HYDROLOGIC INFORMATION REPORT SUPPORTING WATER AVAILABILITY ASSESSMENT

High Prairie Study Area, WRIA 30

Prepared for: WRIA 30 Water Resource Planning & Advisory Committee

Project No. 070024-013-01 • June 28, 2011

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Aspect CONSULTING

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Contents

List of Tables

List of Figures

Appendices

1 Project Objectives and Report Organization

Within Water Resource Inventory Area 30 (WRIA 30), aka the Klickitat River basin, there are several areas with potential for substantial future population growth, including portions of the Swale Creek, Little Klickitat, Lower Klickitat, and Columbia Tributaries subbasins. The WRIA 30 Watershed Management Plan [WPN and Aspect Consulting, LLC (Aspect) 2004] identified data gaps that needed to be addressed in order to help determine the quantities of water available for appropriation, including:

- Refine estimates of actual water use; and
- Delineate specific aquifer zones within the subbasins.

The WRIA 30 Watershed Management Plan calls for conducting water availability studies and collecting data that will facilitate the processing of water rights. Washington State Department of Ecology (Ecology) provided funding (Grant No. G1000101) to complete water availability studies in priority areas of WRIA 30, including the Dallesport area (western Columbia Tributaries subbasin), the Fisher Hill/Appleton area (northwestern Lower Klickitat subbasin), and, the subject of this report, the High Prairie area (straddling western Swale Creek and eastern Lower Klickitat subbasins). Figure 1.1 provides a map of the various subbasins of WRIA 30 and the High Prairie study area, covering portions of the Lower Klickitat and Swale Creek drainages.

For previous water availability studies of Little Klickitat and Swale Creek subbasins in WRIA 30 (Aspect, 2007), the WRIA 30 Water Resource Planning and Advisory Committee (WRIA 30 PAC) coordinated with John Kirk, hydrogeologist for Ecology Central Regional Office, regarding additional information required prior to Ecology's processing of new water right applications in the Swale Creek Basin east of the Warwick Fault. Based on these discussions, the following information was determined to be needed for the High Prairie area:

1. Determine how much additional water could be appropriated without exceeding the average annual recharge to the aquifer, and document uncertainty in that estimate.
2. Assuming all the water available was appropriated, quantitatively determine the pumping impact (magnitude and timing/duration) on the Klickitat River and its tributaries (e.g., Swale, Dillacort, and Wheeler Creeks), if any, and document uncertainty.
3. Obtain information about the aquifer hydraulic properties to allow assessment of interference\impairment to existing wells from the approval of new water rights.

Item 1 is related to water available for appropriation of new water rights. Items 2 and 3 are related to potential for impairment associated with new appropriations. However, a quantitative assessment of pumping impacts is beyond the scope of this assessment; impairment can also depend on the quantity and location of new water rights being applied for. It was therefore decided that the best value from this assessment can be obtained by refining the hydrogeologic conceptual site model including collection of field data within the study area.

Therefore, the objectives of this assessment for the High Prairie study area include:

1. Creation of a hydrogeologic conceptual model, including the most definitive interpretation of the hydrostratigraphy and groundwater flow system to date;
2. Establishment of a groundwater level monitoring network; and
3. Creation of a study area-scale water balance, assisting in the determination of water availability for the study area.

1.1 Report Organization

The following sections of this report include:

- Water Level Monitoring
- Conceptual Model of Hydrogeologic Conditions, which includes assessment of groundwater-surface water continuity
- Water Balance
- Conclusions and Recommendations

2 Water Level Monitoring

An important element of the study is establishment of a well network in which groundwater levels can be monitored. The water level data are used to evaluate groundwater flow directions within the aquifer system and, with continued long-term measurements, document aquifer response to short-term conditions (e.g. seasonal and pumping stresses) and longer-term trends that can provide empirical information regarding sustainable levels of groundwater withdrawal. The water level monitoring activities for the study area are described below.

2.1 Expansion of Well Monitoring Network

A monitoring network of 14 wells located within the High Prairie area was previously established as part of the Swale Creek subbasin water availability study (Aspect, 2007). This initial monitoring network had biannual (pre-irrigation and post-irrigation) water level measurements dating back to June of 2007. For this study, the High Prairie monitoring network was expanded from 14 to 23 wells.

The establishment of the expanded water level monitoring network was conducted in accordance with a Quality Assurance Project Plan (QAPP) prepared for the project (Aspect, 2010a). Members of the PAC and local community assisted in the effort by contacting local well owners to request permission to access their well and inform them of the study objective.

The first step for establishing the expanded water level monitoring network involved compilation of addresses of prospective wells based on well locations from Ecology's on-line well log database (http://apps.ecy.wa.gov/welllog/). Additional wells were added to the prospective water level monitoring network list based on personal contacts of local community members.

The prospective water level monitoring network wells were prioritized in order to (1) provide spatial coverage of the basin and (2) provide a representative number of wells completed[1] in the various basalt aquifers to allow for potential differentiation of water levels within respective hydrostratigraphic units. For wells completed in the interflow zones between the basalt units, water levels were considered to be representative of the underlying basalt aquifer. Within the High Prairie study area, The Dalles Formation, in addition to the overlying alluvium, landslide, and the continental sedimentary deposits are not considered to be significant aquifers due to the limited extent of these deposits and the limited number of wells completed within these respective units. Therefore, for the purposes of this assessment, these aquifers (collectively termed unconsolidated aquifer) were not included in the water level monitoring network.

[1] A well being "completed" in a specific aquifer zone(s) indicates that it is open to, thus assumed to be withdrawing groundwater from, that zone. A well that is cased across an aquifer zone is not considered to be completed within that zone.

Once the list of prospective monitoring network wells was established, local well owners were contacted to request permission to access their wells as part of the field reconnaissance. Only wells for which owner permission was granted were visited as part of the field reconnaissance. If permission was not granted for a well in an area of needed spatial coverage, the well owner of a lower priority prospective water level monitoring network well was contacted in its place. If a well owner granted permission to access their well, but wanted to be present during the measurements, personnel from Aspect or the Klickitat County Natural Resources Department (Klickitat County) called and set up a time with the respective owner in which to do so.

Personnel from Aspect and Klickitat County conducted a field reconnaissance during the week of June 28, 2010, with the objective of identifying accessible existing wells to include in the expanded monitoring network.

During the field reconnaissance, each wellhead was examined in the field to determine whether an access port was available for the respective water level measurements. If suitable access existed, the depth to water in the well was measured. Because most of the wells had pumps installed, care was taken to avoid getting the electric water level indicator, if used, caught on pump wiring or other items in the well. Only wells for which water levels could be readily measured were retained as part of the water level monitoring network. The location of the wells retained for the water level monitoring network were documented with field notes, photographs, and surveyed locations so that subsequent water level measurements can be taken if owner permission continues to be received.

Following completion of the field reconnaissance, the water level monitoring network for the High Prairie study area consisted of 23 wells. This includes 14 wells that were retained from the 2007 study, and 9 additional monitoring wells. However, well T03/R13-3R1 is no longer included in the monitoring network due to numerous obstructions within the well, and the owner of well T04/R14-31L1 asked to long longer be included in the monitoring network. Table 2.1provides a summary of the wells included in the water level monitoring network, and Figure 2.1 displays locations of the wells.

2.2 Well Survey

Prior to the field reconnaissance, locations and groundwater levels for wells in the study area were based on Ecology’s online well log database. Wells in the well log database are located based on the center of the quarter-quarter section listed on the well log. Errors in identifying the appropriate quarter-quarter section on the well logs are relatively common. In addition, the well elevation is assumed to be the elevation at the center of the respective quarter-quarter section as indicated by the USGS’ Digital Elevation Model (DEM). In areas of relatively large vertical relief, this can cause significant errors in the well elevation and thus the calculated groundwater elevations. Therefore, to provide a more accurate and representative picture of groundwater elevations (and thus flow directions), it is necessary to obtain accurate (surveyed) well locations and elevations for wells included in the water level monitoring network.

As part of the field reconnaissance, wells included in the water level monitoring network were surveyed by a Klickitat County Public Works surveyor using a high-resolution Global Positioning System (GPS), with a base station at a known control point to allow for real-time differential correction. Because of the distances over which the wells were spread, the surveyor established additional control points throughout the study area. The location (Washington State Plane South Coordinates, NAD 83 datum) and elevation (NAVD 88 datum) of the water level measuring point for each well was surveyed to a reported precision of plus or minus 1.0 and 0.1 foot, respectively. Table 2.1 presents the survey data for wells within the monitoring network.

2.3 Water Level Measurements

Three rounds of water level measurements were collected from the expanded monitoring network wells during this study: May/June 2010 and April 2011, generally representing pre- or early-irrigation conditions; and November/December 2010, representing post-irrigation conditions. The water level measurements are provided in Table 2.2.

In order to provide an accurate "snapshot" of pre-irrigation and post-irrigation groundwater levels, an attempt will be made during subsequent monitoring events to collect the water level measurements for the High Prairie area within a 1-week period of time, if possible.

2.3.1 Water Level Measurement Procedures

Depth-to-water measurements were conducted using either an electric water level indicator (tape) or a sonic water level indicator (sounder)[2], depending on well access. The former provides greater precision, but has the significant disadvantage of potentially becoming permanently caught on wiring or other appurtenances within the well casing. The latter has less precision but is much faster to use and, more importantly, does not have the risk of becoming caught in the well. During the initial round of water level measurements (April 2010), field personnel used both the electric tape and the well sounder for all wells which had suitable access in order to establish instrument accuracy and suitability for each well. A quality control (QC) evaluation of the sonic sounder performance, using actual data from WRIA 30 monitoring efforts, is provided in the QAPP (Aspect, 2010a).

All depth-to-water measurements were made relative to the top of well casing or other defined measuring point at the wellhead. The selected measuring point for each well was marked in magic marker, if possible, and was documented in the field form so that it can be reproduced in subsequent measurement rounds. A table of static water level measurements from the respective wells logs was carried in the field. Measurements that varied greatly from previous measurements in a given well (accounting for differences between pre- and post-irrigation) were repeated for confirmation.

[2] Global Water WL600 or equivalent instrument.

Electric Water Level Indicator

When the electric water level indicator was used, each depth-to-water measurement was made to a precision of 0.01 foot. The water level indicator was lowered to contact the water in the well casing (contact determined by a light or beep on the indicator) and the reading noted. The indicator was then immediately withdrawn out of the water and the measurement repeated. If the two readings were consistent, the reading was recorded on a field form along with the measurement date and time. If the two readings were not consistent, measurements were repeated until a reproducible result was obtained. If repeated water level measurements indicated the presence of rising/falling water levels due to pumping influences, it was noted as such on the respective field form. Other pertinent information regarding the well or the depth-to-water measurement were also recorded in the field notes.

If an electric water level indicator was used for the depth-to-water measurement, the lower couple of feet of tape was rinsed and wiped with a clean paper towel. Any rust or other visible material on the water level indicator after a measurement was also wiped off using a clean paper towel prior to the next measurement.

Sonic Water Level Indicator

When the sonic water level indicator was used, each depth-to-water measurement was made to a precision of 0.1 ft. The sonic water level indicator was programmed with the regional monthly temperature setting suggested by the manufacturer. The sonic water level indicator was placed flush with the top of the casing, and the depth-to-water was displayed on a LCD screen. The measurement was repeated until a reproducible result was obtained. If the two readings were consistent, the reading was recorded in the field notes along with measurement date and time. If the two sonic water level readings were not consistent, or the water level appeared to be incorrect based on well construction or regional hydrologic information, then the depth-to-water was measured solely with an electric water level indicator.

3 Conceptual Model of Hydrogeologic Conditions

3.1 Hydrostratigraphy

A generalized geologic history of the WRIA 30 subbasins, including Swale Creek and Lower Klickitat subbasins within which the High Prairie study area occurs, is provided in the WRIA 30 Level 1 watershed assessment (WPN and Aspect, 2004). Based on that information and subsequent evaluation, hydrostratigraphic units within this study area include (from youngest to oldest):

- Alluvium (Qa);
- Landslide deposits (Qls);
- Continental sedimentary deposits (QMc);
- The Dalles Formation (Mc[d]);
- Ellensburg Formation (Mc[e]);
- Wanapum basalt (Priest Rapids (Mv[wpr]), Roza (Mv[wr]), and Frenchman Springs (Mv[wfs]) members); and
- Grande Ronde basalt (Mv[g]).

Both the Wanapum and the Grande Ronde basalts are formations of the Columbia River Basalt Group (CRBG), which consisted of widespread extrusion of numerous basalt flows originating from vents located in the Pasco area (Bauer and Hansen, 2000). Sedimentary interbeds deposited between the individual basalt flows are collectively referred to as the Ellensburg Formation (Mc[e]).

The surface geology and geologic structures from Washington Department of Natural Resources (WDNR) 1:100,000 scale digital mapping are shown on Figure 3.1. Detailed hydrogeologic cross sections (Figures 3.2 to 3.4) were developed to better define the depth and distribution of the local hydrostratigraphic units, the presence of geologic structures (faults and folds), and the occurrence of water-bearing zones within the study area. In addition, cross section H-H' (Figure 3.5) from the 2007 Swale Creek subbasin water availability study *(*Aspect, 2007*)* was revised based on new information provided by the additional study area cross sections.

The cross sections were developed using well logs from Ecology's well log database, WDNR geologic mapping, and available information from other studies. The cross sections integrate the following data from each well log: location of well to the nearest quarter-quarter section; well depth; cased interval; static water level; depth and thickness of geologic units encountered; water-bearing zones, if reported; and the surface elevation from the USGS DEM. Appendix A provides a summary of the well completion details from the well logs in the study area.

3.1.1 Groundwater Occurrence

Groundwater in the study area generally occurs within the bedrock units of the Columbia River Basalt Group (CRBG). Although there are pockets of unconsolidated deposits found at the surface in the study area (Figure 3.1), these units are not expected to be a significant source of groundwater due to their limited continuity and thickness.

Groundwater in the CRBG occurs primarily within the tops of the individual flows (flow tops) that became vesicular (porous) as gas bubbles escaped the flows during cooling, and/or within the fractured flow bottoms (sometimes referred to as pillows). Flow tops and bottoms – collectively referred to as interflow zones – are usually porous and permeable, and therefore transmit water more readily than the intervening massive portions of the basalt flow interior, which generally constitute flow barriers, except where fractured. A permeable flow top is normally present for each flow, while permeable flow bottoms range from relatively thick units to completely absent.

In addition, terrestrial sediments can be deposited between the underlying flow top and overlying flow bottom during time periods between basalt flows. These sediments are collectively considered part of the Ellensburg formation (Mc[e]) and can be either relatively permeable or impermeable; depending on composition, thickness, and lateral extent (Brown, 1979). Based on the cross sections (Figures 3.2 to 3.5) and the individual well logs, the water-bearing interflow zones in the study area have thicknesses ranging between 10 and 80 feet. However, both the lateral continuity and thickness of the water-bearing interflow zones are highly variable. This leads to variability in depths and productivity of water wells throughout the study area.

3.1.2 Hydrostratigraphic Unit Descriptions

The younger hydrostratigraphic units overlying the CRBG in the study area include (Figure 3.1): alluvium (Qa), landslide deposits (Qls), continental sedimentary deposits (QMc), and the Dalles Formation (Mc[d]). As previously discussed, these units – collectively termed the unconsolidated aquifer for this assessment – are not expected to be a significant source of groundwater on the scale of the study area. The following sections provide a brief description of the hydrostratigraphic units found within the study area.

Alluvium

Within the study area, the alluvium can be highly variable in composition (ranging from clay to gravel), resulting from stream-channel, side stream, overbank, fan, and lacustrine deposits (Korosec, 1987). The only notable occurrence of alluvium within the study area is along the Klickitat River, forming the western boundary of the study area (Figure 3.1). Groundwater occurrence within the alluvium is generally limited to the coarse-grained (sand and gravel) deposits, and no wells are known to be completed[3] in this unit.

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[3] A well being “completed” in a specific aquifer zone(s) indicates that it is open to, thus assumed to be withdrawing groundwater from, that zone. A well that is cased across an aquifer zone is not considered to be completed within that zone.

Landslide Deposits

The landslide deposits consist of a poorly sorted mixture of fine-grained sediments interspersed with gravels and boulders (Korosec, 1987). These deposits are typically found along the sides of the Klickitat River and Swale Creek canyons, forming the western and eastern boundaries of the study area, respectively (Figure 3.1). There is also an area of landslide deposits mapped in the south-central region of the study area, to the southeast of an unnamed southwest-northeast trending thrust fault, termed for this assessment as the “Columbia Hills thrust fault” (Figure 3.1). Due to the localized occurrence and heterogeneous consistency of these deposits, they are not expected to be a significant source of groundwater, and no wells are known to be completed in this unit.

Continental Sedimentary Deposits

The continental sedimentary deposits consist of poorly consolidated gravel and lesser amounts of sand, silt, and clay representing poorly sorted channel deposits (Korosec, 1987). These deposits are mapped in an isolated area in the southeastern region of the study area (Figures 3.1 and 3.3). The coarse-grained deposits appear to be water-bearing, but the unit is not considered a significant aquifer due to the relatively limited extent of the deposits. A single well (T03/R13-24N1; Appendix A) indicates that the continental sedimentary deposits can be as much as 290 feet thick within the study area. The static water level of this well was 173 feet below ground surface (bgs) and the yield was approximately 45 gallons per minute (gpm). However, this well was completed across both the continental sedimentary deposits and the underlying CRBG, and the specific water-bearing unit is not certain based on the log.

Dalles Formation

The Dalles Formation can be found to the northwest of the unnamed southwest-northeast trending thrust fault located in the southwestern region of the study area (Figures 3.1 and 3.3). This unit consists of thickly bedded, gray, volcaniclastic and sedimentary deposits (Korosec, 1987), which can as much as 190 feet thick in the study area. Several wells are completed solely in the Dalles Formation, including: T03/R13-28E1, T03/R13-28P7, and T03/R13-29K1 (Appendix A). Based on the well logs, these wells have static water levels ranging between 50 and 120 feet bgs and yields ranging from 20 and 120 gpm. In addition, there are numerous wells completed across both the Dalles Formation and the underlying CRBG.

Columbia River Basalt Group (CRBG)

The CRBG units are regionally continuous and, in the study area, have a collective thickness of several thousand feet. The Wanapum basalt is consistently present beneath the study area, except where removed by erosion within incised drainages (Klickitat River, Dillacort Canyon, Wheeler Canyon, and Swale Creek), and to the south of the Columbia Hills thrust fault, where it was uplifted and eroded (Figure 3.1). Where present, the Wanapum basalt is relatively thick, with thicknesses ranging between 500 and 900 feet based on the cross sections (Figures 3.2 to 3.5). The Wanapum basalt consists of three separate members (from youngest to oldest [shallowest to deepest]): the Priest Rapids (Mv[wpr]), Roza (Mv[wr]), and Frenchman Springs (Mv[wfs]) described briefly below.

- **The Priest Rapids member** is generally exposed at the surface across the majority of the study area. However, it is absent (eroded away) along several of the drainages in the western and eastern study area (Klickitat River, Dillacort Canyon, Wheeler Canyon, Swale Creek, and the respective tributaries), and to the south of the Columbia Hills thrust fault in the southern region of the study area (Figure 3.1). Where present, the Priest Rapids member can be as much as 300 feet thick, in the central portion of the study area (Figure 3.3).
- **The Roza member** is generally exposed at the surface in the vicinity of the major drainages and their respective tributaries. However, lower down in the canyons the Roza member is absent, and the underlying sequences of CRBG are exposed at the surface. The Roza member is also absent to the south of the southern thrust fault (Figure 3.1). Where present, the Roza member can be as much as 150 feet thick (Figure 3.4), to the north of the Columbia Hills thrust fault.
- **The Frenchman Springs member** is also generally exposed at the surface in the major drainages and their respective tributaries. However, lower down in the canyons the Frenchman Springs member is absent, where the underlying Grande Ronde basalt is exposed at the surface. The Frenchman Springs member is also absent immediately to the south of the Columbia Hills thrust fault, before surfacing in the vicinity of the Columbia Hills anticline. Where present, the Frenchman Springs member generally ranges between 450 and 600 feet in thickness across the study area (Figures 3.2 to 3.5).

Underlying the Wanapum basalt is the Grande Ronde basalt, which is the most laterally extensive and thickest of the CRBG formations, constituting 85 to 88 percent of the total volume of the CRBG (Vaccaro, 1999). The Grande Ronde basalt is present beneath the entire study area, but is generally exposed at the surface only at the base of deeply incised drainages (Klickitat River, Swale Creek, and Dillacort Canyon; Figure 3.1). The Grande Ronde basalt is also exposed at the surface immediately to the south of the Columbia Hills thrust fault. As the cross sections indicate (Figures 3.2 to 3.5), there are numerous wells open to and withdrawing groundwater from both the Wanapum and Grande Ronde basalts, but very few wells are completed solely in the Grande Ronde, except where it is exposed in the vicinity of the Klickitat River, Dillacort Canyon, Wheeler Canyon, Johnson Canyon, and Swale Creek drainages, and to the south of the Columbia Hills thrust fault. In the latter area, wells T03/R13-27 and T03/R13-27Q1 are completed solely in the Grande Ronde basalt and are included in the water level monitoring network. These wells have reported static water levels ranging between 100 and 265 feet bgs and yields of about 15 gpm.

