Appendix C - Hydrogeologic Setting

For Limited License Application LL1621

Walla Walla Basin Watershed Council

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Walla Walla Basin Hydrogeologic Setting

This report presents a summary of alluvial aquifer hydrogeologic conditions regionally and within the area of the multi-site AR program (Figure 1). For more details of area hydrogeology, the reader is referred to Newcomb (1965), Barker and McNish (1976), GSI (2007, 2009a, 2009b) and WWBWC (2010) and other citations as presented herein.

Hydrostratigraphy

Five alluvial sediment hydrostratigraphic units are mapped in the project area, including: (1) Quaternary fine unit, (2) Quaternary coarse unit, (3) Mio-Pliocene upper coarse unit, (4) Mio-Pliocene fine unit, and (5) Mio-Pliocene lower coarse unit. The following sections describe the basic physical characteristics of each suprabasalt sediment unit and top of basalt.

Quaternary Units

Quaternary Fine Unit

Newcomb (1965) and several subsequent investigators (Fecht and others, 1987; Busacca and MacDonald, 1994; Waitt and others, 1994) described a variety of Quaternary aged fine (clay/silt/fine sand dominated) units in the area of the Walla Walla Basin. Above elevations of approximately 1150 to 1200 feet above mean sea level (msl), these strata consist predominantly of loess. Isolated hills found on the valley floor and much of the upland area north of the Walla Walla River consist predominantly of Missoula flood deposited silt and sand referred to as the Touchet Beds. Reworked flood deposits and loess form local accumulations of fine strata across the valley floor near major streams. These strata are grouped into a single unit referred to as the Quaternary fine unit. The thickness of this unit varies greatly, depending on local topography, depth of stream incision, and original depositional patterns.

Variation in unit thickness and its absence locally, especially along modern stream courses, likely reflects both depositional factors and post-deposition erosion. For example, the wide distribution of the Quaternary fine unit around the northern edge of the Basin primarily reflects widespread deposition followed by localized deep erosion along relatively, ephemeral stream courses. Conversely, the fact that the unit is thin to absent along major stream courses (notably the Touchet River, Walla Walla River, and Mill Creek) likely reflects, at least in large part, the erosive effects of these major streams incising into and removing Pleistocene Cataclysmic Flood deposits and eolian deposited fines.

Quaternary Coarse Unit

Uncemented and nonindurated sandy to gravelly strata is found in the shallow subsurface beneath much of the Basin. These gravely deposits are basaltic, moderately to well bedded, have a silty to sandy matrix, and contain thin, local silt interbeds. These uncemented and nonindurated basaltic gravels generally are equivalent to Newcomb's (1965) younger alluvial sand and gravel and are referred to currently as the Quaternary coarse unit. This sequence of uncemented gravel is interpreted to record stream deposition in the Walla Walla Basin by streams draining off the adjacent Blue Mountains. These streams are inferred to include the ancestral courses of the modern stream drainage. Based on stratigraphic relationships the Quaternary coarse unit predates, is contemporaneous with, and post-dates Missoula flood deposits. Given this, the Quaternary coarse unit probably ranges in age from a few years old to as old as 1 million years or more.

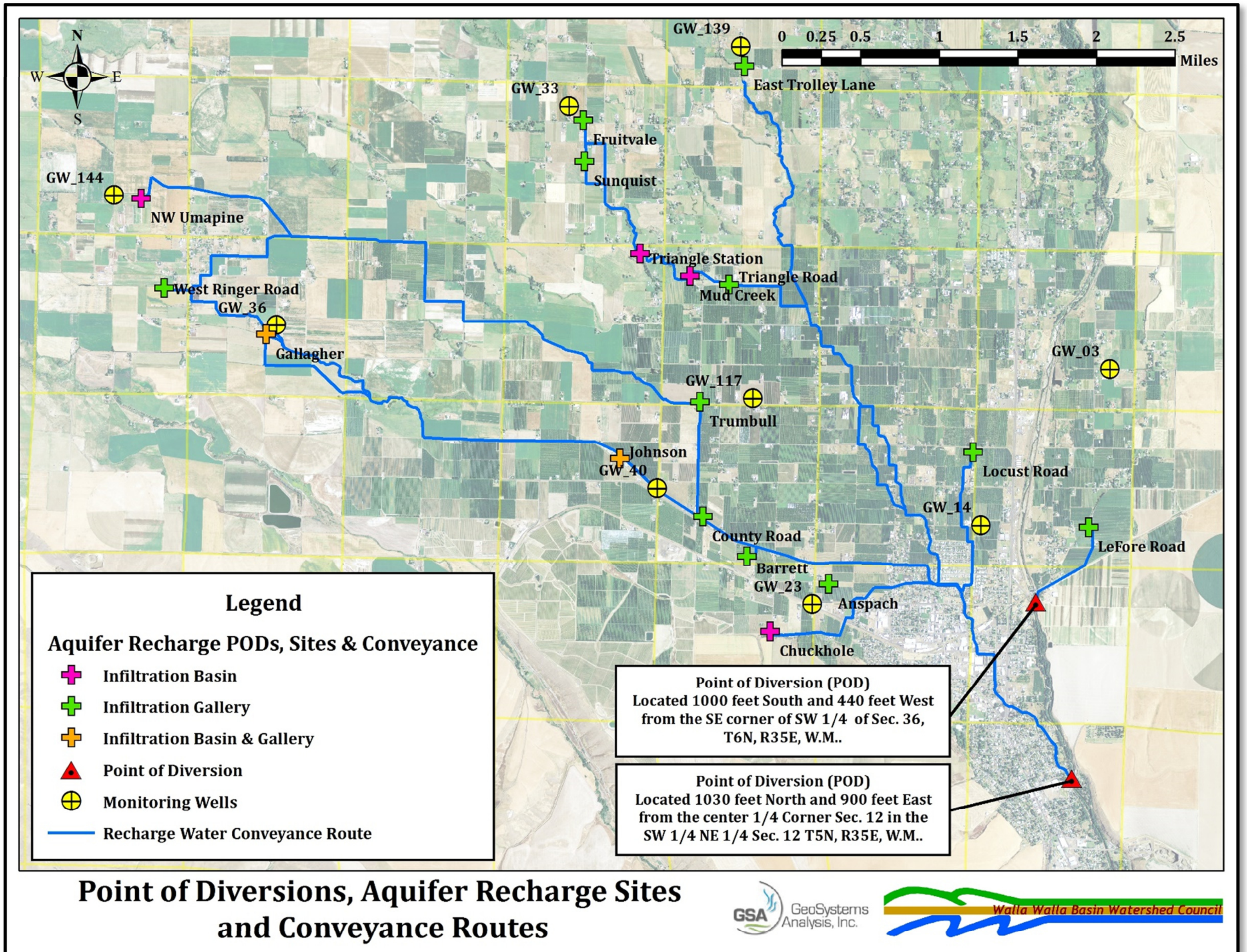

Figure 1 - Points of diversion (PODs), aquifer recharge sites and conveyance systems for limited license 1621.

Both depositional and erosional mechanisms can explain Quaternary coarse unit distribution. Its planar-tabular distribution in the Milton-Freewater area and the area beneath and east of Walla Walla probably reflects deposition in shallow, braided channel complexes on an active (or recently active) braid plain. To the west, elongate patterns may reflect gravel deposition down the topographically low axis of the Basin as it has existed in the recent geologic past (last 1 to 2 million years). The elongate areas where the unit is absent potentially reflect areas of non-deposition because of the absence of channels and/or post-depositional erosion. The highs and lows apparent in the top of this unit along the base of the Horse Heaven Hills are interpreted to be related to the deformation and uplift of these hills. During that uplift, the surface of the unit has been deformed, in some areas uplifted, in other areas, down-dropped.

MIO-PLIOCENE STRATA

The primary basin-filling alluvial strata in the Basin include a sequence of indurated sand, gravel, siltstone, and claystone generally equivalent to Newcomb's (1965) old gravel and clay. Based on lithologic and stratigraphic relationships these indurated suprabasalt sediments are inferred to have a Miocene to late Pliocene age (10+ to ~3 million years old). These strata are subdivided into three mappable units – Mio-Pliocene upper coarse unit, Mio-Pliocene fine unit, and Mio-Pliocene basalt coarse unit.

MIO-PLIOCENE UPPER COARSE UNIT

The Mio-Pliocene upper coarse unit consists of a sequence of variably cemented sandy gravel, with a muddy to sandy, silicic to calcic matrix. This unit underlies much of the Walla Walla Basin. Field reconnaissance reveals thin, localized, discontinuous caliche at the top of these strata at some locations. Based on physical characteristics displayed by analogous strata in rare outcrops, field reconnaissance, and a small number of borehole log descriptions these strata are predominantly basaltic in composition and typically have a slightly too well developed red, red brown, and yellow brown color. The Mio-Pliocene upper coarse unit generally is continuous beneath the entire Basin, being absent only in a few, relatively small areas.

Isopach data for this unit shows that it varies greatly in thickness, ranging from just a few feet thick to over 500 feet thick. The thickest accumulations of the unit tend to be along the southern edge of the Basin adjacent to the base of the Horse Heaven Hills where it generally ranges from 200 to more than 500 feet thick, and along the eastern edge of the Basin. The unit is interpreted to have been deposited predominantly in a braided stream system by the ancestral Walla Walla River, Mill Creek, and larger tributaries. These streams delivered large volumes of coarse detritus onto the basin floor as it subsided and the bounding uplands were uplifted. Generally, these streams merged into a single, main Walla Walla River ancestral stream that generally flowed to the west, much like the modern stream. In addition, faulting may also have played a role in unit distribution.

MIO-PLIOCENE FINE UNIT

The Mio-Pliocene upper coarse unit generally is underlain by fine deposits variously described as silt, clay, sandy clay, and sandy mud having blue, green, gray, brown, and yellow colors. These strata are designated the Mio-Pliocene fine unit. This unit is thickest in the northeastern, north, central, and western Basin where it can range between 300 and 500 feet thick. These areas generally are located north and west of areas of thickest accumulation of the overlying Mio-Pliocene upper coarse unit. Depositional, erosional, and structural factors similar to those that are interpreted to affect the overlying unit also are interpreted to have had a role in controlling Mio-Pliocene fine unit distribution.

Mio-Pliocene Basal Coarse Unit
The basal coarse unit consists of arkosic-micaceous sand and silt in the basal portion of the Mio-Pliocene section directly overlying basalt. These strata form an interval several tens of feet to over 100 feet thick. This unit, with its distinctive arkosic mineralogy, is very different petrographically from other strata comprising the Mio-Pliocene sequence in the Basin. Because of this distinctive mineralogy, this unit is inferred to have been deposited by the ancestral Salmon-Clearwater River, which entered the Basin from the north.

Top of Basalt
The alluvial sequence overlies the Columbia River Basalt Group (CRBG) beneath the entire basin area. The top of the CRBG, while irregular, forms the base of the alluvial sequence, and it generally appears to dip downwards off the highlands surrounding the Basin, in to the center of the Basin. Given this, the top of basalt in the Basin ranges from the ground surface around the basin margins, to a depth of over 800 feet near the center of the basin.

Alluvial Aquifer Hydrogeology
Groundwater in the Walla Walla Basin region occurs in two principal aquifer systems: (1) the unconfined to confined suprabasalt sediment ("alluvial") aquifer system which is primarily hosted by Mio-Pliocene conglomerate and Quaternary Coarse Unit, and (2) the underlying confined CRBG aquifer system (Newcomb, 1965).

The majority of the alluvial aquifer is hosted by Mio-Pliocene strata, although the uppermost part of the aquifer is found, at least locally, in the overlying Quaternary coarse unit. The alluvial aquifer is generally characterized as unconfined, but it does, at least locally, display evidence of confined conditions. Variation between confined and unconfined conditions within the aquifer system is probably controlled by sediment lithology (e.g., facies – coarse versus fine) and induration (e.g., cementation, compaction). Groundwater movement into, and through, the suprabasalt aquifer also is inferred to be controlled by sediment lithology and induration. Generally, the deeper portions of the alluvial aquifer unit are more likely to exhibit confined conditions relative to the shallower portions of the aquifer.

Aquifer Properties
Given the physical properties of the Quaternary course unit (non-indurated sand and gravel) versus those of the Mio-Pliocene upper coarse unit (e.g., finer matrix and the presence of naturally occurring cement), the Mio-Pliocene upper coarse unit probably has generally lower permeability and porosity than the Quaternary coarse unit. Consequently, suprabasalt aquifer groundwater flow velocities are inferred to be less where the water table lies within the Mio-Pliocene strata and/or the gradients are higher than where it lies within the younger, more permeable Quaternary strata. In addition, where the Quaternary coarse unit is saturated, this uncemented, high permeability gravel and sand may form preferred pathways for groundwater movement and areas of increased infiltration capacity in the shallow parts of the suprabasalt aquifer system.

Very little hydraulic property information is available for the alluvial aquifer system. Newcomb (1965) reports average effective porosity of 5 percent in his old gravel (i.e., the Mio-Pliocene upper coarse unit). Given the physical characteristics of the overlying Quaternary coarse unit, we suspect its average effective porosity is higher.

Basin-wide estimates of the hydraulic properties of alluvial aquifer system were made by Barker and Mac Nish (1976) as part of their effort to produce a digital model of this aquifer system. This modeling work used estimated hydraulic conductivity of 1.5×10^{-4} feet/second to 7.6×10^{-3} feet/second and transmissivity of 10,000 $feet^2$/day to 60,000 $feet^2$/day for the entire alluvial aquifer system. As with Newcomb's (1965) effective porosity estimate, we suspect hydraulic conductivity and transmissivity would be higher in saturated Quaternary coarse unit strata than in the saturated Mio-Pliocene upper coarse unit.

