3.0 Overview of Hanford Hydrogeology

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This chapter discusses the varied and complex hydrogeologic setting of the Hanford Site. The deposition and later removal of sedimentary units in certain areas by cataclysmic flooding add to the difficulty in making hydrogeologic interpretations. The following discussion provides a basic summary of Hanford Site hydrogeology.

3.1 Stratigraphic Setting

The Hanford Site lies within the Pasco Basin (Figure 3-1). The geology of the Hanford Site has been studied extensively over the years. The regional geologic setting of the Pasco Basin and the Hanford Site has been described in the following documents:

- BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*
- DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin*
- DOE/RW-0164, *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*
- "Geohydrologic Setting of the Hanford Site, South-Central Washington" (Lindsey et al. 1994).
- RHO-BWI-ST-4, *Geological Studies of the Columbia Plateau – A Status Report*
- WHC-SD-ER-TI-003, *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports*.
- WHC-SD-EN-EE-004, *Revised Stratigraphy for the Ringold Formation, Hanford Site, South-Central Washington.*

The geologic setting for the 200 Areas has been investigated and reported in the following documents:

- HW-61780, *Subsurface Geology of the Hanford Separations Area*
- PNL-6820, *Hydrogeology of the 200 Areas Low-Level Burial Grounds – An Interim Report*
- PNNL-12261, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington*
- PNNL-13858, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-West Area and Vicinity, Hanford Site, Washington*
- RHO-BWI-ST-5, *Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge*
- RHO-BWI-ST-14, *Subsurface Geology of the Cold Creek Syncline*
- RHO-ST-23, *Geology of the Separations Areas, Hanford Site, South-Central Washington*
- RHO-ST-42, *Hydrology of the Separations Area*
- WHC-SD-EN-TI-012, *Geologic Setting of the 200-East Area*.

The geology of the 100 Areas has been described in the following documents:

- WHC-SD-EN-EV-027, *Hydrogeology of 100-N Area, Hanford Site, Washington*
- WHC-SD-EN-TI-132, *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington*
- WHC-SD-EN-TI-133, *Geology of the 100-B/C Area, Hanford Site, South-Central Washington*
- WHC-SD-EN-TI-221, *Geology of the 100-FR-3 Operable Unit, Hanford Site, South-Central Washington*.
- WHC-SD-EN-TI-294, *Hydrogeology of the 100-K Area, Hanford Site, South-Central Washington.*

The geology of the 300 Area is described in *Geology and Hydrology of the 300 Area and Vicinity, Hanford Site, South-Central Washington* (WHC-EP-0500).

BHI-00184 provides a stratigraphic interpretation for the Ringold Formation based on facies associations and defines the areal extent of these suprabasalt units in the Pasco Basin. DOE/RL-2002-39 presents the standardized stratigraphic nomenclature for post-Ringold Formation sediments. A generalized stratigraphic column showing the nomenclature is provided in Figure 3-2.

As deposition of the basalt flows and sediments was occurring, structural forces were causing the down-warping of the Pasco Basin as well as uplifting and folding of the surrounding basalt ridges (Figure 3-3). As these structural features developed, they tended to control the locations of ancestral and present-day rivers and their associated sedimentary deposits. The following subsections discuss the various stratigraphic layers, from oldest (deepest) to youngest (shallowest).

3.1.1 Columbia River Basalt Group

The lowest geologic unit of interest for this report is the Columbia River Basalts, which consists of an assemblage of continental flood basalts covering an area of more than 160,000 square kilometers. These flood basalts were erupted from ~17 to ~6 million years ago. Within the Pasco Basin, the Elephant Mountain flows of the Saddle Mountains Basalt Formation are generally the uppermost basalt flows. The Elephant Mountain Member of the Saddle Mountains Basalt, dated at 10.5 million years, is a Miocene-age, medium- to fine-grained tholeiitic continental flood basalt. Beneath the 200 Areas of the Hanford Site, the Elephant Mountain Member consists of two flows and ranges in thickness from 20 to 30 meters (RHO-BWI-ST-14).