Ellensburg Formation

Sediments deposited between the various basalt flows are part of the Ellensburg formation. Where the sediments are coarse-grained (sand/gravel), they may transmit groundwater in usable quantity. However, because the composition, thickness, and extent of the interbeds are highly variable, groundwater production from these units is correspondingly variable. In many localities, the productivity of the interbeds is often low because of limited lateral extent and changes in composition. Within the study area, the interbeds (Mc[e]) can range from being absent to as much as 20 feet thick. As previously discussed, water levels from the interflow zones are considered to be representative of the underlying basalt aquifer; therefore, for the purposes of this study the interflow zone is also considered to be part of the underlying basalt aquifer.

3.2 Geologic Structures

The major geologic structures (faults and folds) in the project area, taken from WDNR 1:100,000 geologic mapping, are identified on both the geologic map (Figure 3.1) and the cross sections (Figures 3.2 to 3.5). The study area is structurally bound to the south (Figure 3.1) by the Columbia Hills, a structurally complex collection of folds and faults (Newcomb, 1969).

The Columbia Hills is part of the Yakima Fold Belt, which formed from regional north-south compression that began during the deposition of the Grand Ronde basalt approximately 16 million years ago (Reidel et al., 1989). This compression resulted in the formation of the southwest-northeast trending folds (synclines and anticlines) and the associated reverse and thrust faults (older rocks are slid upward over younger rocks) found in the region. The Columbia Hills thrust fault, with several hundred feet of vertical displacement, is likely associated with the formation of the Columbia Hills. In addition, there are a series of generally southwest-northeast trending synclines and anticlines as you move north of the Columbia Hills. These include the Mosier syncline in the western region of the study area, a series of unnamed synclines and anticlines in the northern region of the study area, and the Swale Creek syncline and Horseshoe Bend anticline, east of the study area (Figure 3.1).

The individual flows of the CRBG dip away from anticlines and towards synclines. Within the study area, immediately to the north of the Columbia Hills, the basalt flows generally dip between 20 and 50 degrees to the north (Newcomb, 1969), with the greatest dip (75 degrees) occurring where the Laurel fault intersects the Columbia Hills anticline (Figure 3.1; T03/R13-30). The small northwest-southeast trending anticline to the north of the Columbia Hills (Figure 3.1; T03/R13-26) has a dip of between 15 and 45 degrees away from its axis. Several other relatively small northwest-southeast trending synclines and anticlines (Figure 3.1; T03/R13-24) have even smaller dips, ranging between 2 and 3 degrees away from the axes of the anticlines and towards the respective synclines.

Superimposed upon the major southwest-northeast trending structures within the study area are numerous northwest-southeast trending normal faults (younger rocks are slid downward over older rocks) and strike-slip faults (rocks are slid laterally past each other), likely created from a rotational component of the same north-south compression that resulted in the southwest-northeast trending structures (Reidel et al., 1989). Within the study area, this includes one normal fault and two right-lateral strike-slip faults. The normal fault is unnamed and located in the western region of the study area (Figure 3.1). Based on the geologic map, there is likely between 100 and 300 feet of vertical displacement associated within this fault. The two right-lateral strike-slip faults include the Laurel fault, which extends through the center of the study area, and the Warwick fault located along the eastern boundary of the study area.

In the subsurface, folds and faults may represent partial or complete barriers to lateral groundwater flow, laterally compartmentalizing flow within the study area. Newcomb (1961 and 1969) theorized that tight anticlinal folding of basalt forms breccia (broken rock) and fine-grained fault gouge between the individual flows near the axis of an anticline, which decreases the transmissivity of the basalt and impedes groundwater flow across the anticlinal crest. In addition, due to the folding and upwarping of the individual flows in the creation of the anticlinal crest, higher heads are needed for groundwater to flow over this crest. Fault gouge may also decrease the transmissivity of the basalt units in the vicinity of both normal and reverse faults. If significant displacement occurs across these faults to offset the water-bearing interflow zones, the faults may act as impermeable barriers to lateral groundwater flow.

Although there is generally no vertical offset associated with strike-slip faults, fault gouge may impede groundwater flow across these faults. On the east end of the Swale Creek subbasin, the Warwick fault was shown to provide an effective barrier to groundwater flow within the CRBG, based on mounding (hundreds of feet) of groundwater behind the fault (Aspect, 2007). However, neither the Snipes Butte nor the Goldendale faults, similar strike-slip faults father east of the Warwick Fault, were shown to act as complete barriers to groundwater flow. In both of these cases, lineaments associated with nearby synclines may provide a permeable conduit for groundwater flow across the low-permeability faults (Aspect, 2010b). Based on the groundwater level data and inferred flow directions, the Laurel fault also likely acts as low-permeability barrier to groundwater flow in the study area (see Section 3.3.2).

3.3 Groundwater Conditions

3.3.1 Unconsolidated Aquifer

As previously discussed, the surficial units of the unconsolidated aquifer are not expected to be a significant source of groundwater. Within the study area, the only wells completed solely within this aquifer are completed within the Dalles Formation (T03/R13-28E1, T03/R13-28P7, and T03/R13-29K1). These wells have static water levels ranging between 50 and 120 feet bgs and yields of between 20 and 120 gpm, based on the well logs.

Due to the limited continuity and thickness of the unconsolidated aquifer and the limited number of wells completed within this aquifer, it is not possible to accurately determine groundwater flow directions for this aquifer. The scattered occurrences of the unconsolidated aquifer wells relative to the basalt aquifer wells also do not allow for a reliable determination of vertical gradients between the unconsolidated aquifer and the underlying basalt aquifers. However, in areas where unconsolidated materials rest upon a low-permeability flow interior (not a permeable interflow zone) of the underlying CRBG, it is expected that groundwater flow in the unconsolidated material will follow the subsurface topography of the bedrock, with springs often occurring at the downgradient extents of the unconsolidated aquifer (Piper, 1932). Conversely, in areas where the immediately underlying CRBG consists of relatively permeable interflow zones, it is expected that there is a downward gradient from the unconsolidated materials into the basalt, especially during the early part of the year when there is significant precipitation. Under these circumstances, recharge from the unconsolidated aquifer to the underlying basalt aquifers is expected.

3.3.2 Basalt Aquifers

Based on Vaccaro (1999), regional groundwater flow within the Grande Ronde basalt in the study area is inferred to be to the southwest, towards the Klickitat River. Although Vaccaro (1999) does not provide an inferred groundwater flow direction for the overlying Wanapum basalt in the study area, it is assumed to be in a similar direction. A groundwater elevation contour map created as part of the Swale Creek subbasin water availability study also inferred a similar groundwater flow direction for the basalt aquifers in the High Prairie area (Aspect, 2007).

In general, local groundwater flow within the CRBG is expected to be towards major surface water bodies, away from anticlinal axes and in the direction of regional geologic dip of the basalt flows (Steinkampf, 1989). During the formation of an anticline, the compression of the various basalt flows leads to both the folding and uplift of the respective flows. Erosion of the upper flows will later expose the lower flows at the surface, thus allowing for the areal recharge of the respective flow. For this reason, groundwater generally flows away from these relatively high points of recharge and down the geologic dip.

Of the 23 wells in the current High Prairie water level monitoring network, 18 wells are completed in (open to) the Wanapum basalt, 3 in the Grande Ronde basalt, and 2 wells in both the Wanapum and the Grande Ronde (Figure 2.1). Water levels from the interflow zones between the various members and formations of the CRBG are considered to be representative of the underlying basalt aquifer. As the cross sections illustrate (Figures 3.2 to 3.5), a majority of the wells within the study area are completed across multiple members of the Wanapum basalt (Priest Rapids, Roza, and Frenchman Springs), or across both the Wanapum and the Grande Ronde basalts. Therefore, for the purposes of this study, one groundwater elevation contour map is created for the Wanapum basalt as a whole (Figure 3.6). The Grande Ronde basalt has significantly lower groundwater levels than observed in the Wanapum, therefore a second groundwater elevation contour map was also created for the Grande Ronde (Figure 3.7). However, there are a limited number of Grande Ronde wells located between the Columbia Hills thrust fault and the Laurel fault, and between the Swale Creek syncline and the monocline associated with the Horseshoe Bend anticline. Therefore, the Grande Ronde groundwater elevation contours are not extended into these portions of the study area (Figure 3.7).

Figures 3.6 and 3.7 present the groundwater elevation contour maps for the Wanapum and Grande Ronde basalt aquifers, respectively, developed using April 2011 water level data from the study area water level monitoring network, supplemented by well log data (water levels at time of drilling). Since the well log water levels were collected over decades of time, and multiple seasons of the year (irrigation and non-irrigation), they reflect annual and seasonal changes in groundwater levels, in addition to errors associated with the well locations and DEM elevations. Therefore, the April 2011 water level monitoring network measurements from surveyed well locations (Table 2.1) were used to verify and supplement the historical data by gathering a basin-wide “snapshot” of groundwater levels over a relatively short (5-day) period of time. The data collected for this study are reliable data upon which interpretations of groundwater conditions are primarily based.

The resulting groundwater elevation contour maps represent an aggregate interpretation of the Wanapum and Grande Ronde basalt aquifer groundwater data. Due to the disparity in accuracy between the well log water levels and the surveyed water levels, and the fact that the water levels are from wells spanning one or more vertically distinct water bearing zones within the basalt, the interpreted groundwater elevation contours may be inconsistent with water level measurements in individual wells, but are considered representative of the Wanapum and Grande Ronde basalt aquifer groundwater flow systems on a basin scale. Most importantly, establishment of the water level monitoring network also allows for future monitoring to document seasonal or longer-term changes in the groundwater flow system.

Groundwater Flow Directions

Based on the groundwater elevation contour maps (Figures 3.6 and 3.7), groundwater flow in the Wanapum and Grande Ronde basalt aquifers within the study area is:

- to the southwest (towards the Klickitat River) west of the Laurel fault;
- to the north-northwest (towards Wheeler Canyon) east of the Laurel fault and north of the western extension of the Horseshoe Bend anticline; and
- to the south-southeast (towards Swale Creek) east of the Laurel fault and south of the western extension of the Horseshoe Bend anticline.

Continuity of groundwater with study area streams is described in Section 3.6.

While a regional groundwater flow regime is defined from the groundwater elevation mapping, there are numerous folds and faults within the study area (Figure 3.1), which can act as barriers to groundwater flow (Section 3.2). Topographically, the High Prairie area is essentially a peninsula, bounded on three sides by deeply incised drainages (Swale Creek and Klickitat River). In addition, the major geologic structures of the Columbia Hills bound its southern end. Consequently, the CRBG aquifer zones within the study area are “compartmentalized” by geologic structures and topography (incised drainages). This geologic situation can hydraulically isolate individual CRBG aquifer “blocks” from the rest of the aquifer, limiting its recharge area to within the footprint of the aquifer “block”.

Based on the groundwater elevation mapping, the following sections provide a brief description of local groundwater flow directions within the study area, which are controlled in part by the numerous geologic structures.

Columbia Hills Fold/Fault System

Immediately to the north of the Columbia Hills anticline and to the south of the Columbia Hills thrust fault, the Grande Ronde basalt is exposed at the surface. In this area, groundwater flow in the Grande Ronde basalt is generally to the southwest, parallel to the trend of the Columbia Hills thrust fault (Figure 3.7). Due to the significant offset (several hundred feet) across the Columbia Hills thrust fault, the fault likely acts as a barrier to groundwater flow; this barrier likely limits subsurface flow (recharge) into study area aquifers from the Columbia Hills. In addition, due to the relatively steep dip of the basalt flows away from the Columbia Hills (see Section 3.2), there is also likely a component of northwesterly flow, away from the axis of the Columbia Hills anticline.

West of Laurel Fault

To the north of the Columbia Hills thrust fault and to the southwest of the Laurel fault, a majority of the wells are completed in the Wanapum basalt. Based on Figure 3.6, the local groundwater flow direction within the Wanapum basalt aquifers is primarily to the southwest, away from the Laurel fault, and towards the Klickitat River. Based on a significant difference in groundwater levels on both sides of the Laurel fault, it appears that the Laurel fault acts as a low permeability barrier to groundwater flow. This is consistent with the hydraulic behavior of the Warwick Fault – the same type of fault – in the Swale Creek subbasin, immediately to the east (Aspect, 2007). The highest groundwater levels occur immediately to the southwest of the Laurel fault, which is indicative of a recharge zone to the Wanapum basalt aquifers. In addition, the groundwater level data suggest a small component of groundwater flow in Sections 14 and 23 (T03/R13) that is towards the southeast, parallel to the trend of the Laurel fault.

East of Laurel Fault

To the east of the Laurel fault, there are two major groundwater flow directions: to the north versus to the south of the western extension of the Horseshoe Bend anticline (mapped by WDNR as a monocline).

To the north of the Horseshoe Bend monocline, groundwater flow in both the Wanapum basalt and the Grande Ronde basalt aquifers is primarily to the north-northwest, away from the axis of the monocline, and towards the syncline that parallels Wheeler Canyon (Figures 3.6 and 3.7). In this area, there are numerous wells completed in both the Wanapum and Grande Ronde basalt aquifers. However, the groundwater recharge sources for the upper members of the Wanapum basalt may be greatly limited due to the deeply incised tributaries to Wheeler Canyon. Many of these tributaries are incised down into the deeper Roza and/or Frenchman Springs members, thus isolating the shallower basalt aquifer zones in this region. There are also smaller components of groundwater flow in this region to the northwest, towards Johnson Canyon, and to the northeast, towards lower Swale Creek canyon.

To the south of the Horseshoe Bend monocline, groundwater flow in the Wanapum basalt aquifers is primarily to the south-southeast, away from the axis of the monocline and towards the Swale Creek syncline and upper Swale Creek canyon (Figure 3.6). In this region of the study area, a majority of the wells are completed in the Wanapum basalt aquifers. Based on the groundwater elevation contour map, there is also a smaller component of groundwater flow in the vicinity of Sections 12 and 13 (T03/R13) that is to the northwest, parallel to the Laurel fault. Groundwater in the Wanapum basalt aquifers in this region likely discharges into Johnson Canyon.

3.3.2.1 Vertical Gradients

Because many of the wells within the study area are completed across multiple members of the Wanapum basalt or across both the Wanapum and the Grande Ronde basalts, it is difficult to determine exact vertical gradients between individual aquifer zones. However, the groundwater levels on the cross sections (Figures 3.2 to 3.5) generally indicate a downward vertical gradient – i.e., the groundwater levels of the wells completed in the upper flows of the CRBG are generally higher than the groundwater levels of the wells completed in the lower flows. Based on the cross sections (Figures 3.2 to 3.5) and the groundwater elevation contour maps (Figure 3.6 and 3.7), groundwater levels are between 200 and 400 feet lower in the Grande Ronde basalt compared to the Wanapum basalt.

3.4 Aquifer Hydraulic Parameters

Table 3.1 presents a summary of both regional and local aquifer hydraulic parameters, including lateral hydraulic conductivity, transmissivity and storativity. Hydraulic conductivity is a quantitative measure of an aquifer's ability to transmit water. Transmissivity is hydraulic conductivity multiplied by aquifer thickness and is a measure of how much water can move through the aquifer and thus the aquifer's productivity. Storativity is the product of specific storage and aquifer thickness, where specific storage is defined as the volume of water (cubic feet) that a 1 cubic foot volume of aquifer releases from storage when the water level drops 1 foot.

Regional hydraulic parameters for the Columbia Plateau aquifer system were estimated by the USGS as part of its Regional Aquifer System Analysis program (Vaccaro, 1999), and are provided in Table 3.1. Estimates of lateral hydraulic conductivity were initially based on specific capacity data from select well logs. Values for a well's specific capacity (pumping rate divided by drawdown; units of gpm/ft) can be used to calculate aquifer transmissivity based on the empirical equation (Driscoll, 1986):

$$T = 2000\frac{Q}{s}$$

Where: T = Transmissivity (gpd/ft)

Q = Yield of well (gpm)

s = Drawdown in well (ft)

The Q/s term is the well's specific capacity as defined above. Because drawdown increases with pumping duration, the specific capacity is typically defined for a specific pumping time.

In addition, the USGS provided estimates of hydraulic conductivity, transmissivity, and storage coefficient values based on hydrogeologic modeling of the Columbia River basalt aquifer system throughout the Columbia Plateau (Vacarro, 1999; Hansen et al., 1994; Whiteman et al., 1994). A summary of these results are also provided in Table 3.1.

More localized hydraulic parameters for the Wanapum basalt aquifers within the study area were estimated based on the specific capacity data from wells included in the water level monitoring network (Table 2.1) or on the cross sections (Figures 3.2 to 3.5). The only well included in the water level monitoring network in which the well log had specific capacity data was well T03/R13-28L1. This well is completed in the Priest Rapids member of the Wanapum basalt and has a short-term specific capacity of 2.4 gpm/foot.

There are only a few wells on the cross sections which have specific capacity data available on the well logs, including wells T03/R13-23L1 and T03/R14-19F1 (Figure 3.3), and T03/R13-15C1 (Figure 3.4). Well T03/R13-23L1 is completed across both the

Priest Rapids and Roza members, and has a yield of 20 gpm, with a specific capacity of 0.13 gpm/foot. Well T03/R14-19F1 is completed across both the Roza member and the upper portion of the Frenchman Springs member. This well has a yield of 7 gpm, with a specific capacity of 0.07 gpm/foot. Well T03/R13-15C1 is also completed across both the Roza member and the upper portion of the Frenchman Springs member. This well has a yield of 8 gpm and a specific capacity of 0.08 gpm/foot. The aquifer transmissivity estimates from these specific capacity data are summarized in Table 3.1.

The relatively limited specific capacity data indicate relatively low aquifer productivity, although this can be attributable to well construction (well losses) in addition to aquifer transmissivity. The data suggest that the Priest Rapids member of the Wanapum basalt may be a slightly more productive aquifer than either the Roza member or the upper portions of the Frenchman Springs member in certain regions of the study area. Based on Table 3.1 data, the Priest Rapids member has transmissivity values ranging between 35 and 630 ft^2/day (between 260 and 4,700 gpd/ft); while the Roza member and the upper portion of the Frenchman Springs member has transmissivity values ranging between 19 and 21 ft^2/day (between 140 and 160 gpd/ft). However, it important to note that the productivity of the basalt aquifers can be highly variable due to the presence of nearby geologic structures (folds and faults), and the nature and extent of interflow zones.

3.5 Long-Term Water Level Trends

The measured groundwater levels over time (groundwater elevation hydrographs) for the High Prairie study area are illustrated on Figure 3.8. Although only a limited number of groundwater level measurements have been collected from the expanded monitoring network wells to date (2 pre-irrigation and 1 post-irrigation monitoring events), groundwater level measurements from as many as nine monitoring events have been collected since 2007 from the original monitoring network wells, established as part of the Swale Creek subbasin water availability study (Aspect, 2007). Non-static groundwater level measurements (noted in Table 3.1) were not included in the groundwater hydrographs.

Based on Figure 3.8, many of the monitoring network wells have had relatively stable groundwater levels (less than 5 feet of fluctuation) since 2007, and the small fluctuations can likely be attributed to either seasonal changes or long-term precipitation trends. However, several wells (T03/R13-3B1, T03/R13-22P1, and T03/R13-22C1) have shown recent declines in groundwater levels that may only partially be attributed to long-term precipitation trends (see Section 3.5.1). The groundwater level in well T03/R13-3B1 has declined about 10 feet since the Spring 2010 (pre-irrigation) water level measurement. The groundwater level in well T03/R13-22P1 has also declined about 10 feet, but the decline has occurred since the Fall 2009 (post-irrigation) water level measurement. The biggest measured water level decline in the study area has occurred in well T03/R13-22C1. In this well, the groundwater level has declined about 25 feet since the Spring 2009 (pre-irrigation) water level measurement. Communication with the owner of one of the wells confirms that water level declines have been observed over the past two decades.

Well T03/R13-3B1 is completed in the lower Priest Rapids and upper Roza members of the Wanapum basalt (Figure 3.4). The well is also located about 3,000 feet to the east of

Johnson Canyon (tributary to Wheeler Canyon), about 4,000 feet east of the Laurel fault, about 1,000 feet west of a minor unnamed tributary to Wheeler Canyon, and about 5,000 feet west of a major unnamed tributary to Wheeler Canyon (Figure 2.1). As discussed in the Groundwater Occurrence section (Section 3.3), the Laurel fault likely acts as at least a partial barrier to lateral groundwater flow. In addition, all of the tributaries to Wheeler Canyon surrounding well T03/R13-3B1 are incised down into at least the Roza member of the Wanapum basalt. Therefore, since well T03/R13-3B1 is completed in the lower Priest Rapids and upper Roza members, its production aquifer zone is likely "compartmentalized", with a limited recharge area, which could eventually lead to declining groundwater levels within the well. Due to the limited groundwater recharge source, water levels within the aquifer could also be more sensitive to local precipitation trends.