Groundwater Level and Flow Direction

Recent efforts by the WWBWC have begun to build a picture of alluvial aquifer water level conditions in the eastern and southern Walla Walla Basin. This data is compiled and available online at the WWBWC's website at http://www.wwbwc.org. Please see Appendix A for a water table map of the Walla Walla Valley built from these data. Based on these data, and earlier investigations the following basic observations relative to alluvial aquifer water level and flow direction can be made:

- Groundwater flow in the alluvial aquifer system generally is from east to west. Locally this flow may converge towards the Walla Walla River and other streams where the alluvial aquifer water table is higher than the stream. Where this occurs, streams are, in part, fed by groundwater discharge. However, along many reaches of the Walla Walla River and other streams in the Basin, the alluvial water table may at least locally be below the bed of the stream during some or all of the year. When and where this occurs, such stream reaches probably lose water to the alluvial aquifer, thus acting as a recharge source for groundwater.
- Water level within the alluvial aquifer varies seasonally. Barker and MacNish (1976, p. 25) determined that the month of January was the time of year when this aquifer is under the smallest amount of pumping stress and that water table most reflect unmodified conditions. In some portions of the Basin, seasonal changes in the water table elevation can be as great as 50 feet (Newcomb, 1965; Pacific Groundwater Group, 1995).
- Groundwater level declines have been ongoing for a number of years, although recent AR efforts have reversed these trends at least locally near existing sites, in particular the Johnson site (WWBWC, 2010 and WWBWC, 2014b).

Aquifer Recharge and Discharge

Recharge to the alluvial aquifer is derived from infiltration of surface waters (e.g., where streams enter the basin), leakage from irrigation ditches, applied irrigation water, direct precipitation, and to a lesser extent leakage from the CRBG aquifer system (Newcomb, 1965; Barker and MacNish, 1976; Pacific Groundwater Group, 1995). The majority of this recharge probably occurs in the spring when streams flowing into the Basin reach peak discharges. Precipitation on parts of the Basin floor where the Quaternary coarse unit and older the Miocene-Pliocene upper coarse unit lie at, or near, the surface may also provide some natural recharge. Evaluation of these various sources of recharge to the alluvial aquifer suggests that direct precipitation and applied irrigation water are the dominant sources of recharge (Bauer and Vaccaro, 1990; Pacific Groundwater Group, 1995; WWBWC, 2010). With flood control and channelization of the Walla Walla River and smaller streams, natural recharge via infiltration from surface waters has probably decreased with continued development.

Artificial recharge of the alluvial aquifer from agricultural practices and water conveyance systems has become an important component of the Basin's hydrologic system since the 1920's and 1930's. This recharge is thought to have historically contributed water to at least some shallow water wells and springs (Newcomb, 1965; WWBWC, 2010). Artificial recharge probably occurs through irrigation ditch leakage and infiltration past the root zone in irrigated fields. With the advent of ditch/channel lining and reduction in the practice of flood irrigation, this type of recharge has probably decreased. Reduced natural and artificial recharge and pumping account for some of the decreased alluvial aquifer water table levels. Decline in water table levels in-turn probably account for reduced spring flows and base level discharge to the Walla Walla River.

Discharge from the alluvial aquifer occurs in a number of ways, including direct discharge to streams, springs and seeps, pumped water wells, evapotranspiration, and localized leakage to the CRBG aquifer system (Newcomb, 1965; Barker and Mac Nish, 1976; Pacific Groundwater Group, 1995).

ALLUVIAL AQUIFER WATER QUALITY

Historical water quality data available include a groundwater quality report prepared by Richerson and Cole (2000) and source water and groundwater quality reporting done for several AR sites, including the Johnson site. Based on Richerson and Cole (2000), the Johnson site data (WWBWC, 2010), and groundwater quality data collected from other AR sites in the Walla Walla Basin (GSI, 2009a, 2009b and WWBWC, 2014a) some basic observations with respect to alluvial aquifer water quality can be made, including the following:

- With respect to nutrient type constituents, including nitrate-N, TKN, phosphate, and ortho-phosphate water quality in the area generally has not been significantly degraded. In addition, the groundwater down gradient of AR sites generally show declines in constituent concentrations, which are interpreted to reflect dilution of ambient groundwater concentrations by lower concentration AR water.
- Other parameters, such as TDS, chloride, and electrical conductivity also commonly show evidence of down gradient reductions attributed to AR activities. These trends are interpreted as evidence of dilution of these parameters in groundwater by AR water.
- The synthetic organic compound (SOC) data indicate that AR operations have essentially no influence on SOC's present in groundwater.

In addition to these observations, the Hall-Wentland data are instructive as they show the importance of natural leakage from surface waters (which typically are the same waters these AR sites use for source water) in influencing local groundwater chemistry.

Through the Oregon Department of Environmental Quality (ODEQ) Pesticide Stewardship Partnership (PSP) Program pesticides in surface waters of the Walla Walla watershed have been monitored since 2005, however this summary only looked back to 2009. The monitoring results provide an indication of potential introduction of pesticides to groundwater by way of recharged surface water. Of the pesticides monitored in the PSP Program, measured detections above the lowest aquatic life toxicity benchmark established by ODEQ can be summarized as follows.

- Chlorphyrifos (Lorsban) has been detected above the benchmark standard over the length of the monitoring program.
- Diuron was detected above the benchmark standard in years 2010 and 2011, however, detections above the benchmark standard have not been measured after 2011.
- Malathion has once been detected above benchmark standards, occurring in 2014.

- Azinphosmethly (Guthion) was detected above the benchmark standard in years 2009, 2010, and 2011, however, detections above the benchmark standard have not been measured after 2011.

The PSP Program results indicate that of the over 100 pesticides analyzed, four pesticides have at one time been detected above the benchmark standard and in general maximum concentrations detected are decreasing over time.

Recharge Site Hydrogeology

Building on the preceding summary of basin wide hydrogeologic conditions, the following sections provide basic highlights of specific hydrogeologic conditions at each AR site. Geologic cross-sections for each site are built from the WWBWC's basin wide geologic and hydrogeologic model.

Anspach

Figure 2 provides a geologic cross-section of the Anspach site. Geologic units present at the Anspach site are as follows:

- Quaternary fines unit: This unit is interpreted to not be present at the site, but it is mapped in the area just to the northwest where it is less than 1 foot to approximately 20-30 feet thick.
- Quaternary coarse unit: At the site this unit is interpreted to extend from the ground surface downwards approximately 65 feet.
- Mio-Pliocene upper coarse unit: This unit is approximately 85 feet thick in the immediate vicinity of the site. To the southeast it is interpreted to directly overlie basalt. To the west it overlies the Mio-Pliocene fine unit.
- Mio-Pliocene fine unit: This unit is mapped as pinching out directly beneath the site. Just to the west and northwest of the site it is interpreted to thicken, as the top of basalt gets deeper.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site
- Top of Basalt: The site is interpreted to overlie an area where the top of basalt gets deeper just a short distance to the northwest. At and beneath the southeastern part of the site top of basalt may be as little as 120 feet bgs. To the northwest it is interpreted to be over 205 feet bgs.

The alluvial aquifer water table generally lies near the base of the Quaternary coarse unit or near the top of the Mio-Pliocene upper coarse unit. Depth to water varies from about 15-35 feet depending on season (irrigation/non-irrigation). Groundwater flow direction in the alluvial aquifer at this site is interpreted to generally be to the northwest.

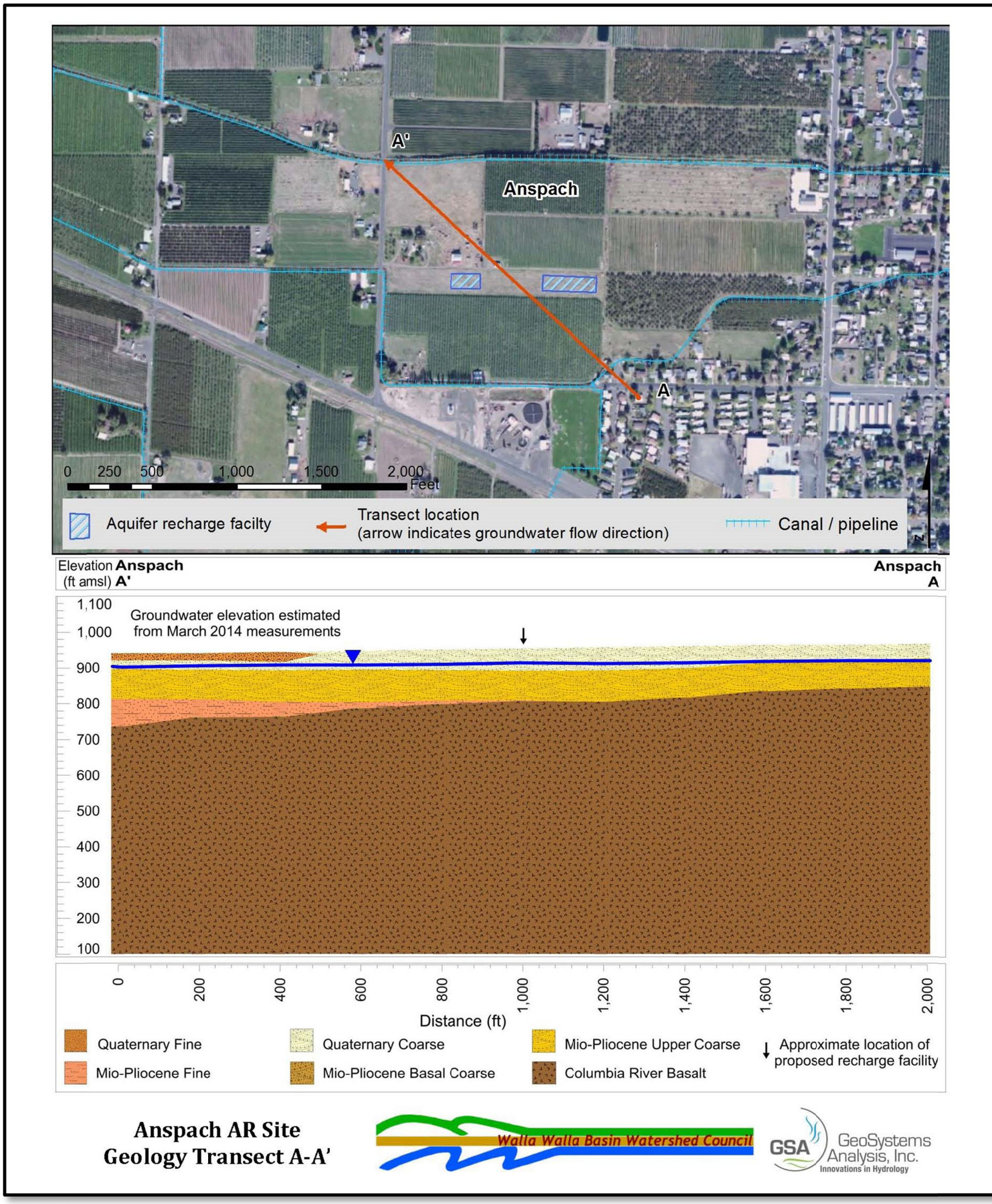

Figure 2 - Geologic cross section of the Anspach aquifer recharge site.

Barrett

Figure 3 provides a geologic cross-section of the Barrett site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be absent beneath the site.
- Quaternary coarse unit: This unit is interpreted to underlie the entire site area, ranging from approximately 40 to 75 feet thick.
- Mio-Pliocene upper coarse unit: This unit also underlies the entire site area and is interpreted to range from approximately 105 to 120 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 80 to 90 feet thick.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site
- Top of Basalt: Beneath the site the top of basalt appears to dip to the west-northwest and it lies at depths of 240 to 265 feet bgs.

Beneath the Barrett site, the alluvial aquifer water table appears to generally lie within the Quaternary coarse unit, at a depth of approximately 30 feet bgs. The groundwater flow direction at the site is generally to the northwest.

