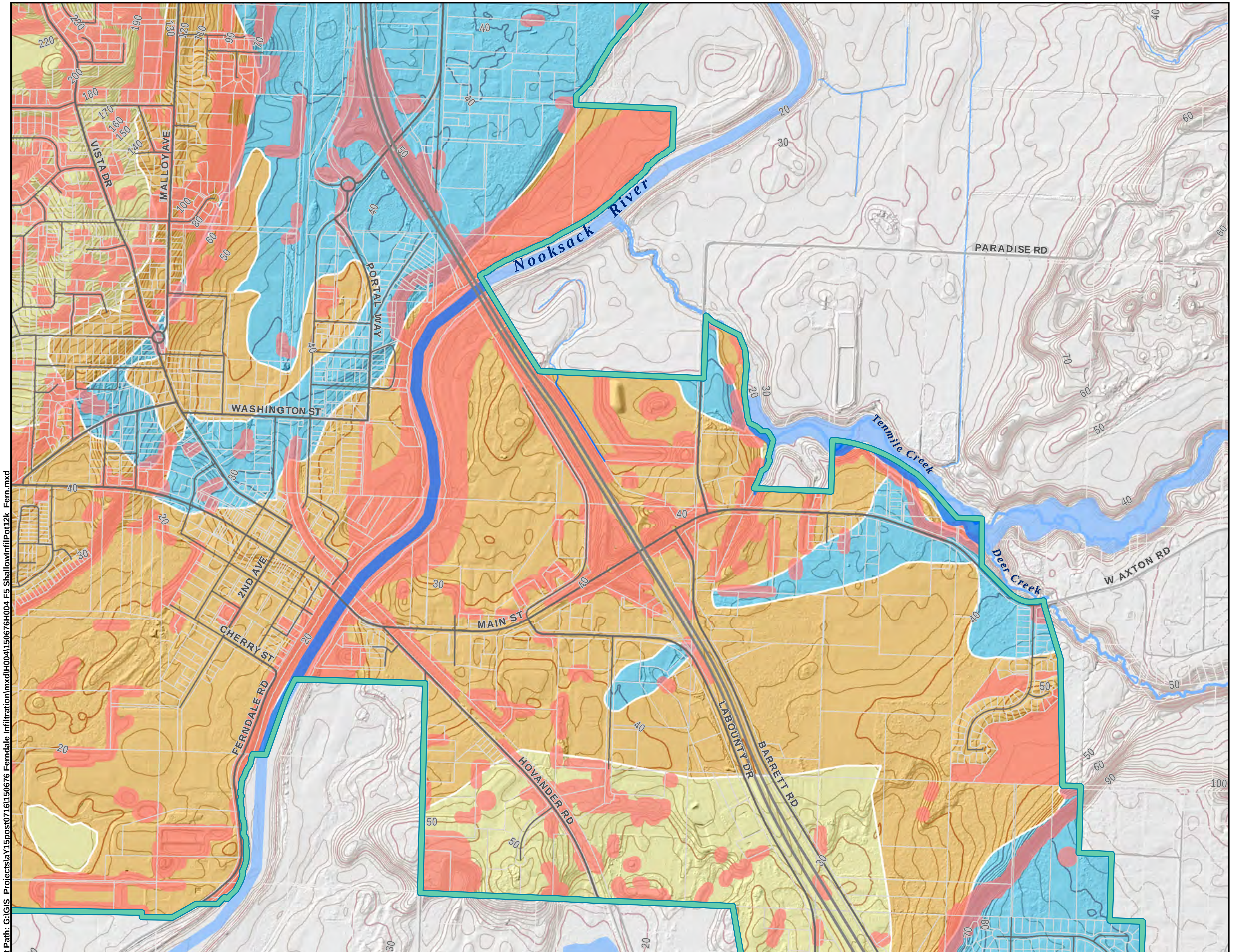
BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

SHALLOW INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	5-D



LEGEND:

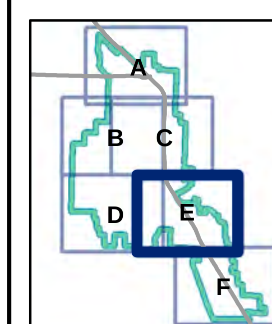
- PROJECT BOUNDARY
- INFEASIBLE AREA

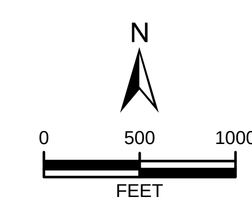
SHALLOW INFILTRATION POTENTIAL

- HIGH
- MEDIUM
- LOW
- CONTOUR 10 FT
- CONTOUR 2 FT
- PARCEL

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005. GRID CELL SIZE IS 6'.
WA STATE PLANE NORTH (FIPS 4601), NAD83(HARN)
NAVD88 GEOID03, US SURVEY FEET. CONTOURS FROM LIDAR
CONTOURS SMOOTHED FOR DISPLAY
WHATCOM CO: PARCELS 4/17, HYDRO, CITY BOUNDARY
WSDOT: STATE ROUTES
CITY OF BELLINGHAM: ROADS 3/17
CITY OF FERNDALE UGA

