TECHNICAL MEMORANDUM

Date: October 30, 2012 | **Project No.:** 113-93087.003
To: Bill Stalzer, | **Company:** Stalzer and Associates Inc.
From: Michael Klisch, L.Hg. and David Banton, L.Hg.
cc: | **Email:** mklisch@golder.com

RE: RESPONSE TO COMPLIANCE ISSUES FROM EASTERN WASHINGTON REGION GROWTH MANAGEMENT HEARINGS BOARD – WALLA WALLA COUNTY CRITICAL AQUIFER RECHARGE AREA

1.0 INTRODUCTION

This memorandum provides response to a compliance order from the Eastern Washington Region Growth Management Hearings Board (GMHB) regarding Walla Walla County's (County) Critical Aquifer Recharge Area (CARA) Best Available Science (BAS) review (Golder Associates Inc. [Golder] 2011) for the County's Critical Aquifer Recharge Area (CARA) ordinance. The response is based on review of existing sources of information.

The GMHB raised the following compliance issues regarding the hydrogeologic component of the BAS review:

- Compliance Issue C – Designation – Exclusion of Airport from CARA:
  - Provide BAS regarding horizontal hydraulic conductivity.
  - Reconcile and clarify whether or not the aquifer contamination risk at the Airport satisfies the Growth Management Act's (GMA) standard of being a vulnerable aquifer as indicated by the combined effect of land uses and hydrogeologic conditions that contribute directly or indirectly to or facilitate contamination of groundwater.
- Compliance Issue D – Methodology for Determining Aquifer Vulnerability to Contamination:
  - Provide additional information on whether or not the aquifer is vulnerable to contamination conveyed through Zone 2 recharge areas.
  - If vulnerability is found, classify/designate Zone 2 recharge areas according to whether or not the Shallow Gravel Aquifer (SGA) is vulnerable to contamination from identified Zone 2 recharge areas.

These compliance issues are addressed in the following sections of the memorandum.

2.0 COMPLIANCE ISSUE C – DESIGNATION – EXCLUSION OF AIRPORT FROM CARA

The Walla Walla Airport area is within the areal extent of the SGA as mapped by the County (Golder 2011). In the area of the Walla Walla Airport, the SGA is not exposed at the ground surface; rather the SGA is present beneath about 40 to 60 feet of Touchet Beds based on geologic cross-section C-C' presented in Derkey and others (2006) and presented in Figure 1. Thus, recharge from precipitation must infiltrate through the surficial soils, Touchet Beds, and unsaturated SGA materials before reaching the

Golder Associates Inc.
18300 NE Union Hill Road, Suite 200
Redmond, WA 98052 USA
Tel: (425) 883-0777 Fax: (425) 882-5498 www.golder.com

water table in the SGA. Similarly, any potential contaminants must infiltrate through the same unsaturated materials before reaching the water table in the SGA.

2.1 BAS Data Regarding Hydraulic Conductivity

The Walla Walla Airport (Airport) area is underlain by Touchet Beds. The soils developed over most of the Airport area have been mapped predominantly as Walla Walla silt loam (USDA website 2012) with a Unified Soil Classification System (USCS) classification of ML – non-plastic or low plasticity silt. Derkey and others (2006) describe the Touchet Beds as:

> *Glacial slackwater flood deposits, consisting of two types: an older sequence with subtle rhythmic bedding and a younger sequence that contains conspicuous rhythmic bedding. The older sequence is predominantly light gray or tan to white sand with minor silt, clay, and sparse pebbles and some local, ice-rafted gravel indicating subaqueous to aqueous origin. It exhibits faint rhythmic bedding when observed from a distance under low-angle light conditions and higher (spring) moisture conditions. The younger sequence consists of well stratified, normally graded, fine- to medium-grained felsic to basaltic sand at the base, grading upward to felsic silt. Rhythmically bedded Touchet beds exhibit soft sediment deformation features. Individual beds range from a few centimeters to 1 m (3 ft) thick (Waitt, 1985). Remnant buttes in Mill Creek valley are rhythmically bedded Touchet beds; north of Mill Creek Valley, well-bedded deposits overlie massive-appearing Touchet beds and are sometimes draped over hilltops of older deposits. Up to 2 m (7 ft) of loess mantles most of the Touchet beds; however, because it is inconsistently distributed and thin, it is not mapped separately. Cross-cutting clastic dikes are common (Fecht and others, 1999) in roadcuts of Touchet beds in the two quadrangles. Unit Qfst1 indicates Touchet beds underlying the older, more dissected rolling hills, and unit Qfst2 is Touchet beds underlying the younger, less dissected terraces.*