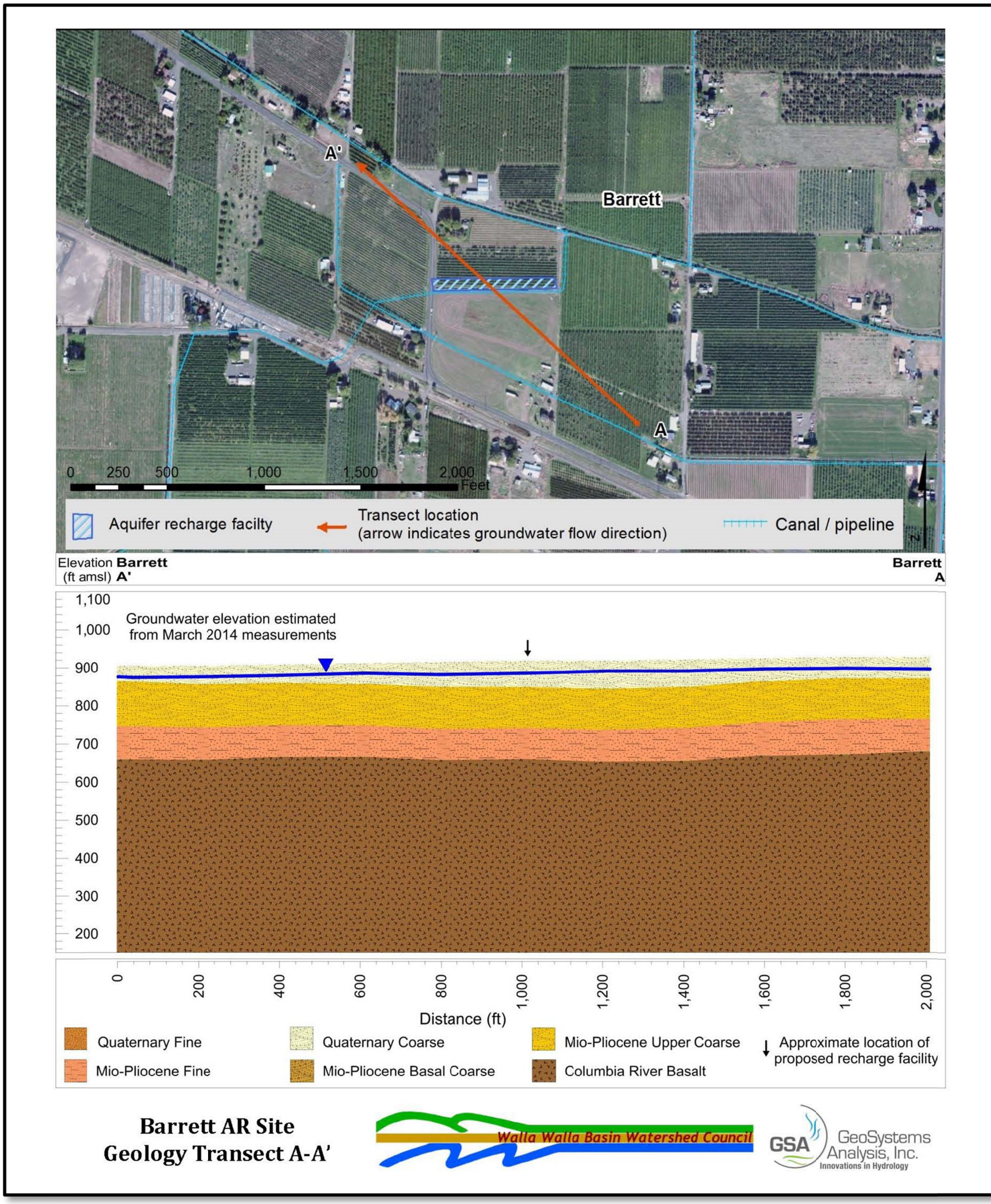

Figure 3 - Geologic cross section of the Barrett aquifer recharge site.

CHUCKHOLE

Figure 4 provides a geologic cross-section of the Chuckhole site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be approximately 40 feet thick beneath the site. This unit is not present down hydraulic gradient from the site.
- Quaternary coarse unit: This unit does not underlie the approximate location of the site, however, it becomes present down hydraulic gradient of the site at a thickness of approximately 40 feet.
- Mio-Pliocene upper coarse unit: This unit is interpreted as being approximately 20 feet thick beneath the site and increases in thickness to over 80 feet down hydraulic gradient.
- Mio-Pliocene fine unit: This unit is not present beneath the site.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site.
- Top of Basalt: Beneath the site the top of basalt is interpreted to be at a depth of 60 feet bgs and deepens to over 130 feet bgs down hydraulic gradient, however, there is large uncertainty in the depth to basalt at the Chuckhole site. It is possible that the depth to basalt is significantly deeper than 60 feet bgs based on the log for nearby well GW23 in which basalt was not encountered over its total depth of 118 feet bgs.

The depth to the alluvial aquifer water table is approximately 40 feet bgs (based on well GW_23), within the uppermost part of the Mio-Pliocene upper coarse unit. The groundwater flow direction at the site is generally to the northwest.

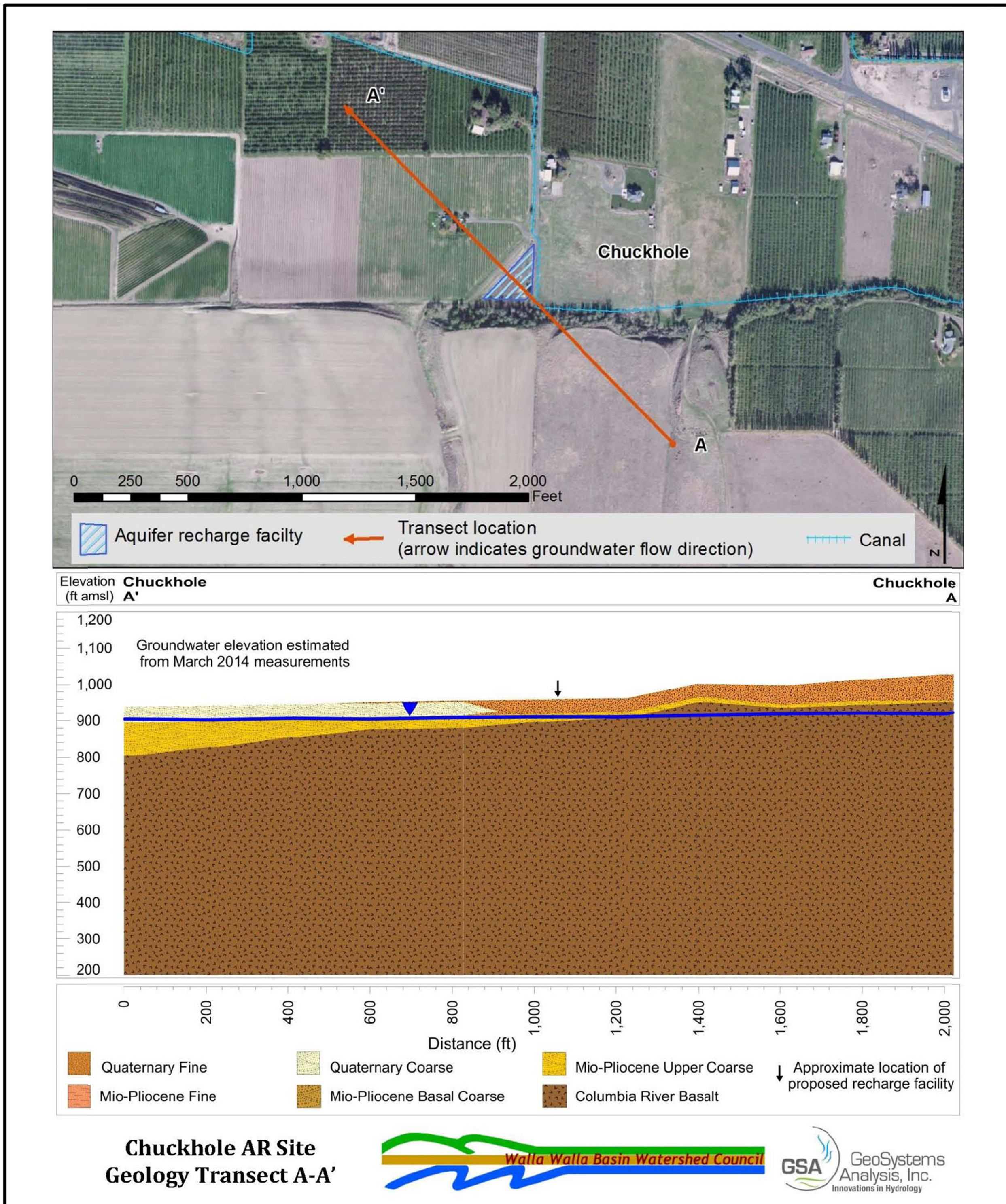

Figure 4 - Geologic cross section of the Chuckhole aquifer recharge site.

County Road

Figure 5 provides a geologic cross-section of the County Road site. Geologic units present in the vicinity of the County Road site are as follows:

- Quaternary fines unit: This unit is not present beneath the site.
- Quaternary coarse unit: This unit underlies the approximate location of the site with an approximate thickness of 50 feet and decreases in thickness to 35 feet down hydraulic gradient from the site.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to be approximately 120 feet to 160 feet thick.
- Mio-Pliocene fine unit: This unit underlies the entire site area where it is interpreted to be approximately 85 feet to 125 feet thick.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site.
- Top of Basalt: Beneath the site the top of basalt generally lies at a depth of 270 feet bgs, deepening to approximately 300 feet bgs down hydraulic gradient.

The depth to the alluvial aquifer water table varies throughout the year from approximately 35 to 50 feet bgs (based on well GW_40), being shallower when water is present in the adjacent canal. Based on these water table depths, the alluvial aquifer water table resides in the Quarternary coarse unit and uppermost part of the Mio-Pliocene upper coarse unit. The groundwater flow direction at the site is generally to the north-northwest.

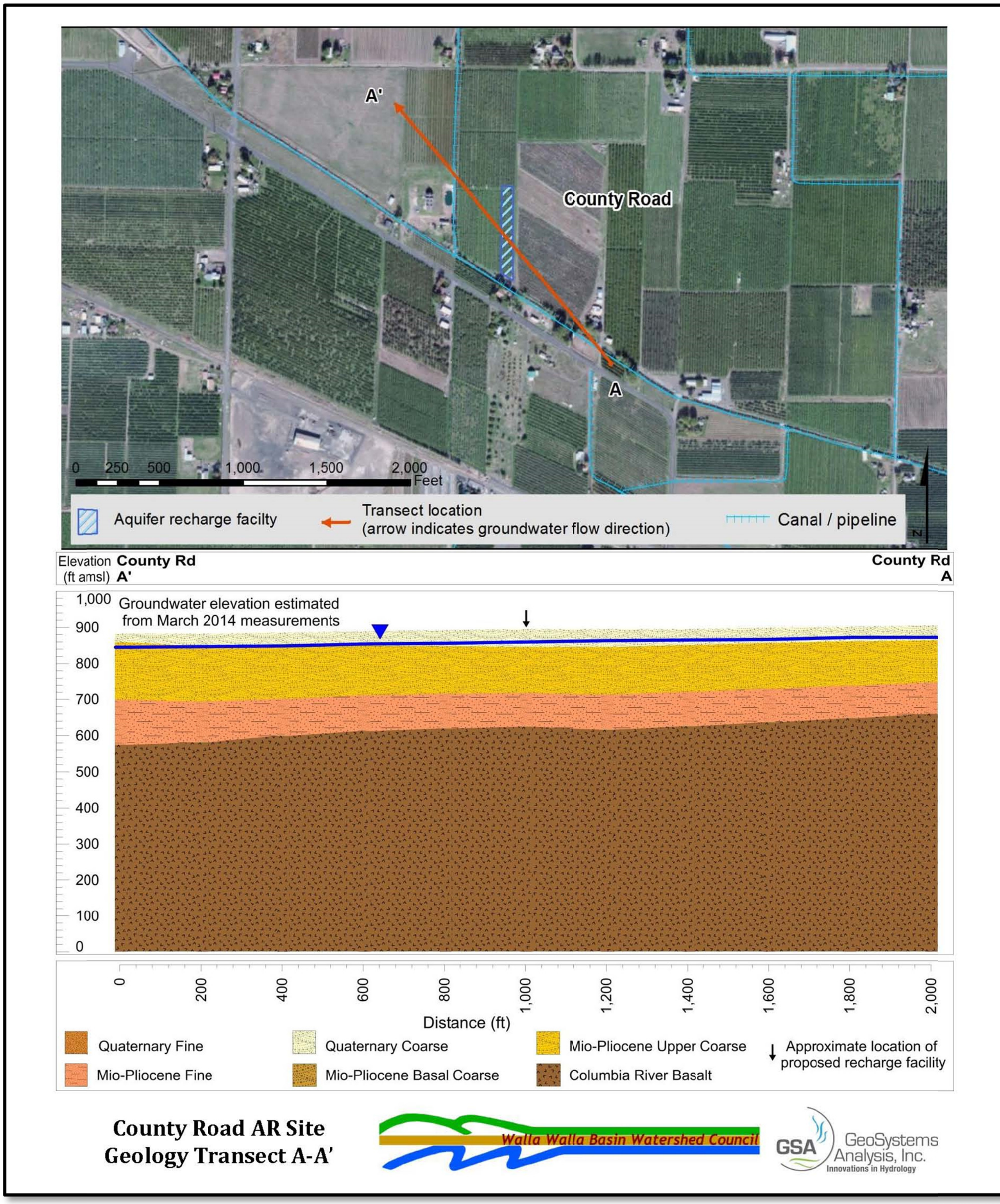

Figure 5 - Geologic cross section of the County Road aquifer recharge site.

EAST TROLLEY LANE

Figure 6 provides a geologic cross-section of the East Trolley Lane site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be absent beneath the site.
- Quaternary coarse unit: This unit underlies the approximate location of the site with an approximately thickness of 30 to 35 ft, however, it is interpreted to be absent directly east of the site.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to be approximately 250 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 450 feet thick.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site.
- Top of Basalt: Beneath the site the top of basalt generally lies at a depth of 740 feet bgs.

The depth to the alluvial aquifer water table is approximately 30 to 35 feet bgs (based on well GW_139), which places the water table in the lower part of the Quaternary coarse unit or in the Mio-Pliocene upper coarse unit where this unit is interpreted to extend to the surface. The groundwater flow direction at the site is generally to the north-northwest.

