ADDENDUM TO THE 2007 HYDROLOGIC INFORMATION REPORT SUPPORTING WATER AVAILABILITY ASSESSMENT FOR SWALE CREEK SUBBASIN, WRIA 30

Evaluation of Swale Valley

Prepared for: Klickitat County Department of Natural Resources

Project No. 070024-12-01 • June 30, 2010

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Introduction

This report updates the 2007 Hydrologic Information Report Supporting Water Availability Assessment (Water Availability Report) for the Swale Creek and Little Klickitat subbasins, providing supplemental data and analyses specific to the Swale Valley portion of the Swale Creek subbasin. The Swale Creek subbasin (Figure 1) has a higher water use than most of the other subbasins within Water Resource Inventory Area 30 (WRIA 30) – the Klickitat River Basin – and is an area of WRIA 30 with potential for substantial future growth if additional water supplies (water rights) were made available. Applications for new water rights have been pending in the Swale Creek subbasin for more than 20 years.

Swale Creek is identified as water-quality impaired (Category 5) for water temperature on Ecology's current water quality assessment list, and is considered to have inadequate instream flow to meet future water demands of any significance. The WRIA 30 Watershed Management Plan anticipates that additional water demands in the Swale Creek subbasin will be met using new supplies from groundwater, not surface water.

As described in the 2007 Water Availability Report (Aspect Consulting, 2007a), the Swale Creek subbasin can be divided into the Swale Valley, a broad, alluvial-filled swale upstream (east) of Warwick, and Swale Canyon, a deeply incised bedrock canyon downstream (west) of Warwick (Figure 1). Any future water demands of any significance in the subbasin are expected to occur within Swale Valley, and the vast majority of the pending water right applications in the subbasin are within the Valley.

Project Objectives

The focus of this updated assessment is to further assess water availability specifically for the Swale Valley portion of the Swale Creek subbasin, and assess whether, for the purposes of future processing of pending water right applications, the aquifers beneath Swale Valley constitute distinct sources of water (bodies of public groundwater). Therefore, the specific objectives of this assessment are to:

1. Refine the hydrogeologic conceptual model for the Swale Valley to incorporate data collected since 2007;
2. Update the previous subbasin-scale water balance specific to Swale Valley, to assist in determination of water availability; and
3. Assess whether, based on hydrologic conditions, distinct "sources of water", as defined in the context of processing water right applications, can be defined within the Swale Valley in accordance with Ecology Water Resource Program Policy POL-2010.

Report Organization

The following sections of this report include:

- Updated Conceptual Model of Hydrologic Conditions
- Water Balance Results for Swale Valley
- Assessment of Sources of Water within Swale Valley
- Conclusions and Recommendations

Appendix A provides details of the Swale Valley water balance.

Updated Conceptual Model of Hydrogeologic Conditions

The 2007 Water Availability Report encompassed both the Little Klickitat River and Swale Creek subbasins. As described in that report, the large eastern portion of the Swale Creek subbasin, namely the Swale Valley (Figure 2), is bound by a series of geologic structures: to the west by the northwest-southeast trending Warwick fault, to the north by the southwest-northeast trending Horseshoe Bend anticline, and to the south by the southwest-northeast trending Columbia Hills anticline/fault system. A groundwater elevation contour map, based on 2007 measurements, confirmed that these structural boundaries were also hydraulic barriers to lateral groundwater flow (Aspect Consulting, 2007a).

Since the 2007 Water Availability Report, additional groundwater and surface water level data has been collected within the Swale Valley (see the following section). Therefore, the conceptual model of hydrogeologic conditions within the Swale Creek subbasin has been updated to include this data for the Swale Valley, specifically the groundwater-surface water interactions between the shallow alluvium aquifer and Swale Creek, which was a data gap identified in the 2007 report.

New Hydrologic Data Collection since 2007 Report

The following hydrologic data collection activities have been completed since issuance of the 2007 Water Availability Report:

- Collection of an additional six rounds of groundwater level measurements for wells included in the established water level monitoring network (Spring and Autumn measurements for three years). Figure 2 presents the location of the groundwater and surface water level monitoring locations in the Swale Valley and Swale Canyon portions of the Swale Creek subbasin.

- A new dedicated shallow monitoring well (SWC-MW-1; Figure 2) was installed in the alluvium aquifer east (upgradient) of the Warwick fault in 2009 (Aspect Consulting, 2009a). The well was surveyed, and a pressure transducer was installed in the well, allowing collection of continuous (2-hour) groundwater level data since May 21, 2009.

- An existing unused water well completed in the alluvium aquifer was also instrumented for continuous water level monitoring, including surveying. The Miller well is located approximately two miles east of SWC-MW-1 (Figure 2). Continuous (2-hour) water level data has been collected from the Miller well since February 5, 2009.

- Three new continuous-recording stream gages were installed on Swale Creek in November 2008. As shown on Figure 2, the stations are located near the confluence with the Klickitat River (SWC-03), just downstream of Swale Valley near the Harms Road bridge (SWC-02), and upstream of Highway 97 (SWC-04) (Aspect Consulting, 2009b). Stream gage SWC-02 was installed at the location closest to the downstream end of Swale Valley where a section of stream channel deemed suitable for gaging was present. The stations were surveyed, and continuous stream stage (i.e. surface water elevation) data have been collected at each since November 25, 2008. Rating curves were also developed for each station to correlate stream stage to discharge, resulting in a continuous record of stream discharge data for three locations on Swale Creek. However, due to lack of high flow discharge measurements collected at SWC-02, flows above approximately 50 cfs should be treated as estimates. Similarly, flows above about 11 cfs at SWC-04 (Swale Creek at Highway 97) should also be considered estimates (Aspect Consulting, 2009c).

Hydrostratigraphy

The primary hydrostratigraphic units within Swale Valley include, from the surface down, unconsolidated alluvium and sedimentary rocks (collectively termed the alluvium aquifer for this report), Wanapum basalt, and Grande Ronde basalt. Detailed descriptions of these units are provided in the 2007 Water Availability Report.

As previously discussed in the 2007 Water Availability Report, the shallowest water-bearing interflow zone of the Wanapum basalt, immediately underlying the alluvium, is in direct hydraulic continuity with the alluvium and is therefore considered part of the alluvium hydrostratigraphic unit. However, the available data indicate that there is limited hydraulic continuity between the alluvium aquifer and the deeper basalt interflow zones. This is because the massive basalt flow interiors provide relatively impermeable confining layers between the alluvium and deeper basalt aquifer zones. Aquifer test data from the City of Goldendale’s municipal water supply wells within Swale Valley (Basse Well No. 1 and Well No. 2; Figure 2) provided evidence to support this. No drawdown was observed in a nearby alluvium aquifer well (Basse farm well) during 72-hour pumping tests of the Basse wells (Aspect Consulting, 2002).

Regionally across much of the Columbia River Basin, the Wanapum and Grande Ronde basalt units are considered as separate hydrostratigraphic units. However, in at least one area of Swale Valley, there is evidence of hydraulic continuity between the Wanapum and Grande Ronde basalts. Similar static water levels were observed in both the

Wanapum and Grande Ronde basalts during the drilling of Basse Well No. 1 for the City of Goldendale (Aspect Consulting, 2002). This can be attributed to numerous lineaments observed in the vicinity of Basse Well No. 1. The lineaments are inferred to consist of nearly vertical fractures that do not show any indication of movement and are not lined with clayey fault gouge, therefore providing a potential conduit for vertical hydraulic continuity between the Wanapum and Grande Ronde basalts. The lineaments appear to parallel the axis of the Swale Creek syncline and could be related to regional cooling and shrinking of the individual basalt flows or from later tectonic activities (AESI, 2001).

In contrast, there are differences in the static water levels between the various flows of the Wanapum and Grande Ronde basalts in the neighboring Little Klickitat River subbasin, indicating limited hydraulic continuity between them. This information includes:

- Based on hydrographs of a well near Blockhouse Creek (T04/R15E-16F) with 4 piezometers set at 4 different stratigraphic intervals (40 to 210 feet; 215 to 330 feet; 325 to 440 feet; and 500 to 580 feet), there appears to be a distinct difference in static water levels (approximately 200 feet) below a depth of 500 feet (Brown, 1979). This represents a difference in heads between the Simcoe Mountain Volcanics and upper portions of the Wanapum basalt aquifers (Priest Rapids and Roza members) relative to the lower Wanapum basalt aquifer (Frenchman Springs member). Based on this, the Wanapum is inferred to not be in continuity with the underlying Grande Ronde.

- GeoEngineers (1995) also observed that, in the Goldendale area, wells completed in the Roza and upper Frenchman Springs members (depths of less than 500 feet) had static water levels less than 30 feet below the ground surface, while wells completed in the lower Frenchman Springs, and possibly the Grande Ronde aquifers (depths of greater than 500 feet), had static water levels more than 200 feet below ground surface.

- Temperature and fluid resistivity profiles conducted in the City of Goldendale’s Third Street well, while it was open to both the Wanapum and Grande Ronde basalts, indicates that water entering the well from the Wanapum basalt would flow down the well and recharge the Grande Ronde basalt during both pumping and non-pumping conditions (AESI, 1999). The downward gradient is indicative of the Grande Ronde basalt having a lower head than the Wanapum and not being in good hydraulic continuity with the Wanapum basalt.

In summary, while information from the neighboring Little Klickitat River subbasin, and many areas throughout the Columbia River Basin, indicates that the Wanapum and Grande Ronde basalts are hydraulically distinct aquifer systems, the only reliable information specific to Swale Valley (Basse wellfield drilling) indicates that the Wanapum and Grande Ronde basalts are in reasonable hydraulic continuity beneath Swale Valley.

Geologic Structures

As previously discussed here and in the 2007 Water Availability Report, groundwater within the Wanapum and Grande Ronde basalt aquifer beneath Swale Valley is hydraulically bound to the west by the Warwick fault, to the south by the Columbia Hills anticline/fault system, and at least partially to the north by the Horseshoe Bend anticline. Figure 2 illustrates the geologic structures mapped in the Swale Creek subbasin (DNR 1:100,000 geologic mapping). Additional groundwater and surface water data collected since the 2007 Water Availability Report continues to support this.

As outlined in the 2007 Water Availability Report, the primary evidence that the Warwick fault is an effective barrier to groundwater flow in the basalts includes the hundreds of feet of groundwater mounding upgradient of the Warwick Fault (see Figure 3), the lack of groundwater discharge (springs) observed within Swale Canyon upstream of the fault even though the canyon fully incises the Wanapum sequence, and the fact that significant groundwater discharge occurs into the eastern wall of Swale Canyon where the fault intersects it (approximately at river mile 4). In contrast to the basalt aquifer, the available information indicates that the Warwick fault partially restricts, but does not prevent, groundwater flow in the alluvium aquifer, as described in more detail below.

In the central and eastern portions of Swale Valley, two major parallel geologic structures include the Snipes Butte fault and the Goldendale fault/anticline system (Figure 2). These faults are folded (anticline) strike-slip faults (lateral, not vertical, offset) like the Warwick fault[1]. Because the Warwick fault is a confirmed hydraulic barrier in the basalt aquifers, one can infer that the Snipes Butte and Goldendale faults would also represent hydraulic barriers to groundwater flow in the basalts, but the available evidence does not indicate that, as outlined below.

The Goldendale fault is the farthest east mapped major fault in the Swale Creek subbasin. An aquifer test performed at the City of Goldendale's nearby Dingmon well (T04/R16-28), within 1 mile north of the Swale Creek subbasin boundary, indicated the presence of a low permeability boundary to the Wanapum basalt aquifer that is interpreted to be the Goldendale fault (Aspect Consulting, 2008a). Therefore, it is believed that the Goldendale fault provides a barrier to groundwater flow in the vicinity of the Dingmon well. However, PEI's (1988) aquifer test of the City of Goldendale's Third Street well (T04/R16-16), about 2 miles north of Swale Creek subbasin boundary, did not document any type of low permeability boundary indicative of the Goldendale fault. Several independent groundwater elevation contour maps, including AESI (2000), Aspect Consulting (2007a), Aspect Consulting (2008a), and Figure 3 in this report do not show an obvious discontinuity in groundwater elevations across the Goldendale fault. Aspect Consulting (2008a) hypothesized that there may be lineaments associated with the Little Klickitat syncline in the vicinity of the Third Street well, like those observed in the vicinity of the Swale Creek syncline. The two synclines were created in the same rocks in response to the same tectonic forces, so the same type of brittle fracture at the two fold axes is a reasonable assumption. If present, these lineaments may provide a permeable conduit for groundwater flow across the otherwise low-permeability Goldendale fault,

[1] The Warwick, Snipes Butte, and Goldendale faults, and Laurel fault west of Swale Canyon, were all formed in response to the same tectonic forces.

thus preventing significant impoundment of water behind the fault and the lack of an observed low permeability aquifer boundary during pumping tests. However, there is currently only limited groundwater level data available to support this hypothesis and no conclusive evidence identifying lineaments crossing the Goldendale fault.

Brown (1979) hypothesized that an artesian well located at the base of Snipes Butte in the Little Klickitat subbasin may reflect the impoundment of groundwater behind the fault, suggesting the Snipes Butte fault represents a hydraulic barrier. However, several independent groundwater elevation contour maps for the basalt aquifers in the area, including Luzier (1969), Brown (1979), Aspect Consulting (2007a), and Figure 3 in this report, do not indicate any abrupt groundwater elevation changes associated with Snipes Butte fault to suggest it is a significant hydraulic barrier. The lineaments along the axis of Swale syncline near the Basse wellfield appear to extend across the Snipes Butte fault (AESI, 2001). This information, with the lack of water level changes across the fault, suggests that lineaments may provide a permeable conduit across the fault, preventing it from creating a significant hydraulic barrier in the basalt aquifers within Swale Valley.