Newcomb (1965) describes the Touchet Beds as:

> *A deposit of horizontally bedded silt and fine sand, marked by distinctive gravel, cobbles, and boulder inclusions and by peculiar structural features, overlies all other Pleistocene and older materials.*

2.1.1 Horizontal Hydraulic Conductivity

Based on the descriptions of the Touchet beds and cross sections by Derkey and others (2006) and Newcomb (1965), the Touchet Beds consist of sand and silt deposited in thin, rhythmic beds with a total thickness of about 10 to 50 feet. There are no site-specific horizontal hydraulic conductivity data available for the Touchet Beds at the Walla Walla Airport. Information on the hydraulic conductivity of the Touchet Beds was obtained from a literature search. Values of hydraulic conductivity for the Touchet Beds from the literature are summarized in Table 1. The values of horizontal hydraulic conductivity for Touchet Beds are variable, ranging from about 1 to 20 feet per day (ft/d), reflecting the variability of the geologic materials comprising the Touchet Beds (silt to fine to medium sand). The higher values of horizontal hydraulic conductivity likely reflect sandier beds, while the lower values likely reflect finer-grained materials. The reported values for horizontal hydraulic conductivity of the Touchet Beds are within ranges reported in the literature for similar geologic materials (Freeze and Cherry 1979; Dominico and Schwartz 1990) for fine to medium sand and silt (Table 1).

2.1.2 Vertical Hydraulic Conductivity

There is limited information on the vertical hydraulic conductivity of the Touchet Beds. The available information and the rhythmically-bedded nature of the Touchet Beds suggest that the vertical hydraulic conductivity of the Touchet Beds is lower than the horizontal hydraulic conductivity by a factor of about 3 to 100 (Table 1), or about 0.009 to 8 ft/d).

2.1.3 Well Logs

Well logs on file with the Washington State Department of Ecology ([Ecology] 2012) were reviewed to provide additional information on subsurface conditions and geologic units in the Airport Area. There are well logs on file for the Airport area including a production well and several monitoring wells. The well logs indicate:

- The Airport production well is completed in the basalt aquifer underlying the SGA. The well log from the production well indicates 29 feet of "brown clay" likely corresponding to Touchet Beds and loess was intersected. Clay is typically a low-permeability material (e.g. Freeze and Cherry 1979). These materials overlie cemented and uncemented gravels and clay corresponding to SGA materials. The depth to water in the SGA was about 55 feet below ground surface (bgs) at the time of drilling in 1962.
- The monitoring wells in the Airport area include several shallow (less than 10-foot deep) soil borings that all intersected silty sand, but did not penetrate the full thickness of the silty sand. There are also several deeper (up to 190 feet deep) monitoring wells that indicated about 20 to 25 feet of silt or silty clay likely corresponding to Touchet Beds and loess was intersected overlying silty gravel and sand of the SGA. The silty clay and clay materials are typically low permeability (e.g. Freeze and Cherry 1979). The depth to water in the wells ranged from about 85 to 90 feet bgs at the time of drilling in 1996.

The well logs indicate that low-permeability materials, including Touchet Beds and cemented gravels, are present above the water table in the SGA.

2.1.4 Water Table

The water table in the SGA in the Airport area is about 55 to 85 feet bgs. Therefore, infiltrating recharge (and potential contaminants) must travel vertically through a variable thickness of low to moderate-permeability materials in the unsaturated zone before reaching unsaturated, coarser-grained materials or the water table.

2.2 SGA Aquifer Contamination Risk in the Airport Area

The migration of potential contaminants in infiltrating precipitation (groundwater recharge) to the SGA in the Airport area is governed by the hydraulic conductivity, hydraulic gradient, and effective porosity of the Touchet Beds and underlying geologic materials, and the attenuation potential of the geologic materials. Once any potential contaminants reach the SGA, transport of these contaminants to potential receptors is controlled by the aquifer hydraulic properties (horizontal hydraulic conductivity and effective porosity) and the horizontal component of hydraulic gradient and the attenuation properties of the aquifer matrix.

There is some surface water runoff from the Airport area to tributaries of Mill Creek and Mud Creek. Discharge of stormwater runoff from the Airport area is regulated by Ecology under an Industrial Stormwater General Permit (number WAR000425).