The uppermost surface of the Elephant Mountain Member (basalt) is considered the base of the suprabasalt aquifer system (bedrock) because of its low permeability relative to the overlying sediments. This surface is interpreted and mapped to be a groundwater no-flow boundary, except in areas where it has been partially eroded (e.g., north of the 200 East Area).

The basalt surface beneath the 200 Areas dips south, forming the southern limb of the Gable Mountain anticline/northern limb of the Cold Creek syncline ("Paleodrainage of the Columbia River System on the Columbia Plateau of Washington State – A Summary" [Fecht et al. 1987]). Two smaller basalt folds or anticlinal ridges trending northwest-southeast extend above the water table and create barriers to groundwater flow just north and east of the 200 East Area (Figure 3-3).

Intercommunication of groundwater between the uppermost basalt-confined aquifer and overlying suprabasalt aquifer system has been documented in some areas of the Hanford Site, most notably beneath the B Pond (see Chapter 8.0) (RHO-BWI-ST-14).

One of these areas of intercommunication is identified in the area of Gable Gap, where the ancestral Columbia River and/or cataclysmic flooding has eroded away the upper basalt units, exposing the lower units and interbeds to the suprabasalt aquifer (PNL-10817, *Hydrochemistry and Hydrogeologic Conditions Within the Hanford Site Upper Basalt Confined Aquifer System*). It is important to note that with the cessation of disposal of large volumes of wastewater to the ground surface, the dominant flow is up in most of these intercommunication areas. It is well documented that groundwater flow is from the deeper basalt aquifers upward to the unconfined aquifer.

The basalt geology on Gable Butte, which is structurally elevated above the unconfined aquifer, consists of a complex network of faults and anticlines that are not discussed here. RHO-BWI-ST-14 provides a more detailed discussion.

Sedimentary interbeds, collectively referred to as the Ellensburg Formation, were deposited in between many of the flows of the Saddle Mountains Basalt. The Ellensburg Formation includes fluvial and lacustrine sediments that consist of muds, sands, and gravels.

3.1.2 Ringold Formation

Cessation of the Miocene flood basalt eruptions was followed by a period of sedimentary buildup within the center of the Pasco Basin, which is evidenced by the thick sedimentary sequence of the Ringold Formation. The Ringold Formation was deposited from ~10.5 to ~3.9 million years ago (late Miocene to Pliocene) (DOE/RW-0164). The Ringold Formation can be divided into three broad facies types, depending on the proximity to the ancient river systems and basaltic ridges of the time (Figure 3-4):

- Type I facies: Consists of gravel and associated sand and silt representing a migrating channel deposit of the ancestral Columbia and/or Salmon-Clearwater river systems. This type of sediment is generally confined to the central portion of the Pasco Basin.
- Type II facies: Comprises mainly overbank sand, silt, and clay deposited around the margins of the basin, away from the main fluvial channel system.
- Type III facies: A fanglomerate facies comprising angular basaltic debris derived from side-stream alluvium shed onto the flanks of basalt ridges. This facies occurs only locally around the extreme margins of the basin.

The alternating coarse and fine sediments deposited during movement of the river channel are the basis for various stratigraphic nomenclature systems. The various nomenclatures have been based on either lithofacies units ("Ringold Formation of the Pleistocene Age in Type Locality, The White Bluffs, Washington" [Newcomb 1958]; RHO-ST-23; SD-BWI-DP-039, *Suprabasalt Stratigraphy Within and Adjacent to the Reference Repository Location*) or upward-fining fluvial cycles (*Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report* [PSPL 1982]). Studies of the Ringold Formation in the early to mid-1990s indicated that the formation contains significant, previously undocumented stratigraphic variation. Since that time, two separate Hanford Site stratigraphic classifications have come into use. One classification, developed in BHI-00184, is based on lithology; the second classification, developed by Pacific Northwest National Laboratory (PNNL-10886, *Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report*; PNL-8971, *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 93 Status Report*), combines the geology with the hydrologic properties of the material