Groundwater Conditions

As previously discussed, an additional six rounds of groundwater level measurements have been collected in Swale Creek subbasin since issuance of the 2007 Water Availability Report. Table 1 provides a summary of the groundwater level measurements collected from the Little Klickitat/Swale Creek subbasin water level monitoring networks. Figure 3 shows the network of monitoring wells and the most recent (May 2010) water level measurements with associated groundwater elevation contours.

Alluvium Aquifer

With the addition of the new shallow alluvium monitoring well (SWC-MW-1), there are now eight wells within the Swale Creek subbasin water level monitoring network which are completed within the alluvium aquifer (Figure 2). Based on the available groundwater elevation measurements, the general groundwater flow direction in the alluvium aquifer is down-basin, from east to west (Figure 3).

Based on the May 2010 groundwater level measurements, there still appears to be an upward vertical gradient between the alluvium aquifer and the underlying Wanapum basalt aquifer in the center of Swale Valley Basin (well pair located in Sections 10 and 14 of T03/R15E) – consistent with data presented in the 2007 Report. The head difference remains relatively small (approximately 2 feet) at that well pair. Further to the east, there is a greater head difference (approximately 12 feet), that indicates a downward vertical gradient between the alluvium aquifer and the underlying Wanapum basalt aquifer (well pair located in Section 32 of T04/R16E and Section 4 of T03/R16E). Because the individual wells of the well pairs are located approximately ¾ of a mile apart and the wells are completed as open hole, these are only general estimates of the vertical gradient.

The available data suggest that the Warwick fault restricts but does not create a barrier to groundwater flow in the alluvium aquifer. Geologic mapping and cross sections indicate the alluvium aquifer is present on both sides of the fault (e.g. cross section D-D’ in the

2007 Water Availability Report). Visual observations show that the Swale Valley just east of the Warwick fault is broad and marshy throughout the year, whereas less marshy conditions exist west of the fault, suggesting some impoundment of water east of the fault. Data from the alluvium well located closest to the upgradient side of the fault (monitoring well SC-MW01; Figure 2) confirms that the water table in the alluvium aquifer is locally near ground surface. Upstream areas of Swale Creek are typically drier than near Warwick, suggesting the alluvium aquifer water table surfaces near the fault, since there is not surface runoff to sustain the wetter conditions throughout the dry season. The marshy conditions near Warwick may result from the topographic constriction caused by the outcropping fault – significantly narrowing the width of alluvium aquifer as it crosses the fault – rather than a complete subsurface barrier in the alluvium aquifer itself. Figure 4 is an aerial photo of Swale Creek in the Warwick area, overlain with topographic contours that illustrate the constriction, and the mapped surficial geologic units and Warwick fault trace (the geologic units are displayed in very light color so as to not obscure the underlying photo). The figure illustrates the alluvium (light yellow) narrowing in width, but extending through the "notch" in the topographic ridge created by the anticlinal fold of Wanapum basalt at the Warwick fault (basalt in very light reddish-brown).

Based on the collective information, we conclude that the Warwick fault is not a barrier to groundwater flow in the alluvium aquifer, and Swale Creek is in direct hydraulic continuity with the alluvium aquifer across the aquifer's entire length.

Basalt Aquifer

Figure 3 provides the groundwater elevation contour map for the Wanapum basalt aquifer based on the most recent groundwater level measurements (May 2010). As done for the 2007 Water Availability Report, water levels from available well logs[2] were used to supplement the most recent groundwater level measurements. Although the well log water levels have been collected over decades of time and various seasons (irrigation and non-irrigation) they help provide an aggregate interpretation of the Wanapum basalt aquifer groundwater data on the subbasin scale, with the water level monitoring network groundwater level measurements being more heavily weighted in the creation of the groundwater elevation contours due to their greater accuracy.

The May 2010 groundwater elevation contour map and resultant regional groundwater flow directions are generally consistent with the June 2007 groundwater elevation contour map and flow directions (Aspect Consulting, 2007a). Within the eastern portion of Swale Valley, groundwater in the basalt aquifer system flows generally from east to west, with flow into the Little Klickitat subbasin generally east of approximately the Snipe Butte fault. Conversely, in the western portion of Swale Valley, groundwater in the basalt aquifer flows to the north from the Columbia Hills anticline/fault system forming the Valley's south boundary, and to the south from the Horseshoe Bend anticline forming the Valley's north boundary (Figure 3).

[2] Depths to water are from the time of well completion, as reported on the well log, used in conjunction with ground surface (wellhead) elevations from the USGS' digital elevation model (DEM) to calculate groundwater elevation, as described in Aspect Consulting (2007a).

The Warwick fault forms a structural closure to the basalt aquifer system along the western end of Swale Valley, as originally concluded by Newcomb (1969) and confirmed by the measured groundwater mounding upgradient of it (Figure 3). This is also confirmed empirically by the lack of spring discharge observed within Swale Canyon south of Warwick fault, during both wet and dry seasons (Aspect Consulting, 2003a; 2003b). Swale Canyon fully incises through the Wanapum Basalt sequence (Grande Ronde outcrops on the canyon floor) so, if significant discharge from the Wanapum were occurring, it should be visible in the canyon.

Consequently, the collective data indicate that basalt aquifer groundwater is discharged from the Swale Valley in one of two ways: flowing to the northwest into the Little Klickitat subbasin, or being withdrawn by wells and used consumptively. As groundwater in the basalt aquifer flows from the eastern end of Swale Valley (upgradient of Snipes Butte fault), the majority discharges into the Little Klickitat subbasin, from the area east of the Horseshoe Bend groundwater divide. A smaller percentage of the flow continues into the western portion of Swale Valley to replenish the quantity of groundwater withdrawn by wells there.

The primary difference between the June 2007 and May 2010 groundwater elevation contour maps are the significantly lower groundwater elevations (between 35 and 45 feet) observed in Goldendale's Basse Wells No. 1 and No. 2 (T03/R15-13B1 and T03/R15-12H1). However, these wells are used for municipal water supply and the 2010 water levels are reflective of recent pumping. There were also slightly higher groundwater elevations in the eastern portion of the subbasin (T04/R17E-29D1 and T04/R17E -32P1). A more detailed discussion of long-term changes in groundwater levels follows.

Long-Term Water Level Trends

Evaluation of long-term trends in groundwater levels provides insight regarding aquifer response to precipitation patterns and sustainability of the existing level of groundwater withdrawal in Swale Valley. One of the wells included in the Swale Creek subbasin water level monitoring network (T03/R14-25C1) was initially monitored by the United States Geological Society (USGS) from 1983 to 2001, before being monitored as part of the City of Goldendale's water level monitoring network starting in 2001. Several other wells included in the Swale Creek subbasin water level monitoring network were also monitored by the City of Goldendale starting in 2001, including T03/R14-29A1, T03/R15-12H1, T03/R15-13B1, T03/R15-20H1, T03/R16-7X1, T03/R16-17N1, T03/R16-18NW1, and T04/R16-34H1.

Swale Creek (Surface Water) in Swale Valley

Less than 2 years of continuous stream discharge monitoring is currently available for Swale Creek within the Valley, but the available data provide the first reliable information regarding its response to precipitation and the amount of baseflow provided by alluvium aquifer discharge.

Daily average discharge hydrographs for the three Swale Creek gaging stations are presented in Figure 5. The hydrograph at each station is typically very flashy, with large peak flows in response to precipitation events during the winter and spring, and extended periods of very little or zero flow in the summer and fall. Swale Creek in both Swale Valley and Swale Canyon is typically reduced to a series of disconnected pools of water from about June through October (Aspect Consulting 2003a, 2003b; Aspect Consulting and WPN, 2009; see also the steam flow hydrographs on Figure 5 of this report, demonstrating lack of flow seasonally at all stations).

Alluvium Aquifer

Approximately 2 years of continuous monitoring data is available for two wells in the alluvium aquifer, but one of those wells (Miller well; T03/R15E-20H1) has been monitored for two additional years prior to start of continuous monitoring. One alluvium well (T03/R14-25C1) has been monitored periodically for 26 years (1983-2009), although it has occasionally been obstructed.

Based on the continuous monitoring data, water levels in the alluvium aquifer appear to respond with very little lag time to precipitation events, which is typical of shallow unconfined aquifers. Daily average groundwater hydrographs from monitoring well SWC-MW-1 (February 2009 through April 2010) and the Miller well (November 2008 through April 2010) are presented on Figure 6. During the summer and fall of 2009, when very little precipitation occurred in Swale Valley, both wells observed a water level decline on the order of approximately 3.5 feet before they stabilized with the onset of early fall precipitation and then rebounded with abundant winter rains.

Based on the alluvium well groundwater hydrographs presented on Figure 7 (dashed hydrographs), the Miller well (T03/R15E-20H1) has not shown any declines in groundwater levels over the period June 2007 through May 2010. This is consistent with a majority of alluvium aquifer wells monitored since 2007. The only exception is alluvium well T03/R15-14D1, which shows a nearly 5-foot decrease in groundwater levels over the 3-year period. Conversely, alluvium well T04/R17-32P1 showed an approximately 10-foot increase over the same time period. Due to the limited period of groundwater level measurements and the relatively small changes in groundwater levels, it is currently not possible to provide a definitive explanation for the changes at these wells.

Most notably, the alluvium well with a 26-year monitoring record (T03/R14-25C1) shows a very stable long-term water level trend (Figure 7).

Basalt Aquifer

Figure 7 also provides long-term groundwater hydrographs for wells completed in the Wanapum basalt aquifer, based on measurements collected twice per year. As with many of the alluvium aquifer wells discussed above, a majority of the wells completed in the basalt aquifer show seasonal variations in groundwater levels ranging between 5 and 15 feet. For these wells the lowest groundwater levels were consistently observed during the post-irrigation measurements (November) and the highest groundwater levels were consistently observed during pre-irrigation measurements (April - June). The seasonal high groundwater levels follow the wet season, when the greatest amount of recharge to the aquifer occurs. Meanwhile, the seasonal low groundwater levels follow the dry/irrigation season, when there is little recharge to the aquifer and increased withdrawals. One exception to this is well T04/R17-30A1, which had a higher groundwater level during the November 2007 measurement. However, it is important to note that not all of the basalt aquifer wells show seasonal variations in groundwater levels.

As with the alluvium aquifer, a majority of the wells completed in the basalt aquifer do not show a consistent trend in groundwater levels over the time period of measurement. The exceptions are wells T03/R14-14Q1, T03/R14-29A1, T03/R16-7X1, T04/R17-30A1, and T03/R16-18NW1. Generally, groundwater levels in these wells have declined between 10 and 20 feet over the period of monitoring. However, the locations of these wells are scattered across Swale Creek subbasin and the decreases in the groundwater levels do not appear to be related to a subbasin-wide trend.

The decline in groundwater levels at the above wells may be partially attributed to the below-average precipitation observed in the area since the late 1990s, and, longer term, since 1984. Figure 8 presents both the annual precipitation and the mean annual precipitation (upper portion of figure) and the cumulative departure from the mean annual precipitation (lower portion of figure) in Goldendale (NOAA Station #453222) and at Satus Pass for the period of record (1931 - 2009)[3]. Note that individual months with more than 5 days of missing data were not used for monthly or annual precipitation statistics, so those years are not displayed on Figure 8. With the exception of 1995-1998 (based on Goldendale data[4]) and 2006 (based on Satus Pass data), annual precipitation has been at or below the mean annual precipitation since 1984.

One of the basalt wells discussed above which has had a significant decline in groundwater levels is well T03/R14-29A1. This well is located to the west of Warwick fault (just outside Swale Valley), where the primary source of recharge is likely from the Columbia Hills (Figure 3). Due to the limited recharge area, this well is likely to be relatively sensitive to recent precipitation trends. Therefore, we infer that below-average precipitation explains at least a portion of the almost 15-foot decline in groundwater levels observed since 2001. Further evidence for this area's dependence on precipitation trends is the almost 5-foot increase in groundwater levels observed at the well during the Spring of 2007, following an above-average precipitation year in 2006. Although the remaining wells with longer-term decreasing groundwater level trends do not have nearly as obvious of a correlation to precipitation, they may be more sensitive to precipitation trends relative to other wells in Swale Valley.

Interaction of Swale Valley Groundwater and Adjacent Surface Waters

As previously discussed in the 2007 Water Availability Report, the Columbia Hills anticline/fault system provides an effective barrier to groundwater flow across the

[3] The cumulative departure plot is an effective way to illustrate longer-term trends in precipitation which influence groundwater levels regionally (e.g. extended wet or drought periods). The absolute values on the plot's y axis have little meaning since they depend on the year started. However, the scale of the y axis and shape of the curve are not dependent on year started.
[4] The 1995 and 1998 data points for Goldendale are not plotted on Figure 8 because of gaps in the daily record; however, even with the missing data, the annual precipitation is at or above average.

southern boundary of Swale Valley. Therefore, groundwater in both the alluvium and basalt aquifers in Swale Valley is not in hydraulic continuity with the Columbia River.

In the western portion of Swale Valley, both the Warwick fault (west) and the Horseshoe Bend anticline (north) are effective barriers to groundwater flow in the basalt aquifers and prevent significant hydraulic continuity with the Little Klickitat River.