The SGA as mapped by the County is present, but not exposed at the surface, in the Airport area (Golder 2011). It is overlain by a variable thickness of fine- to medium-grained, rhythmic-bedded Touchet Beds (Figure 1). Information presented by Derkey and others (2006) suggests that the Touchet Beds are about 40 to 50 feet thick in the area of the Airport (Figure 2). Information from well logs from the Airport area suggests that the Touchet Beds may be about 20 to 25 feet thick. The well logs suggest the depth to water in the SGA in the Airport area may be about 55 to 85 feet bgs.

2.2.1 Susceptibility

The Airport area was classified as low susceptibility (Golder 2011). The susceptibility rating of the SGA in the Airport area was rated as low because:

- In the Airport area, the SGA is overlain by low to moderate permeability Touchet Beds consisting of rhythmically-bedded sand and silt. The vertical hydraulic conductivity of the Touchet Beds is likely lower than the horizontal hydraulic conductivity because of the rhythmically-bedded nature of the deposits. Lower-permeability materials will restrict the downward migration of contaminants from potential source areas to higher-permeability sandy beds and the SGA. The U.S. Geological Survey (USGS) estimated groundwater recharge in the Airport area to be about 0.5 to 2 inches per year (in/yr), lower than the estimated recharge of 2 to over 10 in/yr where the SGA is exposed at the ground surface (Bauer and Vacarro 1988). This suggests the Airport area is underlain by materials that are lower permeability than the SGA, and limit groundwater recharge.
- The fine-grained nature of the Touchet Beds provides opportunities for attenuation of potential contaminants, slowing or restricting the downward migration of potential contaminants to the SGA.
- The depth to water is about 55 to 85 feet below ground. Thus, there is a considerable thickness of unsaturated (vadose) zone materials above the water table, and the travel time for any potential contaminants is greater than if the water table were near the ground surface. In addition, many of the geologic materials in the unsaturated zone are fine- to medium grained which are lower-permeability and have greater attenuation potential than coarse-grained SGA materials.

2.2.2 Contaminant Loading Potential

The zoning in the Airport area is classified as Airport Development (AD). The Airport Development District (WWCC 17.16.015 - Permitted uses—Airport development district) includes the following provisions:

17.16.015 - Permitted uses—Airport development district.

A. The airport development district permits the full range of agricultural, aviation, industrial, office and commercial, public and quasi-public uses and incidental accessory uses.

B. Specific use or uses of buildings and sites will be permitted by approval of the airport board, based on its land use and development plan. (Ord. 187 (Exh. A (part)), 1986).

Therefore, under the AD zoning designation, there may be development or land uses that have the potential to impact groundwater quality. These include storage or use of fuel, pesticides, herbicides, or other chemicals depending on the type of land use. The Airport area outside of the AD zone is zoned for 40-acre agricultural use and as such presents a low contaminant loading potential.

There are sites in the AD-zone area that are permitted and regulated by Ecology to generate or store hazardous materials (Golder 2011). These sites have the potential to affect groundwater quality in the event of releases to the environment resulting from improper storage or handling.

There are several sites in the AD-zone area where releases to the environment have occurred in the past. These sites are permitted and regulated by Ecology. Most of the sites did not have an impact to groundwater. In all cases the sites have been, or are in the process of being remediated, and are not threats to groundwater (Golder 2011).

Of the sites at the Airport where releases to the environment have occurred, there are two sites where groundwater has been impacted. The U.S. Army Corps of Engineers Motor Pool Site (Site ID 782) had six monitoring wells installed following observations of fuels spills in the early 1990's. Benzene and lead were detected in two of the wells in samples collected between 1993 and 1995. Following remedial activities in 1996, benzene and lead were no longer detected (Ecology 2009). The Walla Walla Airport (Site ID 774) was reported to have petroleum contamination of groundwater; however, no information was found on analytical results. The site has been remediated.

There are no waste disposal sites at the Airport.

2.2.3 Vulnerability Classification

Many of the uses allowed in the AD zone use, store, or generate hazardous materials, and given the concentration of such uses in one zone, they present some contaminant loading potential risk through improper storage, handling, or a spill event. Because uses that generate or store hazardous materials are permitted and regulated by Ecology and because Best Management Practices (BMP's) are required, the contaminant loading potential risk in the AD zone is not high. Additionally, records indicate that releases to the environment have occurred in the past and two sites that have been remediated affected groundwater quality. Consequently, a moderate risk of contaminant loading potential does exist in the AD zone.