Wells T03/R13-22P1 and T03/R13-22C1 are in relatively close proximity (about 1,500 feet apart) and are likely completed in the same Frenchman Springs interflow zone[4]. Based on the cross section (Figure 3.3), this interflow zone does not appear to be of significant thickness or extent, which likely explains why the water level decline is relatively localized. Due to the limited thickness and extent of the interflow zone, the aquifer may also be more sensitive to local precipitation trends (discussed in the following section).

3.5.1 Precipitation Trends

An analysis of the long-term precipitations trends was performed to assess correlation with the groundwater level declines observed in the wells discussed above. Precipitation data from the National Oceanic and Atmospheric Administration (NOAA) Weather Observation Stations in Goldendale (Station Nos. 453222 and 453226), were used to determine precipitation trends for the study area. Based on location, elevation, and surrounding topography, the Goldendale stations are assumed to be the most representative of the actual precipitation for the High Prairie study area. Brown (1979) also provided a distribution of mean (average) annual precipitation for Klickitat County, which confirms this. Goldendale has a mean annual precipitation of 16.7 inches for the station's period of record (1931 - 2010). The basin-scale water balance (Section 4) assumes an average annual precipitation of 19 inches/year for the study area as a whole, based on regional climatic modeling results; however, the regional modeling does not provide annual precipitation values over time, which is needed for the precipitation trend analyses, therefore the Goldendale data are used here.

The upper half of Figure 3.9 presents both the annual precipitation and the 16.7-inch mean annual precipitation for the period of record. In addition, a cumulative departure from the mean annual precipitation is presented in the lower half of Figure 3.9. The cumulative departure analysis adds the inches above or below the average precipitation for each year into a running total, and thereby illustrates longer-term drought or wet periods. It is important to note that individual months with more than 5 days of missing data were not used for monthly or annual precipitation statistics.

[4] Both wells are cased with a 40 foot screen interval across the interflow zone.

Based on Figure 3.9, the decline of groundwater levels in the monitoring network wells discussed above (T03/R13-3B1, T03/R13-22P1, and T03/R13-22C1) may partially be attributed to the below-average precipitation observed in the Goldendale area since the late 1990s, and longer-term, since 1984. With the exception of years 1995-1998[5], 2003, and 2010, the annual precipitation at Goldendale has been at or below the mean since 1984. However, if the decline of groundwater levels in the wells discussed above is directly related to the recent below-average precipitation, there must be a relatively significant lag-time, since the decline in groundwater levels were not observed until 2009. In short, it does not appear that the observed localized water level declines in the study area are attributable solely to precipitation trends. The current water year (Fall 2010-present) has had above-average precipitation to date, so continued water level monitoring will determine whether the observed rate of water level decline slows or reverses in response.

3.6 Interaction of Groundwater and Surface Waters

3.6.1 Springs and Creeks

Based on Newcomb (1969), there are several springs located in the southwestern region of the study area. These springs are caused by groundwater percolating through the relatively permeable unconsolidated deposits, primarily the Dalles Formation (Mc[d]), along the top of the CRBG before discharging in intermittent or perennial springs at the downgradient extent of the unconsolidated deposits (Piper, 1932). Within the study area, Newcomb (1969) maps springs at the downgradient extent of the Dalles Formation in Sections 20, 21, 27 and 29 of T03/R13 (Figure 3.1).

In addition, although not mapped by Newcomb (1969), there are also likely springs that occur at the downgradient extent of the CRBG, where streams and rivers have incised into and exposed the basalt interflow zones at the surface. Based on the geologic map (Figure 3.1), this likely includes: the Klickitat River, Knight Canyon, Dillacort Canyon, Wheeler Canyon, several tributaries to Wheeler Canyon, and Swale Creek. The cross sections (Figures 3.2 and 3.3) illustrate that these drainages should have springs discharging from the Priest Rapids and Roza members of the Wanapum basalt in their upstream portions (i.e. interflow zones within the basalts intersect the drainages). In their downstream portions, where the streams and rivers have incised deeper into the CRBG, there may also be springs discharging from the Frenchman Springs member of the Wanapum basalt and the upper flows of the Grande Ronde basalt. Brown (1979) maps springs within the study area along the Klickitat River in Sections 8, 17, and 19 (T03/R13), and within Wide Sky Canyon (T03N R13E Section 31; labeled Alder Spring on a USGS topographic map).

Based on the above discussion, the source of water for the smaller drainages in the study area (Knight Canyon, Dillacort Canyon, Wheeler Canyon, and the tributaries to Wheeler Canyon) is likely a combination of precipitation runoff and groundwater discharge from the various basalt interflow zones. There is groundwater continuity with these creeks, but

[5] The 1995 and 1998 data points for Goldendale are not plotted on Figure 3.9 because of gaps in the daily record; however, even with the missing data, their annual precipitation is at or above average.

the quantity of spring discharge is not sufficient to maintain perennial baseflow throughout their lengths. Groundwater interactions with Swale Creek and the Klickitat River are discussed in the following sections.

3.6.2 Swale Creek

The Swale Canyon portion of Swale Creek forms the eastern extent of the High Prairie study area (Figure 2.1). As illustrated on Figures 3.6 and 3.7 and previously discussed in Section 3.3.2, there are components of groundwater flow to the east of the Laurel fault that are towards Swale Creek. However, as discussed in Aspect (2007), there appears to be little baseflow contribution from the basalt aquifers to Swale Canyon to the west of the Warwick Fault. More groundwater discharges to Swale Canyon in its lowermost 3 or 4 miles where the canyon is east of the Warwick Fault, but the major springs appear to discharge from the east side of the Canyon, not the west (High Prairie) side. The limited baseflow contribution to Swale Creek from the basalt aquifers beneath High Prairie is likely due to the limited groundwater recharge area available between the Laurel fault and Swale Creek Canyon. In this area, the Priest Rapids is the only member of the Wanapum basalt exposed at the surface (other than within drainage features). Therefore, most of the areal recharge due to precipitation is likely occurring within the Priest Rapids member of the Wanapum basalt. In order for this recharge to reach the Roza and Frenchman Springs members, the groundwater must pass through the relatively impermeable flow interiors of the respective members of the Wanapum basalt.

3.6.3 Klickitat River

The Klickitat River forms the western extent of the High Prairie study area (Figure 2.1). In addition to precipitation runoff, the river likely receives spring discharge from the basalt interflow zones, most of which is via the incised streams discussed in Section 3.6.1 (e.g., Dillacort Canyon). As the A-A’ (Figure 3.2) and the B-B’ (Figure 3.3) cross sections illustrate, the Klickitat River is in direct hydraulic continuity with flows lower down in the Grand Ronde basalt sequence. Based on the cross sections, groundwater levels within the wells adjacent to the Klickitat River are between 20 and 50 feet below the river. However, it is important to note that the well locations adjacent to the river are quarter-quarter section locations, and there could be significant error associated with the ground surface elevations and thus the groundwater elevations. Therefore, based on the available groundwater level data, the Klickitat River appears to be a slightly losing to slightly gaining[6] stream adjacent to the study area.

[6] A losing stream discharges water to the groundwater system, whereas a gaining stream receives water (baseflow) from groundwater.

4 Water Balance

For this assessment, we prepared a basin-scale water balance representing current conditions for the High Prairie study area, using the same general methodologies applied in the prior water availability assessments for Swale and Little Klickitat subbasins of WRIA 30 (Aspect, 2007 and 2010b) and the WRIA 31 Level 1 Watershed Assessment (Aspect and WPN, 2004). Appendix B details the water balance methods and assumptions.

Using the water balance analysis, we estimate an average annual total water use within the study area of approximately 81 acre-feet/year; of this total use, about 9 acre-feet/year (11%) is consumed while the rest is return flow becoming groundwater recharge. Based on the collective information, including discussion with residents, we estimate that nearly all of the water use in the study area is for residential supply, with approximately 95% of that supplied by permit-exempt private wells.

Based on the proportion of water rights (certificates + permits) appropriated for the study area (as recorded in Ecology's Water Rights Tracking System [WRTS]), and information obtained from residents, we estimate that approximately 72% of the total water use in the study area is supplied by groundwater versus 28% from Swale Creek and smaller streams (Dillacort, Johnson, and an unnamed tributary to Wheeler Creek). The accuracy and validity of the water rights information in Ecology's Water Rights Tracking System (WRTS) is not known, and the recorded water right information may overstate surface water use within the study. Notably, the WRTS includes several Klickitat River water rights for irrigation use but, based on review of current aerial photographs, reconnaissance of the area, and discussion with residents, this larger-scale irrigation water use is not occurring currently; therefore, we assume no water use in the study area currently supplied by the Klickitat River.

Treatment of residential wastewater in the study area is accomplished via septic tanks, so that water that is used but not consumed (termed return flow) is returned to the groundwater system as artificial recharge. Because residential water use is largely nonconsumptive (based on USGS statistics), the water balance estimates that the annual consumptive groundwater use is less than 1 percent of the annual groundwater recharge for the study area as a whole. This calculation "nets out" recharge of return flow from groundwater use, so the net water input and output for the groundwater system can be compared.

However, as is common in WRIA 30, the study area's basalt aquifers are compartmentalized, as described in Section 3, and the volume of groundwater production is not uniformly distributed across the study area. Documenting groundwater use versus recharge for localized areas would require considerable additional information and is beyond the scope of this basin-scale study. Instead, an expanded water level monitoring network has been established for the study area, and continued monitoring of water levels, particularly in areas of greater population density and groundwater production, will provide the best indication (empirical) regarding sustainability of current pumping, and capacity to accommodate additional future withdrawals (i.e. groundwater availability for appropriation).

5 Conclusions and Recommendations

The primary conclusions and recommendations from this assessment are as follows:

- The primary sources of water supply for the study area include groundwater withdrawal from the Columbia River Basalt Group aquifer system and surface water diversions from the Klickitat River, with lesser supplies from other surface waters (Swale Creek and smaller streams).
- The Columbia River Basalt Group consists of the Wanapum and Grande Ronde basalt formations within the study area, which are further subdivided into individual members. Aquifer zones occur in vertically distinct interflow zones within each member. Based on the available data, groundwater levels appear to be between 200 and 400 feet deeper in the Grande Ronde basalt aquifers than in the shallower Wanapum basalt aquifers.
- The Wanapum basalt aquifers are the primary source of groundwater supply for the study area as a whole. However, the Grande Ronde basalt provides a significant groundwater source in the southernmost and northeastern portions of the study area.
- Where data were sufficient, groundwater elevation contour maps were created for both the Wanapum and Grande Ronde basalt aquifers. However, the northwest-trending Laurel fault, running generally through the center of the study area, acts as low permeability barrier to lateral groundwater flow. Groundwater elevations are also highest in this central portion of the study area. West of the Laurel fault, groundwater flows to the southwest with discharge to the Klickitat River and its tributary stream (e.g., Dillacort Canyon). Groundwater to the east of the Laurel fault and to the north of the extension of the Horseshoe Bend anticline generally flows to the north, towards Wheeler Canyon and lower Swale Creek canyon. Groundwater to the east of the Laurel fault and to the south of the extension of the Horseshoe Bend anticline generally flows to south-southeast, towards upper Swale Creek canyon.
- The Klickitat River is in direct hydraulic continuity with flows lower down in the Grande Ronde basalt sequence. Based on groundwater levels in the wells adjacent to the river, the river appears to be a slightly losing to slightly gaining stream adjacent to the study area. The Klickitat River also receives water via spring discharge from the upper flows of the Grande Ronde and the Wanapum basalts.
- Swale Creek is in direct hydraulic continuity with the Grande Ronde basalt, but spring discharge from the Grande Ronde or Wanapum basalt aquifers does not appear to be a significant source of water to Swale Creek.
- To better assess groundwater-surface water continuity in important tributary creeks (e.g., Dillacort and Wheeler Creeks), we recommend installation,

calibration, and long-term operation of streamflow gages on creeks where landowner permission is granted.

- Groundwater elevation monitoring has been conducted twice a year (spring and fall) in the original study area monitoring network wells, with up to nine rounds of measurements collected since 2007. For this study, the monitoring network was expanded from 14 to 23 wells, providing more complete spatial coverage of the area. To date, three rounds of groundwater level measurements have been collected from the expanded water level monitoring network .
- Based on the groundwater level hydrographs, seasonal increases and decreases in groundwater levels of less than 5 feet have occurred in many of the wells. Most wells show no clear increasing or decreasing long-term trend over the period of record. However, groundwater level declines of 10 feet are observed in wells T03/R13-3B1 and T03/R13-22P1, and a groundwater level decline of 25 feet has been measured in well T03/R13-22C1. Communication with a local well owner confirms that declines have occurred over the past two decades. Groundwater level declines in these wells may be partially, but not completely, due to below-average precipitation over the period of monitoring. In addition, the groundwater level decline observed in well T03/R13-3B1 may also be partially due to the well being surrounded by drainages that have cut deeply into the basalt aquifers, and isolated the well from a laterally continuous source of groundwater recharge. Wells T03/R13-22P1 and T03/R13-22C1 appear to be completed in a relatively thin and non-extensive basalt aquifer zone. Due to the limited thickness and extent of this interflow zone, and proximity to a major geologic fault to the south, the wells may be drawing from an aquifer zone with a limited source of recharge.
- On the scale of the entire study area, the annual quantity of consumptive groundwater use is less than 1 percent of the annual groundwater recharge. This suggests that additional groundwater is available for appropriation and use within the study area. However, the analysis assumes uniform distribution of groundwater recharge and groundwater pumping across the entire study area; it does not account for localized pumping. In addition, potential for impairment to senior water users and surface water bodies would need to be determined individually for each pending water right application.
- A groundwater level monitoring network has been established that provides the opportunity, with continued landowner permission, to track future changes in the groundwater system of the High Prairie study area. Evaluation of long-term groundwater level trends provides key empirical information regarding sustainability of groundwater production in the study area, and thus availability of additional groundwater for supply purposes. It is critical to continue monitoring to track long-term trends in water levels, particularly given the apparent compartmentalized nature of the basalt aquifers within the study area. In addition, we recommend coordinating with the local community to identify well(s) across the study area that can be instrumented with a data logger (downhole pressure transducer) to allow frequent water level measurements. This information can provide more detailed understanding of groundwater response to local pumping, as well as seasonal and longer-term changes.

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Limitations

Work for this project was performed and this report 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 WRIA 30 Water Resource Planning & Advisory Committee for specific application to the referenced property. This report does not represent a legal opinion. No other warranty, expressed or implied, is made

Table 2.1 - Groundwater Level Monitoring Network

High Prairie Water Availability Study
WRIA 30, Washington

Study Area	Ecology Well Log Data						Well Survey Data				
	Ecology ID	TRS Label	Well Log Date	Dia. (in)	Depth (ft)	Unit of Completion	Northing[1] (SPS 83; ft)	Easting[1] (SPS 83; ft)	Top of Casing Elevation[2] (NAVD 88; ft)	Casing Stick-up (ft)	Comments
High Prairie	140432	T03/R13-3B1	11/12/86	6	76	Wanapum	162902.9	1472929.6	2011.17	1.02	
High Prairie	141250	T03/R13-3R1	4/15/87	6	745	Wanapum & Grande Ronde	159389.4	1472760.9	2146.99	1.65	No longer monitored due to numerous obstructions in the well.
High Prairie Expansion	377250	T03/R13-4L1	10/25/95	6	620	Wanapum & Grande Ronde	160519.0	1464962.0	2126.25	1.25	
High Prairie	141715	T03/R13-11M1	8/31/94	6	524	Wanapum	155087.0	1474093.1	2037.44	1.66	
High Prairie	139955	T03/R13-14A1	10/16/92	6	500	Wanapum	152621.1	1478289.8	2181.16	0.81	
High Prairie	377252	T03/R13-14G1	7/7/95	6	500	Wanapum	151451.4	1476350.7	2085.99	-	
High Prairie	477832	T03/R13-14G2	2/28/07	6	458	Wanapum	151661.4	1476308.2	2082.02	1.54	
High Prairie Expansion	136943	T03/R13-14J	5/30/90	6	460	Wanapum	149010.8	1477037.7	2000.84	1.30	Owner does not have well log. Well log chosen based on water level.
High Prairie Expansion	145893	T03/R13-15L1	8/13/87	6	105	Wanapum	149748.7	1470418.5	-	1.05	Limited access; remove expansion bolt. Airline installed to unknown depth. GPS Location.
High Prairie Expansion	144433	T03/R13-20N1	11/22/94	6	520	Wanapum	144704.4	1457869.5	1452.74	1.00	Airline installed at approximate depth of 520 ft.
High Prairie Expansion	384137	T03/R13-20N2	7/15/04	6	530	Grande Ronde	144430.9	1458080.8	1427.90	1.50	Well Tag: AKL-875
High Prairie Expansion	143160	T03/R13-21M1	7/11/97	6	520	Wanapum	145315.8	1463014.1	1745.30	1.05	Sonic water level indicator not accurate.
High Prairie Expansion	145685	T03/R13-21P1	5/6/94	6	200	Wanapum	139938.4	1465005.9	1569.93	0.55	3 wells in Tad Blouin's name. Measured well is different than well log.
High Prairie	335153	T03/R13-22C1	5/9/02	6	225	Wanapum	143235.9	1470655.1	1777.48	1.46	
High Prairie	377254	T03/R13-22P1	10/19/95	6	280	Wanapum	144550.2	1470944.8	1763.36	0.79	
High Prairie	139217	T03/R13-23L1	5/30/81	6	449	Wanapum	145104.1	1475387.6	1808.08	1.05	Originally had an airline installed at depth of 140 ft. Access port later installed (May/June 2010).
High Prairie Expansion	556399	T03/R13-27	8/7/08	6	165	Grande Ronde	140168.2	1469338.5	1747.10	-	Well Tag: APT-283
High Prairie	139404	T03/R13-27Q1	10/27/93	6	310	Grande Ronde	138228.3	1471376.8	1996.03	1.79	
High Prairie	143537	T03/R13-28B1	9/7/94	6	220	Wanapum	143022.4	1466216.1	1622.75	2.38	
High Prairie Expansion	372465	T03/R13-28F1	11/4/03	6	335	Wanapum	140751.7	1464326.2	1527.26	1.45	Well Tag: AHK-331 2 wells; well not currently in use is monitored.
High Prairie	139337	T03/R13-28L1	12/27/72	8	90	Wanapum	141586.1	1465563.3	1498.67	0.88	
High Prairie/ Swale Creek	354742	T03/R14-18N1	5/20/97	6	695	Wanapum	149041.9	1484973.1	2153.66	1.43	
High Prairie/ Swale Creek	302764	T04/R14-31L1	10/12/00	6	506	Wanapum	167675.2	1486274.0	1785.85	2.94	No longer wants to partcipate in monitoring program.

Notes:

[1] Northing and Easting coordinates are in Washington South State Plane coordinate system (NAD 1983 datum).

[2] All elevations are in NAVD 1988 datum.