In the eastern portion of Swale Valley (vicinity of Snipes Butte fault and further east), groundwater in the basalt aquifer system flows into the Little Klickitat subbasin. Information collected since the 2007 Report indicates that, within the Little Klickitat subbasin, there is little hydraulic continuity between the Wanapum basalt and the Little Klickitat River, except in the river's lower reaches, below approximately the Mill Creek tributary (Aspect Consulting, 2007b; 2008b). The Little Klickitat River incises completely through the Wanapum Basalt sequence and, in its lowermost 2/3 mile, into the uppermost part of the Grande Ronde. While there is hydraulic continuity between the Wanapum basalt and the lowermost reaches of the Little Klickitat River, near its confluence with the mainstem Klickitat River, it is inferred that the majority of Wanapum basalt groundwater in the Little Klickitat subbasin discharges to the mainstem Klickitat River or elsewhere outside the Little Klickitat subbasin (described in more detail below).

The alluvium aquifer is in direct hydraulic continuity with surface water in Swale Creek. Water levels in Swale Creek at Harms Road (stream gage SWC-02) and in the two alluvium aquifer wells near the creek (Miller well and SWC-MW-1) respond very quickly to precipitation. Figure 9 displays water levels from the two alluvium aquifer wells and Swale Creek as daily deviations from the period-of-record average for each monitoring point. This approach maintains the magnitude of water level change at each monitoring location, and places each location's data in the same scale despite their elevation differences. Based on these data, the water level response in the Miller well most resembles Swale Creek, which is likely due to its proximity to the creek (approximately 225 feet, compared to approximately 900 feet from SWC-MW-1 to the creek).

The water table at the Miller well drops further in the peak dry season, and then recharges faster in response to precipitation, than does well SWC-MW-1 located closer to Warwick fault. While the difference is somewhat subtle, SWC-MW-1's more muted response may reflect the impoundment (slower draining) of groundwater due to constriction of the alluvium aquifer at the Warwick fault, as described above. West of the fault, the surface water level in Swale Creek at SWC-02 drops at a rate similar to that at the Miller well, and takes longer to rise in response to precipitation. Once it begins rising, however, it increases at a faster rate than either of the alluvium wells.

Note that stream gage SWC-02 is installed within a bedrock pool which provides a stable channel configuration for making stream discharge measurements; this was considered the best site for gaging stream discharge leaving Swale Valley (Aspect Consulting, 2009b). Water appears to be present perennially in the pool, likely reflecting the water table in the surrounding alluvium aquifer; however, due to the bedrock configuration, there is not always flow into or out of the pool. When stream elevations are lower than approximately the average level as shown on Figure 9 (0 difference, occurring between about June and November 2009), there is no flow out of the pool.

Although the alluvium aquifer is in hydraulic continuity with Swale Creek, it likely does not contribute significant baseflow to the creek throughout the year. There is not enough baseflow contribution from the aquifer in Swale Valley to maintain continuous stream flow downstream of the Valley to the mouth of the Swale Canyon during the summer and fall. This was observed during a field reconnaissance of Swale Creek in September 2003 when the entire length of the creek was either dry or was reduced to discontinuous pools (Aspect Consulting, 2003b). The lack of dry season discharge measured at SWC-02, just downstream of Swale Valley, is also illustrated on Figure 5.

Water Balance for Swale Valley

The 2007 Water Availability Report provides a subbasin-scale water balance for the Swale Creek subbasin. Because groundwater is the sole reliable water source for the Swale Valley area, the primary utility of a water balance in the context of water availability is providing perspective on the annual quantity of groundwater withdrawal from the aquifer system as a proportion of the annual quantity of recharge to the aquifer system.

For this assessment, we prepared a water balance for the Swale Valley portion of the subbasin, using the same methodology applied in the 2007 assessment, but reducing the area of interest to just Swale Valley and confirming/updating the 2007 assumptions made for current conditions (e.g., irrigation water use based on irrigated acreage). In addition, it is assumed that all of the groundwater withdrawal occurring within the full subbasin occurs within the Swale Valley. Appendix A details the water balance methods and assumptions.

The conclusion of the Swale Valley water balance is that the current annual quantity of net groundwater withdrawal is approximately 33% of the current annual groundwater recharge. This estimate is a higher proportion than estimated for the entire Swale Creek subbasin, since the Swale Valley is assumed to encompass 100% of the groundwater withdrawal in the subbasin, but only constitutes about 2/3 of the full subbasin area (for recharge to occur within).

Assessment of Sources of Water within Swale Valley

Under Washington State water law, administration of water rights requires determination of “sources of water”. Within each defined source of water, water rights are appropriated in order of priority (“first in time, first in right”). In February 2007, Ecology issued Water Resources Program Policy POL-2010 (Policy 2010) which describes how Ecology should define and delineate water sources for water right permitting and related decisions. Policy 2010 defines a source of water as:

"Surface waters and/or groundwater in hydraulic connection, meeting the following four conditions:

1. They share a common recharge area.
2. They are part of a common flow regime.
3. They are separable from other water sources by effective barriers to hydraulic flow.
4. They are an independent water body for the purpose of water right administration, as determined by Ecology."

Because surface water is not a reliable water supply source within the Swale Valley, the need to determine sources of water within Swale Valley is primarily relevant to permitting new groundwater rights or transferring existing groundwater rights. This section provides our professional opinion regarding delineation of bodies of groundwater within Swale Valley, based on the available information.

The alluvium aquifer, including the uppermost interflow zone of the Wanapum basalt, comprises a distinct body of groundwater. It is in direct hydraulic continuity with Swale Creek across the entire extent of the aquifer, which includes portions of Swale Valley and the area just west of it. The alluvium aquifer system is separable from the deeper basalt aquifer by effective barriers to groundwater flow created by the layered basalt flow interiors; this is demonstrated by pumping test data (Aspect Consulting, 2002).

The deeper basalt aquifer within Swale Valley, comprising the Grande Ronde basalt and the Wanapum basalt excluding its uppermost interflow zone, represents a different body of groundwater from the alluvium aquifer; however, the deeper basalt body of groundwater is not limited to the boundary of Swale Valley. We combine the Wanapum and Grande Ronde basalts into a single body of groundwater beneath Swale Valley, based on information collected during drilling of the City of Goldendale's Basse wellfield (described above). Within the boundaries of Swale Valley, the deeper basalt aquifer is bound on the south by the Columbia Hills geologic structures; on the west side by the Warwick fault. The collective information indicates that, because of the geologic structures, the deeper basalt aquifer within Swale Valley it is not in hydraulic continuity with Swale Creek or the Columbia River. The groundwater divide formed along the Horseshoe Bend anticline, forming the north edge of Swale Valley, separates the aquifer from the lower reaches of Swale Creek[5] (groundwater divides and hydraulic barriers separate bodies of groundwater in accordance with Ecology's Policy 2010). The Horseshoe Bend anticline also limits, but does not prevent, hydraulic continuity of the deeper basalt aquifer in Swale Valley with the Little Klickitat River.

East of the Horseshoe Bend groundwater divide, groundwater in the deeper basalt aquifer flows to the northwest from the Swale Valley into the Little Klickitat subbasin. Consequently, the defined deeper basalt body of groundwater is not confined to Swale

[5] Groundwater from the deeper basalt aquifer discharges to the lower 3 miles of Swale Canyon – from the Warwick fault intersection downstream (north). However, this portion of the aquifer in the Swale Creek subbasin is outside of Swale Valley as defined.

Valley. A small portion of the groundwater in the deeper basalt aquifer discharges to the lowermost reaches of the Little Klickitat River. The quantity of Wanapum + Grande Ronde basalts aquifer discharge to the Little Klickitat River below Mill Creek was measured at 2.4 cfs over 5.8 miles, or 0.4 cfs/mile average, in the dry season of late September 2008 (Aspect Consulting, 2008b). This is a small fraction of the recharge entering the basalt aquifer system.

Comparing the large quantities of groundwater entering the Wanapum/Grande Ronde aquifers in Little Klickitat subbasin versus the measured few cfs of groundwater discharging to the Little Klickitat River indicates that the majority of basalt groundwater in the Little Klickitat subbasin does not discharge via the Little Klickitat River; rather, it discharges the subbasin via deeper zones of the Grande Ronde basalt beneath the Little Klickitat River. We infer that the majority of groundwater discharges to the mainstem Klickitat River downstream of the Little Klickitat River, but this has not been evaluated in detail to date.

In theory, a new groundwater withdrawal from the deeper basalt aquifer within Swale Valley would reduce discharge (baseflow) to the lowermost reaches of the Little Klickitat River. In practice, we expect that the baseflow reduction would be negligible. Estimating the quantity of baseflow depletion in the Little Klickitat River from a new groundwater withdrawal in Swale Valley would be complicated given the following factors:

- Only a fraction of the groundwater in the Wanapum and Grande Ronde basalts within the Little Klickitat subbasin originates as outflow from Swale Valley; and
- Only a fraction of the groundwater in the Wanapum and Grande Ronde basalts within the Little Klickitat subbasin discharges to the Little Klickitat River (the majority discharges to the mainstem Klickitat River or elsewhere outside the subbasin).

Estimating the proportion of Swale Valley deeper basalt groundwater outflow that ultimately becomes Little Klickitat River baseflow might be done using a simplistic water balance approach, including estimating each of the fractions outlined above. Note that the WRIA 30 PAC submitted a preliminary grant application to Ecology (2009-2011 biennium) for funding of a Little Klickitat subbasin hydrologic assessment. A key piece of the assessment was to analyze groundwater-surface water continuity in detail; however, the assessment was not funded at that time.

Conclusions and Recommendations

Based on additional data collection and updated analysis relative to the 2007 Water Availability Report, we provide the following conclusions and recommendations specific to the Swale Valley:

- Regional geologic structures bound the Swale Valley on the south (Columbia Hills), west (Warwick fault), and part of the north (Horseshoe Bend anticline). The geologic structures create effective hydraulic barriers to lateral groundwater flow in the deeper basalt aquifer system (below the shallow alluvium aquifer).

- Because the geologic structures form effective hydraulic barriers, groundwater in the deep basalt aquifer within Swale Valley is not in hydraulic continuity with the Columbia River to the south or Swale Creek to the west. There is groundwater discharge to Swale Canyon, downstream of where the Warwick fault crosses it, from a portion of the Swale Creek subbasin north of the Horseshoe Bend anticline, but this area is outside the Swale Valley.
- Within the eastern portion of Swale Valley, east of the groundwater divide formed along the Horseshoe Bend anticline, groundwater in the deeper basalt aquifer flows into the Little Klickitat subbasin.
- A fraction of the deep basalt aquifer groundwater flowing out of Swale Valley ultimately discharges to the lower reaches of the Little Klickitat River; quantifying the contribution would require additional hydrologic analysis of the Little Klickitat subbasin.
- The total annual groundwater withdrawal (actual use) from Swale Valley is estimated at approximately 33% of annual groundwater recharge. Based on this estimate, and generally stable groundwater level trends over time within the Valley as a whole, we conclude that additional groundwater could be available for appropriation within the Valley. Potential for impairment to senior water users and the temperature-impaired segments of the Little Klickitat River would still need to be determined individually for each pending water right application.
- The alluvium aquifer is a distinct body of groundwater (separate from deep basalt aquifer), and is in direct hydraulic continuity with Swale Creek throughout the Swale Valley. The Warwick fault is not a hydraulic barrier to the alluvium aquifer.
- We recommend continuing water level monitoring in the established well network to continue tracking long-term trends in groundwater levels. These data will continue to inform future decisions regarding sustainability of groundwater pumping and overall water availability on the subbasin scale.

Limitations

Work for this project was performed and this memorandum prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. It is intended for the exclusive use of Klickitat County for specific application to the referenced property. This memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

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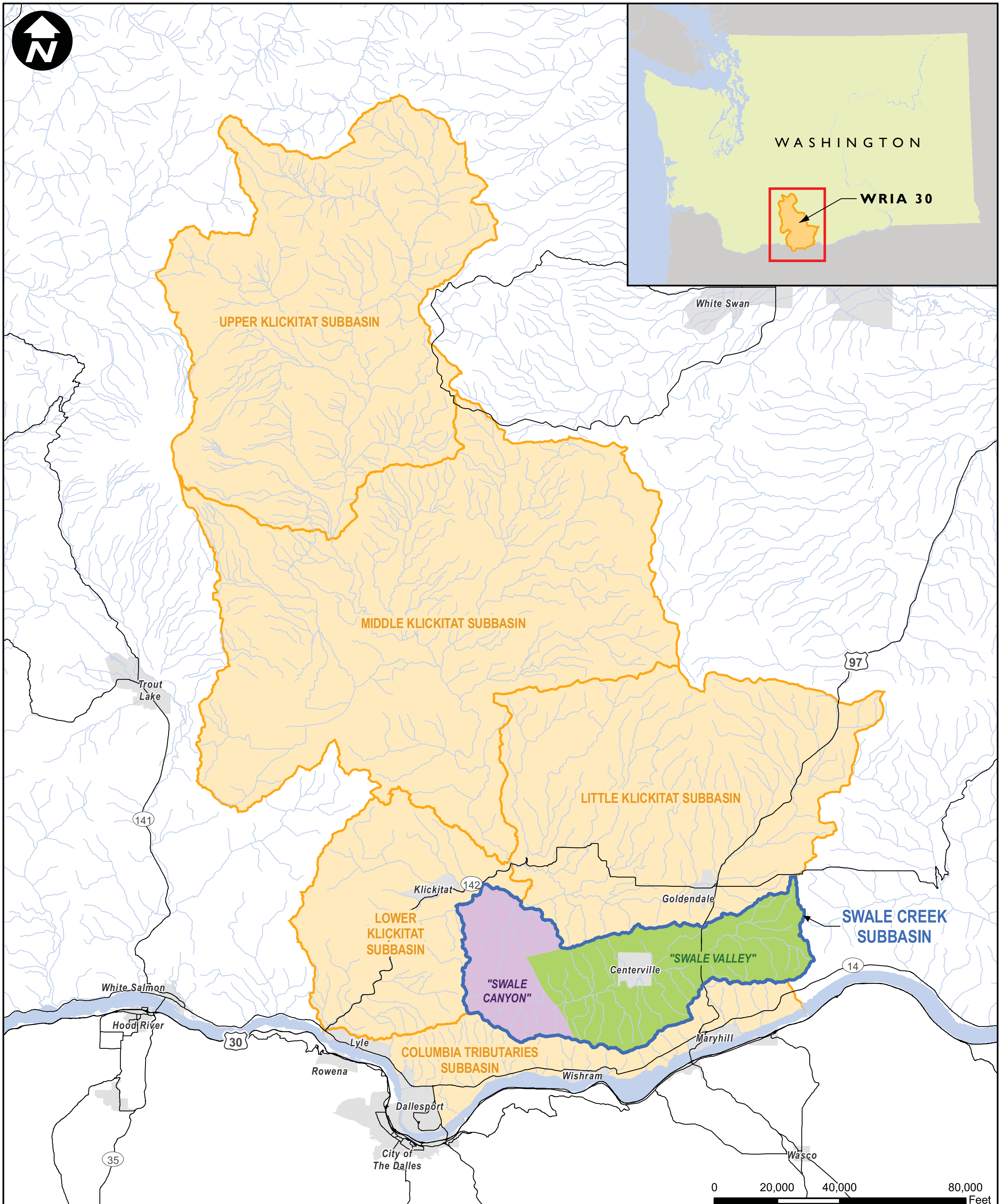
Table 1 - Water Level Monitoring Network Data
WRIA 30 Water Availability Study Addendum