One of the vulnerability criteria under Ecology (2005) is identification of groundwater resources. There are no public water supplies or exempt wells in the Airport area obtaining water from the SGA. Drinking water for the Airport is supplied by a well completed in the basalt aquifer system underlying the SGA. The well is cased into the basalt. The Airport also has an intertie with the City of Walla Walla to provide drinking water.

The vulnerability of the SGA in the Airport AD zone was classified as moderate (Golder 2011). As discussed above, the susceptibility of the SGA in the AD zone is low, but the contaminant loading potential is moderate. In the Airport area outside of the AD zone, the susceptibility of the SGA is low, and the contaminant loading potential is low. Therefore, the area outside the AD zone was designated low vulnerability.

3.0 COMPLIANCE ISSUE D - DESIGNATION - METHODOLOGY FOR DETERMINING AQUIFER VULNERABILITY TO CONTAMINATION

This section describes the methodologies used for determining the aquifer susceptibility and vulnerability to contamination in Zone 2 recharge areas (Golder 2011) and the designation of the CARA for the SGA. The delineation methods followed the methodologies described in Ecology (2005) and the factors outlined in WAC 173-365-190.

3.1 Geological, Soils, and Hydrogeologic Characterization for the SGA

The geological units and soils comprising the SGA as delineated by the County and surrounding area were described based on existing geological mapping (e.g. Derkey and others 2006) and soil surveys (Golder 2011). The SGA as delineated by the County and the surrounding area includes the following areas:

- The area where the coarse-grained, moderate to high-permeability alluvium and Miocene Conglomerate comprising the SGA are exposed directly at the ground surface in the Walla Walla Valley.
- The area where the coarse-grained, moderate to high-permeability alluvium and Miocene Conglomerate comprising the SGA are not exposed at the surface but are present in the subsurface beneath younger, finer-grained, lower permeability geologic units (loess and Touchet Beds).
- The area outside the boundary of the SGA delineated by the County where the SGA thins and pinches out as the basalt surface rises. In this area, there are shallow unconfined aquifers above the basalt bedrock that are confined to river and stream valleys that are in continuity with the SGA as delineated by the County.

3.2 Evaluation of SGA Recharge Areas

Golder (2011) delineated two recharge zones within the SGA Study Area. The delineation of the zones was based on the surfical geologic materials, the properties of these materials, continuity with surface water, and estimated groundwater recharge based on USGS modeling (Bauer and Vaccaro 1988). The two recharge zones delineated are:

- **Zone 1:** Zone 1 is the area where the SGA is *directly exposed* at the ground surface. In this area, the SGA receives recharge from direct infiltration of precipitation and snowmelt. In Zone 1, the SGA has a high degree of continuity with surface water and thus receives recharge from losing reaches of streams. The SGA also receives recharge from leakage from irrigation canals and irrigation returns. Because the SGA is composed of alluvial sands and gravels and Miocene conglomerate materials which are moderately to highly permeable, groundwater recharge rates are high. The USGS estimated recharge rates were about 2 to over 10 in/yr where the SGA is directly exposed at the ground surface (Bauer and Vaccaro 1988).
- **Zone 2:** In Zone 2, the SGA is *present in the subsurface* below a variable thickness of loess and Touchet Beds that form upland areas. This occurs in the vicinity of the Airport (Figure 1) and in other areas of the Walla Walla valley. The SGA receives recharge from infiltration of precipitation and snowmelt, and irrigation returns. The loess and Touchet beds at the ground surface, overlying the SGA, are fine-grained and lower permeability than the underlying SGA materials. Thus, groundwater recharge via infiltration of precipitation and snowmelt to the SGA in areas where it underlies these materials is lower than in areas where the SGA is directly exposed at the ground surface. The USGS estimated groundwater recharge in these areas may be in the range of 0.5 to about 1 to 2 in/yr (Bauer and Vaccaro 1988).
- Because of the low to moderate permeability of the loess and Touchet Beds, there is limited continuity with surface water in the areas where these materials are exposed at the ground surface, and thus limited infiltration of surface water. Surface water generally runs off the upland loess and Touchet Bed areas in small streams and infiltrates once it reaches areas where permeable SGA materials are exposed at the ground surface, or the small streams are tributary to other streams.

Zone 2 also includes the area where the SGA as delineated by the County is not present because the underlying basalt bedrock rises in the subsurface and the SGA thins and pinches out.

3.3 SGA Zone 2 Recharge Areas Susceptibility

The susceptibility of the SGA was ranked based on the geologic and soil properties, groundwater recharge rates and continuity with surface water, depth to water, and the potential for attenuation of potential contaminants.