Table 2.2 - Monitoring Network Groundwater Level Data

High Prairie Water Availability Study
WRIA 30, Washington

Ecology Well Log Data		June 2007 Measurements			November 2007 Measurements			April 2008 Measurements			December 2008 Measurements			April 2009 Measurements			December 2009 Measurements			May/June 2010 Measurements			November/December 2010 Measurements			April 2011 Measurements		
Ecology Well Log ID	TRS Label	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	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
140432	T03/R13-3B1	203.6	1807.5		-	-	Well box frozen shut	-	-	No permission	207.2	1804.0		205.6	1805.6		206.2	1805.0		204.5	1806.7		214.6	1796.6		212.5	1798.7	
141250	T03/R13-3R1	549.5	1597.5		549.7	1597.3		549.7	1597.3		549.7	1597.3		549.4	1597.6		549.0	1598.0		-	-	Not monitored	-	-	Not monitored	-	-	Not monitored
377250	T03/R13-4L1	-	-		-	-		-	-		-	-		-	-		-	-		524.7	1601.6		524.2	1602.1		524.8	1601.4	
141715	T03/R13-11M1	115.1	1922.3		115.1	1922.4		115.2	1922.2		116.1	1921.4		115.4	1922.0		114.8	1922.6		115.5	1921.9		115.7	1921.8		115.8	1921.6	
139955	T03/R13-14A1	435.4	1745.7		434.4	1746.8		435.2	1746.0		434.2	1747.0		435.8	1745.4		-	-	Not monitored	434.8	1746.4		436.1	1745.1		436.5	1744.6	
377252	T03/R13-14G1	195.1	1890.9		196.0	1890.0		197.4	1888.6		197.0	1889.0		196.4	1889.6		196.8	1889.2		195.1	1890.9		197.2	1888.8		197.6	1888.4	
477832	T03/R13-14G2	173.2	1908.8		174.5	1907.6		177.6	1904.4		180.5	1901.6		181.1	1900.9		-	-	Unstable water level	176.8	1905.2		182.7	1899.3		182.7	1899.4	
136943	T03/R13-14J	-	-		-	-		-	-		-	-		-	-		-	-		323.4	1677.5	Rising water level	322.3	1678.5		320.5	1680.4	
145893	T03/R13-15L1	-	-		-	-		-	-		-	-		-	-		-	-		13.4	-		11.4	-		-	-	No Permission
144433	T03/R13-20N1	-	-		-	-		-	-		-	-		-	-		-	-		462.0	990.7		478.4	974.3		478.4	974.3	
384137	T03/R13-20N2	-	-		-	-		-	-		-	-		-	-		-	-		436.5	991.4	Rising water level	326.2	1101.7		343.0	1084.9	Rising water level
143160	T03/R13-21M1	-	-		-	-		-	-		-	-		-	-		-	-		492.4	1252.9		492.5	1252.8		489.3	1256.0	
145685	T03/R13-21P1	-	-		-	-		-	-		-	-		-	-		-	-		179.5	1390.5	Rising water level	179.0	1390.9		177.1	1392.8	
335153	T03/R13-22C1	162.2	1615.3		161.3	1616.2		160.7	1616.8		161.9	1615.6		162.0	1615.5		175.0	1602.5		182.0	1595.5		185.0	1592.5		185.7	1591.8	
377254	T03/R13-22P1	139.5	1623.8	Unstable water level	139.7	1623.7		140.2	1623.2		139.7	1623.7		139.6	1623.8		140.9	1622.5		145.3	1618.1		146.4	1617.0		150.6	1612.8	
139217	T03/R13-23L1	75.3	1732.8	Airline measurement	-	-	Not monitored	-	-	Not monitored	-	-	Not monitored	-	-	Not monitored	-	-	Not monitored	41.7	1766.4		38.6	1769.5		37.5	1770.6	
556399	T03/R13-27	-	-		-	-		-	-		-	-		-	-		-	-		87.6	1659.5		88.7	1658.4		87.6	1659.5	
139404	T03/R13-27Q1	262.3	1733.7		261.4	1734.6		262.2	1733.8		261.8	1734.2		261.4	1734.6		260.0	1736.0		261.4	1734.6		262.4	1733.6		263.3	1732.7	
143537	T03/R13-28B1	141.2	1481.6		145.8	1477.0		141.8	1480.9		145.1	1477.6	Rising water level	141.4	1481.3		143.8	1478.9		142.0	1480.7		143.2	1479.6		139.4	1483.3	
372465	T03/R13-28F1	-	-		-	-		-	-		-	-		-	-		-	-		107.3	1420.0		100.7	1426.6		95.8	1431.5	
139337	T03/R13-28L1	21.4	1477.3	Rising water level	25.2	1473.5		20.4	1478.2		24.4	1474.3	Rising water level	21.0	1477.7		23.0	1475.7		19.4	1479.3		22.6	1476.1		18.6	1480.1	
354742	T03/R14-18N1	516.7	1637.0		518.3	1635.4		517.9	1635.7		519.5	1634.2		518.3	1635.3		-	-	Not monitored	518.6	1635.1		519.1	1634.6		518.7	1635.0	
302764	T04/R14-31L1	267.1	1518.7		265.4	1520.5		264.9	1521.0		265.2	1520.7		265.9	1520.0		264.8	1521.1		-	-	No permission	-	-	Not monitored	-	-	Not monitored

Notes:

[1] Northing and Easting coordinates are in Washington South State Plane coordinate system (NAD 1983 datum).

[2] All elevations are in NAVD 1988 datum.

Table 3.1 - Hydraulic Parameter Estimates for Basalt Aquifers

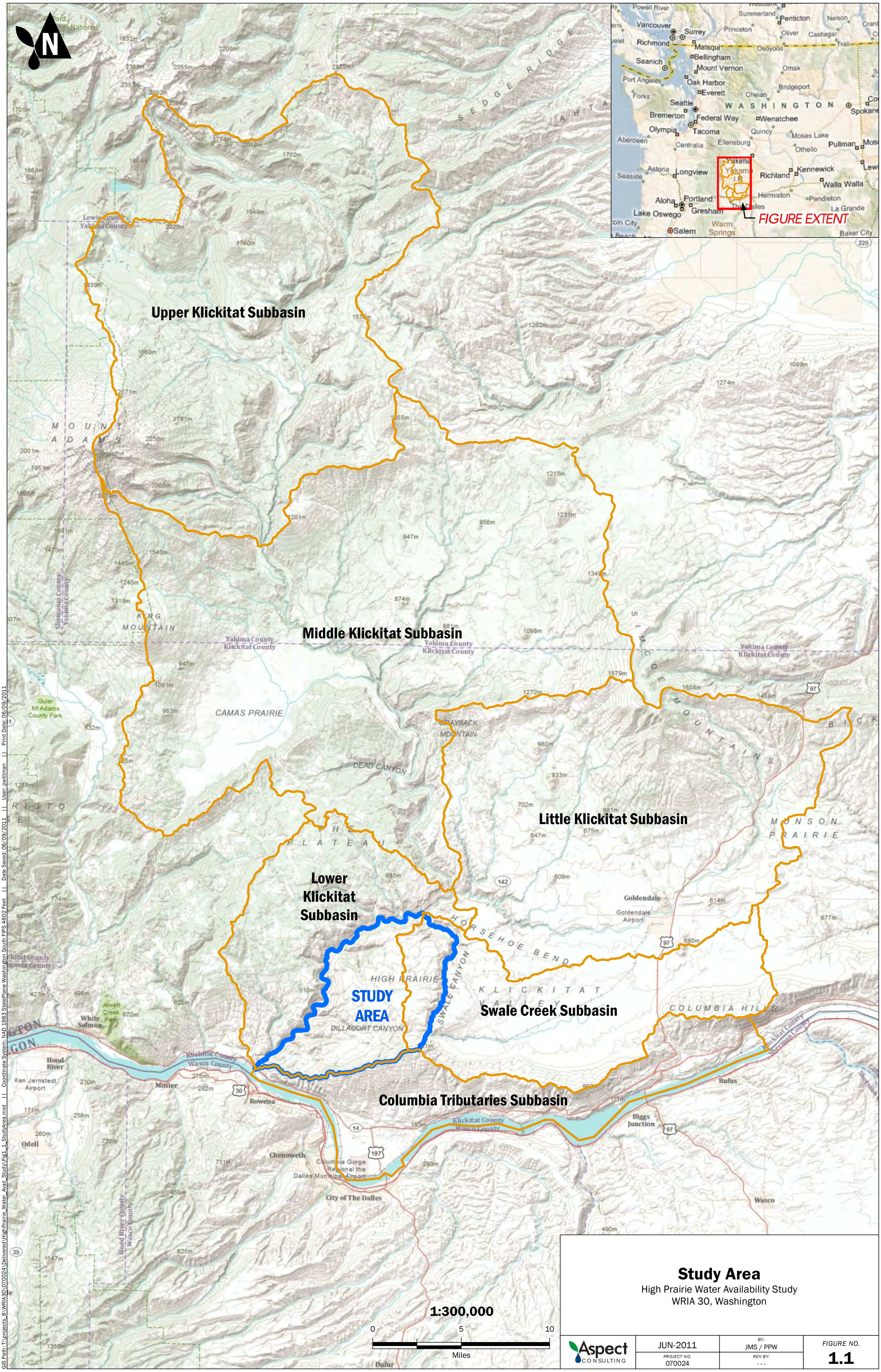
High Prairie Water Availability Study
WRIA 30, Washington

Wanapum Basalt

Hydraulic Conductivity (ft/day)			Transmissivity (ft^2/day)			Storativity (Dimensionless)			Location	Aquifer	Data Type	Source
Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean				
0.087	8	3	4	9331	1339	2.E-06	1.E-04	3.E-05	Columbia Plateau Aquifer System	-	Model	Vacarro, 1999; Whiteman et. al, 1994
0.007	5244	66	-	-	-	-	-	-	Columbia Plateau Aquifer System	-	Specific Capacity	Vacarro, 1999
0.864	3	-	-	-	-	-	-	-	High Praire Area	-	Model	Hansen, Vacarro and Bauer, 1994
-	-	-	-	-	630	-	-	-	T03/R13-28L1	Priest Rapids and Roza	Specific Capacity (Well Log)	Department of Ecology Well Log Database
-	-	-	-	-	35	-	-	-	T03/R13-23L1	Priest Rapids and Roza	Specific Capacity (Well Log)	Department of Ecology Well Log Database
-	-	-	19	21	-	-	-	-	T03/R14-19F1 T03/R13-15C1	Roza and Frenchman Springs	Specific Capacity (Multiple Well Logs)	Department of Ecology Well Log Database

Upper Grande Ronde Basalt

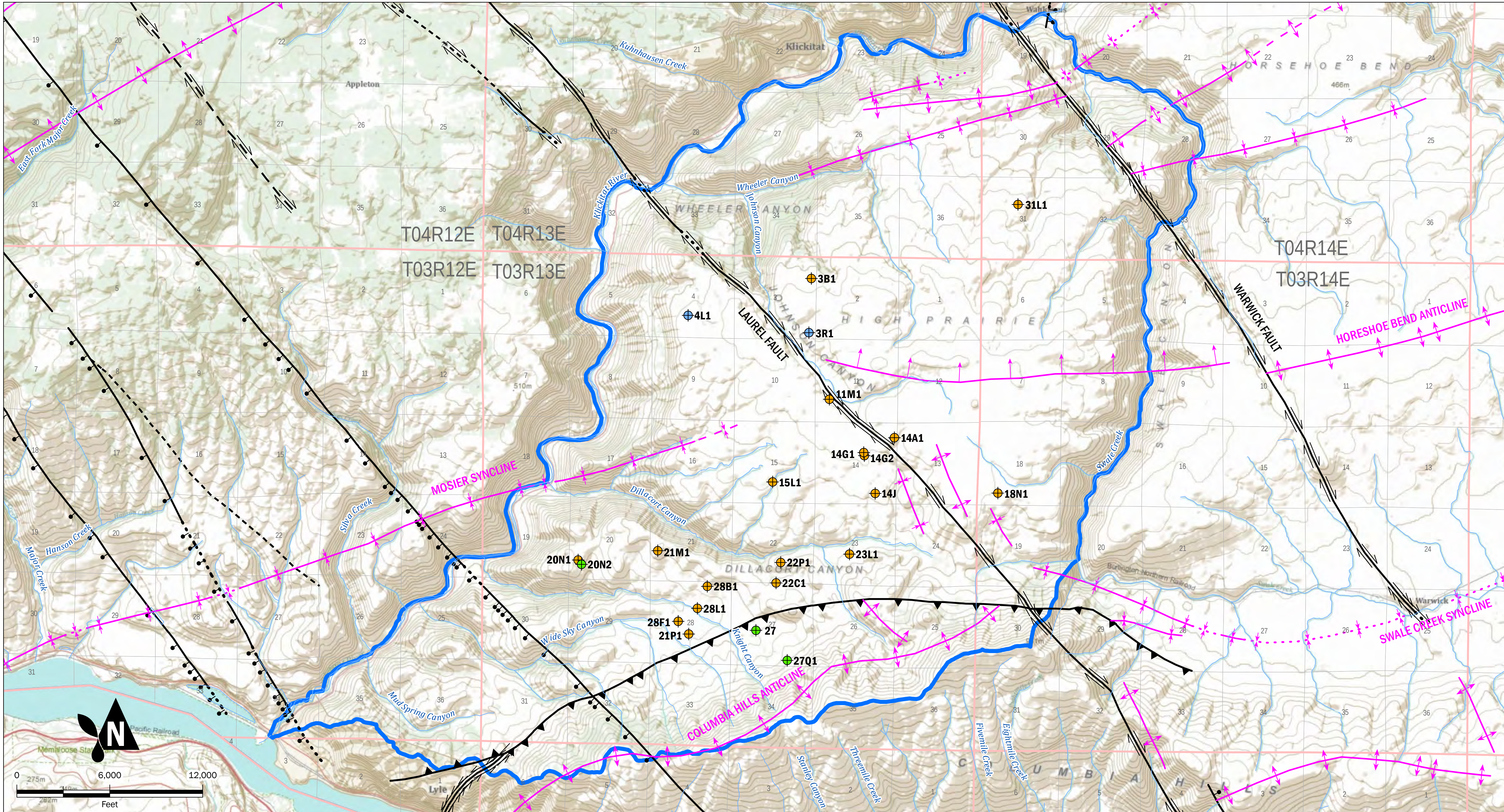
Hydraulic Conductivity (ft/day)			Transmissivity (ft^2/day)			Storativity (Dimensionless)			Location	Aquifer	Data Type	Source
Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean				
0.130	9	2	41	15898	3672	6.E-06	1.E-03	2.E-04	Columbia Plateau Aquifer System	-	Model	Vacarro, 1999; Whiteman et. al, 1994
0.005	2523	50	-	-	-	-	-	-	Columbia Plateau Aquifer System	-	Specific Capacity	Vacarro, 1999
0.864	2	-	-	-	-	-	-	-	High Prairie Area	-	Model	Hansen, Vacarro and Bauer, 1994



Study Area

High Prairie Water Availability Study
WRIA 30, Washington

Aspect CONSULTING	JUN-2011	BY: JMS / PPW	FIGURE NO.
	PROJECT NO. 070024	REV BY: - - -	1.1



Surveyed Groundwater Monitoring Network Well Location (by completion aquifer):

- 3B1 Wanapum
- Wanapum and Grande Ronde
- Grande Ronde

High Prairie Study Area

Township/Range

8 Sections

Folds (Washington DNR 1:100K mapping)

- Anticline (location accurate)
- Anticline (location approximate)
- Anticline (location concealed)
- Syncline (location accurate)
- Syncline (location approximate)
- Syncline (location concealed)
- Monocline, anticlinal bend (location accurate)
- Monocline, anticlinal bend (location concealed)

Faults (Washington DNR 1:100K mapping)

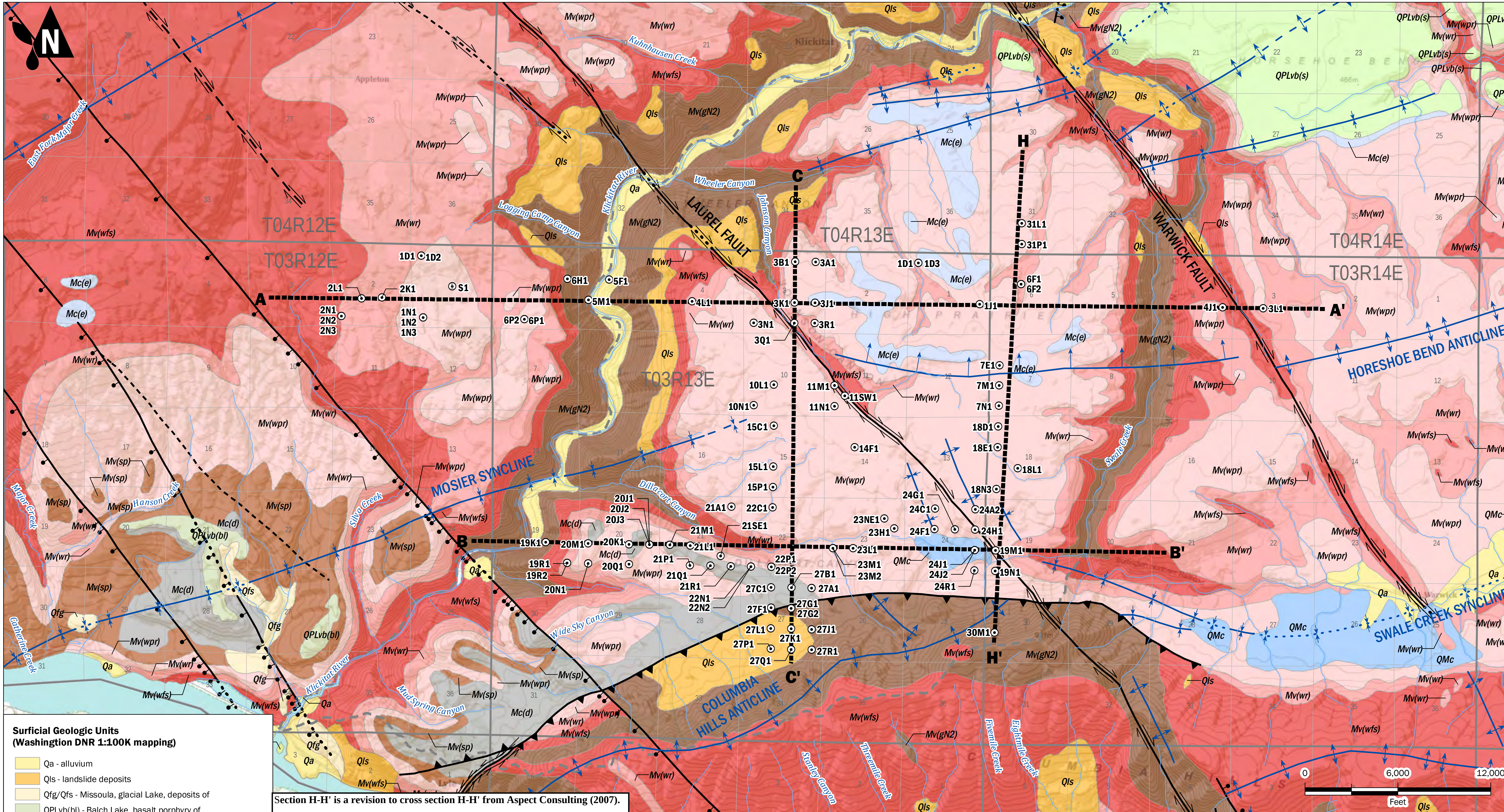
- Thrust fault (location accurate). Sawteeth on upper plate.
- Thrust fault (location concealed). Sawteeth on upper plate.
- Normal fault (location concealed). Bar and ball on downthrown block.
- Normal fault (location inferred). Bar and ball on downthrown block.
- Normal fault (location accurate). Bar and ball on downthrown block.
- Fault, unknown offset (location accurate)
- Fault, unknown offset (location inferred)
- Right-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location approximate). Arrows show relative motion.
- Right-lateral strike-slip fault (location concealed). Arrows show relative motion.
- Left-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location inferred). Arrows show relative motion

Groundwater Level Monitoring Network

High Prairie Water Availability Study
WRIA 30, Washington

Aspect CONSULTING	JUN-2011	BY: JMS / PPW	FIGURE NO.
	PROJECT NO. 070024	REV BY: - - -	2.1

GIS Path: T:\projects_8\WRIA30_070024\Delivered\High Prairie Water Avail Study\Fig2_1_GW_Level_Mon_Net.mxd || Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet || Date Saved: 06/20/2011 || User: pwittman || Print Date: 06/20/2011



Surficial Geologic Units (Washington DNR 1:100K mapping)

- Qa - alluvium
- Qls - landslide deposits
- Qfg/Qfs - Missoula, glacial Lake, deposits of
- QPLvb(bl) - Balch Lake, basalt porphyry of
- QPLvb(s) - Simcoe Mountains, volcanic rocks of
- QMc - continental sedimentary deposits, including Swale Creek Valley [QPLc(s)]
- Mc(e) - Ellensburg Formation
- Mc(d) - Dalles Formation
- Mv(sp) - Pomona Member, Saddle Mountains Basalt
- Mv(wpr) - Priest Rapids Member, Wanapum Basalt
- Mv(wr) - Roza Member, Wanapum Basalt
- Mv(wfs) - Frenchman Springs Member, Wanapum Basalt
- Mv(gN2) - Grande Ronde Basalt, N2

- Cross Section Well
- Cross Section
- High Prairie Study Area
- Township/Range
- 8 Sections

Folds (Washington DNR 1:100K mapping)

- Anticline (location accurate)
- Anticline (location approximate)
- Anticline (location concealed)
- Syncline (location accurate)
- Syncline (location approximate)
- Syncline (location concealed)
- Monocline, anticlinal bend (location accurate)
- Monocline, anticlinal bend (location concealed)