yielding a hydrogeologic stratigraphy (also see PNNL-10886). This report uses the hydrogeologic classification because it is more applicable to the issue of addressing groundwater movement in the suprabasalt sediments. A hydrogeologic summary of these units is presented below. This classification is also consistent with the Hanford Site three-dimensional computer models using this classification and the revised hydrogeology report for the 200 East Area (PNNL-12261).

Hydrostratigraphically, the Ringold Formation is broadly divided into two units: an upper unit, and a lower unit. The upper Ringold unit consists of lacustrine deposits and intercalated fluvial sands. Three coarsening, upward cycles are present where the greatest thickness of these strata is preserved. The lowest cycle grades into interbedded sands and paleosols of the lower Ringold unit. BHI-00184 provides the most detailed description of the upper Ringold unit. The upper Ringold unit forms the bluffs along the Columbia River north and east of the Hanford Site but has largely been removed by erosion from the site itself.

The lower Ringold unit is further subdivided into six subunits (Units 5 through 9 and the lower mud unit). These units represent continental fluvial and lacustrine sediments deposited on the Elephant Mountain Basalt by ancestral Columbia and Clearwater-Salmon rivers during late Miocene to Pliocene time (DOE/RW-0164). The following subsections describe the major units of the lower Ringold Formation, from shallowest to deepest.

3.1.2.1 Ringold Formation Unit 5

Unit 5 is the uppermost of the lower Ringold Formation units in the unconfined aquifer (Figure 3-2) and is composed primarily of fluvial gravels that grade upward into the interbedded fluvial sand and silt of the upper Ringold unit (BHI-00184). Ringold Unit 5 is the location where the top of the uppermost unconfined aquifer resides beneath the 100-B, 100-N, and 100-K Areas; most of the 200 West Area; and the southern and western portions of the 200 East Area.

In the 200 Areas, Unit 5 overlies the lower mud unit and is present everywhere, except the very northeastern portion of the 200 West Area and in the northern portion of the 200 East Area. Within the 200 East Area, Unit 5 is present only in the southern portion, as the remainder has been removed by erosion (PNNL-13858). Both boundary interpretations are slightly different from previous work and suggest that Unit 5 was eroded and/or reworked in the 200 Areas during post-Ringold fluvial incision or Pleistocene flooding events.

Ringold Unit 5 has been removed from Gable Gap and most of the 200 East Area to approximately the May Junction Fault. Unit 5 was not removed from the downthrown side of the fault because of structural displacement into the basin and distance away from the highest forces of the Pleistocene floods (PNNL-12261).

Ringold Unit 5 is absent beneath the eastern part of the “horn” area of the Hanford Site (i.e., the 100-H and 100-F Areas) and beneath the 300 Area.

3.1.2.2 Ringold Formation Units 6 through 7, Overbank Deposits and Upper Mud Unit

Units 6 through 7 consist of fluvial gravels separated by overbank and lacustrine deposits (clay, silt, silty fine-grained sand, and paleosols). The shallowest overbank deposits are known informally as the Ringold upper mud unit in the 100 Areas, where this unit forms the bottom of the unconfined aquifer. These units have been largely removed by later flooding from beneath the 200 Areas, or possibly were never deposited in this area.

3.1.2.3 Ringold Formation Unit 9

The deepest Ringold sediments belong to Unit 9, which is a mixture of clay, silt, fine- to coarse-grained sand, and granule to cobble gravel. In the southern and eastern portion of the 200 East Area, Unit 9 can be subdivided into three hydrogeologic units based on markedly different lithologies and hydraulic properties. The primary subunit is a poorly characterized silt to clay-rich confining zone with low permeability, classified as Unit 9B. Subunits 9A and 9C have much higher permeabilities and lower clay content. Subunits 9A, 9B, and 9C can be differentiated and mapped as separate units using geophysical logs, lithologic logs, and drillers' reports based on the correlation of Unit 9B, where it is laterally continuous.