3.3.1 High Susceptibility

The susceptibility of the SGA was ranked as high in the areas where the coarse-grained alluvial and Miocene Conglomerate comprising the SGA are exposed at the ground surface (SGA Susceptibility Zones 1 and 2; Golder 2011). These areas were ranked as high susceptibility because these materials are moderate to highly permeable, the depth to water is shallow, there is a high degree of continuity with surface water, and groundwater recharge rates are high. These coarse-grained materials also provide limited opportunity for attenuation.

Low Susceptibility

The susceptibility of the SGA was ranked as low (SGA Susceptibility Zone 3; Golder 2011) in areas where:

- The overlying low to moderate-permeability loess and Touchet Beds limit the infiltration of precipitation.
- The vertical hydraulic conductivity of the Touchet Beds is likely lower than the horizontal hydraulic conductivity because of the rhythmically-bedded nature of the deposits (Table 1). Lower-permeability materials will restrict the downward migration of contaminants from potential source areas through the Touchet Beds to the underlying SGA.
- The fine-grained nature of the loess and Touchet Beds provide opportunities for attenuation of potential contaminants, slowing or restricting the downward migration of potential contaminants to the SGA.
- The depth to water in SGA below the upland areas mantled by loess and Touchet Beds is variable depending on the ground elevation. Based on the cross-sections presented in Derkey and others (2006), the thickness of the Touchet Bed and loess above the SGA may be in the range of about 20 to over 50 feet. If the groundwater elevation is at or near the ground surface in areas of the SGA where it is exposed at the ground surface adjacent to the upland areas, there may be 20 to over 50 feet of unsaturated materials above the water table. The thicker section of unsaturated materials, particularly lower-permeability Touchet Beds, results in a greater travel time to the water table and provides additional opportunities for attenuation of potential contaminants.

3.4 Moderate Vulnerability Designation

The vulnerability of the Zone 2 recharge area for the SGA was assessed by evaluating aquifer susceptibility and contaminant loading potential including the land use, locations of known or potential sources of groundwater contamination, groundwater use groundwater quality, waste disposal sites, and agricultural activities (Ecology 2005; WAC 365-190-100). The extent of the SGA delineated by the County includes areas where the SGA is exposed at the ground surface, and areas where the SGA is not exposed at the ground surface but occurs under a variable thickness of low to moderate-permeability sediments. Golder (2011) delineated three zones of aquifer vulnerability for the SGA and shallow alluvial aquifers in river valleys in continuity with the SGA, including the moderate vulnerability zone. The moderate vulnerability zone is the area of the SGA where the SGA is not exposed at the ground surface but is present below a variable thickness of low to moderate-permeability Touchet Beds. This area was rated as low susceptibility (Susceptibility Zone 3). This zone includes areas where industrial land uses are allowed. These uses may store, or use fuel, pesticides, herbicides or other chemicals that have the potential to impact groundwater quality from improper storage or handling or a spill event. However, because these uses are permitted and regulated by Ecology and are required to use BMPs, the contaminant loading potential risk is moderate. This zone has a relatively low density of Group A and B water systems and permit-exempt wells, and some Ecology sites that could potentially affect groundwater quality. For these reasons the overall vulnerability of these areas was rated as moderate, not high. However, they do warrant special consideration since many of the uses have a potential to contaminate groundwater if existing regulations, permits, and BMPs are not followed.

3.5 Summary

3.5.1 Critical Aquifer Recharge Areas

Critical Aquifer Recharge Areas are defined under WAC 365-190-030(3):

> *"Critical aquifer recharge areas" are areas with a critical recharging effect on aquifers used for potable water, including areas where an aquifer that is a source of drinking water is vulnerable to contamination that would affect the potability of the water, or is susceptible to reduced recharge*

The revised CARA for the SGA study area (Golder 2011) was designated based on the results of the vulnerability assessment (Ecology 2005 and WAC 365-190-100 (3) (b)). The area providing a critical recharging effect for the SGA and designated as the SGA CARA was delineated as follows:

- The area where the SGA is exposed at the ground surface was included in the CARA. This area includes the area of Susceptibility Zones 1 and 2 because this is where the greatest recharge to the SGA occurs from direct infiltration of precipitation and snowmelt, and from infiltration of surface water. This area was rated as high susceptibility because of the shallow depth to groundwater, high permeability of the aquifer materials, and high degree of continuity with surface water.

  This area was also ranked as high vulnerability (Vulnerability Zone 1) because of the high aquifer susceptibility, land uses that could potentially affect groundwater quality, the locations of sites that could potentially affect groundwater quality, and because the greatest number of Group A and B water systems and permit-exempt wells obtaining water from the SGA are located within this area.