Contact Information			Ecology Well Log Data						Well Survey Data				June 2007 Measurements		
Well Owner	Well Address/Name	Study Area	Ecology Well Log ID	TRS Label	Completion Date	Dia (in)	Depth (ft)	Aquifer	Northing[1] (SPS 83; ft)	Easting[1] (SPS 83; ft)	Wellhead Elevation[2] (ft MSL)	Casing Stick-up (ft)	Depth to Water (ft bTOC)	GW Elevation[2] (ft)	Comments
Brown	392 Harms Road	Swale Creek	149031	T03/R14-11D1	11/14/98	6	440	Wanapum	158400.6	1504803.3	2053.2	0.87	206.9	1846.3	Rising water level
Mike & Diane Richards	1195 Niva Rd.	Swale Creek	142145	T03/R14-11N1	10/16/97	6	205	Wanapum	153730.0	1505374.3	2012.7	0.59	69.9	1942.8	
Gordon Swank	905 Randall Road	Swale Creek	136750	T03/R14-14Q1	10/18/79	6	200	Wanapum	149063.4	1509276.0	1719.7	0.54	7.3	1712.5	
Bob Edwards	10 Meadowlark Lane	Swale Creek	354742	T03/R14-18N1	5/20/97	6	695	Wanapum	149041.9	1484973.1	2153.7	1.43	516.7	1637.0	
Ron & Deborah Disch	986 Randall Road	Swale Creek	145052	T03/R14-23D1	4/17/98	6	103	Wanapum	147652.3	1505602.8	1697.5	0.47	34.6	1662.9	
William and Donna Lancaster	650 Harms Road	Swale Creek	257441	T03/R14-23E1	7/13/00	6	262	Wanapum	145770.2	1505131.1	1662.1	2.21	76.8	1585.3	
Dave Mattson[3]	Centerville Road (Warwick)	Swale Creek	-	T03/R14-25C1	-	-	80	Alluvium and Wanapum	141882.6	1512560.9	1580.8	-	-	-	No ecology well log; obstructed at 22.8 ft
Lonnie Magnusson[3]	Centerville Road (W. of Harms)	Swale Creek	257442	T03/R14-29A1	8/7/00	6	353	Wanapum	141946.6	1494168.8	1678.3	2.11	63.2	1615.2	Rising water level
Dale Bowdish	2215 Centerville Hwy	Swale Creek	138310	T03/R15-10P1	6/16/94	6	143	Wanapum	153172.6	1532826.4	1610.6	1.76	36.9	1573.7	
City of Goldendale[3]	Basse #2	Swale Creek	314650	T03/R15-12H1	11/14/01	16	679	Wanapum	155984.6	1546301.3	1621.4	1.5	61.0	1560.5	
City of Goldendale[3]	Basse #1	Swale Creek	314651	T03/R15-13B1	10/31/01	16	905	Wanapum	152313.6	1545722.6	1595.9	1.625	31.4	1564.5	
Ron Crawford	510 Dalles Mountain Rd.	Swale Creek	144994	T03/R15-14D1	8/7/79	6	82	Alluvium and Wanapum	152412.8	1536954.3	1605.5	-	33.7	1571.9	
Jim Miller[3]	Garner Road (N. of Bridge)	Swale Creek	140705	T03/R15-20H1	-	6	54	Alluvium	145871.4	1525996.3	1574.8	1.34	5.5	1569.3	
Kay Cameron	645 Cameron Rd	Swale Creek	137418	T03/R15-23H1	8/2/93	6	140	Alluvium and Wanapum	145638.2	1541689.0	1634.7	1.5	56.6	1578.1	
Dennis Jaekel	End of Jaekel Road	Swale Creek	138800	T03/R15-34M1	8/21/79	6	480	Wanapum	132776.8	1531588.3	1940.2	0.7	387.4	1552.8	
Marvin Norris	728 Hoctor Road	Swale Creek	411866	T03/R16-2A1	5/18/05	6	123	Wanapum	163199.1	1572954.6	1855.2	-	57.8	1797.4	
Roberta Hoctor	36 Hoctor Road	Swale Creek	139455	T03/R16-4F1	2/8/81	10	512	Wanapum	161914.2	1559334.0	1740.3	1.3	80.4	1659.9	
Puget Sound Energy[3]	Old Basse Well	Swale Creek	296331	T03/R16-7X1	4/24/69	12	302	Alluvium and Wanapum	-	-	-	-	-	-	-
John Starr[3]	1915 Centerville Hwy	Swale Creek	139604	T03/R16-17N1	9/27/79	8	320	Wanapum	-	-	-	-	-	-	-
Terry Linden[3]	Ty's Well	Swale Creek	137572	T03/R16-18NW1	6/15/72	16	983	Wanapum	-	-	-	-	-	-	-
Bruce Buchanan	440 Schilling Road	Swale Creek	302764	T04/R14-31L1	10/12/00	6	506	Wanapum	167675.2	1486274.0	1785.9	2.94	267.1	1518.7	
Erick & Mary Jean Risheim	280 Harms Road	Swale Creek	138094	T04/R14-35N1	7/28/94	6	300	Wanapum	164498.8	1505579.5	1914.5	1.83	135.2	1779.3	
Stan & Josie Casswell	356 Largent Rd.	Little Klickitat	191874	T04/R15-26H1	5/25/99	6	395	Wanapum	172446.7	1541300.9	1567.9	1.5	34.4	1533.6	Rising water level
Gary Burgess	Horseshoe Bend Rd.	Little Klickitat	302767	T04/R15-29Q1	12/11/00	6	240	Wanapum	169640.1	1524932.9	1720.3	1.5	138.9	1581.4	
Raymond Manning	Mustang Dr. & Morgan Ct.	Little Klickitat	417943	T04/R15-29M1	7/25/05	6	500	Wanapum	171181.3	1521711.9	1689.3	2.29	294.9	1394.4	
Regan Eberhart	Appaloosa Court	Little Klickitat	521074	T04/R15-32F1	2/3/07	6	416	Wanapum	167372.0	1522129.5	1801.8	3.27	177.9	1624.0	
Robert & Bonnie Butler	181 Van Hoy Road	Swale Creek	303003	T04/R16-31M1	8/26/00	6	103	Wanapum	163668.5	1548245.4	1662.2	1.17	22.3	1639.9	
JP Enderby	3517 S. Columbus Ave.	Swale Creek	136513	T04/R16-32J1	5/25/82	6	67	Alluvium and Wanapum	165643.7	1557437.9	1733.9	0.81	62.0	1671.9	
Karl Enyert[3]	Clyde Story Road (S. of Gravel Pit)	Swale Creek	296593	T04/R16-34H1	10/12/71	6	500	Wanapum	167237.9	1567894.2	1804.2	0.49	52.7	1751.5	
Wayne Hoctor	138 Willis Road	Swale Creek	146522	T04/R17-29D1	4/4/91	6	108	Wanapum	171742.5	1584907.1	1999.1	0.58	63.5	1935.6	
Wayne Hoctor	488 #4 Road	Swale Creek	146520	T04/R17-30A1	9/28/73	6	430	Wanapum	173572.1	1583929.0	1997.6	-	277.4	1720.2	Rising water level
Dennis Hoctor	250 Willis Rd.	Swale Creek	139632	T04/R17-32P1	4/29/70	8	228	Alluvium and Wanapum	165764.2	1585021.8	1914.5	-	59.4	1855.2	

	November 2007 Measurements			April 2008 Measurements			December 2008 Measurements			April 2009 Measurements			December 2009 Measurements			May 2010 Measurements		
Well Owner	Depth to Water (ft bTOC)	GW Elevation[2] (ft)	Comments	Depth to Water (ft bTOC)	GW Elevation[2] (ft)	Comments	Depth to Water (ft bTOC)	GW Elevation[2] (ft)	Comments	Depth to Water (ft bTOC)	GW Elevation[2] (ft)	Comments	Depth to Water (ft bTOC)	GW Elevation[2] (ft)	Comments	Depth to Water (ft bTOC)	GW Elevation[2] (ft)	Comments
Brown	200.3	1852.9		200.4	1852.8		-	-	No permission	-	-	No permission	-	-	No permission	-	-	No permission
Mike & Diane Richards	70.1	1942.6		69.8	1942.8	Rising water levels	71.0	1941.7	Recovering water level	68.4	1944.3		69.2	1943.5		68.6	1944.1	
Gordon Swank	-	-		6.6	1713.1		7.8	1711.9		12.3	1707.5		16.1	1703.6		14.8	1704.9	
Bob Edwards	518.3	1635.4		517.9	1635.7		519.5	1634.2		518.3	1635.3		-	-	No measurement	518.6	1635.1	
Ron & Deborah Disch	41.8	1655.7		28.6	1668.9		43.4	1654.1		31.8	1665.7		41.2	1656.3		29.8	1667.7	
William and Donna Lancaster	-	-	No permission	-	-	No permission	-	-	No permission	-	-	No permission	-	-	No permission	-	-	No permission
Dave Mattson[3]	>21.3	NA	No ecology well log; obstructed at 21.3 ft	22.3	1558.5	Obstructed at 22.8 ft	23.4	-	Obstructed at 23.36 ft	21.8	1559.0		-	-	Obstructed at 25 ft	-	-	Obstructed
Lonnie Magnusson[3]	55.7	1622.6		55.9	1622.5		59.7	1618.6		61.4	1616.9		62.7	1615.6		66.2	1612.1	
Dale Bowdish	37.4	1573.2		30.5	1580.1		36.3	1574.3		30.8	1579.8		40.7	1569.9		36.8	1573.8	
City of Goldendale[3]	67.0	1554.4		44.3	1577.1	Basse Wells were not recently pumped	65.9	1555.6	Fluctuating water level	55.5	1565.9		58.5	1562.9		106.0	1515.4	
City of Goldendale[3]	36.2	1559.7		19.6	1576.3	Basse Wells were not recently pumped	38.5	1557.4	Fluctuating water level	27.3	1568.6		31.0	1564.9		66.5	1529.4	
Ron Crawford	36.0	1569.5		29.4	1576.1		35.6	1569.9		30.2	1575.3		38.5	1567.0		33.2	1572.3	
Jim Miller[3]	6.2	1568.6		3.2	1571.5		5.8	1568.9		3.0	1571.8		5.3	1569.5		4.6	1570.2	
Kay Cameron	-	-	No permission	-	-	No permission	60.2	1574.5		56.8	1577.9		60.7	1574.0		57.8	1576.9	
Dennis Jaekel	398.2	1542.0	Pumping water level	396.0	1544.2		-	-	No permission	-	-	No permission	-	-	No permission	-	-	No permission
Marvin Norris	58.2	1797.0		59.5	1795.8		63.4	1791.9		60.4	1794.8		64.2	1791.0		59.8	1795.4	
Roberta Hoctor	82.5	1657.8		79.5	1660.8		81.6	1658.7		79.4	1660.9		81.5	1658.8		79.6	1660.7	
Puget Sound Energy[3]	22.2	-		15.2	-		21.4	-		17.3	-		23.0	-		26.6	-	
John Starr[3]	26.8	-		22.3	-		26.4	-		23.9	-		26.5	-		-	-	No permission
Terry Linden[3]	32.5	-		20.7	-		32.5	-		30.1	-		41.2	-		-	-	Irrigating with pump
Bruce Buchanan	265.4	1520.5		264.9	1521.0		265.2	1520.7		265.9	1520.0		264.8	1521.1		-	-	No permission
Erick & Mary Jean Risheim	135.4	1779.1		134.9	1779.6		134.3	1780.2		133.6	1780.9		133.6	1780.9		133.0	1781.5	
Stan & Josie Casswell	30.9	1537.0		22.5	1545.4	Rising water levels	28.8	1539.1		20.7	1547.2		26.8	1541.1		21.2	1546.7	
Gary Burgess	138.4	1581.9		138.4	1581.9		138.3	1581.9		137.0	1583.3		138.0	1582.3		137.6	1582.7	
Raymond Manning	294.2	1395.1		294.6	1394.7		294.1	1395.2		292.8	1396.5		292.6	1396.7		295.5	1393.8	
Regan Eberhart	177.4	1624.4		178.8	1623.1		-	-	No permission	-	-	No permission	-	-	No permission	-	-	No permission
Robert & Bonnie Butler	25.1	1637.1		21.4	1640.8		23.3	1638.9		21.5	1640.7		23.8	1638.4		-	-	No permission
JP Enderby	63.4	1670.5		60.0	1673.8		61.8	1672.1		59.6	1674.3		61.6	1672.3		60.1	1673.8	
Karl Enyert[3]	56.3	1748.0		52.3	1752.0		55.8	1748.4		52.2	1752.0		55.3	1748.9		-	-	No permission
Wayne Hoctor	65.4	1933.7		64.2	1934.9		65.0	1934.1		63.4	1935.7		64.0	1935.1		62.5	1936.6	
Wayne Hoctor	278.4	1719.2		287.6	1710.0	Rising water levels	293.8	1703.8		280.0	1717.6		297.5	1700.1		-	-	Sonic provides invalid measurement.
Dennis Hoctor	-	-	No permission	-	-	No permission	66.3	1848.2		52.0	1862.5		55.5	1859.0		49.9	1864.6	