Unit 9 dips consistently to the south-southwest, roughly comparable to the basalt structure. Unit 9 increases in thickness from north to south into the Cold Creek syncline, suggesting deposition in an environment of continued structural growth of the Pasco Basin during Ringold time (SD-BWI-DP-039; DOE/RW-0164).

The north-northeastern extent of Unit 9 is approximate and is delineated as the erosional limit of cataclysmic flooding that traversed across the uplifted Gable Butte anticlinal area (PNNL-12261). In the scoured area (interpreted to be north of the erosional boundary), most of the Ringold Formation is all or partially removed and/or reworked within the area of erosion. Evaluation of data from north and east of the B Pond suggests that only portions of Units 9A/9C and 9B are preserved on the lee side and between the smaller anticlinal ridges within the erosional area (PNNL-12261).

In the northern Hanford Site, Unit 9 is present beneath the 100-B/C, 100-K, and 100-N Areas.

3.1.2.4 Ringold Formation Lower Mud Unit (Unit 8)

The Ringold lower mud unit is composed of a thick sequence of fluvial overbank, paleosol, and lacustrine silts and clay, with minor sand and gravel. More detailed descriptions of the lower mud unit are presented in BHI-00184.

The Ringold lower mud unit is the most significant confining unit within the suprabasalt aquifer system on the Central Plateau. The lower mud unit separates the saturated sediments of the suprabasalt aquifer system into an uppermost unconfined aquifer system, often referred to as the Hanford unconfined aquifer, and a lower confined aquifer system referred to as the confined Ringold aquifer system. In the 200 East Area, a secondary confined Ringold aquifer system is composed of subunit 9A/9C gravels separated by subunit 9B. The uppermost unconfined aquifer system includes saturated sediments above the lower mud unit or the top of subunit 9B, or the top of basalt in the areas where the lower mud unit is absent.

BHI-00184 indicates that east of B Pond and south of the 200 East Area, the lower mud unit is regionally continuous throughout the Pasco Basin. However, as BHI-00184 and other publications describe, the lower mud unit is not present on the Gable Mountain anticline, including Gable Gap and the region to the south, extending to the northern boundary of the 200 West Area and including most of the 200 East Area. BHI-00184 suggests the absence of the lower mud unit is due to either depositional thinning onto the basalt structure or truncation by Ringold Unit 5 or Hanford formation sediments. Geologic, geophysical, and hydraulic data indicate that where channeling occurs, erosion appears to have scoured into and/or completely removed all the lower mud unit and Unit 5, with the possible exception of small, localized remnants.

Where the lower mud unit is present, the thickness is between 26 meters (in the 200 West Area) and up to 29 meters (in the 200 East Area), and it dips south to southwest into the Cold Creek syncline, roughly paralleling the basalt structure. The revised structural map of the Ringold lower mud unit illustrates that it is elevated above the groundwater surface east and south of the B Pond, northeast of the 200 West Area, and between the 200 East and 200 West Areas (Figure 3-5). In these areas where the Ringold lower mud unit is at or above the water table, it is mapped as a hydraulic barrier similar to the basalt surface (PNNL-13858).

The hydrogeologic continuity and thickness of the lower mud unit indicate that groundwater within the Hanford unconfined aquifer and confined Ringold aquifer system does not flow vertically through this unit. However, flow along the lateral boundary of the lower mud unit does occur, and where it has been removed by erosion, groundwater from the confined Ringold aquifer system may be in communication with groundwater from the uppermost unconfined aquifer. Also, along the May Junction Fault where uplift has juxtaposed the lower mud unit adjacent to the unconfined aquifer, intercommunication between the Ringold confined and the upper unconfined aquifers may occur.