- Several areas outside the extent of the SGA delineated by the County were included in the CARA. These areas include the alluvial valleys of the major streams and rivers including the valleys of the Touchet River and Dry Creek. This is because these alluvial valleys are rated as high susceptibility and high vulnerability and are in hydraulic communication with the SGA.

3.5.2 Moderate Vulnerability Designation

The area where the SGA was delineated by the County but is overlain by Touchet Beds provides some recharge to the SGA. This area is designated as moderate vulnerability and is excluded from the CARA designation but does warrant special consideration because it directly overlies the SGA and there are some areas that could have a moderate risk of contaminant loading.

- This area includes the Airport where the AD zoning allows a wide variety of uses, including some that have potential to impact groundwater quality if Best Management Practices are not followed or the existing regulations and permitting governing storage, generation, or handling of potential contaminants are not followed. Therefore the contaminant loading potential risk is moderate. Outside the area zoned as AD, most of the land use is agricultural with a low contaminant loading potential.

- There is a variable density of Group A and B wells and permit exempt wells in the moderate vulnerability area. There are no Group A and B wells and permit exempt wells obtaining water from the SGA in the AD zoned area.

- The thickness of the loess and Touchet Beds are variable, with greater travel time to the water table and greater attenuation potential where they are thicker. The thickness and attenuation properties of the Touchet Beds cannot be determined without site specific investigations.

4.0 CLOSING

Please contact us if you have any questions or need additional information.

GOLDER ASSOCIATES INC.

Michael Klisch, L.Hg.
Senior Project Hydrogeologist

David Banton, L.Hg
Principal Hydrogeologist

MPK/DB/nb

Attachments

Table 1	Touchet Beds Hydraulic Conductivity
Figure 1	Airport Area Geologic Map
Figure 2	Airport Area Geologic Cross Section

5.0 REFERENCES

Bauer, H.H., and J.J. Vaccaro, 1988, Estimates of Ground-Water Recharge to the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho, for Predevelopment and Current Land-Use Conditions, U.S. Geological Survey Water-Resources Investigations Report 88-4108;

Derkey, R.E., D.A. Sradling, K.A. Lindsay, and T.L. Tolan, 2006, Geologic map of the College Place and Walla Walla 7.5 Minute Quadrangles, Walla Walla County, Washington, and Umatilla County, Oregon, Washington State Division of Geology and Earth Resources Geologic Map GM-62.

Dominico, P.A. and F.W. Schwartz. 1990. Physical and Chemical Hydrogeology. John Wiley and Sons. New York.

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Prentice-Hall. New Jersey.

Golder Associates Inc. 2011. Best Available Science Update for Critical Aquifer Recharge Areas (Shallow Gravel Aquifer), Walla Walla County. September 20.

Johnson, J., K.A. Didricksen, and J. Taylor. 2007. Modeling Mitigation of Seepage from the Potential Black Rock Reservoir. U.S. Bureau of Reclamation Technical Series No. TS-YSS-25.

Landau Associates, 2004. Remedial Investigation Work Plan, Sudbury Road Landfill, Walla Walla, Washington. April 22.

Newcomb, R.C. 1965. Geology and Ground-Water Resources of the Walla Walla River Basin, Washington-Oregon. Water Supply Bulletin No. 21. State of Washington, Division of Water Resources.

Pacific Groundwater Group, 2012. Retiming Benefits Analysis for Conservation in the Walla Walla, Horse Heaven Hills and South Franklin County Study Areas. Prepared for Franklin Conservation District and the Washington Department of Ecology. Publication Number 12-12-005.

Petrides, A. 2008. Modeling Surface Water and Groundwater Interactions near Milton-Freewater, Oregon. Oregon State University Master of Science Thesis, March 17.

Petrides, A., and J. Scherberg. 2010. Interim report on the Development of a Numerical Walla Walla Basin Surface and Ground Water Model. Prepared for Walla Walla Basin Watershed Council.

United States Department of Agriculture (USDA), Soil Conservation Service, Online Washington Soil Survey Data, http://www.or.nrcs.usda.gov/pnw_soil/wa_reports.html, accessed June 28, 2011.

Washington State Department of Ecology (Ecology). 2005. Critical Aquifer Recharge Areas – Guidance Document, Laurie Morgan, author. Washington State Department of Ecology Publication Number 05-10-028. January.