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE





BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

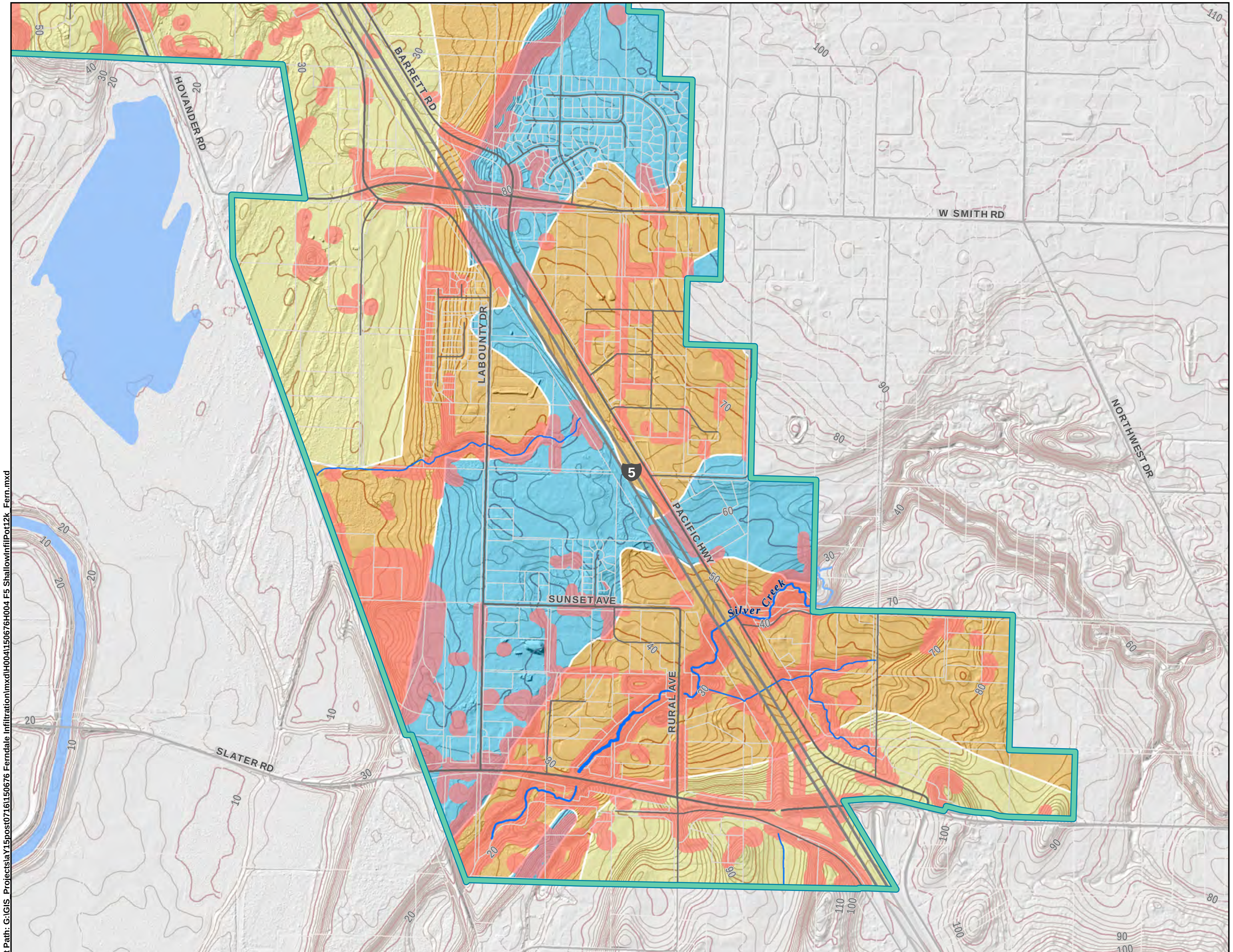
associated earth sciences incorporated

SHALLOW INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	5-E

Document Path: G:\GIS_Projects\aY15post0716\150676 Ferndale Infiltration\mxd\H004\150676H004 F5 ShallowInfilPot12k_Ferm.mxd



LEGEND:

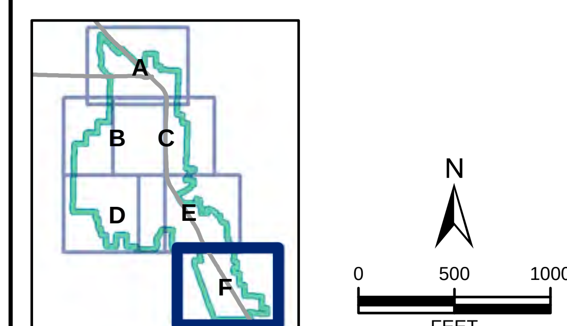
- PROJECT BOUNDARY
- INFEASIBLE AREA

SHALLOW INFILTRATION POTENTIAL

- HIGH
- MEDIUM
- LOW
- CONTOUR 10 FT
- CONTOUR 2 FT
- PARCEL

DATA SOURCES / REFERENCES:
PSLC LIDAR 2005. GRID CELL SIZE IS 6'.
WA STATE PLANE NORTH (FIPS 4601), NAD83(HARN)
NAVD88 GEOID03, US SURVEY FEET. CONTOURS FROM LIDAR
CONTOURS SMOOTHED FOR DISPLAY
WHATCOM CO: PARCELS 4/17, HYDRO, CITY BOUNDARY
WSDOT: STATE ROUTES
CITY OF BELLINGHAM: ROADS 3/17
CITY OF FERNDALE UGA