3.1.3 Cold Creek Unit

After deposition of the Ringold Formation sediments, a period of regional incision occurred, followed by soil development and deposition of windblown sediments during the late Pliocene to early Pleistocene ("Late-Cenozoic Stratigraphy and Tectonic Evolution Within a Subsiding Basin, South-Central Washington" [Bjornstad 1985]). These deposits are referred to as the Cold Creek unit. In the eastern portion of the Pasco Basin, the Cold Creek unit is not found and, therefore, was either not deposited or was eroded later by the Columbia River or cataclysmic flooding.

Several different facies associations are represented by the Cold Creek unit, including (1) mainstream alluvial, (2) calcic-paleosol, (3) side-stream-alluvial, (4) colluvial, and (5) overbank-eolian facies associations (Figure 3-6). The Cold Creek unit in the 200 West Areas is represented by the calcic paleosol (the early Palouse soil) and overbank/eolian(my bad, this was wrong facies) facies (Cold Creek silt unit [CCU_z]), which is a silt and/or well-sorted, fine sand.

In much of the 200 East Area and elsewhere in the Pasco Basin, a quartzo-feldspathic sandy gravel above the Ringold Formation and below the more basaltic Hanford formation has been identified. This intermediate gravel is referred to as the Cold Creek gravel unit (CCU_g) (*Conceptual Models for Migration of Key Contaminants Through the Vadose Zone and Into the Upper Unconfined Aquifer Below the B-Complex* [PNNL-19277]). The CCU_g is mineralogically similar to the Ringold Formation, with the exception that it often caves and heaves during drilling. The loose, unconsolidated nature of these sediments suggests that they are post-Ringold in age and belong to a mainstream gravel facies of the Cold Creek unit. These most likely represent fluvial deposits from the ancestral Columbia River, perhaps equivalent to the pre-Missoula gravels (PSPL 1982) identified east of the 200 Areas. The upper surface of the CCU_g unit shows ~10 meters of relief.

3.1.4 Hanford Formation

The "Hanford formation" is the informal name given to Pleistocene-age cataclysmic flood deposits in the Pasco Basin (DOE/RL-2002-39, RHO-BWI-ST-4; DOE/RW-164; "Quaternary Geology of the Columbia Plateau" [Baker et al. 1991]; Lindsey et al. 1994). Sources for the floodwaters included Glacial Lake Missoula, pluvial Lake Bonneville, and ice-margin lakes that formed around the margins of

the Columbia Plateau (Baker et al. 1991). These floods periodically inundated the Pasco Basin during the Pleistocene, often eroding existing sediments ("Pre-Wisconsin Glacial Outburst Floods: Pedogenic and Paleomagnetic Evidence from the Pasco Basin and Adjacent Channeled Scabland" [Bjornstad and Fecht 1989]). As the flood waters encountered restricted flow through Wallula Gap, both coarse- and fine-grained sediments entrained in the flood waters were deposited within the basin. As the flood waters gradually drained away, both deposition and erosion occurred. This sequence of events occurred a number of times, leaving behind distinct geomorphic features (Figure 3-7) and creating a complex stratigraphy within the Hanford formation, with lenses of sand and silt surrounded by sand and gravel. However, fine-grained sediments are mainly found near the margins of the basin, and coarse-grained sediments are found in the central portion where the flood currents were stronger.

The Hanford formation forms a nearly continuous blanket over the entire Hanford Site, except near flood-scoured Gable Butte/Gable Mountain and other basalt outcrops. In the northern portion of the 200 West Area, the Hanford formation directly overlies basalt; further to the south, it overlies the Cold Creek units and Ringold Formation. The Hanford formation consists predominantly of unconsolidated sediments covering a wide range in grain size: from boulder-size gravel, to sand, silty sand, and silt. Gravel clasts are composed of mostly sub-angular to sub-rounded basalt. Mineralogically, the sand fraction of the Hanford formation averages ~50% mafic rock fragments (i.e., basalt) and ~50% quartz feldspar (RHO-ST-23).