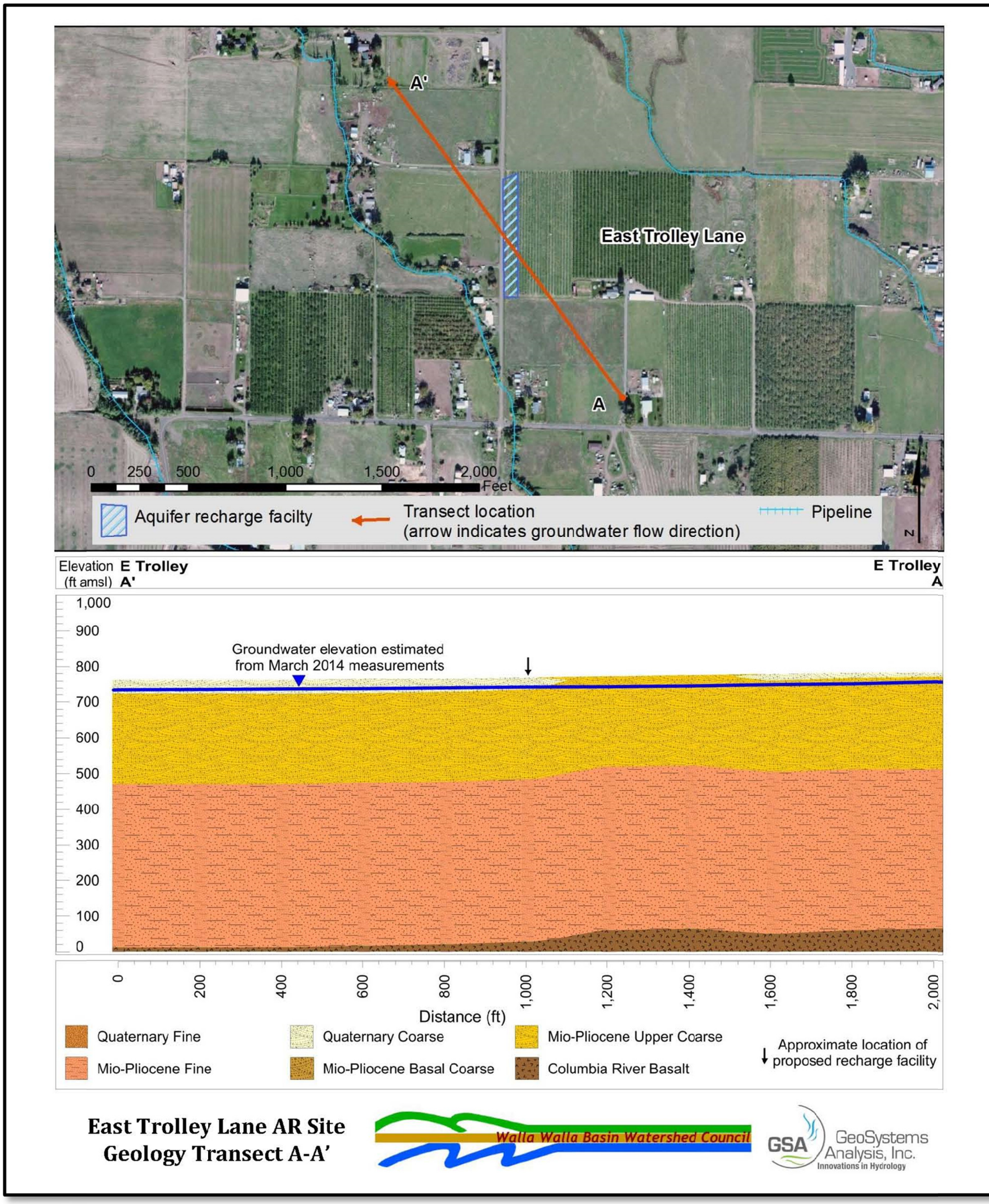

Figure 6 - Geologic cross section of the East Trolley Lane aquifer recharge site.

Fruitvale

Figure 7 provides a geologic cross-section of the Fruitvale site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is not present beneath the site, however, it is interpreted to be present in thicknesses less than 20 feet down hydraulic gradient from the site.
- Quaternary coarse unit: This unit is mapped to be present in the site area, ranging from approximately 60 feet thick beneath the site to 35 feet thick where the Quaternary fines unit is present.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to range from approximately 230 to 240 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 525 feet thick beneath the site.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site.
- Top of Basalt: Beneath the site the top of basalt generally lies at a depth of 820 feet bgs.

The depth to the alluvial aquifer water table is approximately 25 to 35 feet bgs (based on well GW_33), within the Quaternary coarse unit. The groundwater flow direction at the site is generally to the north-northwest.

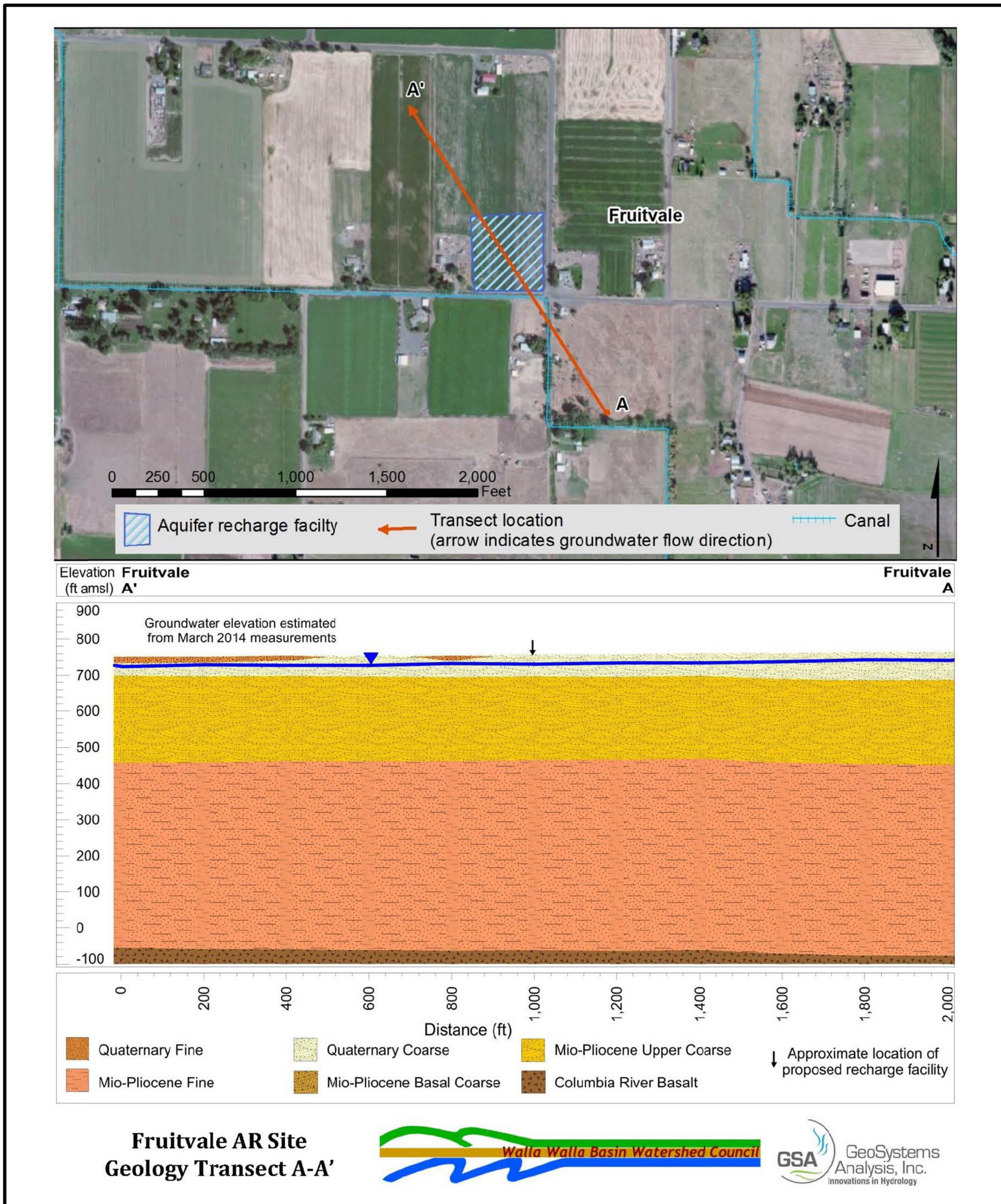

Figure 7 - Geologic cross section of the Fruitvale aquifer recharge site.

GALLAGHER

Figure 8 provides a geologic cross-section of the Gallagher site. Geologic units present in the vicinity of the Gallagher site are as follows:

- Quaternary fines unit: This unit forms the uppermost geologic unit across the proposed site, ranging in thickness from approximately 5 feet to 15 feet.
- Quaternary coarse unit: This unit ranges from approximately 15 feet to 40 feet thick beneath the site.
- Mio-Pliocene upper coarse unit: This unit is interpreted as being approximately 100 feet thick beneath the site.
- Mio-Pliocene fine unit: This unit ranges from approximately 280 feet to 310 feet thick beneath the site.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site.
- Top of Basalt: Beneath the site the top of basalt is interpreted to be at a depth of 415 feet bgs to 460 feet bgs.

The depth to the alluvial aquifer water table ranges between approximately 26 and 35 feet bgs (based on well GW_36), within the Quaternary coarse unit and the uppermost part of the Mio-Pliocene upper coarse unit. The groundwater flow direction at the site is generally to the northwest.

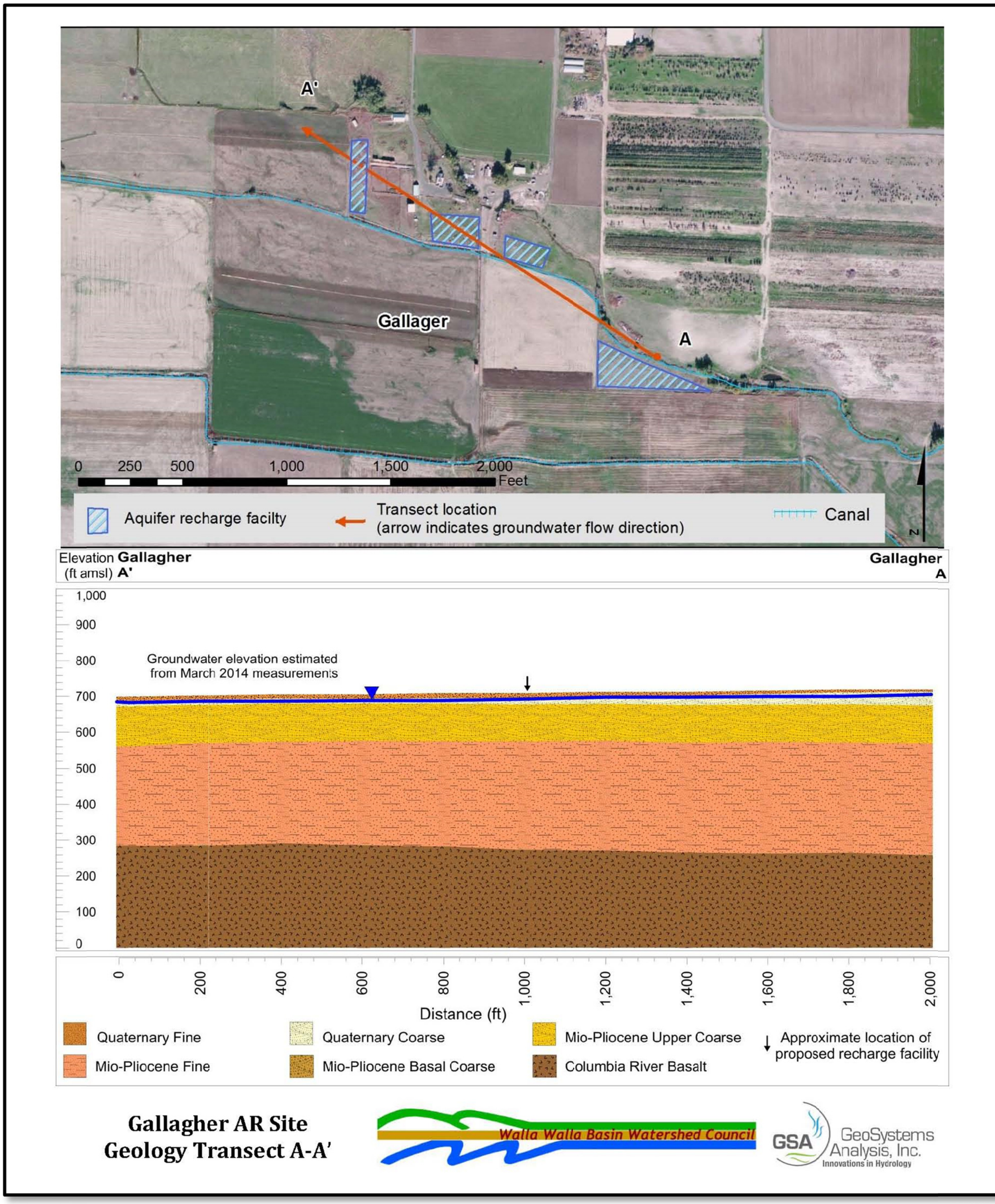

Figure 8 - Geologic cross section of the Gallagher aquifer recharge site.

Johnson

Figure 9 provides a geologic cross-section of the Johnson site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be essentially absent from this site, although thin surface occurrences are present offsite to the west and east. In addition, excavation work during infiltration gallery construction revealed a thin, local surface silty-sand that could be assigned to this unit. Nevertheless, where present in the immediate area, the unit is generally less than 10 feet thick.
- Quaternary coarse unit: This unit forms the uppermost geologic unit across the site area (except for the localized fines noted in the preceding bullet). Beneath the site the unit generally is interpreted to be 20 to 55 feet thick.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to range from approximately 125 to 155 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 205 to 235 feet thick.
- Mio-Pliocene basal coarse unit: This unit underlies the entire site area where it is interpreted to be approximately 40 to 125 feet thick, increasing to the west-northwest.
- Top of Basalt: Beneath the site the top of basalt generally deepens to the west-northwest, ranging from approximately 425 feet below ground surface (bgs) to 550 feet bgs.

The alluvial aquifer water table generally varies between the basal part of the Quaternary coarse unit and the upper part of the Mio-Pliocene upper coarse unit, rising and falling seasonally and in response to AR and canal operations. Depth to water varies seasonally from 10 to 50 feet bgs according to on-site monitoring wells. Groundwater flow at the site generally is towards the west-northwest.