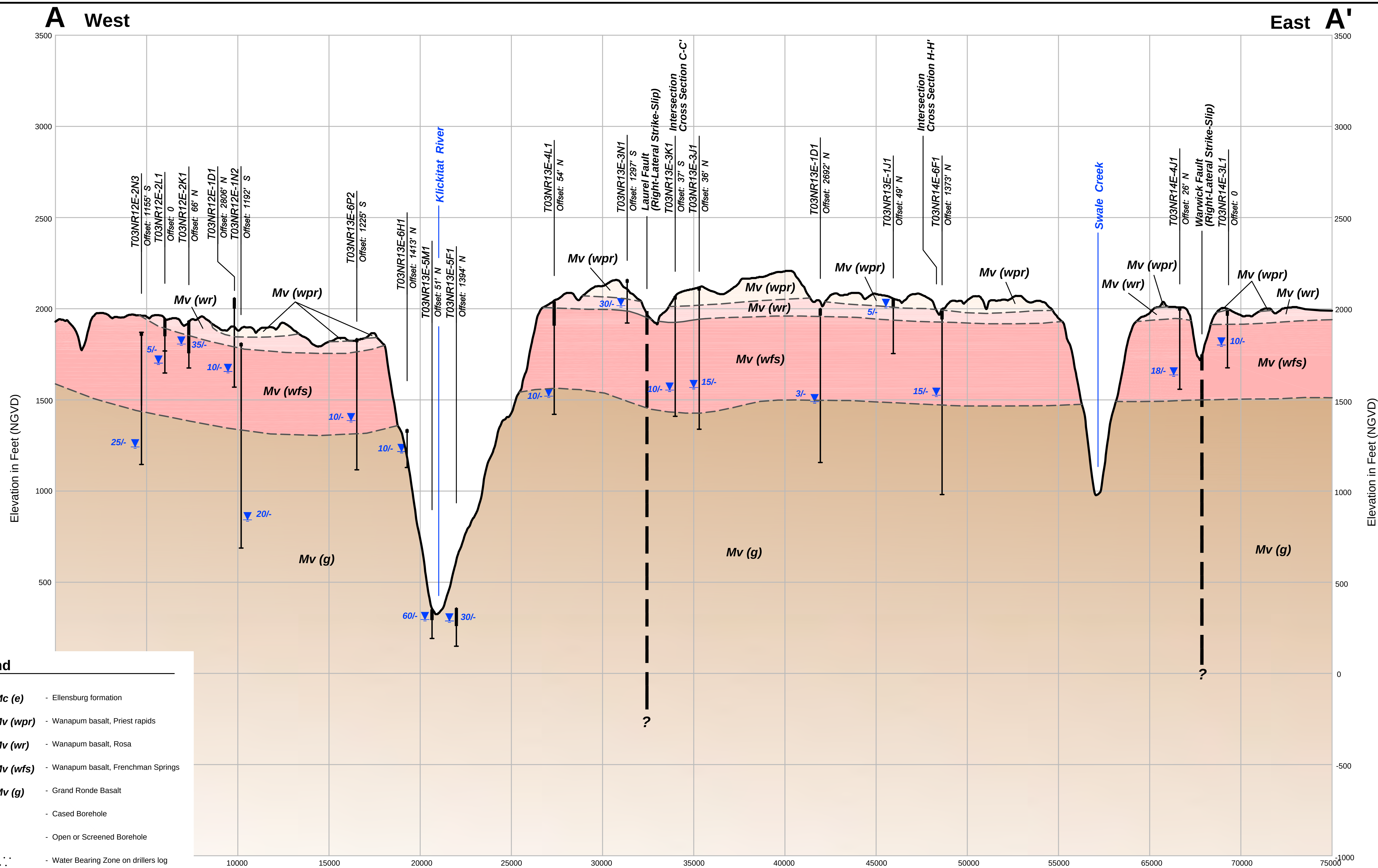
Faults (Washington DNR 1:100K mapping)

- Thrust fault (location accurate). Sawteeth on upper plate.
- Thrust fault (location concealed). Sawteeth on upper plate.
- Normal fault (location concealed). Bar and ball on downthrown block.
- Normal fault (location inferred). Bar and ball on downthrown block.
- Normal fault (location accurate). Bar and ball on downthrown block.
- Fault, unknown offset (location accurate)
- Fault, unknown offset (location inferred)
- Right-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location approximate). Arrows show relative motion.
- Right-lateral strike-slip fault (location concealed). Arrows show relative motion.
- Left-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location inferred). Arrows show relative motion

Cross Section Location and Geologic Map

High Prairie Water Availability Study
WRIA 30, Washington

Aspect CONSULTING	JUN-2011	BY: JMS / PPW	FIGURE NO. 3.1
	PROJECT NO. 070024	REV BY: - - -	



Legend

	Mc (e)	- Ellensburg formation
	Mv (wpr)	- Wanapum basalt, Priest rapids
	Mv (wr)	- Wanapum basalt, Rosa
	Mv (wfs)	- Wanapum basalt, Frenchman Springs
	Mv (g)	- Grand Ronde Basalt
		- Cased Borehole
		- Open or Screened Borehole
WB		- Water Bearing Zone on drillers log
		- Water level on drillers log
20/0.13		- Well yield (gpm) / specific capacity (gpm/ft)
		- Fault/Fold

Vertical Exaggeration = 10X
Scale: 1" = 5000' Horiz.
1" = 500' Vert.

0 5000 10000
Feet

Aspect CONSULTING

Cross Section A-A'

High Prairie Water Availability Study
WRIA 30, Washington

DATE: June 2011
DESIGNED BY: DFR/AAE/JMS
DRAWN BY: PMB
REVISED BY:

PROJECT NO. 070024
FIGURE NO. 3.2

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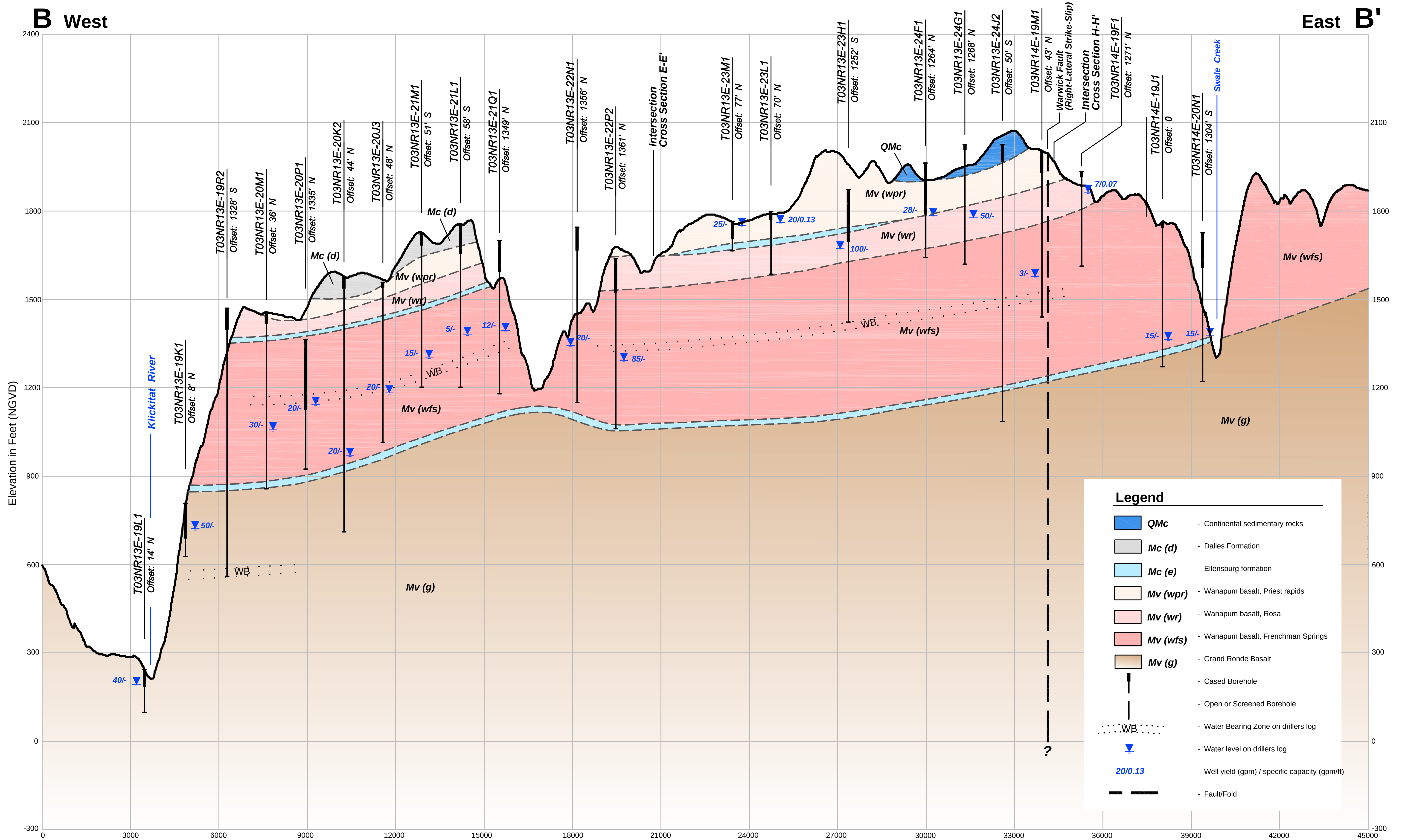


Vertical Exaggeration = 10X
Scale: 1" = 3000' Horiz.
1" = 300' Vert.

0 3,000 6,000
Feet

Aspect CONSULTING

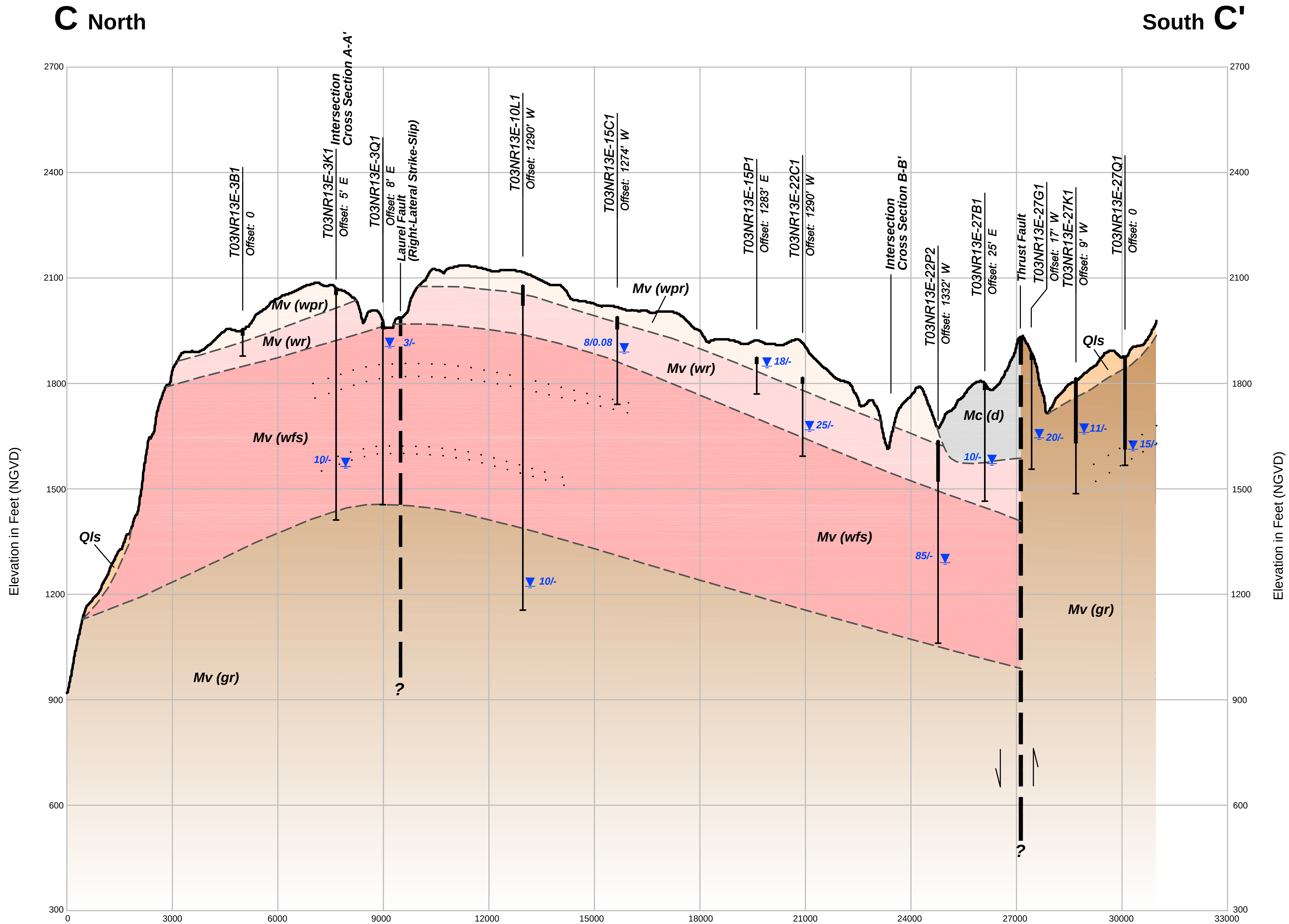
Cross Section B-B'

High Prairie Water Availability Study

WRIA 30, Washington

DATE:	June 2011
DESIGNED BY:	DFR/AAE/JMS
DRAWN BY:	PMB
REVISED BY:	
PROJECT NO.	070024
FIGURE NO.	3.3

Q:\WRIA\070024 WRIA 30\2011-06\070024-BB.dwg



Legend

	Qls	- Landslide
	QMc	- Continental sedimentary rocks
	Mc (d)	- Dalles Formation
	Mc (e)	- Ellensburg formation
	Mv (wpr)	- Wanapum basalt, Priest rapids
	Mv (wr)	- Wanapum basalt, Rosa
	Mv (wfs)	- Wanapum basalt, Frenchman Springs
	Mv (gr)	- Grand Ronde Basalt
		- Cased Borehole
		- Open or Screened Borehole
	WB	- Water Bearing Zone on drillers log
		- Water level on drillers log
	20/0.13	- Well yield (gpm) / specific capacity (gpm/ft)
		- Fault/Fold

Vertical Exaggeration = 10X
Scale: 1" = 3000' Horiz.
1" = 300' Vert.

0 3,000 6,000
Feet

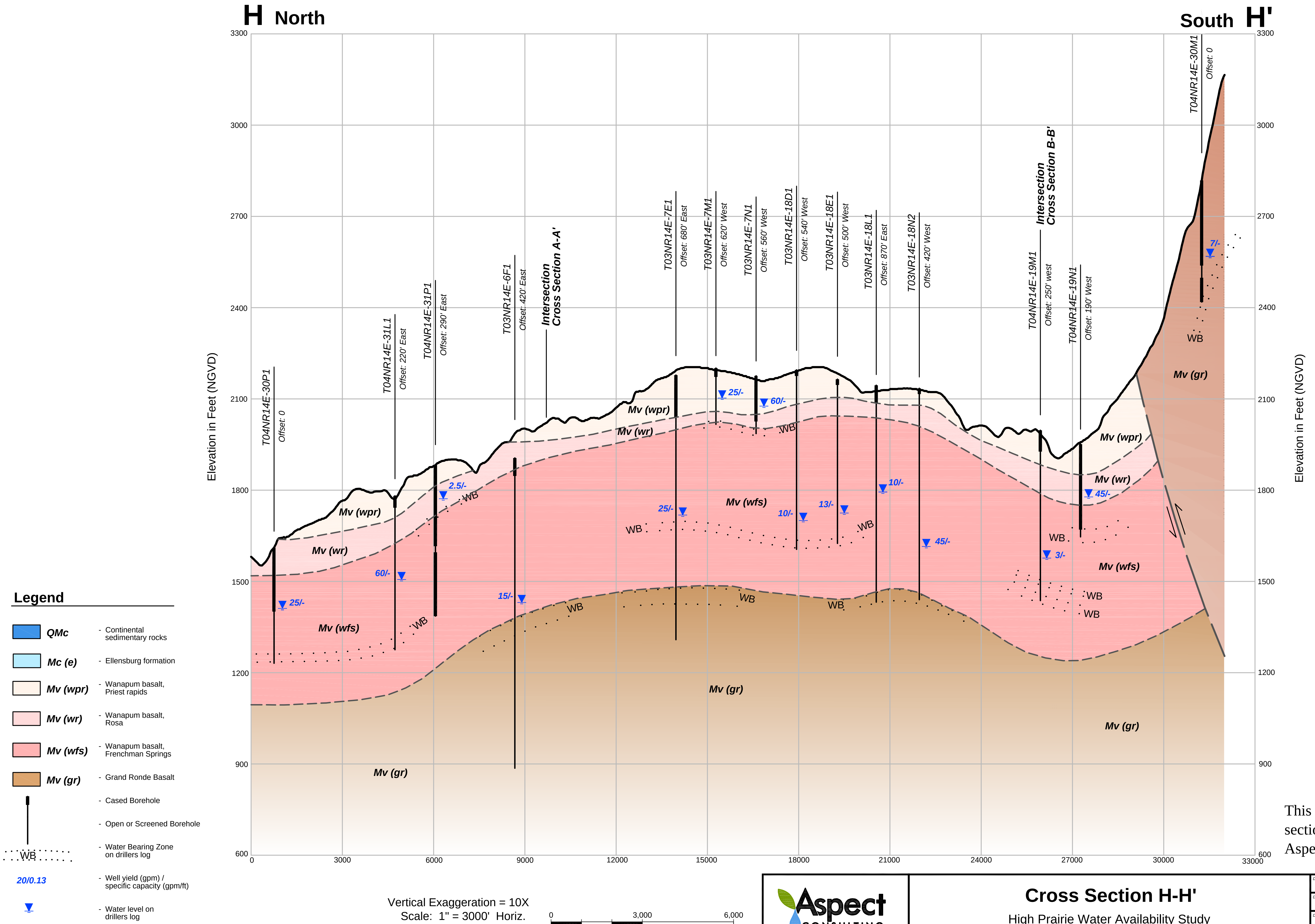
Aspect CONSULTING

Cross Section C-C'

High Prairie Water Availability Study
WRIA 30, Washington

DATE: June 2011	PROJECT NO. 070024
DESIGNED BY: DFR/AAE/JMS	
DRAWN BY: PMB	FIGURE NO. 3.4
REVISED BY:	

Q:\WRIA 30\070024 WRIA 30\2011-06\070024-EE.dwg



Vertical Exaggeration = 10X
Scale: 1" = 3000' Horiz.
1" = 300' Vert.

0 3,000 6,000
Feet

This is a revision to cross section H-H' presented in Aspect (2007).

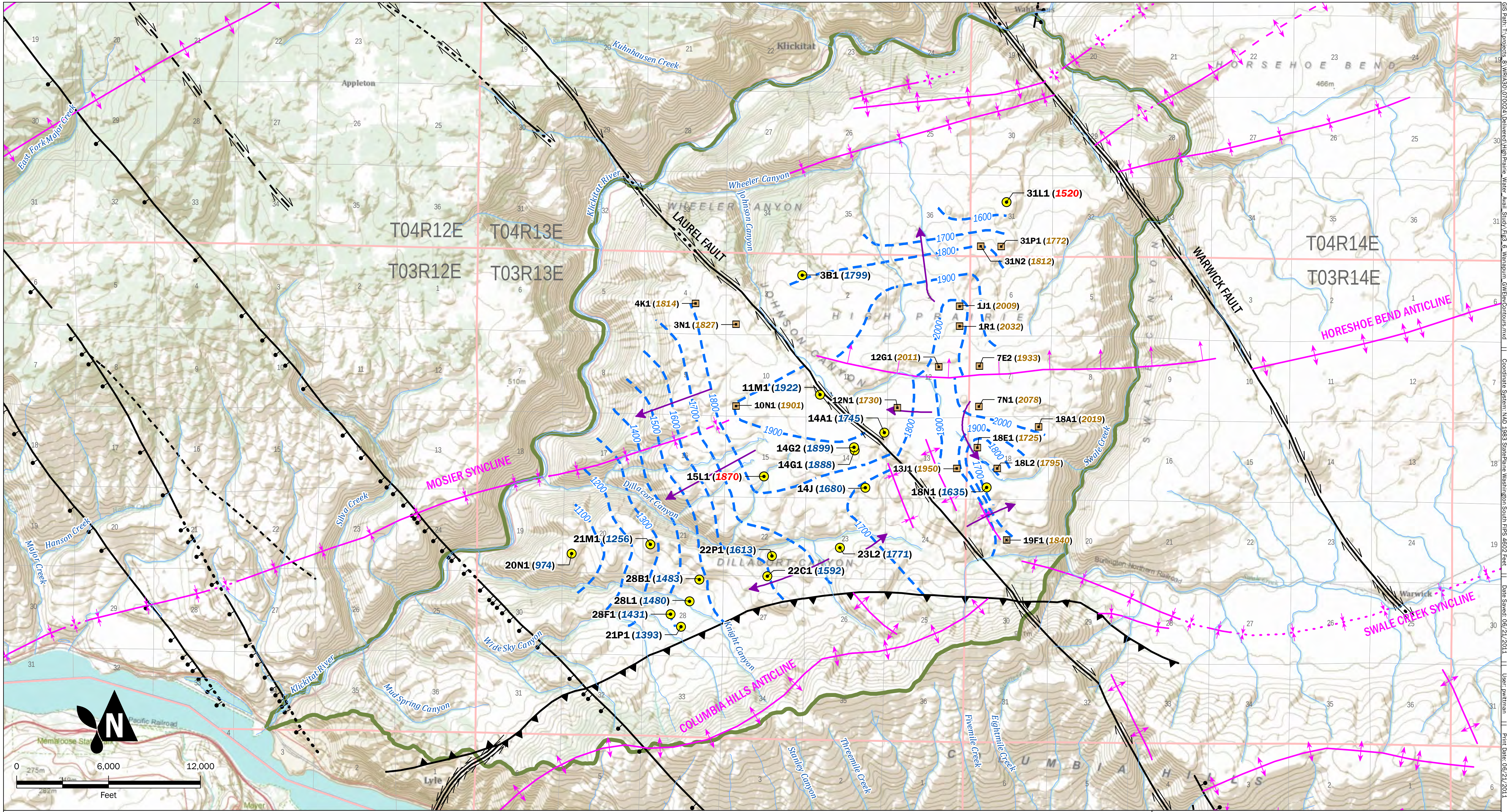
Aspect CONSULTING

Cross Section H-H'