Cataclysmic flood deposits of the Hanford formation have been classified into three facies types (gravel, sand, and interbedded sand- and silt-dominated), which grade into one another both vertically and laterally. The three facies may interfinger with or grade from gravel to sand, or sand to fine-grained facies, but rarely from gravel to fine-grained facies.

3.1.4.1 Gravel-Dominated Facies

The gravel-dominated facies of the Hanford formation consists of coarse-grained basaltic sand and granule- to boulder-size gravel. These deposits display an open-framework texture, plane to low-angle massive bedding, and large-scale planar cross-bedding in outcrop. Gravel-dominated beds sometimes grade upward into sand- and silt-dominated facies. Gravel clasts are dominantly basalt with lesser amounts of Ringold Formation clasts, granite, quartzite, and gneiss (WHC-SD-EN-TI-012). The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main cataclysmic flood channels (i.e., the Pasco Basin channelway [Figure 3-7]).

3.1.4.2 Sand-Dominated Facies

The sand-dominated facies of the Hanford formation consists of fine- to coarse-grained sand and granule gravel. The sands typically have high basalt content and are commonly referred to as black, gray, or "salt-and-pepper" sands. The sands may contain small pebbles and rip-up clasts, pebble-gravel interbeds, and often grade upward into thin (less than 1 meter) zones of silt-dominated facies. This facies commonly displays plane lamination and bedding, and also less flood channels during the waning stages of flooding. This facies is transitional between the gravel-dominated facies and the silt-dominated facies, and is the major component of the Hanford sand plain (Figure 3-7).

3.1.4.3 Interbedded Sand- and Silt-Dominated Facies

The interbedded sand and silt-dominated facies of the Hanford formation

consists of thin-bedded, plane-laminated, and ripple cross-laminated silt and fine- to coarse-grained sand. Beds are typically a few centimeters to a meter thick and commonly display normally graded bedding (WHC-SD-EN-TI-012). Sediments of this facies were deposited under slack water conditions and in back-flooded areas (DOE/RW-0164; Baker et al. 1991). This facies is typified by the stratigraphy found through the various flood bars (Figure 3-7).

3.1.5 Clastic Dikes

Clastic dikes are vertical to sub-vertical sedimentary structures that crosscut normal sedimentary layering. Clastic dikes are a common geologic feature of the Hanford formation in the 200 Areas, especially in the sand- and silt-dominated facies. Clastic dikes are much less common in the gravel-dominated facies of the Hanford formation.

Clastic dikes occur in swarms and form four types of networks (BHI-01103, *Clastic Injection Dikes of the Pasco Basin and Vicinity: Geologic Atlas Series*): (1) regular-shaped polygonal patterns, (2) irregular-shaped polygonal patterns, (3) pre-existing fissure fillings, and (4) random occurrences. Regular polygonal networks resemble four- to eight-sided polygons and typically range from 3 centimeters to 1 meter in width, 2 meters to greater than 20 meters in depth, and 1.5 to 100 meters along strike. Smaller dikelets, sills, and small-scale faults and shears are commonly associated with master dikes that form the polygons.

In general, a clastic dike has an outer skin of clay with coarser infilling material. Clay linings are commonly 0.03 to 1.0 millimeters in thickness, but linings up to ~10 millimeters are known. The width of individual infilling layers ranges from as little as 0.01 millimeters to more than 30 centimeters, and their length can vary from ~0.2 meters to more than 20 meters. Infilling sediments are typically poor- to well-sorted sand but may contain clay, silt, and gravel (HNF-4936, *Subsurface Conditions Description Report for the S-SX Waste Management Area*). The importance of clastic dikes in determining the migration potential of contaminants from the near-surface disposal facilities to the water table is still debated.