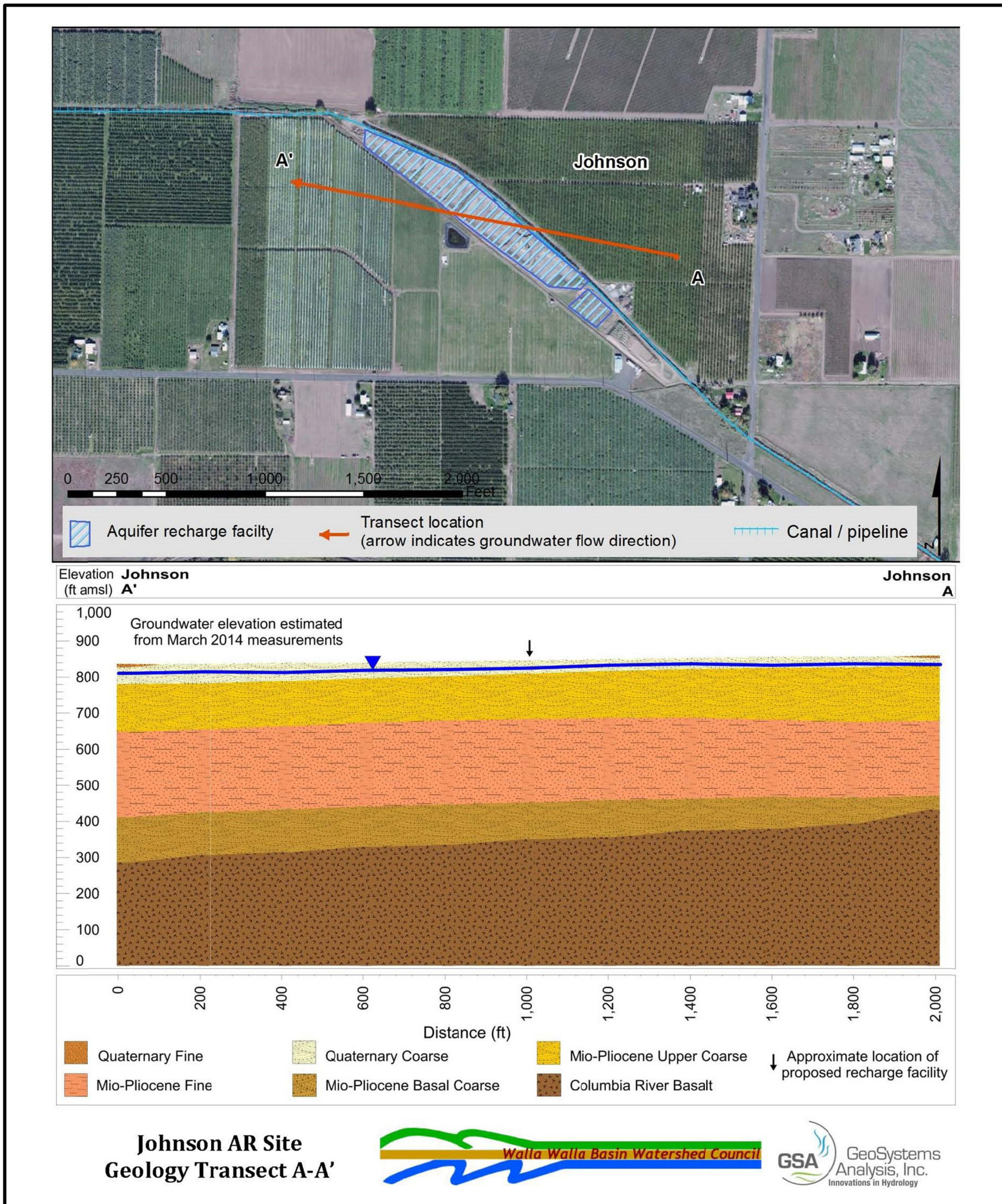

Figure 9 - Geologic cross section of the Johnson aquifer recharge site.

LeFore Road

Figure 10 provides a geologic cross-section of the LeFore Road site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be approximately 20 feet thick beneath the site. This unit is not present down hydraulic gradient from the site.
- Quaternary coarse unit: This unit underlies the approximate location of the site with an approximate thickness of 25 feet and ranges upwards to 45 feet thick away from the site.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to be approximately 155 to 170 feet thick.
- Mio-Pliocene fine unit: This unit underlies the entire site area where it is interpreted to be approximately 80 to 90 feet thick.
- Mio-Pliocene basal coarse unit: This unit is present beneath the site at a thickness of 40 to 50 ft.
- Top of Basalt: Beneath the site the top of basalt generally lies at a depth of 350 feet bgs.

The depth to the alluvial aquifer water table is approximately 20 to 30 feet bgs (based on well GW_03), which places the water table in the uppermost part of the Quaternary coarse unit. The groundwater flow direction at the site is generally to the north-northwest.

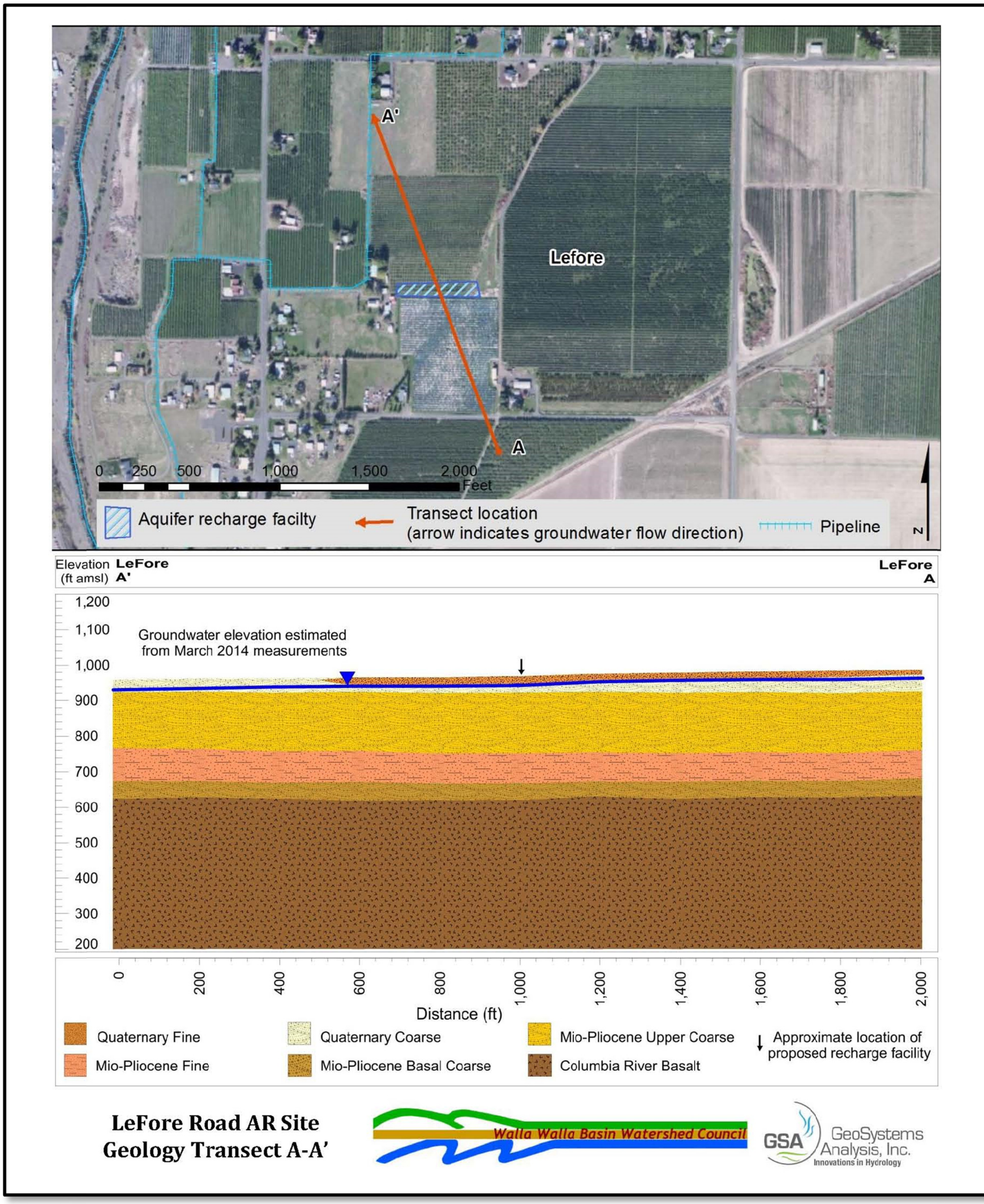

Figure 10 - Geologic cross section of the LeFore Road aquifer recharge site.

Locust Road

Figure 11 provides a geologic cross-section of the Locust Road site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be absent beneath the site.
- Quaternary coarse unit: This unit forms the uppermost geologic unit across the site area, ranging from approximately 120 to 180 feet thick.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to range from approximately 95 to 155 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 10 feet thick to 70 feet thick, increasing to the south-southeast.
- Mio-Pliocene basal coarse unit: This unit underlies the entire site area where it is interpreted to be approximately 10 to 50 feet thick, increasing to the west-northwest.
- Top of Basalt: Beneath the site the top of basalt is interpreted to be at a depth of 310 feet bgs to 360 feet bgs.

The depth to the alluvial aquifer water table is approximately 40 to 45 feet bgs (based on well GW_14), within the Quaternary coarse unit. The groundwater flow direction at the site is generally to the north-northwest.

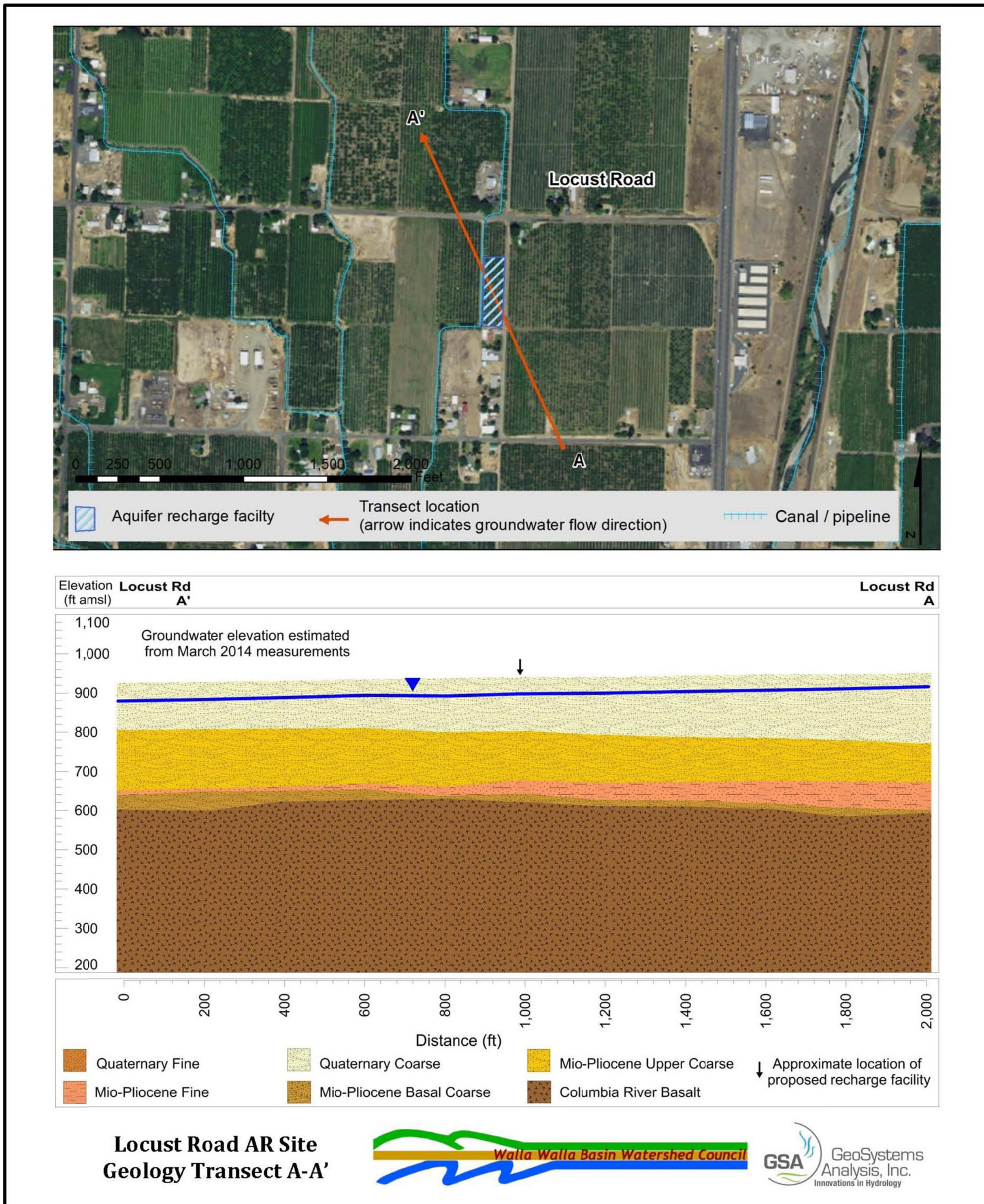

Figure 11 - Geologic cross section of the Locust Road aquifer recharge site.