High Prairie Water Availability Study
WRIA 30, Washington

DATE: June 2011	PROJECT NO. 070024
DESIGNED BY: JJP/DFR	
DRAWN BY: PMB	FIGURE NO. 3.5
REVISED BY:	

Q:\WRIA\070024 WRIA 30\2011-06\070024-HH.dwg



Wanapum Basalt Wells and Water Levels

Monitoring Network Well Locations:

- **21M1** (1256) — Well with April 2011 Water Level
- **31L1** (1520) — Well with Water Level from Date Other Than April 2011

Non-Surveyed (Qtr-Qtr Section) Well Locations:

- *1R1* (2032) — Well with Well Log Water Level

- High Prairie Study Area
- Township/Range
- Sections
- 100-ft Wanapum Basalt Groundwater Elevation Contours
- Groundwater Flow Direction Arrow

Folds (Washington DNR 1:100K mapping)

- Anticline (location accurate)
- Anticline (location approximate)
- Anticline (location concealed)
- Syncline (location accurate)
- Syncline (location approximate)
- Syncline (location concealed)
- Monocline, anticlinal bend (location accurate)
- Monocline, anticlinal bend (location concealed)

Faults (Washington DNR 1:100K mapping)

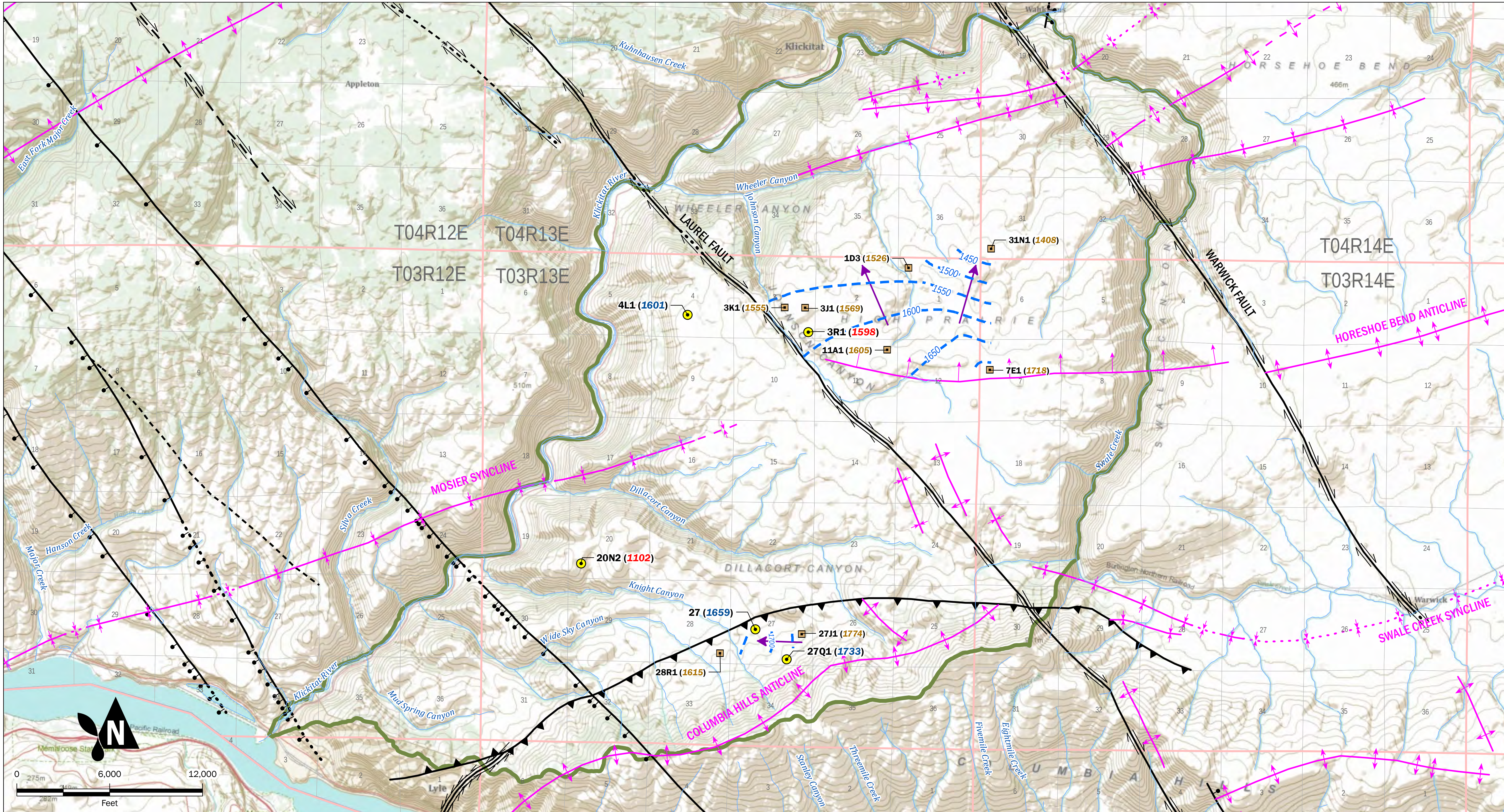
- Thrust fault (location accurate). Sawteeth on upper plate.
- Thrust fault (location concealed). Sawteeth on upper plate.
- Normal fault (location concealed). Bar and ball on downthrown block.
- Normal fault (location inferred). Bar and ball on downthrown block.
- Normal fault (location accurate). Bar and ball on downthrown block.
- Fault, unknown offset (location accurate)
- Fault, unknown offset (location inferred)
- Right-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location approximate). Arrows show relative motion.
- Right-lateral strike-slip fault (location concealed). Arrows show relative motion.
- Left-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location inferred). Arrows show relative motion

Groundwater Elevation Contour Map - Wanapum Basalt

High Prairie Water Availability Study
WRIA 30, Washington

Aspect Consulting	JUN-2011	BY: JMS / PPW	FIGURE NO.
	PROJECT NO. 070024	REV BY: - - -	3.6

GIS Path: T:\projects_8\WRIA30\070024\Delivered\HighPrairie_Water_Avail_Study\Fig3_6_Wanapum_GWElevContours.mxd || Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet || Date Saved: 06/21/2011 || User: pwittman || Print Date: 06/21/2011



Grande Ronde Basalt Wells and Water Levels

Monitoring Network Well Locations:

- 21M1 (1256) — Well with April 2011 Water Level
- 31L1 (1520) — Well with Water Level from Date Other Than April 2011

Non-Surveyed (Qtr-Qtr Section) Well Locations:

- 1R1 (2032) — Well with Well Log Water Level

- High Prairie Study Area
- Township/Range
- Sections
- 50-ft Grande Ronde Basalt Groundwater Elevation Contours
- Groundwater Flow Direction Arrow

Folds (Washington DNR 1:100K mapping)

- Anticline (location accurate)
- Anticline (location approximate)
- Anticline (location concealed)
- Syncline (location accurate)
- Syncline (location approximate)
- Syncline (location concealed)
- Monocline, anticlinal bend (location accurate)
- Monocline, anticlinal bend (location concealed)

Faults (Washington DNR 1:100K mapping)

- Thrust fault (location accurate). Sawteeth on upper plate.
- Thrust fault (location concealed). Sawteeth on upper plate.
- Normal fault (location concealed). Bar and ball on downthrown block.
- Normal fault (location inferred). Bar and ball on downthrown block.
- Normal fault (location accurate). Bar and ball on downthrown block.
- Fault, unknown offset (location accurate)
- Fault, unknown offset (location inferred)
- Right-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location approximate). Arrows show relative motion.
- Right-lateral strike-slip fault (location concealed). Arrows show relative motion.
- Left-lateral strike-slip fault (location accurate). Arrows show relative motion.
- Right-lateral strike-slip fault (location inferred). Arrows show relative motion

Groundwater Elevation Contour Map - Grande Ronde Basalt

High Prairie Water Availability Study
WRIA 30, Washington

Aspect CONSULTING	JUN-2011	BY: JMS / PPW	FIGURE NO.
	PROJECT NO. 070024	REV BY: - - -	3.7

Notes:
Any depth-to-water measurements from Table 2.2 which had non-static water levels were not included in the hydrographs.

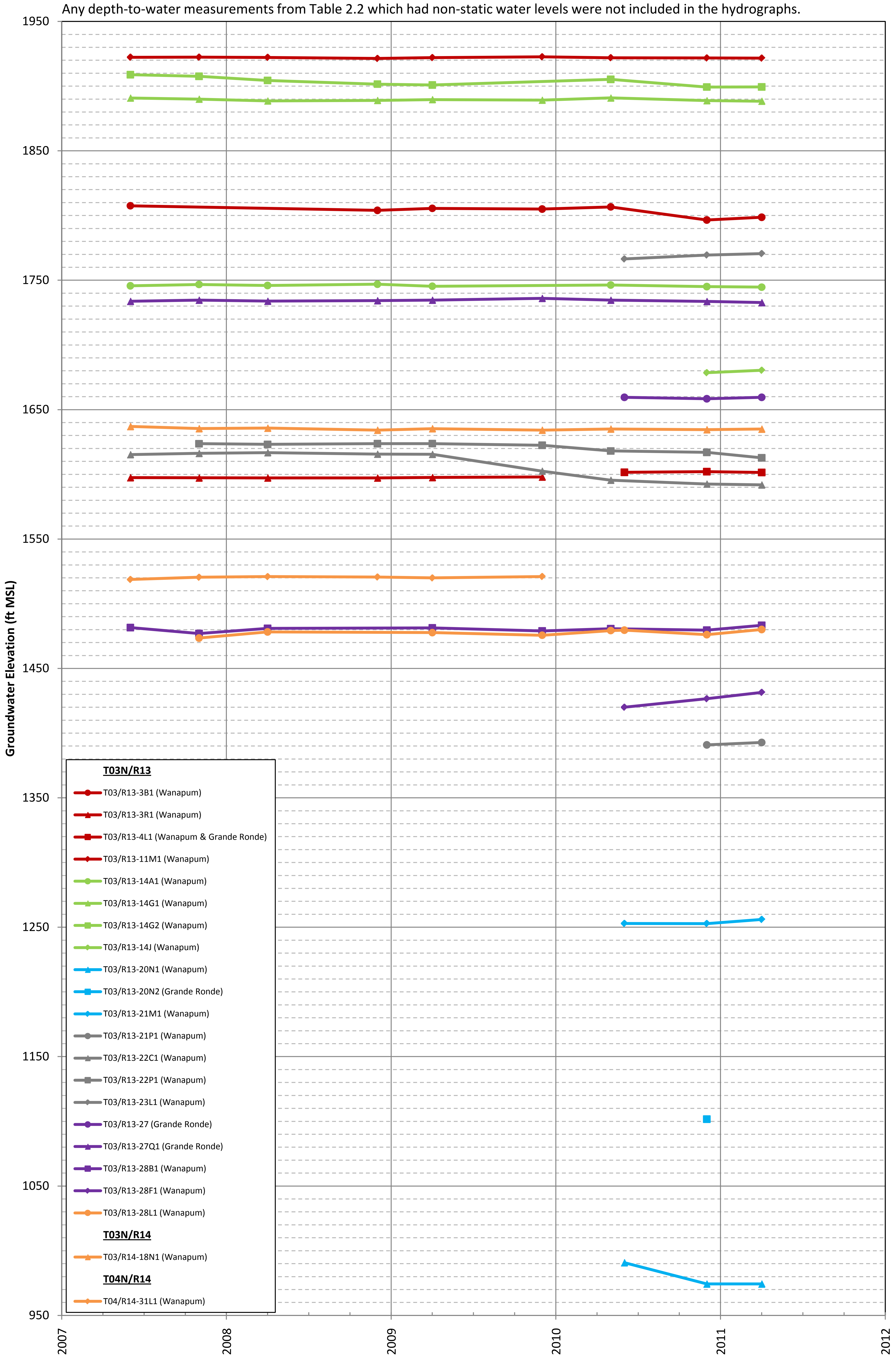
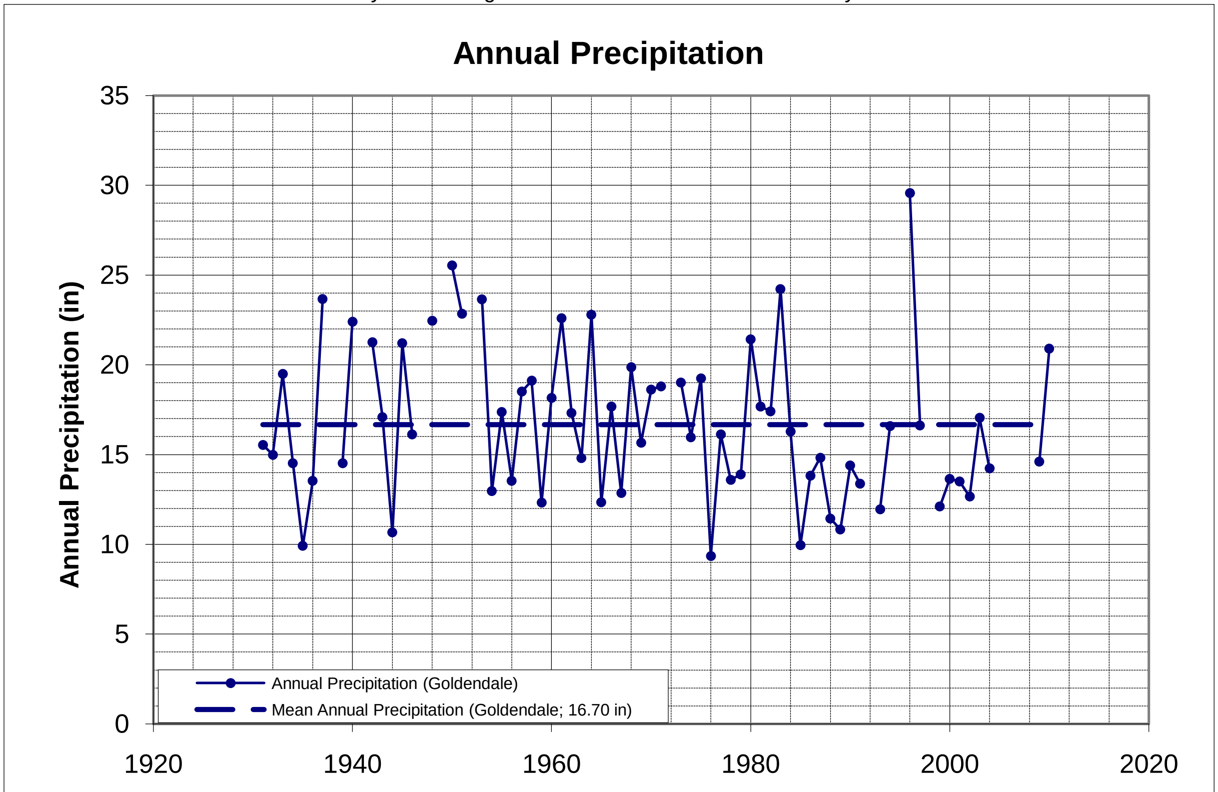


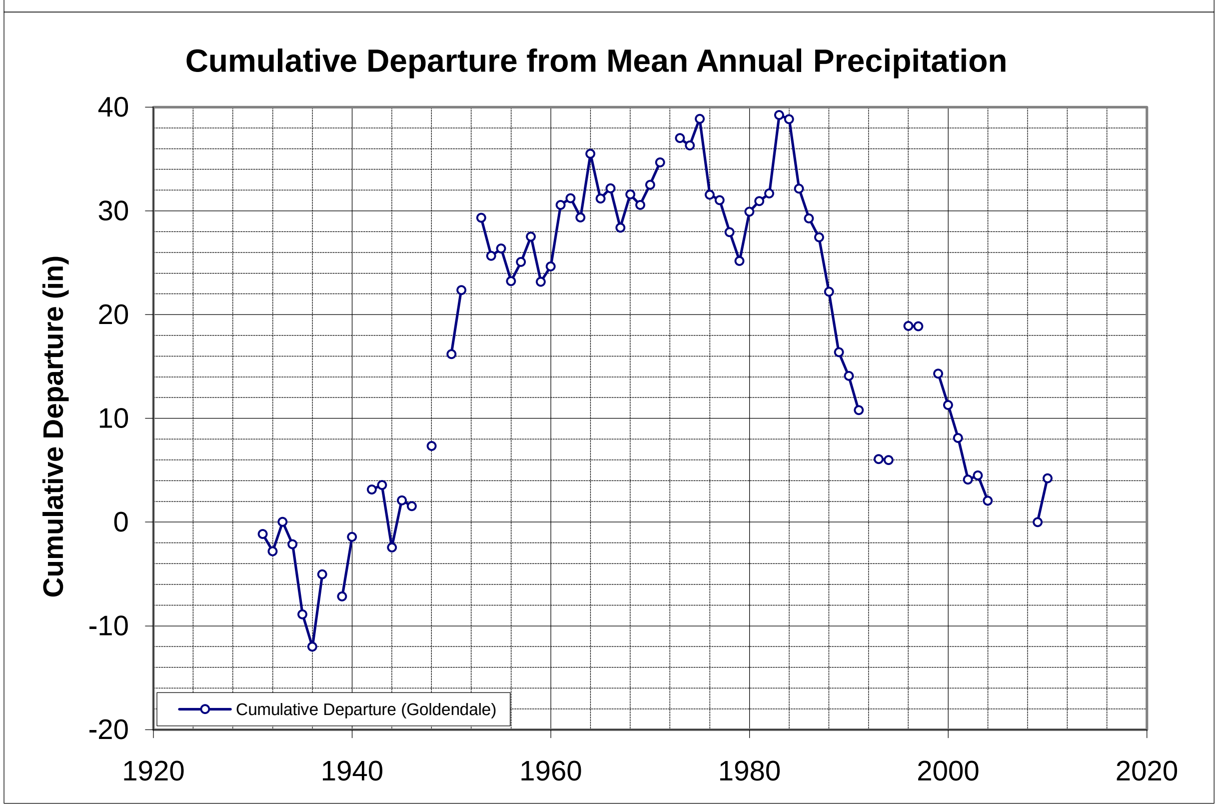
Figure 3.8 - Groundwater Hydrographs
High Prairie Water Availability Study
WRIA 30, Washington

Notes:

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

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





APPENDIX A

Well Completion Summary Table for the High Prairie Study Area

Appendix A - Well Completion Summary Table for the High Prairie Study Area
High Prairie Water Availability Study
WRIA 30, Washington