[1] Northing and Easting coordinates are in Washington South State Plane coordinate system (NAD 1983 datum)
[2] All elevations are in NAVD 1988 datum
[3] Indicates wells included in the City of Goldendale's groundwater level monitoring program



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Swale Creek Subbasin

Addendum to Swale Creek Basin Water Availability Study
WRIA 30, Washington

DATE: June 2010	PROJECT NO. 070024
DESIGNED BY: SJG	
DRAWN BY: PPW	FIGURE NO. 1
REVISED BY: -	

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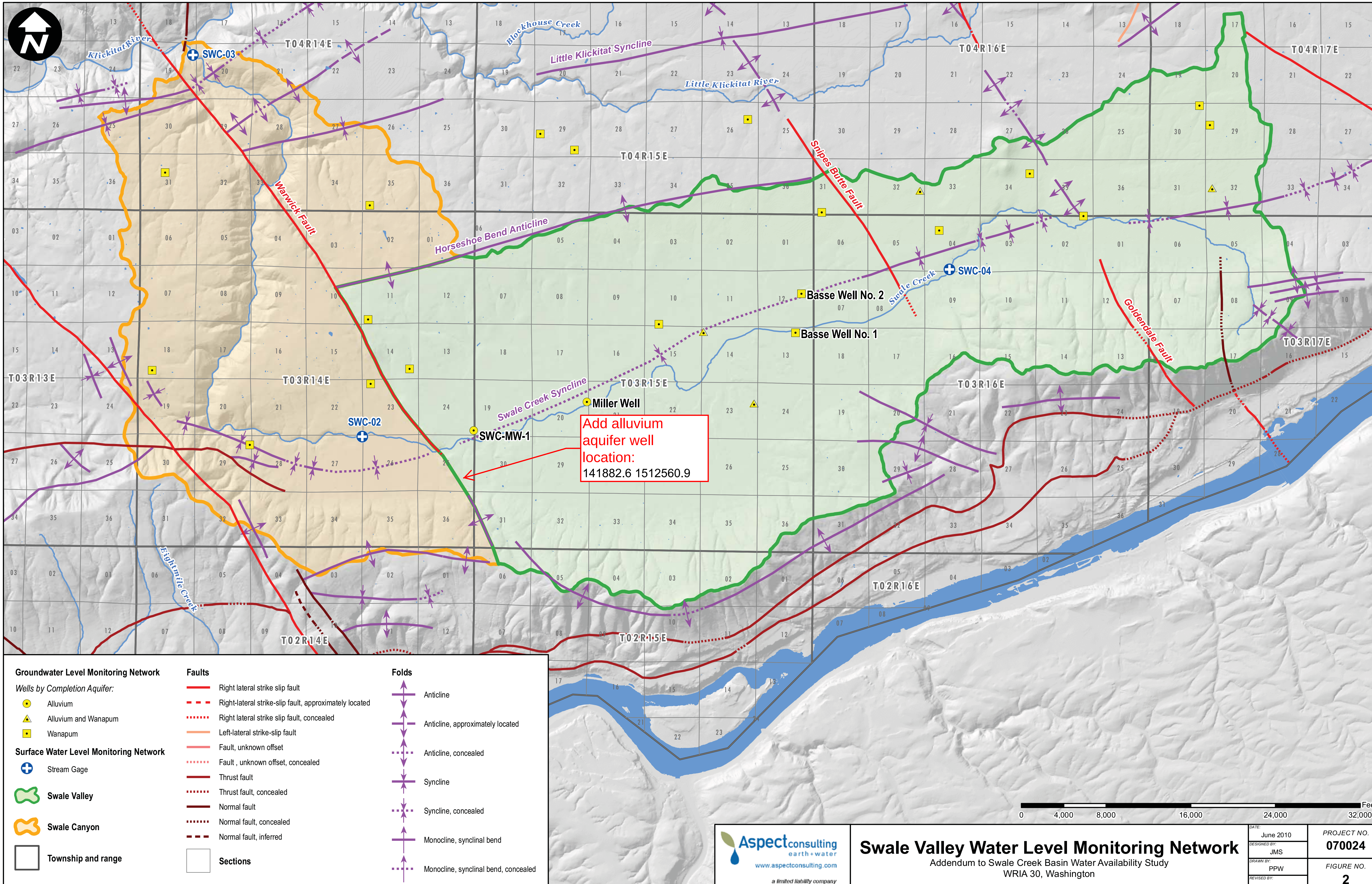
Klickitat River
Blockhouse Creek
Little Klickitat Syncline
Little Klickitat River
SWC-03
T04R14E
T04R15E
T04R16E
T04R17E
Warwick Fault
Snipes Butte Fault
Horseshoe Bend Anticline
Swale Creek
SWC-04
Basse Well No. 2
Basse Well No. 1
Goldendale Fault
T03R13E
T03R14E
T03R15E
T03R16E
T03R17E
Swale Creek Syncline
Miller Well
SWC-MW-1
SWC-02
Add alluvium aquifer well location:
141882.6 1512560.9
Eightmile Creek
T02R14E
T02R15E
T02R16E
Groundwater Level Monitoring Network
Wells by Completion Aquifer:
Alluvium
Alluvium and Wanapum
Wanapum
Surface Water Level Monitoring Network
Stream Gage
Swale Valley
Swale Canyon
Township and range
Faults
Right lateral strike slip fault
Right-lateral strike-slip fault, approximately located
Right lateral strike slip fault, concealed
Left-lateral strike-slip fault
Fault, unknown offset
Fault , unknown offset, concealed
Thrust fault
Thrust fault, concealed
Normal fault
Normal fault, concealed
Normal fault, inferred
Sections
Folds
Anticline
Anticline, approximately located
Anticline, concealed
Syncline
Syncline, concealed
Monocline, synclinal bend
Monocline, synclinal bend, concealed
0
4,000
8,000
16,000
24,000
32,000
Feet
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Swale Valley Water Level Monitoring Network
Addendum to Swale Creek Basin Water Availability Study
WRIA 30, Washington
DATE: June 2010
DESIGNED BY: JMS
DRAWN BY: PPW
REVISED BY: -
PROJECT NO. 070024
FIGURE NO. 2
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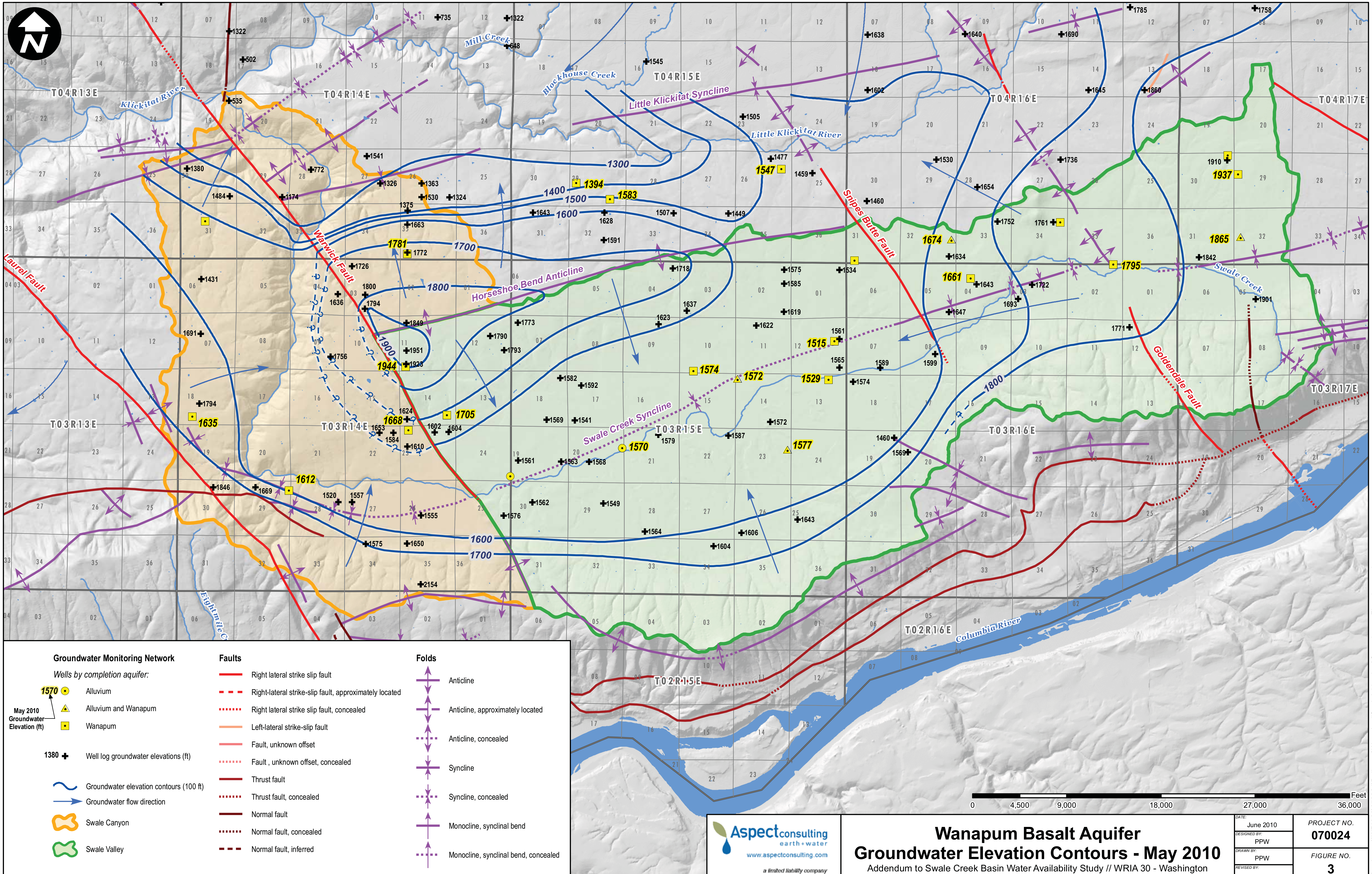