MUD CREEK

Figure 12 provides a geologic cross-section of the Mud Creek site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be present in the site area where it may be approximately 20 feet thick.
- Quaternary coarse unit: This unit is mapped to be present in the site area, ranging in thickness from 25 to 35 feet.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to range from approximately 250 to 265 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 155 feet thick beneath the site and increase in thickness down hydraulic gradient.
- Mio-Pliocene basal coarse unit: This unit underlies the entire site and is interpreted to be approximately 225 feet thick.
- Top of Basalt: Beneath the site the top of basalt generally lies at a depth of 685 feet bgs and possibly increases to a depth in excess of 750 feet bgs down hydraulic gradient.

The depth to the alluvial aquifer water table is approximately 25 to 35 feet bgs (based on well GW_33), within the Quaternary coarse unit. The groundwater flow direction at the site is generally to the north-northwest.

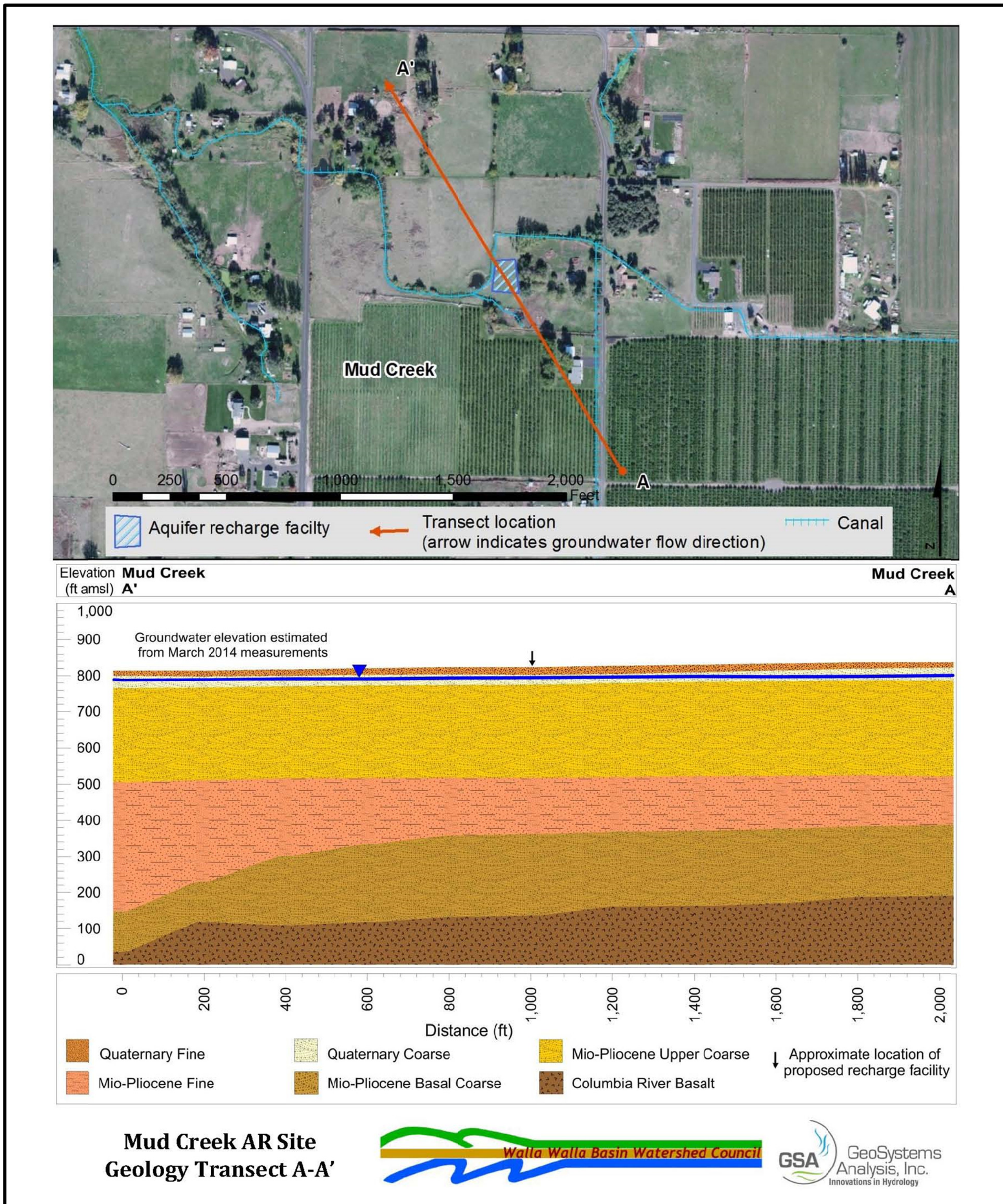

Figure 12 - Geologic cross section of the Mud Creek aquifer recharge site.

NW Umapine

Figure 13 provides a geologic cross-section of the NW Umapine. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be present in the site area where it may be as much as 20 feet thick. However, at the site itself it is absent because it was removed during the excavation of the pit that will be used as the AR facility.
- Quaternary coarse unit: This unit is mapped to be present in the site area, but it is interpreted to be very thin, possibly less than 10 feet thick. As with the Quaternary fine unit, it is interpreted to be absent (as most of this unit may have been removed during digging) at this site.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to range from approximately 200 to 285 feet thick. The infiltration basin may be excavated into the top of the Mio-Pliocene upper coarse unit.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 190 to 275 feet thick.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site
- Top of Basalt: Beneath the site the top of basalt generally lies at a depth of 500 feet bgs.

The depth to the alluvial aquifer water table is approximately 23 to 38 feet bgs (based on well GW_144), which places the water table in lowermost part of the Quaternary fine unit or where present the Quaternary coarse unit. The groundwater flow direction at the site is generally to the west-northwest.

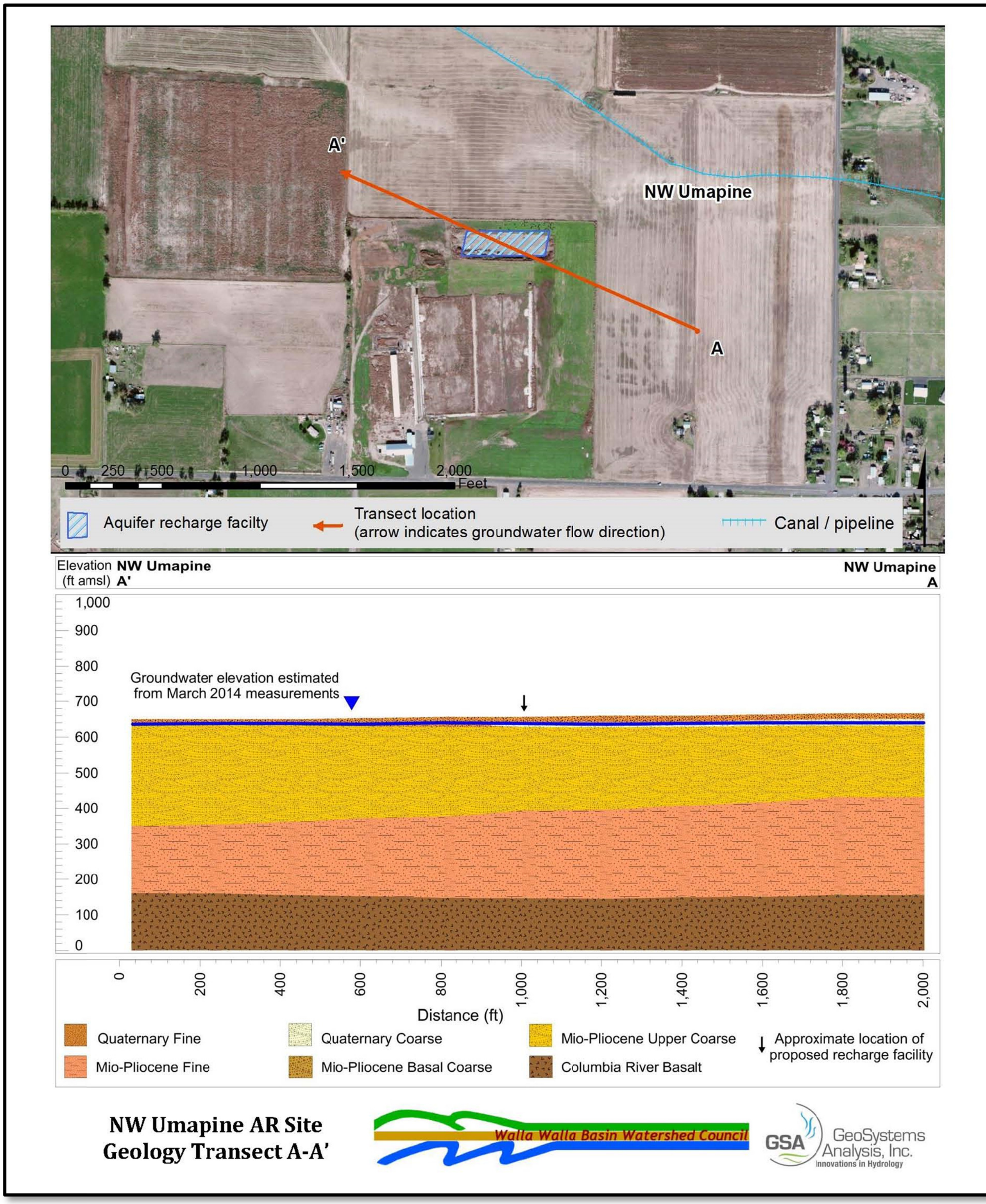

Figure 13 - Geologic cross section of the NW Umapine aquifer recharge site.

SUNQUIST

Figure 14 provides a geologic cross-section of the Sunquist site. Geologic units present in the vicinity of the Sunquist site are as follows:

- Quaternary fines unit: This unit forms the uppermost geologic unit across the proposed site and is interpreted to be approximately 17 feet thick.
- Quaternary coarse unit: This unit underlies the entire site area and is interpreted to be approximately 20 feet thick beneath the site to 50 feet thick down hydraulic gradient from the site.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to become thinner to the northwest, ranging from approximately 305 feet thick to 220 feet thick.
- Mio-Pliocene fine unit: This unit underlies the entire site area where it is interpreted to be approximately 505 feet thick to 555 feet thick.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site.
- Top of Basalt: Beneath the site the top of basalt is approximately 835 feet bgs.

The depth to the alluvial aquifer water table is approximately 25 to 35 feet bgs (based on well GW_33), within the uppermost part of the Quaternary coarse unit. The groundwater flow direction at the site is generally to the north-northwest.

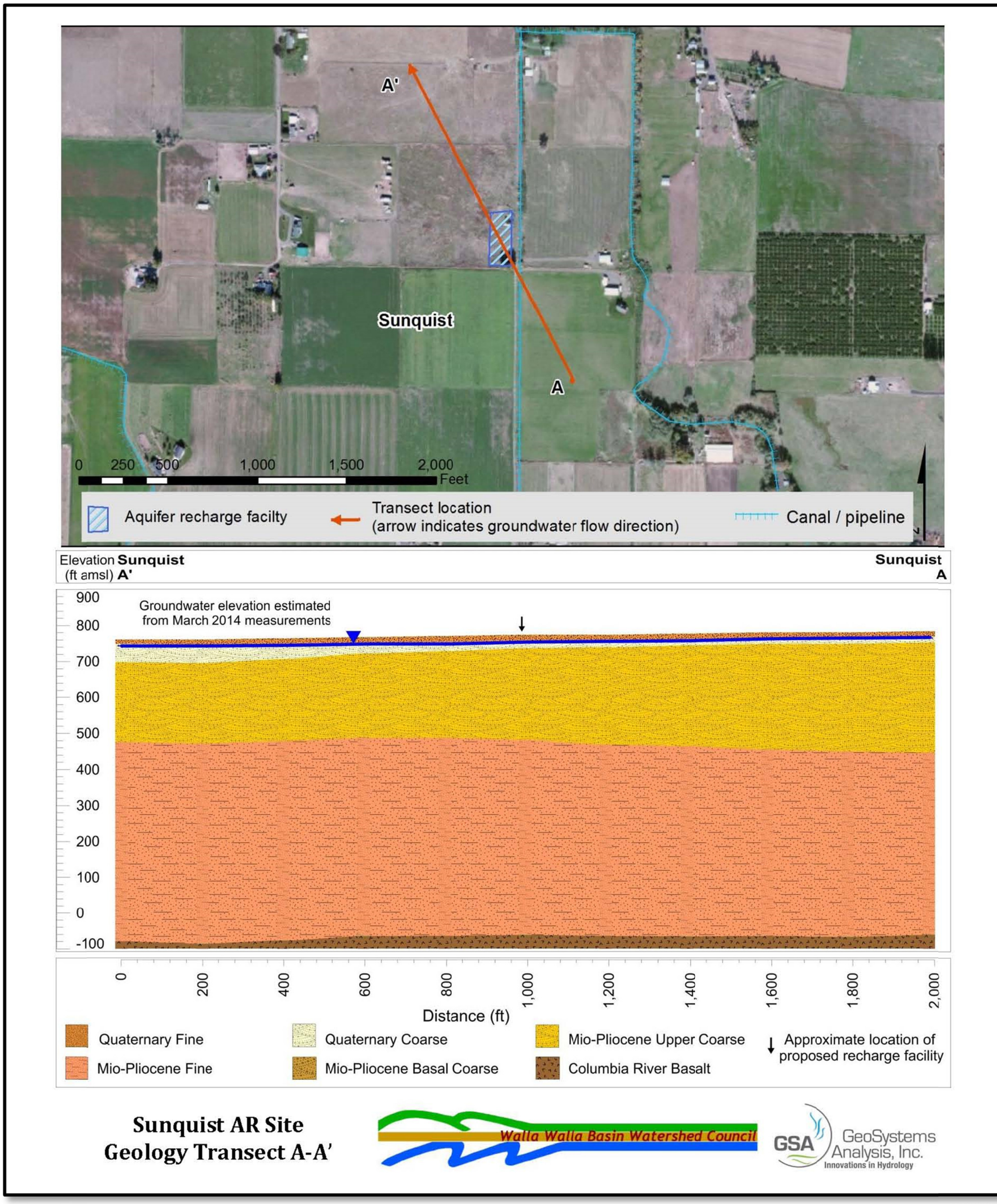

Figure 14 - Geologic cross section of the Sunquist aquifer recharge site.