Well Log ID	Depth (ft)	Dia. (in)	TRS Identifier	Date	Easting (SPS 83)	Northing (SPS 83)
144845	130	6	T03/R12E-1	9/13/1973	1449139	162032
139759	490	6	T03/R12E-1D1	12/19/1985	1447125	164021
139760	717	6	T03/R12E-1D2	11/8/1985	1447125	164021
136731	100	6	T03/R12E-1N1	7/15/1983	1447254	160022
499057	1125	6	T03/R12E-1N2	9/26/2007	1447254	160022
141941	375	6	T03/R12E-1N3	11/14/1974	1447254	160022
417936	270	6	T03/R12E-1N4	8/1/2005	1447254	160022
141942	100	6	T03/R12E-1N5	10/13/1972	1447254	160022
452260	150	6	T03/R12E-2A1	4/17/2006	1445822	163918
136489	260	6	T03/R12E-2K1	6/30/1998	1444589	161309
411871	300	6	T03/R12E-2L1	5/2/2005	1443271	161257
140055	620	6	T03/R12E-2N1	8/9/1982	1441978	160116
380950	400	6	T03/R12E-2N2	5/4/2004	1441978	160116
302694	725	6	T03/R12E-2N3	10/9/2000	1441978	160116
142254	520	6	T03/R12E-2N4	8/30/1977	1441978	160116
380952	400	6	T03/R12E-2N5	5/5/2004	1441978	160116
144992	340	6	T03/R12E-2N6	10/10/1997	1441978	160116
144993	500	6	T03/R12E-2N7	10/17/1997	1441978	160116
257429	105	6	T03/R12E-2P1	5/12/2000	1443314	160082
411873	190	6	T03/R12E-2P2	4/26/2005	1443314	160082
648563	450	6	T03/R12E-2P3	4/20/2010	1443314	160082
254792	595	6	T03/R12E-11C1	11/11/1998	1443303	158830
477834	637	6	T03/R12E-11C2	4/15/2007	1443303	158830
254793	830	6	T03/R12E-11C3	11/6/1998	1443303	158830
499065	68	6	T03/R12E-11D1	9/27/2007	1441970	158884
257433	925	6	T03/R12E-11F1	5/4/2000	1443273	157498
351595	745	6	T03/R12E-11F2	8/30/1995	1443273	157498
405753	560	6	T03/R12E-11J1	3/14/2005	1445962	156096
146451	175	6	T03/R12E-11K1	9/26/1979	1444601	156130
302697	180	6	T03/R12E-11K2	10/4/2000	1444601	156130
146452	660	6	T03/R12E-11K3	10/2/1979	1444601	156130
146453	125	6	T03/R12E-11L1	4/3/1980	1443244	156166
146454	300	6	T03/R12E-11L2	10/20/1977	1443244	156166
137578	785	6	T03/R12E-11M1	9/26/1991	1441883	156198
147279	405	6	T03/R12E-11M2	8/23/1994	1441883	156198
390594	150	6	T03/R12E-11M3	10/12/2004	1441883	156198
476467	945	6	T03/R12E-11M4	4/11/2007	1441883	156198
543334	180	6	T03/R12E-11M5	7/8/2008	1441883	156198
142290	440	6	T03/R12E-11M6	6/22/1998	1441883	156198
556405	960	6	T03/R12E-11M7	9/18/2008	1441883	156198
351594	665	6	T03/R12E-11R1	8/3/1995	1445957	154781
465582	945	6	T03/R12E-11R2	8/14/2006	1445957	154781
397812	600	6	T03/R12E-12M1	12/27/2004	1447281	156075
141096			T03/R12E-13A1	10/25/1975	1451102	153423
335147	300	6	T03/R12E-13B1	4/17/2002	1449824	153435
534975	730	6	T03/R12E-13F1	5/28/2008	1448529	152158
142236	460	6	T03/R12E-13G1	5/16/1992	1449810	152150
141109	120	6	T03/R12E-13H1	9/16/1977	1451090	152142
144936	320	6	T03/R12E-13H2	1/31/1989	1451090	152142
377247	380	6	T03/R12E-13H3	9/23/1995	1451090	152142
141108	200	6	T03/R12E-13NE1	9/21/1973	1450455	152787
137265	205	6	T03/R12E-13Q1	9/17/1973	1449778	149578
137266	250	6	T03/R12E-13Q2	9/19/1973	1449778	149578
138213	155	6	T03/R12E-13Q3	6/25/1998	1449778	149578
257434	540	6	T03/R12E-13R1	5/10/2000	1451068	149579
142371	420	6	T03/R12E-14M1	5/23/1986	1441937	150931
146798	420	6	T03/R12E-14N1	3/13/1976	1441988	149626
138669	700	6	T03/R12E-23D1	6/4/1998	1441985	148319
377248	430	6	T03/R12E-23D2	7/17/1995	1441985	148319
452280	995	6	T03/R12E-23D3	5/17/2006	1441985	148319
138407	305	6	T03/R12E-25A1	10/12/1987	1451029	142939
596858	25	2	T03/R12E-25A2	6/11/2009	1451029	142939
596859	30	2	T03/R12E-25A3	6/9/2009	1451029	142939
596860	25	2	T03/R12E-25A4	6/10/2009	1451029	142939
141415	405	6	T03/R12E-25Q1	7/30/1992	1449688	138995
387100	450	6	T03/R12E-25Q2	9/7/2004	1449688	138995
138300	460	6	T03/R12E-25SW1	6/12/1992	1447726	139678
504590	845	6	T03/R13E-1D1	10/17/2007	1479244	163560
580767	783	6	T03/R13E-1D2	3/30/2009	1479244	163560
596837	605	6	T03/R13E-1D3	3/30/2009	1479244	163560
296506	300	6	T03/R13E-1J1		1483214	160873
137179	198	6	T03/R13E-1R1	8/28/1993	1483202	159567
146771	280	6	T03/R13E-3A1	4/7/1982	1472618	163621
140432	76	6	T03/R13E-3B1	11/12/1986	1471286	163646
613547	540	6	T03/R13E-3D1	10/1/2009	1468628	163694
140431	780	6	T03/R13E-3J1	10/13/1992	1472572	160976
138606	660	6	T03/R13E-3K1	10/16/1984	1471254	160991
672199	510	6	T03/R13E-3N1	8/10/2010	1468613	159685
371226	240	6	T03/R13E-3N2	10/23/2003	1468380	138616
145246	475	6	T03/R13E-3Q1	6/21/1978	1471237	159664
141250	745	6	T03/R13E-3R1	4/15/1987	1472550	159653
257436	705	6	T03/R13E-3R2	6/1/2000	1472550	159653
672201	370	6	T03/R13E-4K1	8/5/2010	1465959	161060
377250	620	6	T03/R13E-4L1	10/25/1995	1464626	161080
140647	55	6	T03/R13E-5B1	2/21/1974	1460627	163793
191836	210	6	T03/R13E-5F1	4/28/1999	1459276	162478
137176	85	6	T03/R13E-5F2	6/30/1996	1459276	162478
137599	165	6	T03/R13E-5F3	6/30/1992	1459276	162478
534979	83	6	T03/R13E-5F4	5/27/2008	1459276	162478
257437	160	6	T03/R13E-5M1	7/5/2000	1457923	161149
565848	58	5	T03/R13E-5P1	10/15/2008	1459254	159796
565849	58	5	T03/R13E-5P2	10/15/2008	1459254	159796
377251	210	6	T03/R13E-6H1	9/28/1995	1456574	162526

Well Log ID	Depth (ft)	Dia. (in)	TRS Identifier	Date	Easting (SPS 83)	Northing (SPS 83)
137203	280	6	T03/R13E-6P1	1/5/1988	1453790	159918
145362	720	6	T03/R13E-6P2	6/8/1994	1453790	159918
138449	160	6	T03/R13E-8G1	11/16/1989	1460603	157158
139123	140	6	T03/R13E-8L1	6/3/1988	1459269	155861
142433	210	6	T03/R13E-8L2	4/26/1983	1459269	155861
137592	925	6	T03/R13E-10L1	11/7/1990	1469915	155674
144967	200	6	T03/R13E-10N1	5/14/1997	1468612	154356
352442	690	6	T03/R13E-11A1	11/18/2002	1477866	158253
690975	685	6	T03/R13E-11H1	10/11/2010	1477851	156915
145099	660	6	T03/R13E-11J1	7/28/1983	1477836	155577
141715	524	6	T03/R13E-11M1	8/31/1994	1473838	155636
452262	410	6	T03/R13E-11N1	4/12/2006	1473829	154296
482799	170	6	T03/R13E-11P1	5/3/2007	1475159	154279
482870	670	6	T03/R13E-11Q1	5/16/2007	1476491	154259
487079	1050	6	T03/R13E-11Q2	5/10/2007	1476491	154259
141166	580	6	T03/R13E-11R1	9/24/1996	1477822	154239
530957	527	6	T03/R13E-11SW1	4/23/2008	1474499	154957
613545	505	6	T03/R13E-12G1	9/21/2009	1481841	156924
317849	545	6	T03/R13E-12H1	8/7/2001	1483171	156930
413154	485	6	T03/R13E-12M1	5/28/2005	1479166	155576
341502	640	6	T03/R13E-12N1	7/4/2002	1479152	154239
191856	750	6	T03/R13E-12NE1	5/7/1999	1482512	157589
139969	520	6	T03/R13E-12R1	6/13/1996	1483139	154286
452346	490	6	T03/R13E-12R2	6/28/2006	1483139	154286
296084	520	6	T03/R13E-13A1		1483119	152934
143963	565	6	T03/R13E-13B1	11/7/1997	1481790	152926
142707	500	6	T03/R13E-13C1	8/18/1998	1480462	152918
296617	250	6	T03/R13E-13C2		1480462	152918
146708	540	6	T03/R13E-13F1	6/9/1988	1480426	151601
316086	580	6	T03/R13E-13G1	10/26/2001	1481747	151602
140761	290	6	T03/R13E-13J1	11/8/1977	1483022	150277
140762	330	6	T03/R13E-13J2	8/12/1977	1483022	150277
144299	650	6	T03/R13E-13J3	10/29/1980	1483022	150277
302621	545	6	T03/R13E-13K1	6/20/2001	1481707	150281
146312	360	6	T03/R13E-13L1	5/9/1994	1480388	150283
140077	190	6	T03/R13E-13M1	10/13/1989	1479073	150288
382349	465	6	T03/R13E-13M2	6/8/2004	1479073	150288
411861			T03/R13E-13M3	5/25/2005	1479073	150288
411874	723	6	T03/R13E-13M4	5/5/2005	1479073	150288
657085	190	6	T03/R13E-13M5	6/18/2010	1479073	150288
145823	490	6	T03/R13E-13N1	1/1/1988	1479047	148975
335155	180	6	T03/R13E-13N2	5/24/2002	1479047	148975
191905	600	6	T03/R13E-13NW1		1479781	152259
372468	358	6	T03/R13E-13P1	10/31/2003	1480356	148967
455737	1000	6	T03/R13E-13Q1	6/2/2006	1481665	148959
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363887	670	6	T03/R13E-13R3	6/12/2003	1482973	148948
139955	500	6	T03/R13E-14A1	10/16/1992	1477803	152915
138799	502	6	T03/R13E-14B1	9/22/1977	1476475	152932
452375	603	6	T03/R13E-14F1	6/3/2006	1475142	151633
377252	500	6	T03/R13E-14G1	7/7/1995	1476460	151619
477832	458	6	T03/R13E-14G2	2/28/2007	1476460	151619
455741	311	6	T03/R13E-14G3	8/16/2006	1476460	151619
136943		10	T03/R13E-14J	5/30/1990	1477761	150294
137743	465	6	T03/R13E-14J1	7/1/1996	1477761	150294
455726	480	6	T03/R13E-14J2	8/2/2006	1477761	150294
141364	477	6	T03/R13E-14Q1	10/20/1992	1476431	148992
142654	468	6	T03/R13E-14Q2	12/26/1987	1476431	148992
393565	280	6	T03/R13E-14R1	11/16/2004	1477738	148982
136950	250	6	T03/R13E-15C1	8/1/1974	1469904	153012
145893	105	6	T03/R13E-15L1	8/13/1987	1469872	150370
145894	105	6	T03/R13E-15P1	6/1/1983	1469855	149048
487080	545	6	T03/R13E-18D1	4/16/2007	1452434	153401
138091	360	6	T03/R13E-18G1	5/7/1979	1455193	152028
138646	322	6	T03/R13E-18Q1	7/21/1998	1455177	149426
143591	220	6	T03/R13E-18Q2	7/23/1998	1455177	149426
352367	340	6	T03/R13E-19B1	10/23/2002	1455169	148116
302607	140	6	T03/R13E-19H1	5/24/2001	1456555	146752
142336	180	6	T03/R13E-19K1	5/7/1997	1455166	145492
411860	141	6	T03/R13E-19K2	6/21/2005	1455166	145492
372476	145	6	T03/R13E-19L1	11/17/2003	1453779	145537
143592	140	6	T03/R13E-19NE1	7/24/1998	1455858	147432
138659	410	6	T03/R13E-19Q1	8/18/1991	1455164	144181
145905	555	6	T03/R13E-19R1	9/24/1993	1456555	144148
452343		6	T03/R13E-19R2	6/23/2006	1456555	144148
145906	910	6	T03/R13E-19R3	9/22/1993	1456555	144148
143309	560	6	T03/R13E-20E1	10/18/1981	1457909	146714
143310	1150	6	T03/R13E-20E2	9/14/1993	1457909	146714
140365	505	6	T03/R13E-20F1	11/12/1990	1459228	146687
141718	720	6	T03/R13E-20F2	9/23/1992	1459228	146687
145049	775	6	T03/R13E-20G1	6/30/1997	1460548	146659
146334	400	6	T03/R13E-20G2	4/28/1982	1460548	146659
137615	475	6	T03/R13E-20J1	8/30/1977	1461864	145337
137616	570	6	T03/R13E-20J2	8/27/1977	1461864	145337
136795	550	6	T03/R13E-20J3	8/26/1996	1461864	145337
418580	225	6	T03/R13E-20K1	6/14/2005	1460547	145364
302717	865	6	T03/R13E-20K2	9/19/2000	1460547	145364
141324	600	6	T03/R13E-20M1	7/26/1993	1457909	145417
144433	520	6	T03/R13E-20N1	11/22/1994	1457909	144119
384137	530	6	T03/R13E-20N2	7/15/2004	1457909	144119
143034	440	6	T03/R13E-20P1	8/31/1996	1459226	144095
143186	500	6	T03/R13E-20Q1	9/26/1983	1460545	144068

Well Log ID	Depth (ft)	Dia. (in)	TRS Identifier	Date	Easting (SPS 83)	Northing (SPS 83)
141466	510	6	T03/R13E-21A1	6/5/1981	1467181	147787
141880	490	6	T03/R13E-21B1	6/9/1981	1465850	147823
142931	550	6	T03/R13E-21L1	4/11/1983	1464503	145283
143160	520	6	T03/R13E-21M1	7/11/1997	1463183	145312
139650	465	6	T03/R13E-21M2	3/25/1991	1463183	145312
145685	200	6	T03/R13E-21P1	5/6/1994	1464494	143994
296085	520	6	T03/R13E-21Q1	7/27/1991	1465809	143969
377253	505	6	T03/R13E-21R1	6/1/1995	1467126	143943
139999	400	6	T03/R13E-21SE1	9/18/1998	1466475	144599
335153	225	6	T03/R13E-22C1	5/9/2002	1469834	147744
254796	595	6	T03/R13E-22N1	11/16/1999	1468439	143917
192268	550	6	T03/R13E-22N2	9/1/1999	1468439	143917
377254	280	6	T03/R13E-22P1	10/19/1995	1469753	143890
496484	577	6	T03/R13E-22P2	9/25/2007	1469753	143890
504591	8		T03/R13E-22P3	10/24/2007	1469753	143890
142467	270	6	T03/R13E-23B1	5/13/1997	1476409	147681
333584	430	6	T03/R13E-23B2	9/26/2001	1476409	147681
137644	450	6	T03/R13E-23H1	6/5/1997	1477688	146368
296316	203	6	T03/R13E-23L1		1475039	145091
139217	449	6	T03/R13E-23L2	5/30/1981	1464503	145283
191847	100	6	T03/R13E-23M1	6/23/1999	1473728	145106
136978	60	6	T03/R13E-23M2	10/20/1980	1473728	145106
137775	470	6	T03/R13E-23NE1	8/3/1993	1477048	147024
145051	550	6	T03/R13E-24A1	10/13/1985	1482937	147621
145510	820	6	T03/R13E-24A2	5/14/1980	1482937	147621
487097	365	6	T03/R13E-24A3	6/8/2007	1482937	147621
499066	145	6	T03/R13E-24A4	8/15/2007	1482937	147621
144057	560	6	T03/R13E-24C1	5/30/1997	1480326	147649
317858	465	6	T03/R13E-24C2	7/30/2001	1480326	147649
302718	320	6	T03/R13E-24F1	4/5/2001	1480302	146336
142515	410	6	T03/R13E-24G1	6/27/1991	1481610	146317
384133	200	6	T03/R13E-24H1	6/30/2004	1482917	146298
138267	482	6	T03/R13E-24J1	5/14/1997	1482897	144977
138268	940	6	T03/R13E-24J2	12/6/1996	1482897	144977
377257	305	6	T03/R13E-24N1	6/15/1995	1484217	143638
411875	890	6	T03/R13E-24R1	6/8/2005	1482877	143654
142051	323	6	T03/R13E-25A1	11/6/1997	1482860	142327
144534	405	6	T03/R13E-25A2	5/8/1996	1482860	142327
148480	345	6	T03/R13E-25A3	5/10/1996	1482860	142327
148481	380	6	T03/R13E-25A4	11/25/1998	1482860	142327
341504	350	6	T03/R13E-25A5	7/19/2002	1482860	142327
140645	205	6	T03/R13E-25B1	10/26/1971	1481551	142355
138637	465	6	T03/R13E-25D1	5/28/1998	1478930	142411
384132	710	6	T03/R13E-25H1	6/24/2004	1482852	140996
413155	400	6	T03/R13E-25H2	6/27/2005	1482852	140996
257439	625	6	T03/R13E-25L1	8/29/2000	1480228	139716
377255	540	6	T03/R13E-25L2	9/16/1995	1480228	139716
556399	165	6	T03/R13E-27	8/7/2008	1472357	139866
144724	300	6	T03/R13E-27A1	10/14/1977	1472360	142522
418100	220	6	T03/R13E-27A2	8/13/1998	1472360	142522
254797	335	6	T03/R13E-27B1	11/11/1999	1471047	142551
140345	170	6	T03/R13E-27B2	6/17/1993	1471047	142551
341503	168	6	T03/R13E-27C1	7/30/2002	1469734	142580
140467	380	6	T03/R13E-27D1	9/19/1996	1468422	142611
144384	235	6	T03/R13E-27D2	4/24/1978	1468422	142611
302700	200	6	T03/R13E-27D3	4/7/2001	1468422	142611
316087	634	6	T03/R13E-27D4	10/8/2001	1468422	142611
648556	665	6	T03/R13E-27D5	2/17/2010	1468422	142611
138658	220	6	T03/R13E-27E1	8/9/1977	1468409	141279
143627	594	6	T03/R13E-27E2	4/29/1995	1468409	141279
386078	65	6	T03/R13E-27E3	7/14/2004	1468409	141279
140589	270	6	T03/R13E-27F1	8/10/1978	1469724	141250
407045	330	6	T03/R13E-27G1	3/31/2005	1471041	141222
136537	155	6	T03/R13E-27G2	5/9/1997	1471041	141222
317859	258	6	T03/R13E-27G3	9/18/2001	1471041	141222
144626	307	6	T03/R13E-27J1	8/8/1978	1472357	139866
142848	280	6	T03/R13E-27K1	10/12/1977	1471036	139894
706790	240	6	T03/R13E-27K2	10/29/2010	1471036	139894
138626	120	6	T03/R13E-27L1	5/3/1996	1469717	139920
139519	225	6	T03/R13E-27P1	7/29/1993	1469706	138591
139404	310	6	T03/R13E-27Q1	10/27/1993	1471031	138564
455794	300	6	T03/R13E-27Q2	8/3/2006	1471031	138564
418581	370	6	T03/R13E-27R1	9/7/2005	1472356	138538
482836	377	6	T03/R13E-28A1	5/18/2007	1467109	142636
143537	220	6	T03/R13E-28B1	9/7/1994	1465798	142660
144681	140	6	T03/R13E-28B2	8/23/1994	1465798	142660
146430	120	6	T03/R13E-28C1	7/10/1981	1464484	142682
146705	160	6	T03/R13E-28C2	5/9/1990	1464484	142682
136832	185	6	T03/R13E-28D1	6/21/1982	1463173	142705
137913	555	6	T03/R13E-28D2	7/21/1981	1463173	142705
144432	195	6	T03/R13E-28D3	10/16/1996	1463173	142705
137630	188	6	T03/R13E-28E1	7/17/1981	1463167	141378
372465	335	6	T03/R13E-28F1	11/4/2003	1467082	139972
137049	155	6	T03/R13E-28F2	11/23/1993	1464477	141354
142885	150	6	T03/R13E-28G1	9/8/1986	1465786	141328
145302	200	6	T03/R13E-28G2	6/12/1997	1465786	141328
145303	165	6	T03/R13E-28G3	5/10/1993	1465786	141328
254798	308	6	T03/R13E-28J1	5/28/1998	1467082	139972
362410	264	6	T03/R13E-28K1	5/28/2003	1465775	139999
390595	183	6	T03/R13E-28K2	10/11/2004	1465775	139999
139337	90	8	T03/R13E-28L1	12/27/1972	1464469	140024
143927	140	6	T03/R13E-28L2	8/2/1977	1464469	140024
145125	165	6	T03/R13E-28L3	6/12/1992	1464469	140024

Appendix A - Well Completion Summary Table for the High Prairie Study Area
High Prairie Water Availability Study
WRIA 30, Washington