Groundwater Monitoring Network
Wells by completion aquifer:
1570 Alluvium
Alluvium and Wanapum
Wanapum
May 2010 Groundwater Elevation (ft)
1380 Well log groundwater elevations (ft)
Groundwater elevation contours (100 ft)
Groundwater flow direction
Swale Canyon
Swale Valley
Faults
Right lateral strike slip fault
Right-lateral strike-slip fault, approximately located
Right lateral strike slip fault, concealed
Left-lateral strike-slip fault
Fault, unknown offset
Fault , unknown offset, concealed
Thrust fault
Thrust fault, concealed
Normal fault
Normal fault, concealed
Normal fault, inferred
Folds
Anticline
Anticline, approximately located
Anticline, concealed
Syncline
Syncline, concealed
Monocline, synclinal bend
Monocline, synclinal bend, concealed
Feet
0
4,500
9,000
18,000
27,000
36,000
Klickitat River
Little Klickitat River
Little Klickitat Syncline
Horseshoe Bend Anticline
Swale Creek Syncline
Swale Creek
Warwick Fault
Snipes Butte Fault
Goldendale Fault
Laurel Fault
Columbia River
Mill Creek
Blockhouse Creek
T04R13E
T04R14E
T04R15E
T04R16E
T04R17E
T03R13E
T03R14E
T03R15E
T03R16E
T03R17E
T02R15E
T02R16E
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Wanapum Basalt Aquifer
Groundwater Elevation Contours - May 2010
Addendum to Swale Creek Basin Water Availability Study // WRIA 30 - Washington
DATE: June 2010
DESIGNED BY: PPW
DRAWN BY: PPW
REVISED BY: -
PROJECT NO. 070024
FIGURE NO. 3
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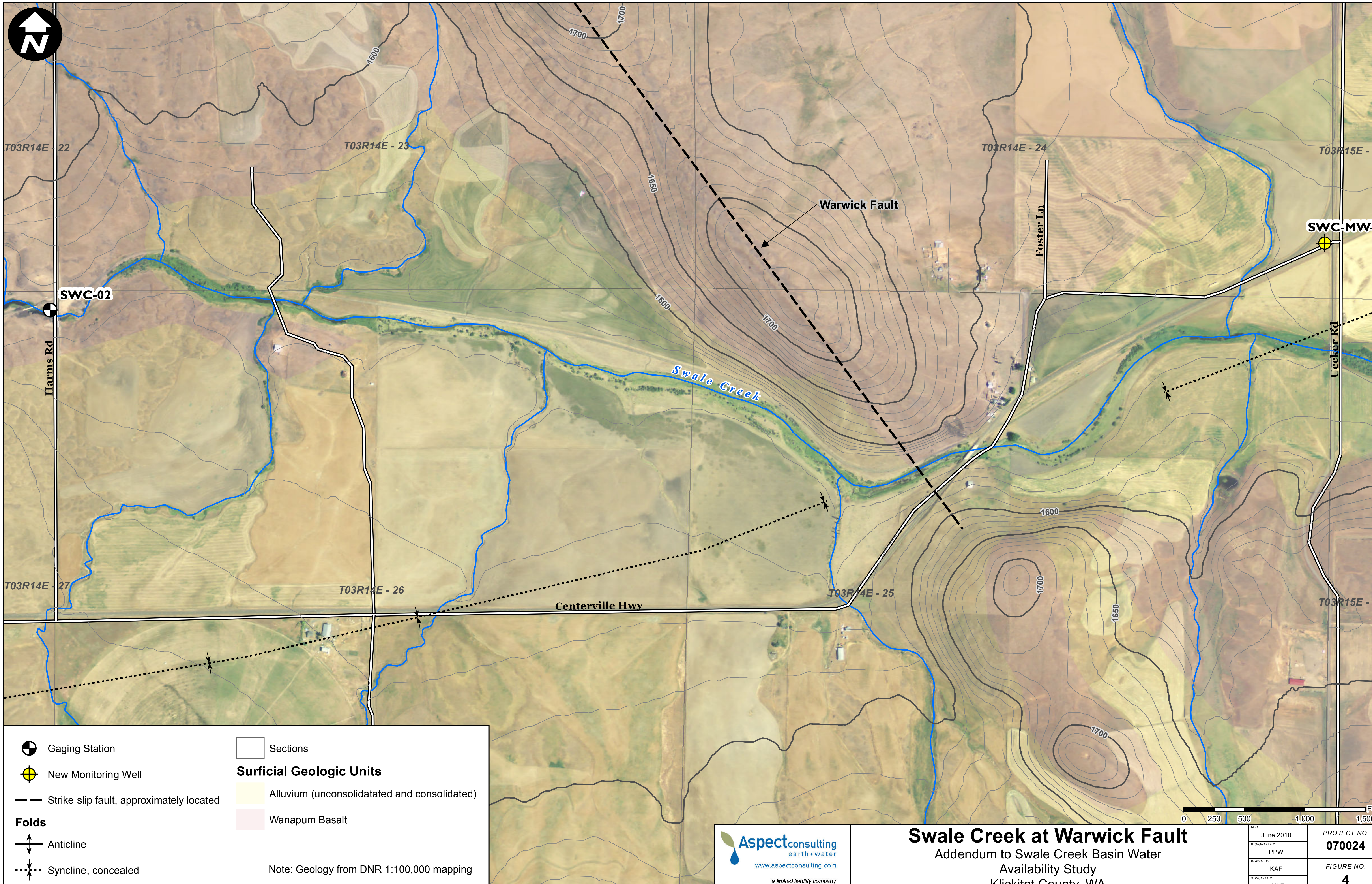

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Swale Creek at Warwick Fault
Addendum to Swale Creek Basin Water Availability Study
Klickitat County, WA

DATE: June 2010	PROJECT NO. 070024
DESIGNED BY: PPW	
DRAWN BY: KAF	FIGURE NO. 4
REVISED BY: KAF	

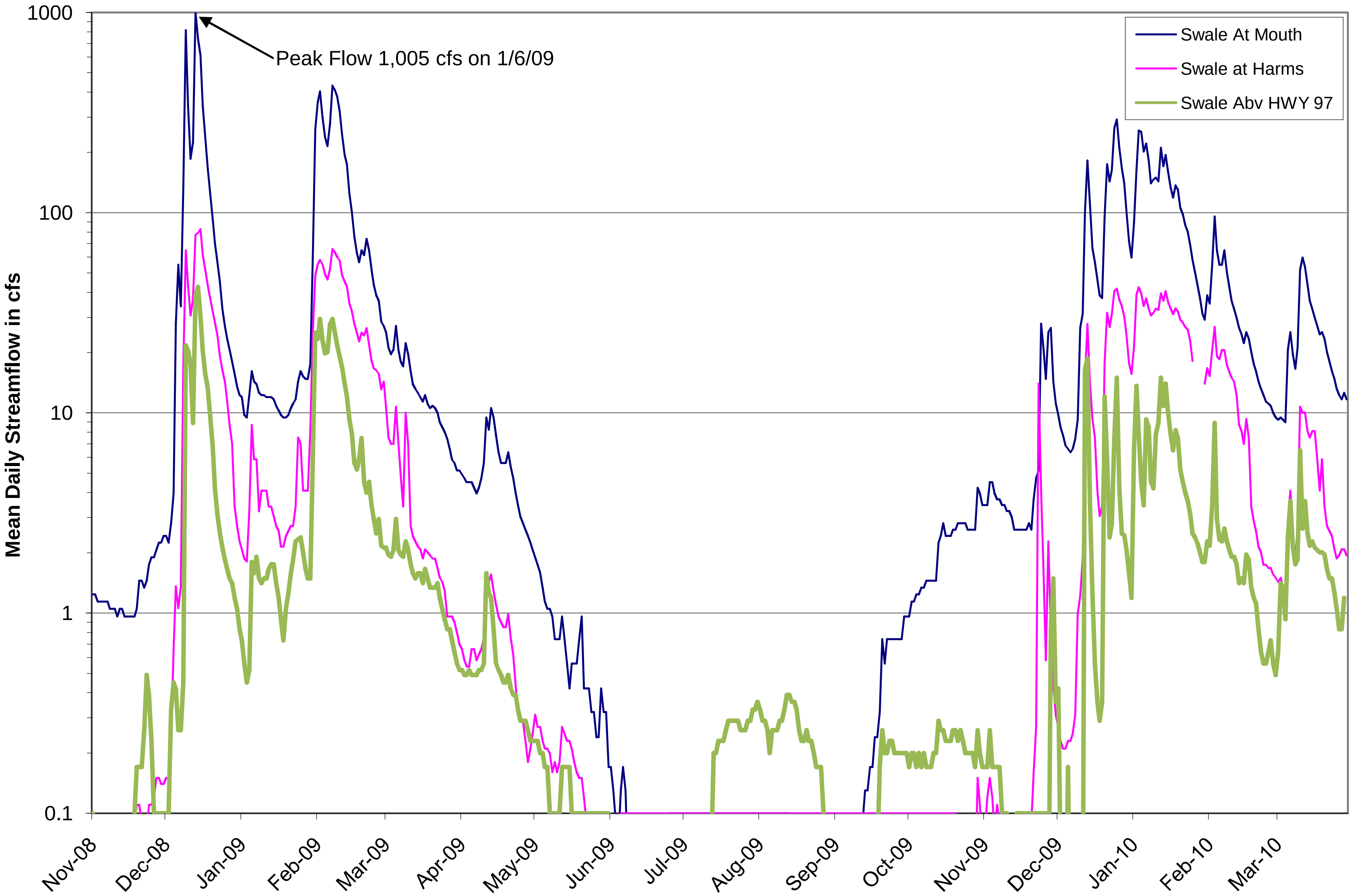

Figure 5 - Swale Creek

Streamflow Hydrographs

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Aspect Consulting

6/30/2010

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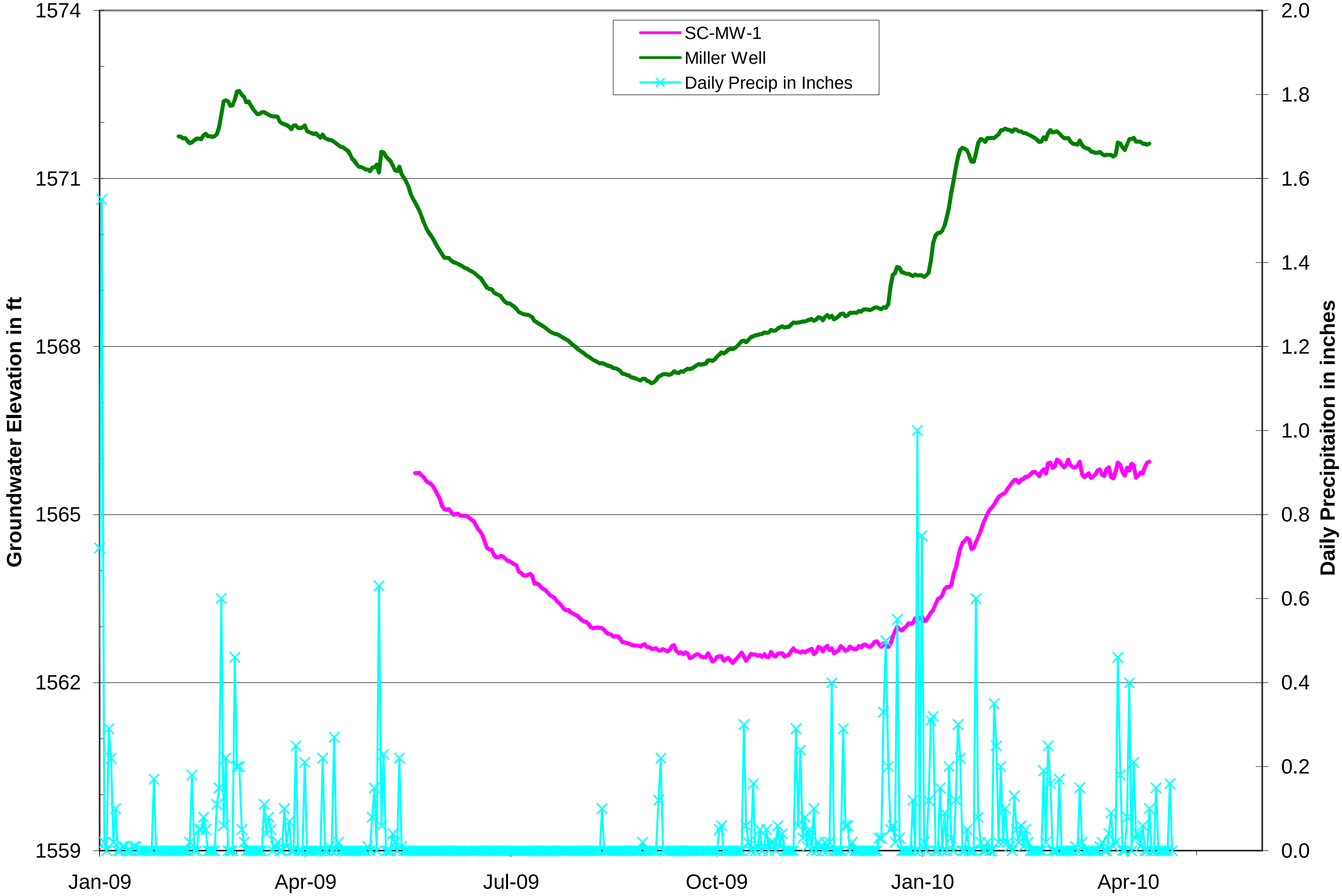

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Figure 6 - Continuous Measurement Hydrographs for Alluvium Aquifer, 2009-2010
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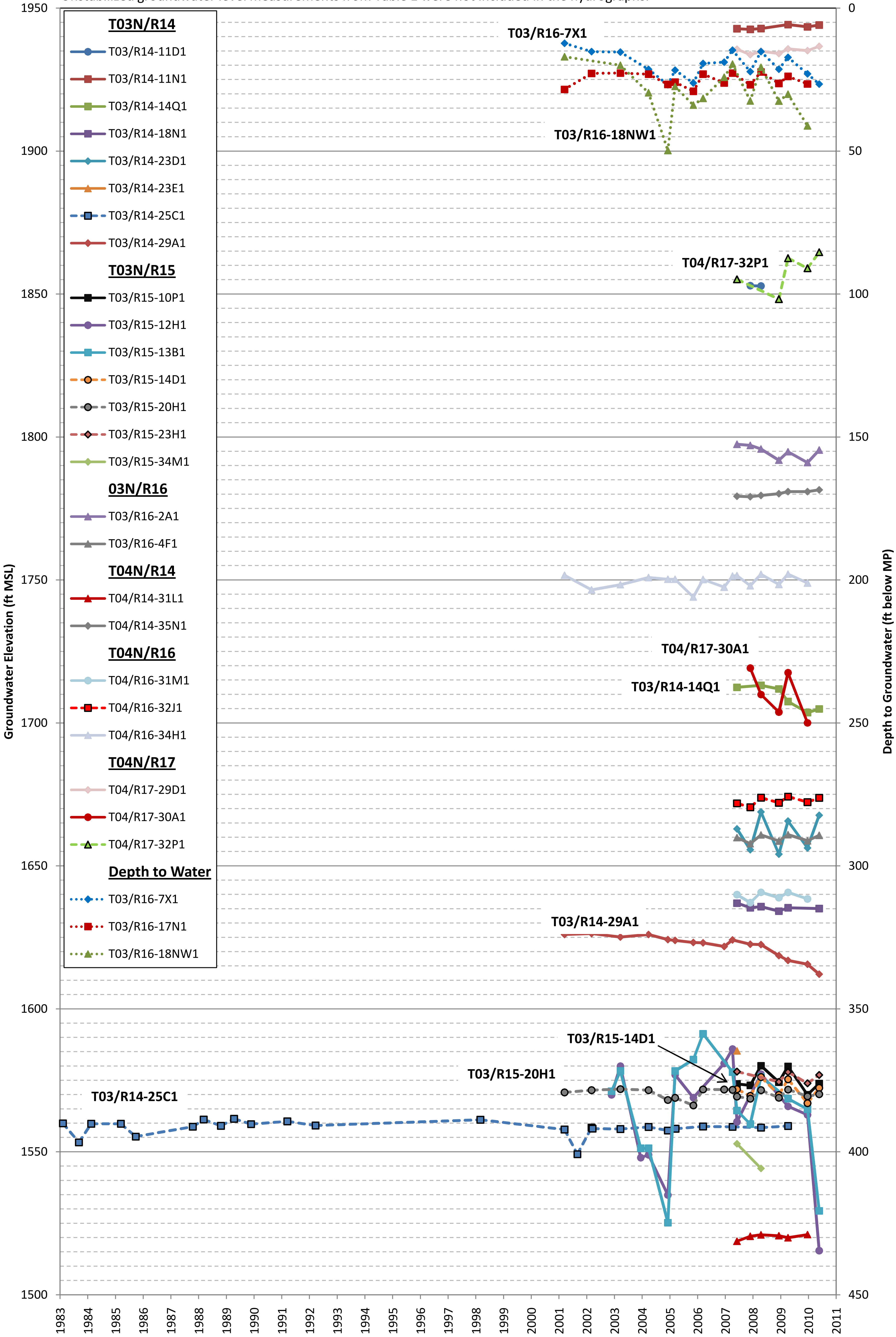
Notes:
Dashed hydrographs are indicative of wells completed in the alluvium aquifer.
Dotted hydrographs are presented as depth-to-water (secondary axis).
Unstabilized groundwater level measurements from Table 1 were not included in the hydrographs.