TRIANGLE ROAD

Figure 15 provides a geologic cross-section of the Triangle Road site. Geologic units present in the vicinity of the Triangle Road site are as follows:

- Quaternary fines unit: This unit forms the uppermost geologic unit across the proposed site, ranging in thickness from 10 feet to 25 feet directly beneath the site.
- Quaternary coarse unit: This unit underlies the entire site area and is interpreted to be approximately 20 to 40 feet thick.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to be approximately 260 feet thick.
- Mio-Pliocene fine unit: This unit underlies the entire site area where it is interpreted to be approximately 150 feet thick beneath the site.
- Mio-Pliocene basal coarse unit: This unit is interpreted to become thicker to the northwest direction, ranging from approximately 160 feet to 245 feet thick.
- Top of Basalt: Beneath the site the top of basalt generally deepens to the northwest, ranging from approximately 605 feet bgs to 675 feet bgs.

The depth to the alluvial aquifer water table is approximately 25 to 35 feet bgs (based on well GW_33), within the Quaternary coarse unit. The groundwater flow direction at the site is generally to the northwest.

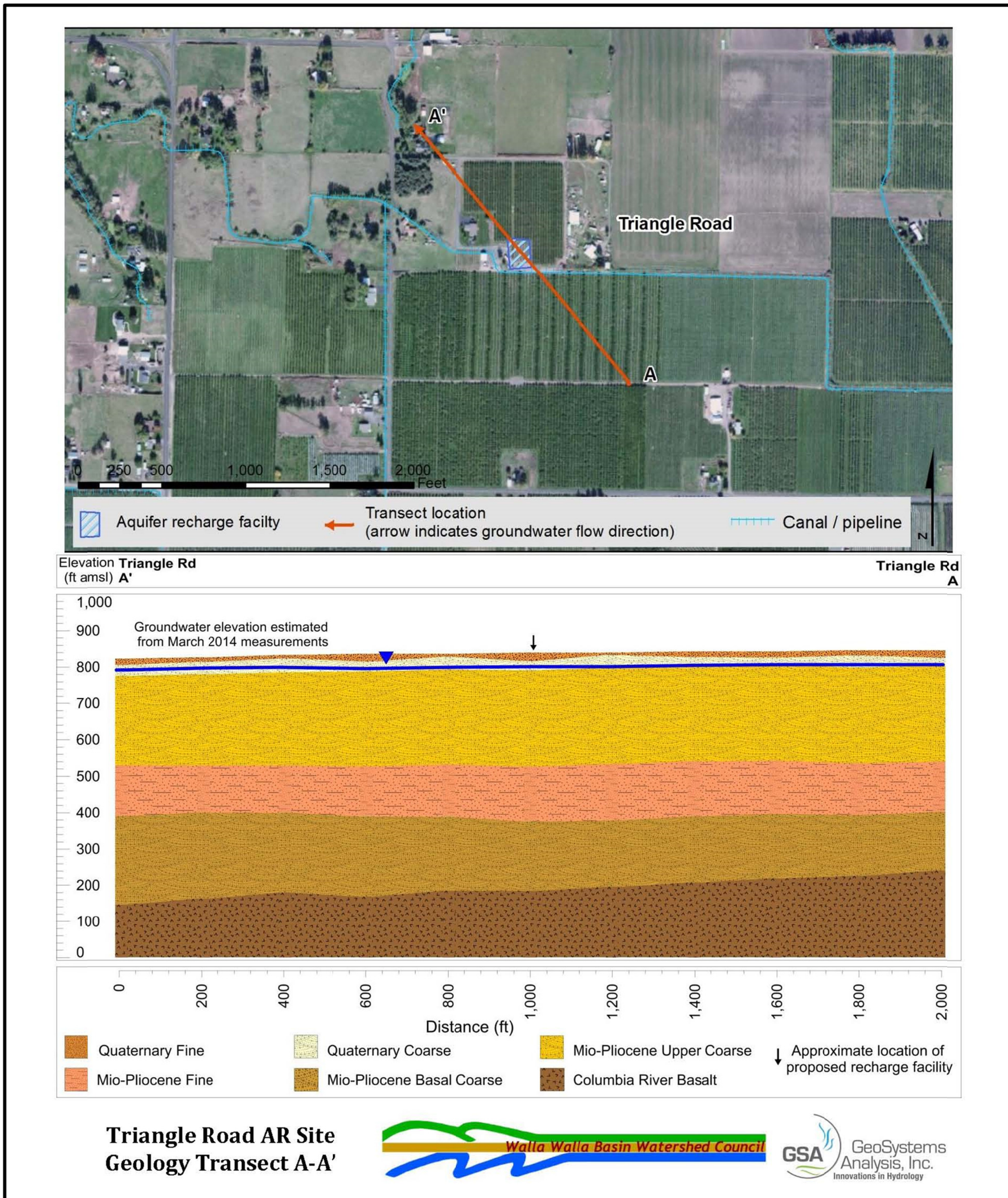

Figure 15 - Geologic cross section of the Triangle Road aquifer recharge site.

TRIANGLE STATION

Figure 16 provides a geologic cross-section of the Triangle Station site. Geologic units present in the vicinity of the Triangle Station site are as follows:

- Quaternary fines unit: This unit forms the uppermost geologic unit across the proposed site, ranging in thickness from 7 feet directly beneath the site to 18 feet within 200 feet of the site. This thin unit will likely be removed during excavation of the infiltration basin.
- Quaternary coarse unit: This unit underlies the entire site area and is interpreted to be approximately 30 to 35 feet thick.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to range from approximately 300 to 315 feet thick.
- Mio-Pliocene fine unit: This unit underlies the entire site area where it is interpreted to be approximately 430 feet thick beneath the site and thins to approximately 140 feet thick southeast of the site.
- Mio-Pliocene basal coarse unit: This unit is interpreted to not present down hydraulic gradient from the site however is upwards of 250 feet thick up hydraulic gradient from the site
- Top of Basalt: Beneath the site the top of basalt is approximately 790 feet bgs.

The depth to the alluvial aquifer water table is approximately 25 to 35 feet bgs (based on well GW_33), within the Quaternary coarse unit. The groundwater flow direction at the site is generally to the north-northwest.

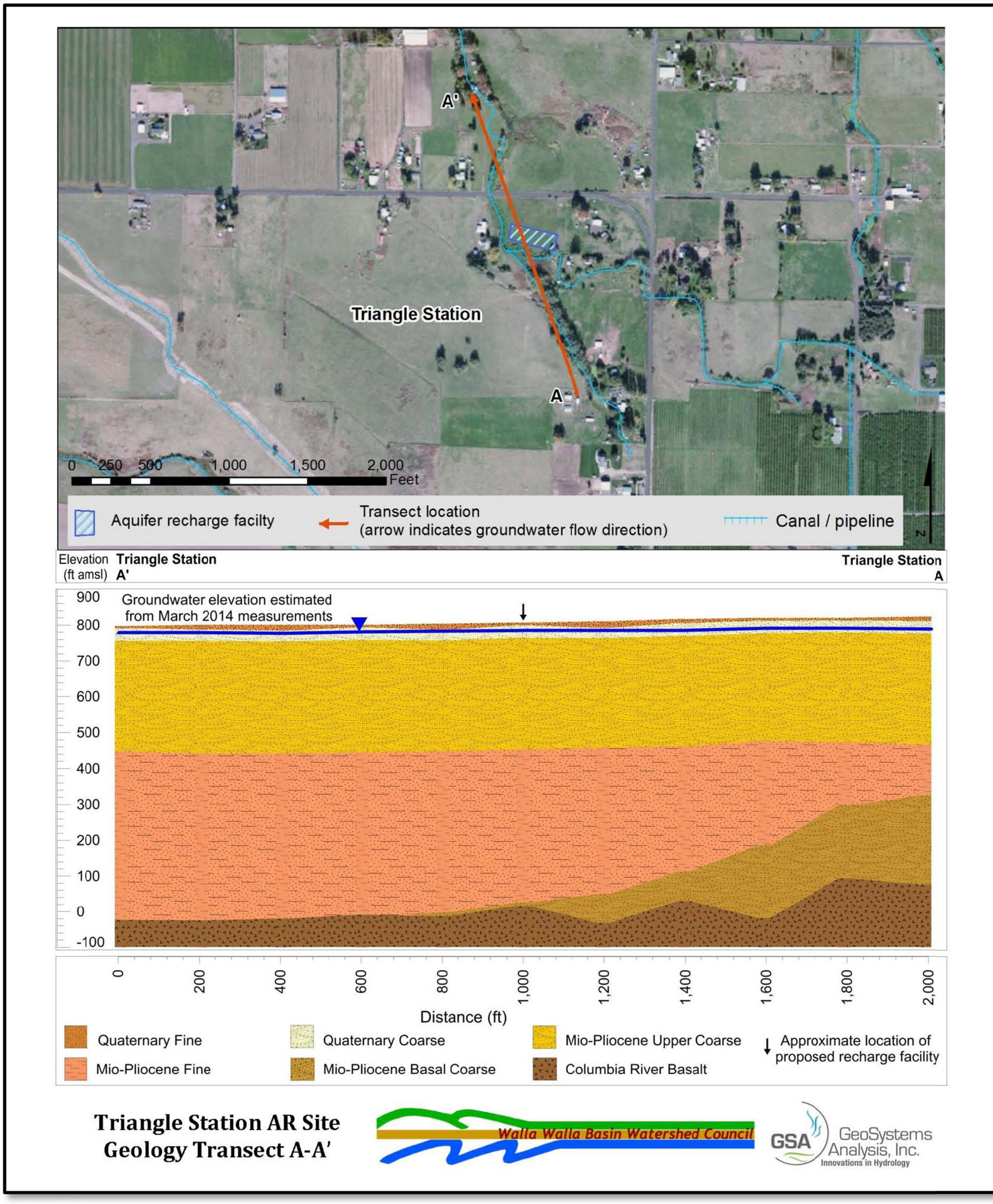

Figure 16 - Geologic cross section of the Triangle Station aquifer recharge site.

TRUMBULL

Figure 17 provides a geologic cross-section of the Trumbull site. Geologic units present in the vicinity of the Trumbull site are as follows:

- Quaternary fines unit: This unit is not present beneath the site.
- Quaternary coarse unit: This unit forms the uppermost geologic unit across the proposed site area where it is interpreted to range from 40 to 45 feet thick.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to range from approximately 220 to 245 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to range from 70 to 120 feet thick, thickening to the northwest.
- Mio-Pliocene basal coarse unit: This unit underlies the entire site area where it is interpreted to range from 55 to 160 feet thick, thickening to the northwest.
- Top of Basalt: Beneath the site the top of basalt generally deepens to the northwest, ranging from approximately 390 feet bgs to 570 feet bgs.

The alluvial aquifer water table generally lies in the Quaternary coarse unit, resulting in the entire Mio-Pliocene upper coarse unit being saturated. In the immediate vicinity of the site depth to groundwater generally is 20 feet or less. However, a series of seasonal springs north of the site suggest groundwater in this area can be much shallower, at least seasonally. To the west, the depth to water is 45 feet bgs or greater just to the east of this site in well GW_117. The groundwater flow direction is interpreted to be to the north-northwest.

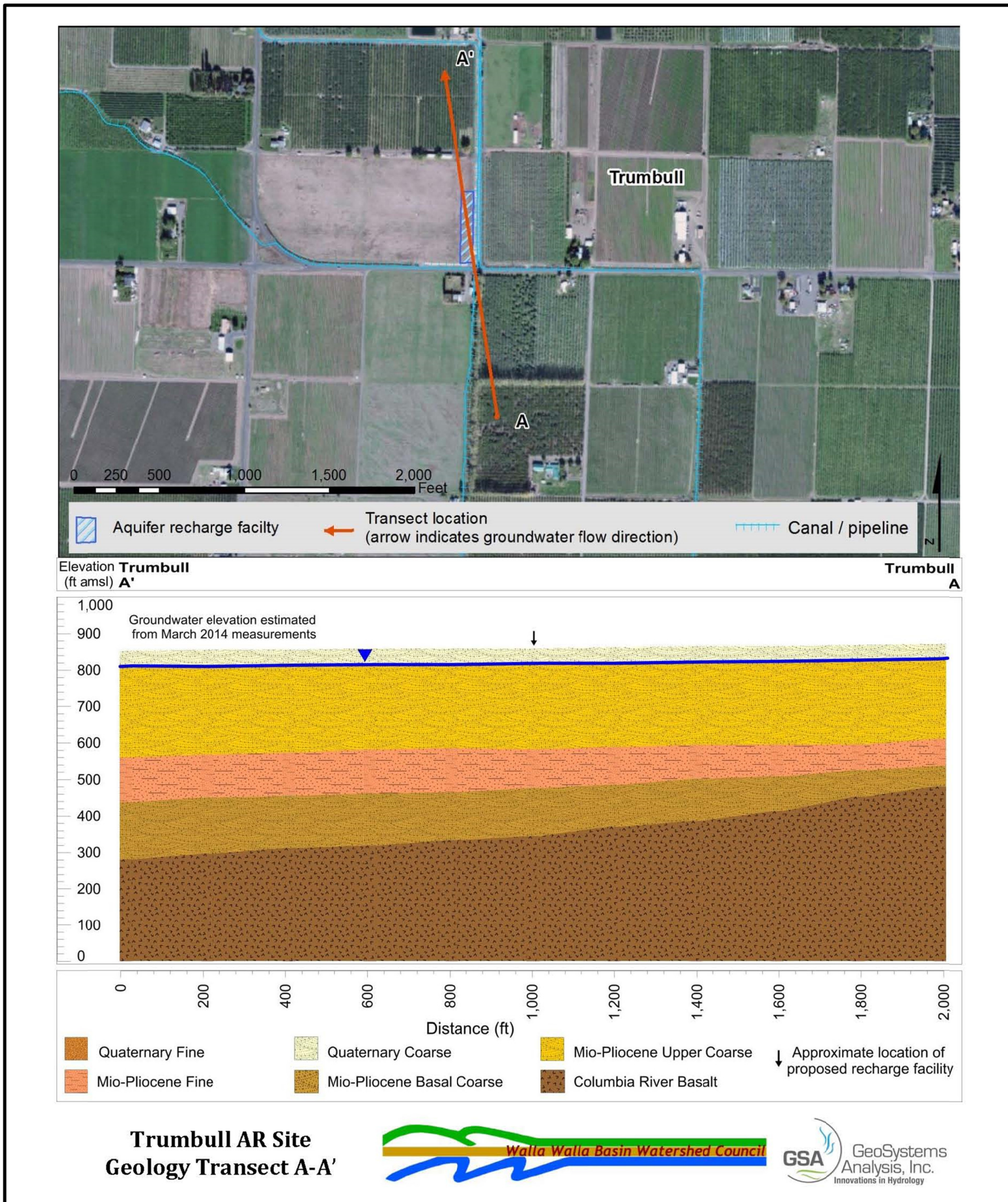

Figure 17 - Geologic cross section of the Trumbull aquifer recharge site.