3.1.6 Holocene Surficial Deposits

Holocene surficial deposits, consisting of silt, sand, and gravel, form a thin (less than 5-meter) veneer across much of the Hanford Site. In the 200 West Area and southern portion of the 200 East Area, these deposits consist dominantly of laterally discontinuous sheets of windblown silt (loess) and fine-grained sand (PNNL-12086, *Hanford Site Groundwater Monitoring for Fiscal Year 1998*).

3.2 Hydrologic Setting

Both unconfined and confined aquifer systems lie beneath most of the Hanford Site. The unconfined aquifer system is located in unconsolidated to semiconsolidated sediments overlying the basalt bedrock. In some areas the inconfined aquifer extends into the fractured upper zone of the underlying basalt. Parts of this aquifer are locally semiconfined or confined (confined Ringold). However, because the entire suprabasalt aquifer system is interconnected on a Hanford Site-wide scale, this system has commonly been referred to as the Hanford unconfined aquifer. Aquifers located within the Columbia River Basalts are referred to as the basalt-confined aquifer system.

3.2.1 Confined Aquifer

Confined aquifers within the Columbia River Basalts are composed of relatively permeable sedimentary interbeds and the brecciated tops of basalt flows. The horizontal hydraulic conductivities of most of these aquifers fall in the range of 10^{-4} to 10^{-10} meters per second. Dense interior sections of the basalt flows have horizontal hydraulic conductivities ranging from 10^{-9} to 10^{-15} meters per second, about five orders of magnitude lower than those of the confined aquifers (DOE/RW-0164). Groundwater in the confined aquifers underlying the Hanford Site results mainly from infiltration of precipitation and stream flow, within recharge areas along the periphery of the Pasco Basin (DOE/RW-0164). Hydraulic head information indicates that groundwater in the confined aquifers flows generally toward the Columbia River and, in some places, toward areas of enhanced vertical flow communication with the unconfined system (*Maps Showing Ground-Water Levels in the Columbia River Basalt and Overlying Materials, Spring 1983, Southeastern Washington* [Bauer et al. 1985]; SD-BWI-TI-335, *Fresh-Water Potentiometric Map and Inferred Flow Direction of Ground Water Within the Mabton Interbed, Hanford Site, Washington State – January 1987*; DOE/RW-0164).

With regard to development of a conceptual model for the unconfined aquifer, the confined aquifer system is important because the two systems are known to be in hydraulic communication in the area northwest of the 200 East Area (RHO-RE-ST-12P, *An Assessment of Aquifer Intercommunication in the B-Pond-Gable Mountain Area of the Hanford Site*; DOE/RL-2008-01, *Hanford Site Groundwater Monitoring for Fiscal Year 2007*). Although the dominant gradient is now upward in the confined aquifer system (flow moving from the confined to the unconfined aquifer), the potential also exists for significant downward groundwater leakage between the two systems in areas where hydraulic heads in the unconfined aquifer were artificially increased.