Aspect Consulting
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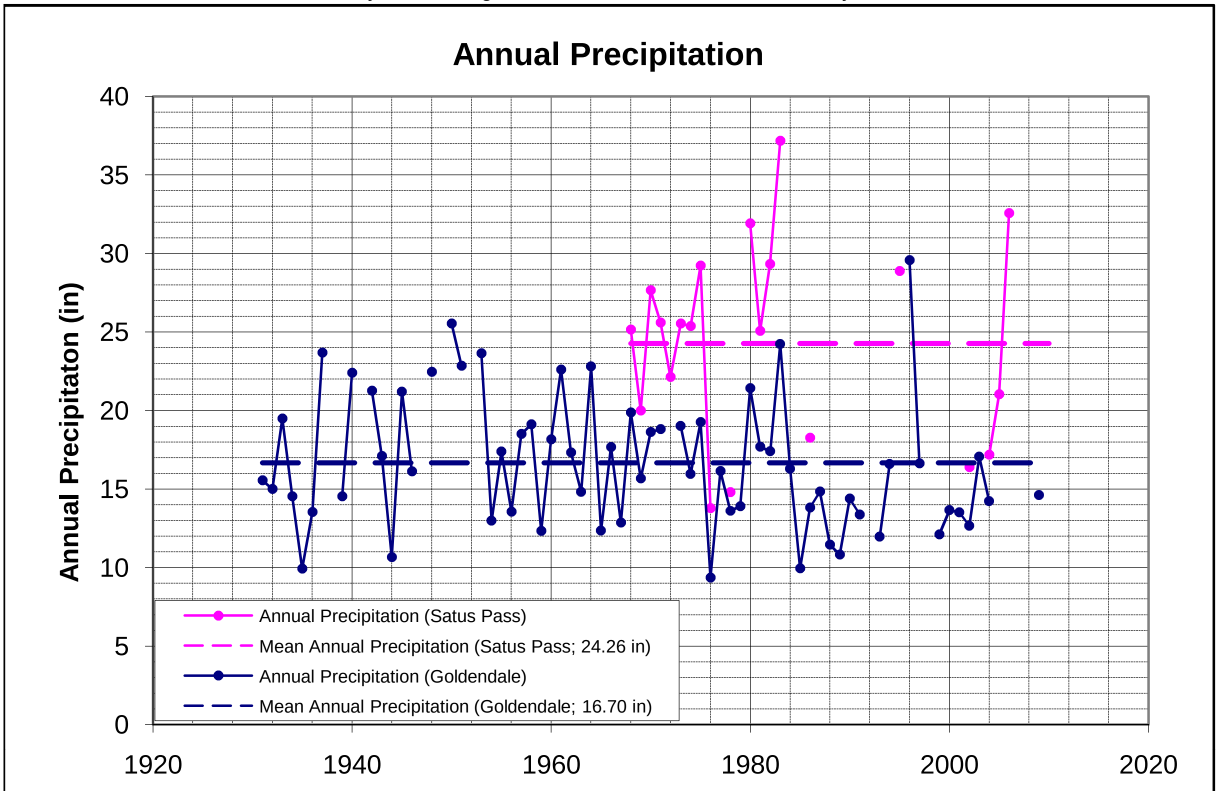
Figure 7 - Longer-Term Groundwater Hydrographs for All Wells Monitored
WRIA 30 Water Availability Study Addendum

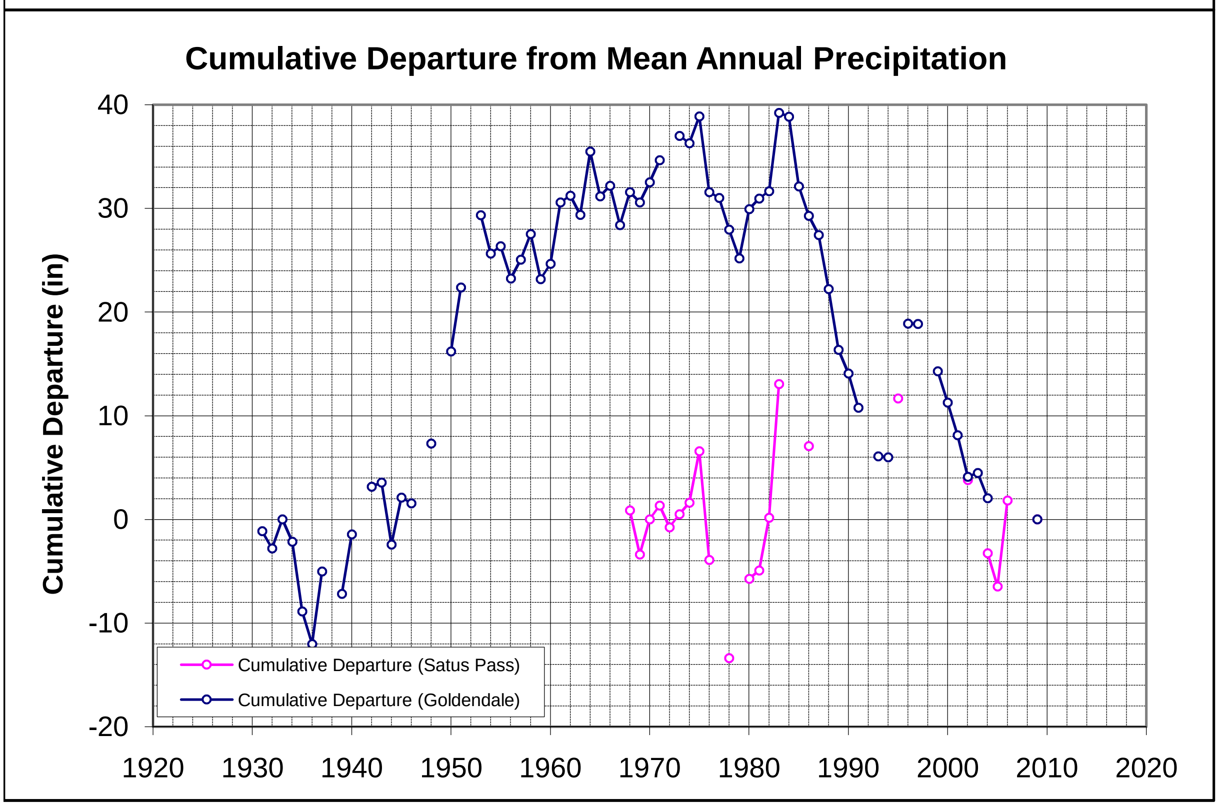
Notes:

Goldendale annual precipitation data from Goldendale (NOAA #453222) and Goldendale 2E (NOAA #453226).

Satus Pass annual precipitation data from Satus Pass 2 SSW (NOAA #457342)

Individual months with more than 5 days of missing data were not used for either monthly or annual statistics.





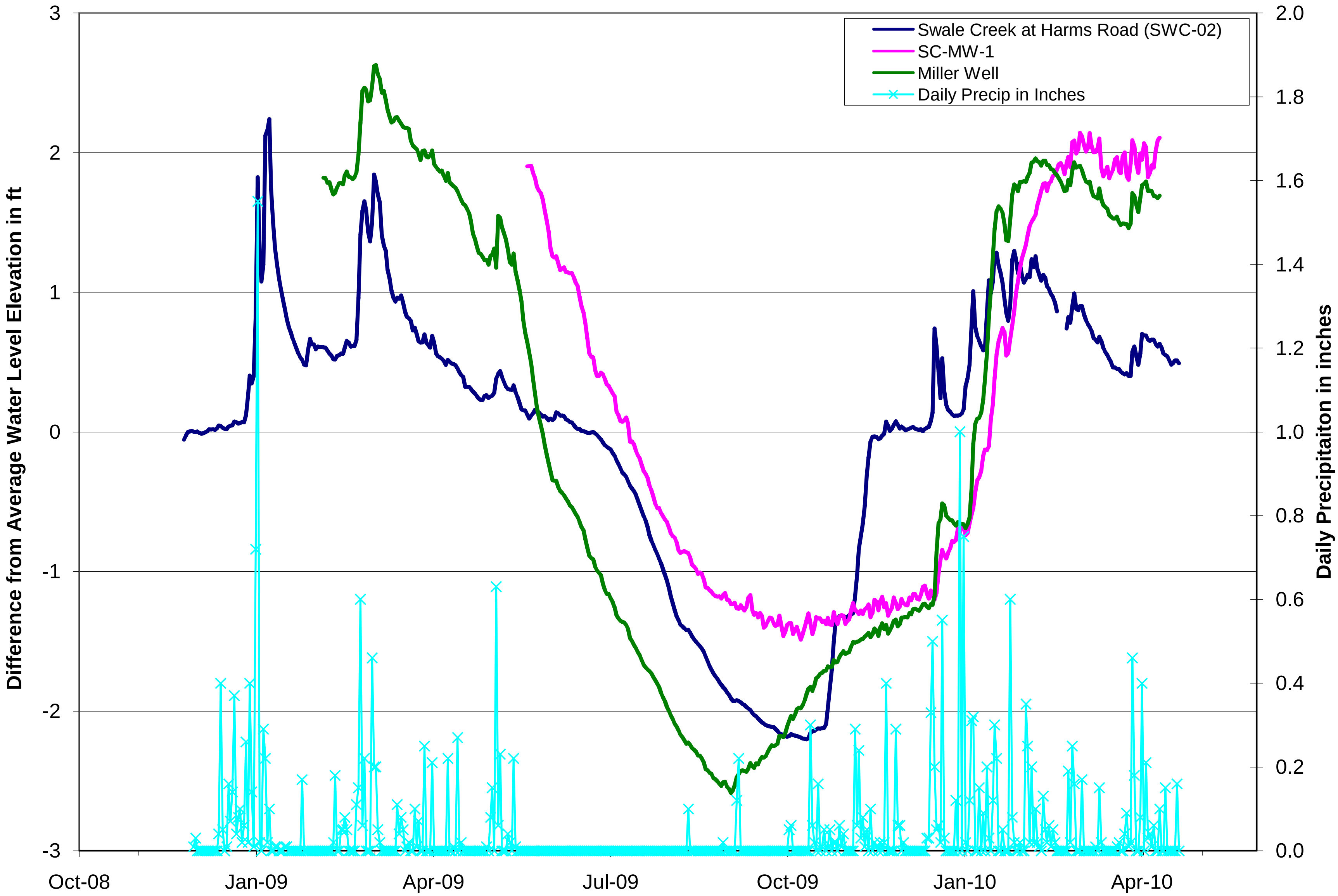


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Figure 9 - Normalized Alluvium Aquifer and Swale Creek Water Levels
WRIA 30 Water Availability Study Addendum

APPENDIX A

Subbasin-Scale Water Balance for Swale Valley

Subbasin-Scale Water Balance for Swale Valley

The conventional subbasin-scale water balance approach partitions precipitation into evapotranspiration (ET: water evaporated from soil, rock, or open water, plus water consumed [transpired] by growing plants), runoff becoming streamflow, and groundwater recharge on an annual basis. Water use by human activities requires the addition of estimated volumes for consumptive water use and return flow to the water balance to complete a full assessment. The current water balance is similar to that applied in the Water Availability Report (Aspect Consulting, 2007a) and updated estimates of water use (both consumptive and return flow). The following subsections present the water use estimates, and then the full water balance, for the Swale Valley portion of the Swale Creek subbasin.

Water Use Estimates for Swale Valley

This section estimates actual water use for the Swale Valley portion of the Swale Creek subbasin, applying the same methodology as used in the 2007 Water Availability Report. The water use information is an important element of the subbasin-scale water balance, supporting the assessment of water availability. The water balance covers only the Swale Valley portion of the subbasin, for the purposes of this assessment.