Well Log ID	Depth (ft)	Dia. (in)	TRS Identifier	Date	Easting (SPS 83)	Northing (SPS 83)
145683	150	6	T03/R13E-28L4	9/25/1996	1464469	140024
145684	165	6	T03/R13E-28L5	5/18/1989	1464469	140024
137551	170	6	T03/R13E-28M1	12/21/1976	1463163	140049
138638	303	6	T03/R13E-28N1	9/11/1983	1463158	138719
504593	230	6	T03/R13E-28N2	11/2/2007	1463158	138719
136611	190	6	T03/R13E-28P1	8/13/1985	1464461	138694
137787	322	6	T03/R13E-28P2	7/17/1996	1464461	138694
137937	310	6	T03/R13E-28P3	6/21/1992	1464461	138694
138235	265	6	T03/R13E-28P4	6/22/1992	1464461	138694
144797	240	6	T03/R13E-28P5	9/9/1977	1464461	138694
144798	340	6	T03/R13E-28P6	10/11/1977	1464461	138694
144896	140	6	T03/R13E-28P7	11/3/1977	1464461	138694
138512	125	6	T03/R13E-28Q1	11/22/1983	1465765	138669
142596	180	6	T03/R13E-28R1	8/31/1979	1467067	138641
556403	185	6	T03/R13E-28R2	9/19/2008	1467067	138641
140923	610	6	T03/R13E-29H1	5/2/1984	1461854	141402
147282	250	6	T03/R13E-29J1	11/2/1998	1461850	140075
137629	120	6	T03/R13E-29K1	10/7/1992	1460529	140105
413156	464	6	T03/R13E-29M1	7/8/2005	1457891	140164
145168	123	6	T03/R13E-29R1	11/13/1990	1461846	138748
145169	213	6	T03/R13E-29R2	11/14/1990	1461846	138748
145170	258	6	T03/R13E-29R3	11/21/1990	1461846	138748
420409	280	6	T03/R13E-29R4	10/7/2005	1461846	138748
140497	308	6	T03/R14E-3D1	8/26/1992	1500282	163342
455795	325	6	T03/R14E-3L1	8/7/2006	1501535	160626
140660	220	6	T03/R14E-3P1	7/23/1974	1501506	159277
139128	425	6	T03/R14E-3R1	7/22/1981	1504136	159232
144625	450	6	T03/R14E-4J1	8/18/1981	1498919	160680
362164	1020	6	T03/R14E-6F1	4/29/2003	1485901	162168
362165	270	6	T03/R14E-6F2	5/1/2003	1485901	162168
352370	870	6	T03/R14E-7E1	11/8/2002	1484499	156945
352452	385	6	T03/R14E-7E2	12/5/2002	1484499	156945
417935	710	6	T03/R14E-7F1	8/2/2005	1485826	156950
377256	185	6	T03/R14E-7M1	6/5/1995	1484480	155629
191850	190	6	T03/R14E-7N1	6/14/1999	1484462	154311
145695	560	6	T03/R14E-7SW1	9/15/1998	1485131	154975
191838	600	6	T03/R14E-7SW2	9/9/1998	1485131	154975
136656	145	6	T03/R14E-9SE1	10/2/1974	1498199	154727
136657	250	6	T03/R14E-9SE2	4/17/1973	1498199	154727
136658	415	6	T03/R14E-9SE3	10/3/1974	1498199	154727
144571	490	6	T03/R14E-9SE4	8/3/1982	1498199	154727
499109	140	6	T03/R14E-10N1	7/26/2007	1500144	154011
316088	180	6	T03/R14E-15Q1	10/21/2001	1502822	148722
140371	450	6	T03/R14E-17A1	9/2/1994	1493657	152885
417937	360	6	T03/R14E-18A1	7/26/2005	1488376	152992
146690	590	6	T03/R14E-18D1		1484404	152979
648564	190	6	T03/R14E-18D2	4/14/2010	1484404	152979
475769	540	6	T03/R14E-18E1	1/19/2007	1484369	151634
136721	398	6	T03/R14E-18L1	6/4/1992	1485669	150283
145631	713	6	T03/R14E-18L2	6/10/1993	1485669	150283
254799	120	6	T03/R14E-18N2	5/12/1997	1484293	148943
354742	695	6	T03/R14E-18N1	5/20/1997	1484293	148943
411876	600	6	T03/R14E-18N3	6/3/2005	1484293	148943
137618	310	6	T03/R14E-19F1	10/20/1972	1486280	145600
346758	324	6	T03/R14E-19F2	1/9/2002	1485607	146275
145998	490	6	T03/R14E-19J1	10/12/1989	1488323	144935
137617	560	6	T03/R14E-19M1	9/23/1977	1484233	144962
145614	280	6	T03/R14E-19N1	5/24/1996	1484217	143638
377257	305	6	T03/R14E-19N2	6/15/1995	1484217	143638
452370	841	6	T03/R14E-19P1	6/7/2006	1485587	143632
145337			T03/R14E-19R1		1488325	143618
335144	465	6	T03/R14E-19R2	5/2/2002	1488325	143618
317860	490	6	T03/R14E-20N1	8/10/2001	1489669	143608
143875	200	6	T03/R14E-22A1	9/10/1997	1504154	147405
627943	390	6	T03/R14E-22A2	10/8/2009	1504154	147405
465585	357	6	T03/R14E-22B1	9/14/2006	1502835	147408
487077	36		T03/R14E-27A1	3/15/2007	1504177	142162
407046	58	6	T03/R14E-27E1	4/25/2005	1500196	140831
530947	282	6	T03/R14E-28G1	6/14/2008	1497553	140858
143919	180	8	T03/R14E-28H1	4/16/1997	1498875	140839
145954	332	6	T03/R14E-29	9/12/1973	1491597	140274
145461	120	6	T03/R14E-29A1	4/26/1978	1493613	142235
257442	353	6	T03/R14E-29A2	8/7/2000	1493613	142235
362159	450	6	T03/R14E-29A3	4/21/2003	1493613	142235
144897	450	6	T03/R14E-29B1	10/4/1991	1492294	142251
534970	390	6	T03/R14E-29B2	6/16/2008	1492294	142251
138401	263	6	T03/R14E-29C1		1490977	142268
141665	160	6	T03/R14E-29G1	7/11/1976	1492270	140929
137498	380	6	T03/R14E-29H1	12/9/1986	1493588	140912
144008	395	6	T03/R14E-30A1	4/12/1994	1488315	142296
377258	473	6	T03/R14E-30B1	9/20/1995	1486943	142301

APPENDIX B

Basin-Scale Water Balance for High Prairie

Basin-Scale Water Balance for High Prairie

The conventional study area-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 water balance analysis for this study area is similar to that applied in the Water Availability Report for Swale Creek and Little Klickitat subbasins [Aspect Consulting, 2007). The following subsections present the water use estimates, and then the full water balance, for the High Prairie study area.

Water Use Estimates

This section estimates actual water use for the High Prairie study area, applying the same methodology as used in previous water availability reports for WRIA 30. The water use information is an important element of the study area-scale water balance, supporting the assessment of water availability.

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

As of May 2010, Farm Services Agency (FSA) staff reported no irrigated areas in the High Prairie study area. Aerial photography indicates areas of cultivated land, but no large areas that appeared irrigated, which is consistent with observations during water level measurement events. Local farmers predominantly plant dry land crops (e.g., wheat, alfalfa); however, there is one home with a small fruit orchard. Some watering of residential lawns occurs, but is assumed in the water balance as a component of residential water use. Based on the collective information, and discussions with a High Prairie resident, the study area is assumed to have no significant irrigation.

Residential and Non-Residential Use

Using data from the state Department of Health (DOH) public water system (PWS) database, an estimated 7 acre-feet of residential water use is supplied by PWS within the study area, based on multiplying each PWS' number of residents served by an assumed 127 gallons per capita day[1] (gpcd), and converting to an annual volume in acre-feet/year (Table B-1). There are only two non-residential connections reported for PWS within the study area. There is no known large-scale non-residential (e.g. commercial, industrial) water use in the study area, whether supplied by a PWS or not. As part of the WRIA 30 Level 1 Assessment [Watershed Professionals Network (WPN) and Aspect, 2004], non-residential water use was estimated to be 34 gallons per day or 0.04 acre feet per

[1] Estimated per capita water demand is an average value from Klickitat Public Utility District values for its multiple public water systems in WRIA 30 (including Lyle), as reported in Aspect Consulting (2007).

year per PWS connection, indicating a negligible non-residential water use within the study area (Table B-1).

Table B-1 – Estimated Annual Public Water System (PWS) Use

PWS ID	PWS Name	Group	Residents Served	No. Total Connects	No. Resid. Connects	No. Non-Resid. Connects	Estimated Annual Water Use in Acre-Feet/Year		
							Residential	Non-Residential	Total
5881	BARTLETT WATER SYSTEM	B	10	2	2	0	1.4	0	1.4
6417	BLOUIN BOTTLED WATER	B	8	2	2	0	1.1	0	1.1
34711	PARADISE FLAT	B	5	2	2	0	0.7	0	0.7
8478	MORNING SONG ACRES	B	2	2	1	1	0.3	0.04	0.34
4120	RIPPLINGER WATER SYSTEM	B	2	2	2	0	0.3	0	0.3
AC022	HIGH PRAIRIE FIRE HALL	B	0	1	0	1	0	0.04	0.04
Water Demand Totals			**27**	**11**	**9**	**2**	**4**	**0.08**	**4**

Assumed residential per capita water use of 127 gallons per day (refer to text).

Self-Supplied (Non-PWS) Water Use

Water uses not supplied by PWS are considered "self-supplied". The self-supplied residential population (domestic wells) was estimated by first determining the total population (571 people) for the study area using 2010 US Census data for census blocks within the study area as determined with GIS analysis. The study area population served by PWS (as determined by DOH database; Table B-1) was then subtracted from the total population to arrive at the self-supplied population. According to DOH records, 27 people in the study area are served by a PWS, leaving an estimated 544 people as self-supplied water users using private domestic wells (Table B-2). Annual water use estimates for the self-supplied population were calculated assuming the same average residential consumption of 127 gpcd as assumed for PWS-supplied residents, and converting that volume of water into acre-feet/year, for a total of 77 acre-feet/year (Table B-2).

Table B-2 – Estimated Self-Supplied Annual Residential Water Use

Total Population in 2010[a]	Population Served by Public Water Systems[b]	Self-Supplied Population	Self-Supplied Water Use in Acre-Feet/Year
571	27	544	77

Notes:

[a] Based on 2010 US Census data for census blocks within the study area.

[b] Based on Washington State Department of Health database of public water systems

There are no known large self-supplied non-residential water users in the High Prairie.

One additional category of minor non-residential water use not included in this water balance is stock watering from wells, which is exempt from water right permitting, and for which no information is available. Stock watering is assumed to be a relatively small component of total water use in the study area.

Consumptive and Non-Consumptive Water Use

Water delivered for use is either consumed by evapotranspiration, or is not consumed, remaining in the study area as return flow that augments streamflow or groundwater sources.

Using domestic water use numbers for Washington State (Solley et al, 1998), it is assumed that 12 percent of the residential uses (PWS-supplied and self-supplied) in the study area are consumptive. We assume the PWS-supplied and self-supplied residents in the study area treat their wastewater via septic tanks and drain fields; therefore, the residential return flow is assumed to be 100% groundwater recharge in the water balance. Since non-residential water use in the study area is so small (less than 0.1 acre-feet/yr), the apportioning between consumptive and non-consumptive uses is inconsequential to the overall water balance.

Summary of Water Uses

Applying the methodology and assumptions described above, the resultant estimated annual consumptive and non-consumptive (return flow) volumes for each use category are presented in Table B-3. The estimated total annual water use (roughly 81 acre-feet/year) is approximately 95% of the appropriated annual water rights for the study area (85 acre-feet/year[2]), based on water right certificates and permits for the study area reported in Ecology's Water Rights Tracking System. However, approximately 95% of the estimated water use is residential use supplied by private wells that are exempt from water right permitting (thus not recorded in Ecology's Water Rights Tracking System).

Table B-3 – Estimated Annual Water Use in High Prairie Study Area

	Water Use in Acre-Feet/Year by Category				
	Irrigation	**PWS-Supplied Residential**	**Self-Supplied Residential**	**PWS-Supplied Non-Residential**	**Total Use in Acre-Feet/Year**
Total Use	0	4	77	0	**81**
Consumptive Use	0	0	9	0	9
Total Return Flow	0	4	68	0	72
Return Flow to Groundwater	*0*	*4*	*68*	*0*	*72*
Return Flow to Surface Water	*0*	*0*	*0*	*0*	*0*

Notes:
PWS: Public water system.
Consumptive uses are assumed to be 12% of residential use, and 16% of non-residential uses. Non-residential use is negligible (<0.1 acre-feet).

On the scale of the study area, we estimate that 11% of the total water use (9 of 81 acre-feet/year) is consumptive use.

[2] Excluding permitted Klickitat River water rights for irrigation use indicated in Ecology's Water Rights Tracking System, which are assumed are not operating (see Water Balance Results below).

Water Balance Calculations

Water Balance Methods

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. The water balance values are presented in Table B-5, with the annual volume values rounded to the nearest 10 acre-feet/year. Return flow quantities are assigned a negative sign in Table B-5 to reflect that they are returned to the watershed as groundwater recharge or streamflow (not consumed).

Mean annual precipitation in the High Prairie is estimated at 19 inches per year, which is the value estimated for the Lower Klickitat subbasin[3] of WRIA 30 in the WRIA 30 Level 1 Watershed Assessment (WPN and Aspect, 2004). The precipitation data for the Level 1 assessment were obtained from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM; Daly and others, 1994; http://www.prism.oregonstate.edu/). PRISM is the USDA's official climatological data. In Section 3.5.1 of this report, precipitation data from Goldendale (16.7 inch/year) are used to assess precipitation trends over time. The PRISM model data provide an average value estimate, not precipitation data over time; however, because the model encompasses the entire study area, it is considered the best available estimate of average precipitation for the water balance analysis. Applying the 19 inches per year across the study area’s approximately 35,600 acres provides an average annual precipitation volume of approximately 56,070 acre-feet/year (Table B-5).

The WRIA 30 Level 1 Assessment applied USGS recharge estimates from a regional modeling study (Bauer and Vaccaro, 1990) to estimate average recharge for the Lower Klickitat subbasin. The USGS’ recharge estimates were developed using a deep percolation model for the entire Columbia Plateau regional aquifer system to represent then-current land use conditions, and the model did cover the entire study area. Using this information, the natural condition mean annual groundwater recharge in the study area is estimated at approximately 7.5 inches, which equates to an annual recharge volume of 22,250 acre-feet/year (Table B-5). An estimated additional 72 acre-feet/year of groundwater recharge is generated by return flow from residential uses (assumed all groundwater recharge); this is equal to the return flow component in Table B-5.

The average annual runoff in the study area was estimated from a continuous-flow stormwater runoff model, WWHM4 (Clear Creek Solutions, 2010). The model uses land cover (vegetated, hard surface, etc.), the land slope gradient, the permeability of the soils, and historical precipitation data to estimate the amount of stormwater runoff. Data from GIS databases for the area were used to determine the land cover, slopes, and soil types for the study area. For residential areas, it was assumed a portion of the lot was impervious (roofs and driveways) and pervious (yards and open land). Higher density residential areas were weighted more heavily towards impervious (90 percent impervious), lower density towards pervious (10 percent impervious).

WWHM4 is used because of its ability to account for soil moisture and recharge before converting the flow into runoff. For this analysis, this feature was a way to reduce runoff overestimation. The

[3] Study area is within the Lower Klickitat subbasin (refer to Figure 1.1 in main body of report).

model was run for each year that annual precipitation data are available. Based on the basin-scale model results, runoff as percent of precipitation ranges from 0.3% to 4.3% annually, with a long-term average of approximately 2.3% . This long-term average value equates to 1,290 acre-feet/year of runoff applied in the water balance. Note that this is a basin-scale estimate, and runoff percentages can be different for specific areas or for specific precipitation events.

Table B-4 – Summary of Land Surface Parameters for WWHM Model of Study Area

Pervious Surfaces in Acres	**Hydrologic Soil Type**			
	A	**B**	**C**	**D**
Forest, Flat	134	633	148	6
Forest, Mod	32	2629	143	89
Forest, Steep	9	2107	375	453
Shrub, Mod	73	5273	2965	128
Shrub, Steep	26	1098	1575	174
Shrub, Flat	174	5088	8298	112
Pasture, Flat	43	461	856	10
Pasture, Mod	0	83	29	1
Pasture, Steep	0	2	1	2
Lawn, Flat	47	970	891	18
Lawn, Mod	9	230	104	11
Lawn, Steep	1	65	7	20
Impervious Surfaces in Acres				
Roads and Roofs, Flat	83			
Roads and Roofs, Mod	52			
Roads and Roofs, Steep	14			
Wetlands	186			
Rock (impervious natural), Flat	16			
Rock (impervious natural), Mod	3			
Rock (impervious natural), Steep	0			
Open Water	13			

Notes:
Total acres used in model are based on those acres with GIS data. Runoff was determined as a percentage of precipitation based on the ratio of runoff to precipitation found via the model results.

There are no reliable study area-scale natural ET estimates (non-irrigated vegetation/soil cover) that can be used in the water balance equations for High Prairie. However, since it was the only undetermined value in the water balance for the basin, we solved the water balance equation (net balance equal to zero) to estimate ET. The resultant ET estimates were 32,590 acre-feet/year for the High Prairie, or 11 inches/year (Table B-5).

Water Balance Results

Table B-5 provides the estimated average annual water quantities (acre-feet/year) associated with each water balance term for the High Prairie study area.

Table B-5 – Annual Water Balance Summary for High Prairie Study Area

	Outputs

	Inputs		Natural Conditions				Water Use	
Area	Precipitation		ET (non-irrigation)		Recharge	Runoff	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 ac-ft [6]	in ac-ft	in ac-ft
35,600	19	56,070	11	32,590	22,250	1,290	10	-70

Notes:

1) Source: Study area average from PRISM data.

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 using 7.5 inches per year.

6) Source: Estimated from WWHM4 stormwater runoff model results, where 2.3% of precipitation volume in study area becomes runoff.

7) All acre-foot quantities rounded to nearest 10.

Water availability is assessed on the basin scale by comparing total consumptive surface water use relative to total streamflow, and total consumptive groundwater use relative to groundwater recharge. There is little surface water use in this study area, 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. Ecology's Water Right Tracking System includes several Klickitat River water rights for irrigation use but, based on review of aerial photographs, reconnaissance of the area, and discussion with residents, this larger-scale irrigation water use no longer occurs. In addition, there are four recorded water right permits and certificates diverting from smaller creeks (Swale Creek and others), totaling 23 acre-feet/year of annual water use, predominantly for irrigation use; use of these recorded water rights is uncertain.

Therefore, the water use assessment concludes that essentially all of the water use in the study area is for residential supply. Therefore, it is assumed that roughly 12% of the water put to beneficial use within the study area is consumed, and 88% is nonconsumptive return flow. Because unconsumed residential water use in the study area is assumed discharged entirely to septic, the entire annual residential return flow quantity is assumed to be groundwater recharge.

For this basin-scale analysis, we assume that the proportion of the study area's total actual water use supplied by groundwater supplies is equal to the 72% proportion of the area's total annual water right volume from groundwater sources as reported in Ecology's Water Right Tracking System (28% supplied from surface waters other than the Klickitat River). By this methodology, the estimated annual groundwater-supplied water use is 72% of the estimated 81 acre-feet/year total use, or 59 acre-feet/year. Of this total water use (essentially all residential), only 12%, or 7 acre-feet/year, is estimated to be consumed. This quantity is only 0.03% of the annual natural groundwater recharge. This calculation "nets out" nonconsumptive groundwater use (return flow) that recharges the groundwater system.

Because the water right information in Ecology's Water Right Tracking System may not accurately represent the water sources supplying the study area, we can generate a more conservative estimate of groundwater consumption as a percent of recharge by assuming the entire estimated 81 acre-feet/year of water use is supplied by groundwater. In this case, an estimated 9 acre-feet/year (12%) is consumed, which is 0.04% of the estimated annual natural groundwater recharge While there is uncertainty in the water balance analysis (detailed in next section), it indicates that total groundwater use is a very small percentage of groundwater recharge for the study area as a whole.

In summary, using the available information, total groundwater use is less than 1 percent of the total annual recharge in the High Prairie study area. However, this assumes that recharge and groundwater pumping are distributed equally across the entire study area; it does not account for localized concentrated pumping or differentiate pumping from vertically distinct aquifer zones. As described in Section 3, the study area's basalt aquifer system appears to be "compartmentalized" by geologic structures and deeply incised valleys. Furthermore, return flow preferentially recharges the shallowest aquifer zones, while pumping in a given area may be predominantly from deeper aquifer zones. Therefore, empirical groundwater monitoring, as has been ongoing in the study area since 2007 under the watershed planning and implementation process, provides the best measure for assessing sustainability of groundwater production in specific localities within the study area.

Uncertainties in Basin-Scale Water Balance

The basin-scale water balance estimate does not accurately reflect hydrologic conditions at all locations within a study area, or during all years, or all seasons. They are meant to represent the generalized long-term average hydrologic conditions of the study area. 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 study area 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 study area-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 High Prairie.

Groundwater recharge as modeled by the USGS also introduces uncertainty into the study area-scale water balance. It was a regional model that included the High Prairie study area but did not specifically model the local conditions of the study area. 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 use of a continuous simulation stormwater model to estimate runoff can introduce some uncertainty into the water balance since the model uses precipitation and ET data that may not be applicable to every portion of the study area. The model uses an HSPF (Hydrological Simulation Program – Fortran) for modeling the stormwater runoff, which is considered to be one of the more robust modeling methods for estimating this term. An HSPF model takes into account soil moisture and storage, whereas most other stormwater runoff models do not. Since there are no gages in streams to measure streamflow draining only the study area, this model provides a reasonable estimate of runoff volumes for the purposes of this study.

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 associated with the other terms are propagated into the resultant ET value for the High Prairie study area.

Finally, the assumed water supply sources for the study area are based on water rights information, which may not accurately reflect current conditions. Groundwater use is of critical importance for the study area; therefore, using available information, the water balance analysis brackets a range of groundwater use estimates, both of which come to the same general conclusion regarding groundwater use as a very small percentage of groundwater recharge annually.

References for Appendix B

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