Ecology. 2009. Periodic Review - US Army Corps of Engineers Motor Pool FS ID#: 782, E Street and 10th Street, Walla Walla, Washington 99362. Eastern Regional Office, Toxics Cleanup Program. September. Ecology. 2012. Online Well Log Database, http://apps.ecy.wa.gov/welllog/index.asp, accessed July 6, 2012.

Zhang, Z.F. and R. Khaleel. 2009. The Interfacial-Area Based Relative Permeability Function. Pacific Northwest National Laboratory, PNNL-18792.

TABLE

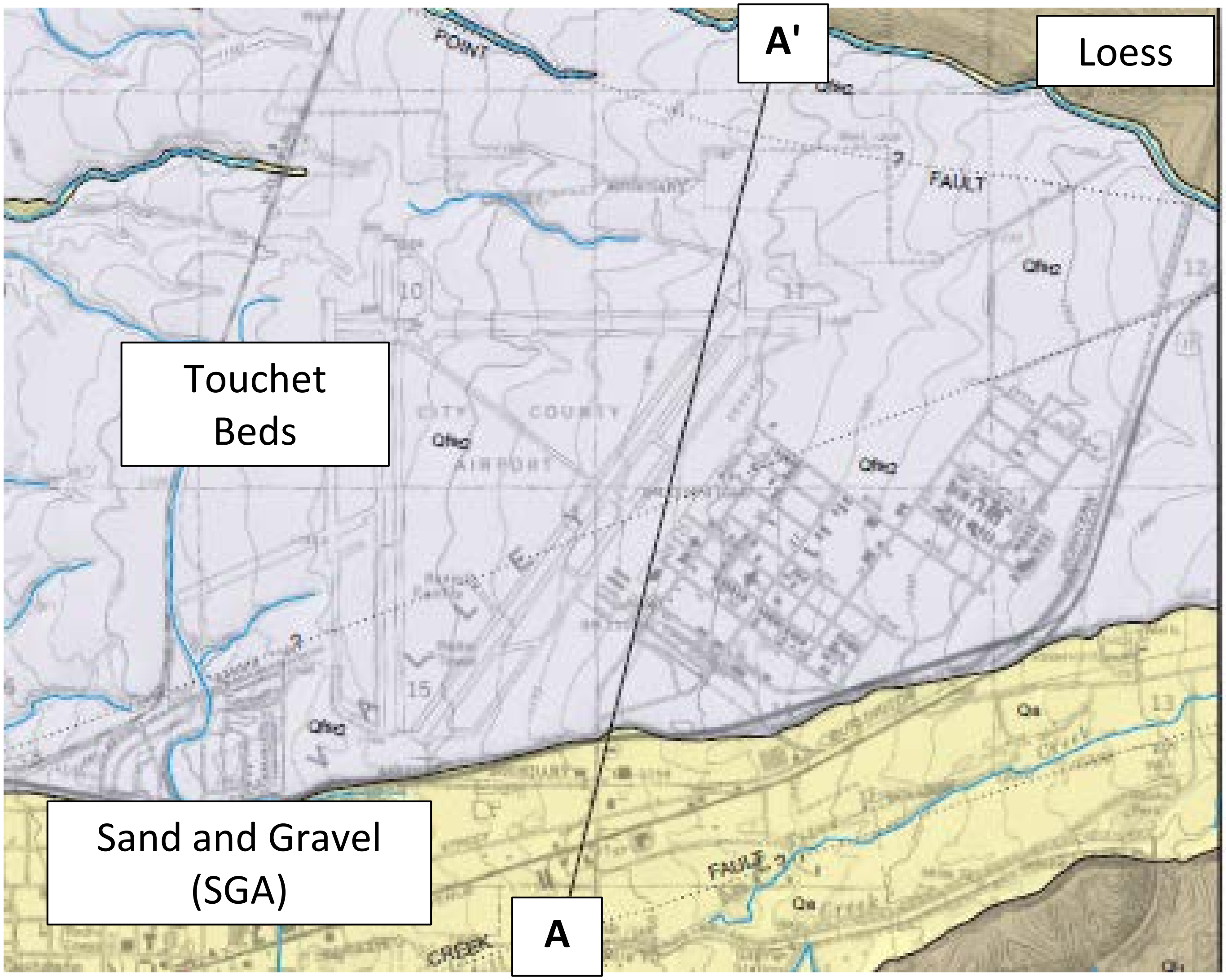
Table 1: Touchet Beds Hydraulic Conductivity