West Ringer Road

Figure 18 provides a geologic cross-section of the West Ringer Road site. Geologic units present in the vicinity of the site are as follows:

- Quaternary fines unit: This unit is interpreted to be absent beneath the site, however, it is present down hydraulic gradient at the site, being approximately 40 feet thick.
- Quaternary coarse unit: This unit is interpreted to underlie the entire site area, being approximately 35 feet thick beneath the site and thinning to 15 feet where the Quaternary fine unit exists.
- Mio-Pliocene upper coarse unit: This unit underlies the entire site area and is interpreted to be approximately 130 feet thick.
- Mio-Pliocene fine unit: This unit also underlies the entire site area where it is interpreted to be approximately 230 to 260 feet thick.
- Mio-Pliocene basal coarse unit: This unit is not present beneath the site
- Top of Basalt: Beneath the site the top of basalt generally lies at a depth of 410 to 460 feet bgs.

Beneath the West Ringer Road site, the alluvial aquifer water table appears to generally lie near the bottom of the Quaternary coarse unit, at a depth of approximately 25 to 35 feet bgs (based on well GW_36). The groundwater flow direction at the site is generally to the northwest.

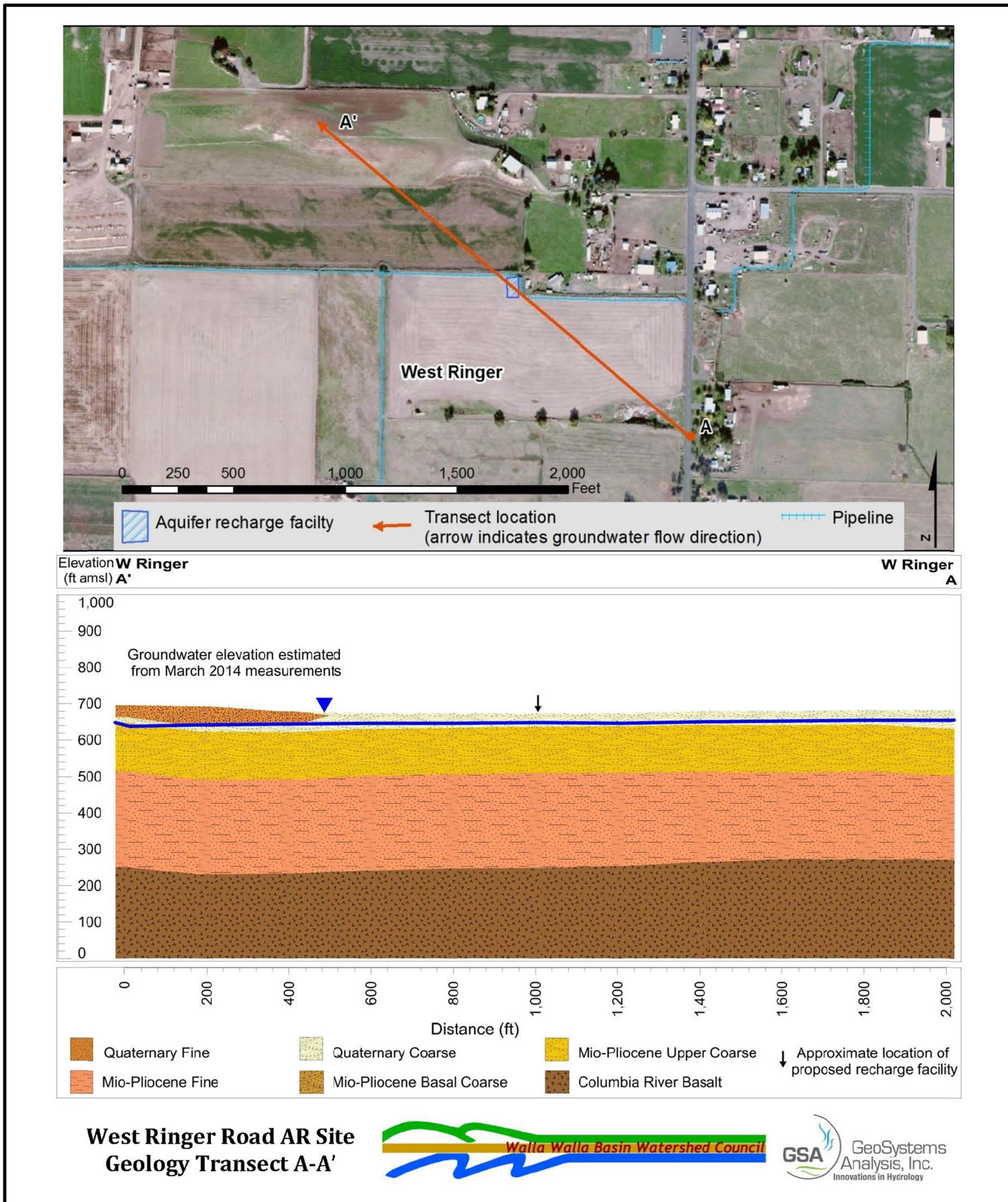

Figure 18 - Geologic cross section of the West Ringer Road aquifer recharge site.

Maximum Area of Impact

The Walla Walla Basin Integrated Water Flow Model (GSA 2015, GSA 2016) was used to evaluate the impact to regional alluvial aquifer groundwater levels that are anticipated from the recharge sites. GSA (2016) simulated groundwater levels for the Increased MAR-Piped scenario, which included all MAR sites in Limited License Application 1621 as well as five MAR sites on the Washington side of the basin, were compared to simulated groundwater levels under conditions in the No MAR-Piped scenario where all MAR sites were inactive. The details of model construction and results for the Increased MAR-Piped and No MAR-Piped scenarios are provided in GSA (2016). Model applied recharge rates are provided in Table 1. Total applied recharge on the Oregon side of the Basin was 12,469 acre-feet per annum (afa) and 2,097 afa on the Washington side of the Basin.

The simulated maximum area of impact (AOI), defined as the area with greater than 1 foot of groundwater elevation change relative to the no MAR scenario, is presented in Figures 19. Of the 152,711 acre model area, the maximum AOI is predicted to encompass 29,952 acres, with 20,122 acres being in Oregon. The maximum predicted groundwater elevation increase of approximately 36 ft is predicted to occur near the Johnson site, which comprises 35% of the total simulated recharge volume (Table 1).

Table 1. Recharge volumes applied in the Increased MAR scenario

Recharge Site	Recharge Rate (acre-ft/yr)	Operational Dates
OREGON SITES		
Anspach	1005.1	11/1 - 1/31 & 3/1 - 5/15
Barrett	1005.1	11/1 - 1/31 & 3/1 - 5/15
Chuckhole	183.9	11/1 - 11/30 & 3/15 - 5/15
County Road	841.6	11/1 - 1/31 & 3/1 - 5/15
East Trolley Lane	183.9	11/1 - 11/30 & 3/15 - 5/15
Fruitvale	183.9	11/1 - 11/30 & 3/15 - 5/15
Gallagher	1340.1	11/1 - 1/31 & 3/1 - 5/15
Johnson	5033.5	11/1 - 1/31 & 3/1 - 5/15
LeFore Road	183.9	11/1 - 11/30 & 3/15 - 5/15
Locust Road	183.9	11/1 - 11/30 & 3/15 - 5/15
Mud Creek	183.9	11/1 - 11/30 & 3/15 - 5/15
NW Umapine	841.6	11/1 - 1/31 & 3/1 - 5/15
Sunquist	183.9	11/1 - 11/30 & 3/15 - 5/15
Triangle Road	183.9	11/1 - 11/30 & 3/15 - 5/15
Triangle Station	92.3	11/1 - 11/30 & 3/15 - 5/15
Trumbull	503.4	11/1 - 1/31 & 3/1 - 5/15
West Ringer Road	335.8	11/1 - 1/31 & 3/1 - 5/15
WASHINGTON SITES		
Detour	211.6	12/1 - 4/15
Last Chance Road	363.6	11/1 - 4/30
Locher Road	735.4	3/1 - 5/30
McDonald Road	238.6	11/1 - 4/30
Stiller Pond	547.5	12/1 - 4/15

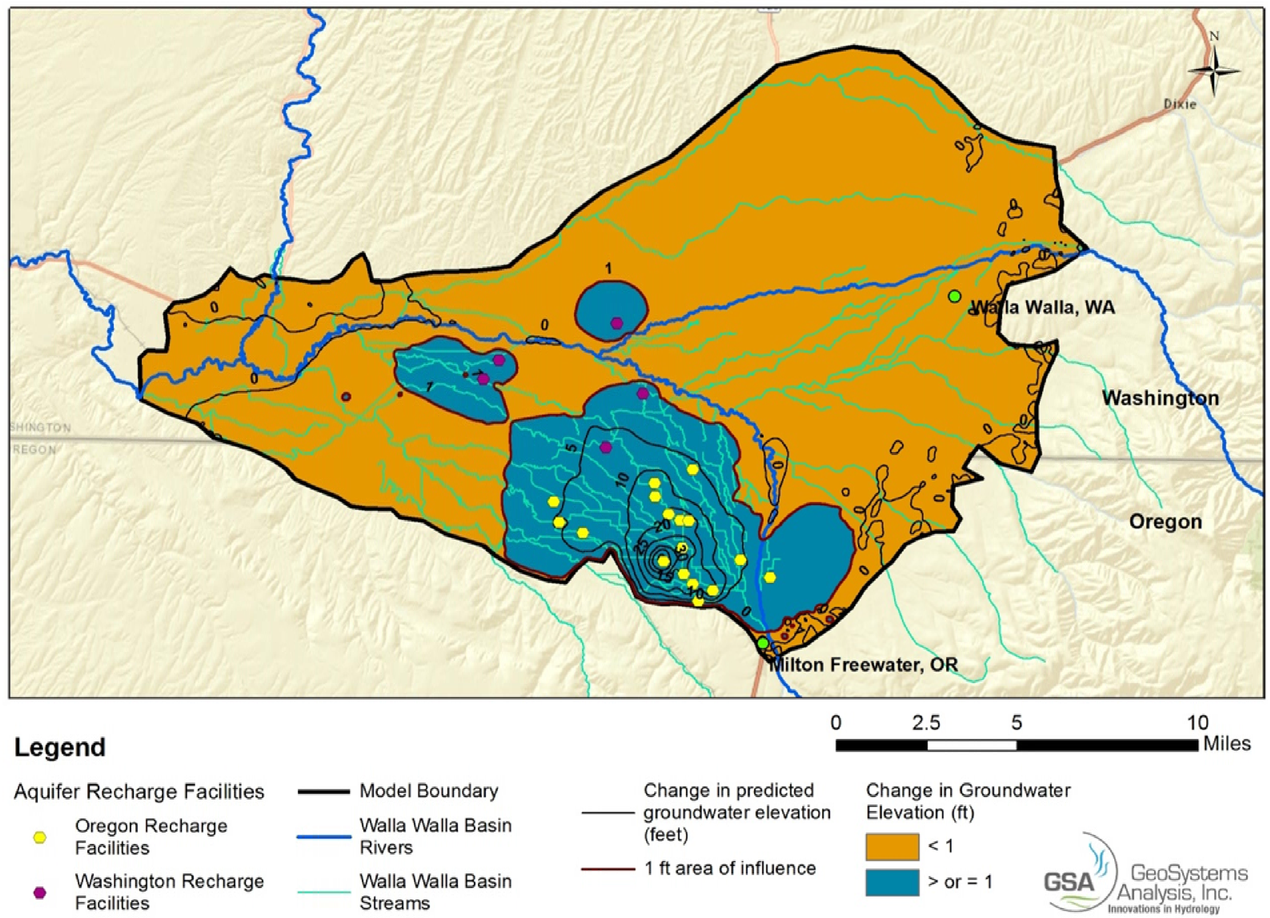

Figure 19 – Predicted groundwater elevation change from aquifer recharge

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APPENDIX A – WALLA WALLA VALLEY – WATER TABLE MAP