As done in the 2007 Water Availability Report, water use is estimated for the major categories of use including irrigation, residential, and non-residential (e.g., commercial/ industrial). The water use estimates represent average current conditions based on available information and numerous assumptions. Actual use varies for any given time period due to factors such as temperature, precipitation, or cropping practices. A summary of the methods and results of estimating each of these water uses are presented below.

Irrigation Use

Annual irrigation water use (acre-feet/year) is estimated by multiplying the irrigated area (acres) in the subbasin by a representative annual irrigation requirement, or water duty (feet/year). As of May 2010, Farm Services Agency (FSA) staff indicated that irrigated acreages for the Swale Creek subbasin used in the Water Availability Report (2007 data) have changed only slightly since that time. The reported total irrigated areas in the Swale Creek subbasin for 2009 is 1,693 acres, compared to 1,674 acres in 2007. All of the irrigation in the subbasin is assumed to occur within Swale Valley.

A water duty of 3.4 acre-feet/acre (40.8 inch/year) is assumed for all irrigated acres. This is the alfalfa water duty used for all irrigation water rights in the 1980s adjudication of surface water rights for the Little Klickitat River Basin. According to FSA and Central Klickitat Conservation District staff, alfalfa makes up the vast majority of irrigated cropland in the Swale Creek subbasin, so it is considered a valid assumption.

Using the acreage and water duty described above, annual irrigation water use (acre-feet/year) is estimated by multiplying the irrigated area (acres) by the annual water duty (feet/year). By this analysis, we estimate that nearly 5,760 acre-feet/year of water is used for irrigation in the Swale Valley (Table A-1). Estimated consumptive use versus return flow components of this use is discussed below.

Table A-1 - Estimated Annual Irrigation Water Use

Subbasin	Irrigated Acres[a]	Alfalfa Water Duty in Feet/Year[b]	Total Irrigation Use in Acre-Ft/Year	Annual Consumptive Quantity in Acre-Ft/Year [c]	Annual Return Flow Quantity in Acre-Ft/Year [c]
Swale Valley	1,693	3.4	5,760	5,180	580

Notes:

[a] From Farm Service Agency, Goldendale Office (May 2010 personal communications).

[b] Assumes alfalfa water duty from 1987 Little Klickitat River Water Rights Adjudication, 40.8 inch/year.

[c] Assumes 90% consumptive use, 10% nonconsumptive return flow.

Residential and Non-Residential Use

Using data from Department of Health public water system (PWS) database, an estimated 2 acre-feet of PWS-supplied residential water use is developed and used within the subbasin, based on multiplying each PWS' number of residents served by 127 gallons per capita day[6] (gpcd), and converting to an annual volume in acre-feet/year. The total PWS-supplied non-residential water use is estimated to be approximately 2 acre-feet/year from the subbasin (Table A-2).

Table A-2 - Estimated Annual Public Water System (PWS) Use

							Estimated Annual Water Use in Acre-Feet/Year		
PWS ID	PWS Name	Group	Residents Served	No. Total Connects	No. Resid. Connects	No. Non-Resid. Connects	Residential	Non-Residential	Total
05881	BARTLETT WATER SYSTEM	B	10	2	2	0	1.4		1.4
08403	HARVEST GOLD BOTTLED WATER	B	5	2	1	1	0.7	1.1	1.8
21127	CENTERVILLE GRADE SCHOOL	A	0	1	0	1	0.0	1.1	1.1
Swale Valley Totals			**15**	**5**	**3**	**2**	**2.1**	**2.2**	**4.3**

[6] Determined from Klickitat Public Utility District (PUD) statistics from multiple PWS in WRIA 30 (Aspect Consulting, 2007a).

Note that a portion of the City of Goldendale's water supply is withdrawn from the Basse wellfield located in the Swale Valley, even though all of that water is used in the Little Klickitat subbasin, where the City is located. Based on information obtained from the City, the average annual withdrawal from the Basse wellfield is approximately 100 acre-feet. Use of that water, in the Little Klickitat subbasin, is not considered in this water balance for Swale Valley; however, the groundwater withdrawal (export) is included.

The self-supplied residential population (domestic wells) was estimated by projecting the self-supplied population in 2000 to 2010 using an annual population growth rate. The self-supplied population in 2000 (105 people) for the entire Swale Creek subbasin was determined for the WRIA 30 Level 1 assessment (WPN and Aspect Consulting, 2004). Based on our knowledge of the subbasin, we assume that 90% of the total subbasin population, or 95 people, reside within Swale Valley. Based on the state Office of Financial Management's projected growth in unincorporated Klickitat County from 2000 to 2010 (1.4% per year), we estimate 109 self-supplied residents in the Swale Valley. Annual water use estimates for the self-supplied population were calculated assuming an average consumption of 127 gpcd and converting that volume of water into acre-feet/year for a total of 15 acre-feet/year (Table A-3).

Table A-3 - Estimated Self-Supplied Annual Residential Water Use

Subbasin	Estimated Self-Supplied Population in 2000[a]	Unincorporated Population Growth Rate Per Year[b]	Projected Self-Supplied Population in 2010	Self-Supplied Water Use in Acre-Feet/Year
Swale Valley	95	1.4%	109	16

Notes:

[a] Total 2000 population for Swale Creek subbasin from Table A-5-13 of WRIA 30 Level 1 Assessment (105 people). It assumed that 90% of the subbasin population, or 95 people, resides within Swale Valley.

[b] Statistics for Klickitat County from Office of Financial Management.

There are no known large non-PWS supplied non-residential water users in the Swale Valley. One category of minor non-residential water use is stock watering from exempt wells and developed springs. Groundwater withdrawal up to 5,000 gpd for stock watering is exempt from water right permitting. Stock watering is considered to be a small component of total water use in the Valley, especially relative to irrigation.

Consumptive and Non-Consumptive Water Use

Water delivered for irrigation is either consumed by evapotranspiration, or the water remains in the subbasin as return flow, where the water is "reused" by augmenting streamflow or groundwater sources. We assumed that 90% of the irrigation water used is consumed, whether transpired by crops or lost to evaporation before the crops can use it (Table A-4). Irrigation is conducted in Swale Valley primarily using a combination of center pivot and wheel lines. A consumptive use percentage of 90% is the average for center pivots with impact heads (95%) and wheel lines (85%), as listed in Ecology's

Guidance 1210 for calculating annual consumptive quantity. The remaining 10% of irrigation use is therefore assumed to be non-consumptive return flow.

The total consumptive irrigation water use is estimated at 5,184 acre-feet/year for the Swale Creek subbasin.

The difference between the amount of water delivered and the amount of water consumed is returned to the watershed (return flow) as either groundwater recharge or streamflow. We assumed the 10% irrigation return flow was partitioned 2/3 to 1/3 between groundwater recharge and streamflow, respectively.

There are no wastewater treatment plants discharging to surface water in Swale Creek subbasin. We assumed all other PWS-supplied and self-supplied water users treat their effluent via septic tanks and drain fields. Therefore all other non-consumptive return flow was considered groundwater recharge.

The resultant estimated non-consumptive return flow volumes for each use category are presented in Table A-4.

Table A-4 – Estimated Water Use in Swale Valley

	Water Use in Acre/Feet/Year by Category				
Subbasin	**Irrigation**	**PWS-Supplied Residential**	**Self-Supplied Residential**	**PWS-Supplied Non-Residential**	**Total Use in Acre-Feet/Year**
Total Use	5,760	2	16	2	**5,780**
Consumptive Use	5,184	0	2	0	5,186
Total Return Flow	(376)	(2)	(14)	(2)	(593)
Return Flow to Groundwater	*(384)*	*(2)*	*(14)*	*(2)*	*(401)*
Return Flow to Surface Water	*(192)*	*0*	*0*	*0*	*(192)*

Notes:

PWS: Public water system.

Water Balance Calculations for Swale Valley

For the water balance, precipitation translates into groundwater recharge, runoff becoming streamflow, evapotranspiration, consumptive water use and return flow on an annual basis, which is expressed by:

Precipitation = Recharge + Streamflow + Evapotranspiration + Consumptive Water Use - Return Flow (non-consumptive use)

Each component of the water balance is described below.

Mean annual precipitation in the Swale Valley is estimated at 23 inches per year, or approximately 103,900 acre-feet/year (Table A-5). Precipitation for each subbasin was compiled from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM; Daly and others 1994) as presented in the Level 1 assessment (WPN and Aspect Consulting, 2004).

Based on the USGS recharge estimates described in Aspect Consulting (2007a), mean annual groundwater recharge in Swale Valley is estimated at approximately 15,800 acre-feet/year (Table A-5).

The annual streamflow (runoff) leaving Swale Valley was estimated from continuous Swale Creek streamflow data collected in 2009-2010 at Harms Road for the period of November 2008 through April 2010 (described in main body of report). The mean annual flow (average of mean daily flows) for the period was 7.6 cfs. This discharge volume was converted to an annual volume of 5,502 acre-feet/year and added to the water balance (Table A-5).

There are no reliable subbasin-scale ET estimates that can be used in the water balance equations for Swale Valley. However, since it was the only undetermined value in the water balance for either basin, we solved the water balance equation (net balance equal to zero) to estimate ET for the Valley. The resultant ET estimates were 77,880 acre-feet/year for the Swale Valley. This value represents ET for the non-irrigated vegetation/soil cover, not irrigated acreage which is accounted for in the irrigation water use values. Therefore, irrigated acres in Swale Valley were subtracted from the total subbasin area before converting ET value into inches/year. The resultant ET value for the subbasin is 17.8 inches/year (Table A-5).

Table A-5 provides the estimated average annual water quantities (acre-feet/year) associated with each water balance term for Swale Valley.

Table A-5 – Annual Water Balance Summary for Swale Valley

	Inputs				Outputs					
Area	Precipitation		ET (non-irrigation)		Recharge	Streamflow		Ground-water Export	Consumptive Use	Return Flow
in ac	in inches [1]	in ac-ft [2]	in inches [3]	in ac-ft [4]	in ac-ft [5]	in cfs[6]	in ac-ft [7]	in ac-ft [8]	in ac-ft	in ac-ft
54,200	23	103,883	17.8	77,880	15,808	8	5,502	100	5,186	-593

Notes:
1) Source: Subbasin average from Goldendale precipitation station.
2) Source: Calculated from value in inches.
3) Source: Calculated in water balance from other parameter estimates.
4) Source: Calculated from ET value in ac-ft.
5) Source: USGS deep percolation model (Bauer and Vaccaro 1990), as reported in WRIA 30 Level 1 Assessment.
6) Source: Mean daily flow based period of recorded flow data for the Swale Creek at Harms Road, Klickitat County data.
7) Source: Calculated from value in ac-ft.
8) Consumptive use and return flow account for pumping Goldendale's Basse wellfield in Swale Creek subbasin with import into Little Klickitat subbasin.

Water availability is assessed on the subbasin scale by comparing of total consumptive surface water use relative to total streamflow, and total consumptive groundwater use relative to groundwater recharge, and comparing estimated actual water use to appropriated water rights. As described in the 2007 Water Availability Report, there is very little surface water use in this subbasin, due to the lack of reliable surface water flow year-round and lack of water storage to capture and make use of the higher winter flows. Consequently, for this assessment, we assume that all water use in the Valley is supplied by groundwater.

Based on the water balance, the estimated total consumptive use of groundwater in the Swale Valley is 33% of annual groundwater recharge. This estimate includes the estimated 100 acre-feet/year of groundwater exported to the Little Klickitat subbasin, none of which is returned to the Swale Valley, so it is all treated as “consumed” with respect to Swale Valley.

Uncertainties in Subbasin-Scale Water Balance

The subbasin-scale water balance estimate does not accurately reflect hydrologic conditions at all locations within a subbasin, or during all years, or all seasons. They are meant to represent the generalized long-term average hydrologic conditions of the subbasin. Quantifying the level of uncertainty in the water balance in terms of +/- percent is difficult at best. However, the sources of uncertainty in calculating the annual water balance for the subbasin can be discussed in terms of the uncertainties associated with each water balance term.

As the primary input to the water balance, precipitation is the single greatest factor in determining the water balance. Fortunately, long-term precipitation monitoring and the advancement of precipitation models (e.g. PRISM) has produced a reliable record of precipitation that can be appropriately applied to the subbasin-scale water balance. However, the precipitation value represents average conditions in the past, and may not necessarily predict average conditions in the future. Year-to-year rainfall fluctuation, seasonal droughts, and the potential for long-term climate change are several factors that add uncertainty to the water balance as a tool to predict water availability within Swale Valley.

Groundwater recharge as modeled by the USGS also introduces uncertainty into the subbasin-scale water balance. It was a regional model which did not specifically model the Swale Creek subbasin; rather the values were determined based on statistical relationships and precipitation in the subject subbasin. Additionally, the recharge estimates were based on a different period of record (1956-1977) than the PRISM precipitation data used in the water balance (1961-1990).

The period of record for streamflow data in Swale Creek is limited to essentially the past two years. Using only a few years of streamflow data in Swale Creek introduces some uncertainty into that term of the water balance.

Since ET was calculated from each water balance equation, no additional uncertainty is introduced into the water balance from attempting to estimate ET. However, uncertainties associates with the other terms are propagated into the resultant ET value for Swale Valley.

Water use in the subbasin is dominated by irrigation as described above. Uncertainties in the total irrigated acreage, annual average water duty, and the total consumptive versus non-consumptive water use add uncertainty to the total water use estimate. Based on information from the local FSA, we are confident that the number of irrigated acres and water duty are the best estimates of current conditions in Swale Valley. Although the water duty is reasonable based on the crop assumption, it is likely conservatively high. Given the magnitude of irrigation water use, even small uncertainties in these values can influence the estimated water use, and thus overall water balance, calculations.