Geologic Unit	Horizontal Hydraulic Conductivity (ft/d)	Vertical Hydraulic Conductivity (ft/d)	Location	Reference
Walla Walla Silt Loam	1 to 4	NA	Walla Walla Valley	Soil Survey of Walla Walla County - Walla Walla Silt Loam
Touchet Beds	21	8.2	Walla Walla Valley	Petrides 2008; Petrides and Scherberg 2010
Touchet Silt Loam	9.9	NA	Modeled Estimates	Zhang and Khaleel 2009
Touchet Beds	1.7 to 2.0	NA	Walla Walla Valley	Petrides and Scherberg 2010
Touchet Beds	4.3	NA	Walla Walla-Sudbury Road Landfill	Landau Associates 2004
Touchet Beds	0.886	0.00886	Black Rock Reservoir - Seepage Model	Johnson and others 2008
"Qf" Aquifer including Touchet Beds	8	NA	Walla Walla Valley	Pacific Groundwater Group 2012
Silty Sand	0.03 to 280	NA	General Range of Values	Freeze and Cherry 1979
Silt, Loess	0.0003 to 0.3	NA	General Range of Values	Freeze and Cherry 1980
Fine Sand	0.05 to 55	NA	General Range of Values	Dominico and Schwartz 1990
Medium Sand	0.3 to 140	NA	General Range of Values	Dominico and Schwartz 1990
Silt, Loess	0.0003 to 5	NA	General Range of Values	Dominico and Schwartz 1990

Notes:
NA: No information

Golder Associates

FIGURES



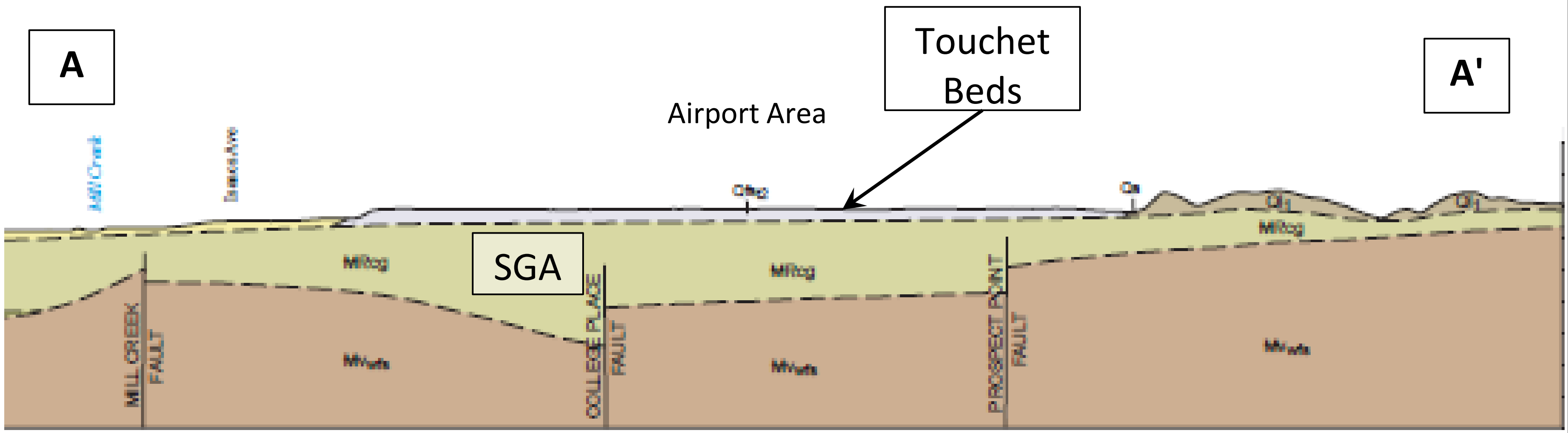
LEGEND

Note:
From Derkey and others 2006

FIGURE **1**

AIRPORT AREA GEOLOGIC MAP

Stalzer/WWC CARA BAS/WA



Key to geologic units: Qa: Alluvium; Qfs_{t2}: Touchet Beds, Ql_1: Loess; MRcg: Miocene Conglomerate; MRf: Miocene fine-grained sediments; Mv_{wfs}: Wanapum Basalt – Frenchman Springs Member (Columbia River Basalt Group).

Shallow Gravel Aquifer includes units Qa and MRcg.

LEGEND

Note:
From Derkey and others 2006 (section C-C')

FIGURE **2**

AIRPORT AREA GEOLOGIC CROSS SECTION

Stalzer/WWC CARA BAS/WA