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE



BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

SHALLOW INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150676H004	9/17	5-F

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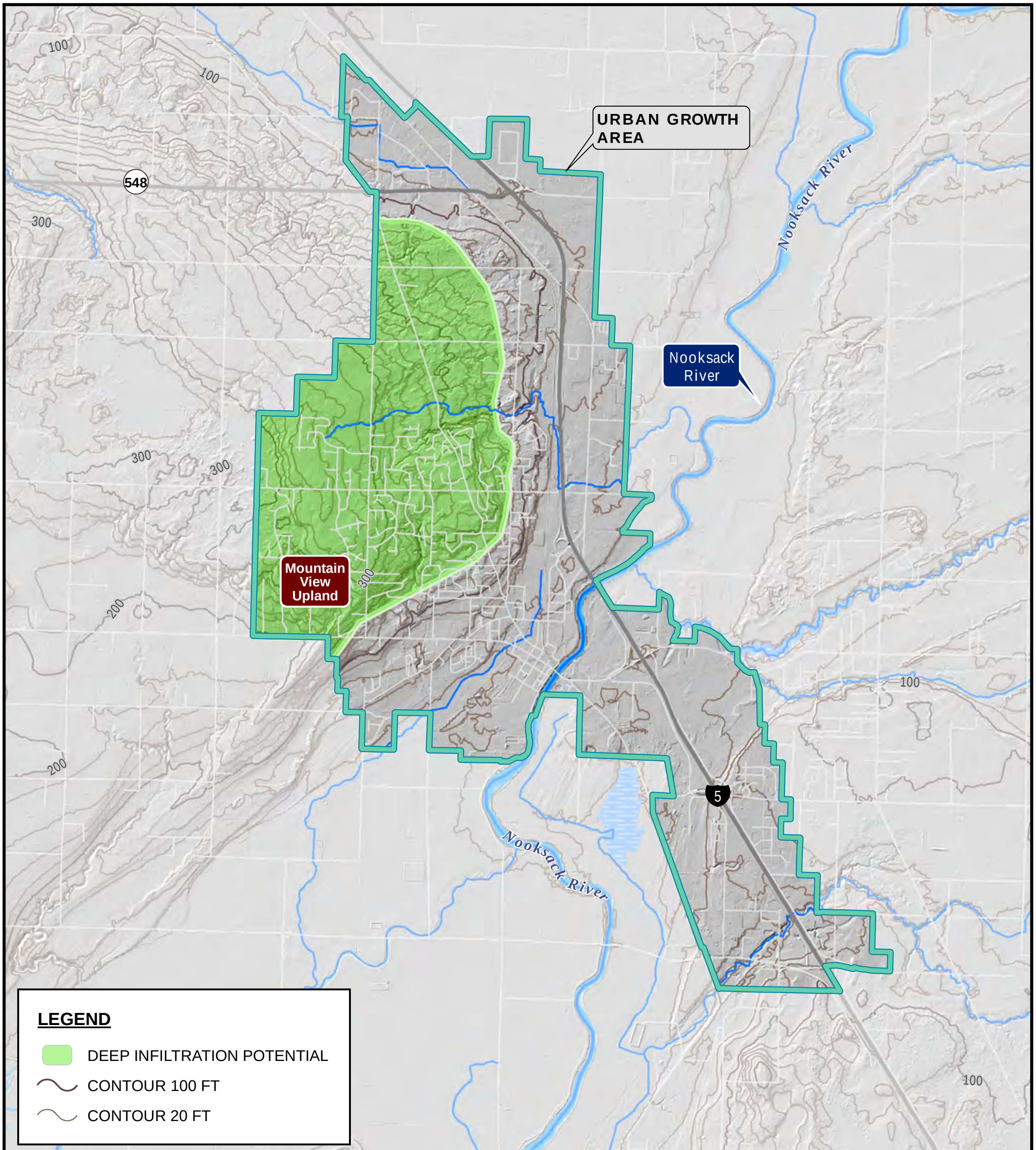

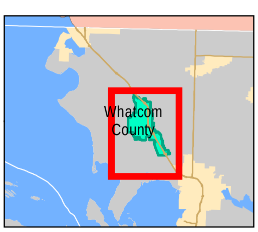

DATA SOURCES / REFERENCES:
PSLC: 2005 LIDAR, HILLSHADE
CITY OF FERNDALE UGA BOUNDARY12/16, WHATCOM CO. ROADS 4/17

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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associated earth sciences incorporated

DEEP INFILTRATION POTENTIAL

FERNDALE INFILTRATION FEASIBILITY STUDY
FERNDALE, WASHINGTON

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