3.2.2 Unconfined Aquifer

Groundwater in the unconfined aquifer at Hanford generally flows from recharge areas in the elevated region near the western boundary of the Hanford Site, toward the Columbia River on the eastern and northern boundaries. The Columbia River is the primary discharge area for the unconfined aquifer. The Yakima River borders the Hanford Site on the southwest and is generally regarded as a source of recharge. Natural areal recharge across the entire Hanford Site depends on a number of variables, most notably soil type and vegetation cover. Thus recharge ranges from a general low of 1.5 centimeters per year for areas with a natural shrub-steepe vegetation cover to a high of 52 centimeters per year for unvegetated areas in the 100-H Area and eastern 200 Areas (PNNL-14702, Rev. 1, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*). It should also be noted that recharge can be artificially reduced/enhanced going as low as 0.04 centimeters per year for engineered evapotranspiration covers or as high as 92 centimeters per year for unvegetated gravel areas. Since 1944, the artificial recharge from Hanford Site wastewater disposal operations has been greater than the natural recharge, estimated at 17.2 centimeters per year (PNNL-18807, *Soil Water Balance and Recharge Monitoring at the Hanford Site – FY09 Status Report*), as an estimated 1.68×10^{12} liters of wastewater was discharged to disposal ponds, trenches, and cribs to date. The volumes of wastewater discharged to the ground surface have steadily declined, from ~14 billion liters in 1990, to ~0.6 billion liters by 2000. In CY 2008 (the last year with records), ~464 million liters of wastewater were discharged to the ground surface. The two largest discharge locations on the Central Plateau are the 200 Area Treated Effluent Disposal Facility (59.6% of the total) and the State-Approved Land Disposal Site (~5% of the total).

The unconfined aquifer at Hanford Site lies mainly within the Ringold Formation and Hanford formation. Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from ~10^{-4} to 10^{-5} meters per second (DOE/RW-0164). Because the Ringold sediments are more consolidated, contain more silt, and are not as well sorted, these sediments are ~10 to 100 times less permeable than the sediments of the overlying Hanford formation. Prior to wastewater disposal operations at the Hanford Site, the uppermost aquifer was almost entirely within the Ringold Formation, and the water table extended into the Hanford formation at only a few locations (*Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington* [Newcomb et al. 1972]). However, wastewater discharges increased the water table elevation and created groundwater mounds under the two main wastewater disposal areas near the 200 East and 200 West Areas. Because of the increased groundwater elevation, the unconfined aquifer now extends upward into the Hanford formation. This change resulted in increased transmissivity because the newly saturated Hanford formation sediments are more permeable.

During the period from 1944 to 1989, the water table increased ~24 meters under a disposal area in the 200 West Area and ~9 meters under disposal ponds near the 200 East Area. The volume of water discharged to the ground at the 200 West Area is actually less than that discharged at the 200 East Area; however, the lower permeability of the aquifer in the vicinity of 200 West Area has inhibited groundwater movement in this area and resulted in a higher groundwater mound. The presence of the groundwater mounds also affected the direction of groundwater movement, causing radial flow from the discharge areas. In *Hanford Site Water-Table Changes, 1950 Through 1980 – Data Observations and Evaluation* (PNL-5506), changes documented in the water table elevation showed that the edge of the mounds migrated outward from the sources over time until about 1980. Water levels have declined in most areas since 1980 due to decreased wastewater discharges (PNL-7498, *Evaluation of Hanford Site Water-Table Changes – 1980 to 1990*).

Since non-permitted discharges of wastewater to unlined ponds ceased in 1984, groundwater levels have been declining across the Hanford Site. The water table has decreased 3 meters in the 200 East Area and 13 meters in the 200 West Area (Figure 3-8). Although some permitted discharges continue today (e.g., Treated Effluent Disposal Facility and State-Approved Land Disposal Site), the water table continues to decline and approach pre-Hanford operational levels. As a result, groundwater flow directions around the Hanford Site are also changing to a more regional direction (see discussion in Chapter 2.0).

In the 1950s through 1960s, groundwater mounds of 6 to 9 meters were present in each of the 100 Areas (WHC-SD-EN-TI-023, *Hydrologic Information Summary for the Northern Hanford Site*). A mound persisted in the 100-N Area until 1991.

3.2.3 Vadose Zone

The Hanford formation and Cold Creek unit comprise most of the vadose zone. The Cold Creek unit (CCU_z and CCU_g) represents relatively thin, but significant, depositional units of post-Ringold and pre-Hanford sedimentation. The vadose zone ranges in thickness from less than 1 meter near the Columbia River to greater than 50 meters beneath the Central Plateau.

Figure 3-1. Location of the Pasco Basin and Hanford Site.

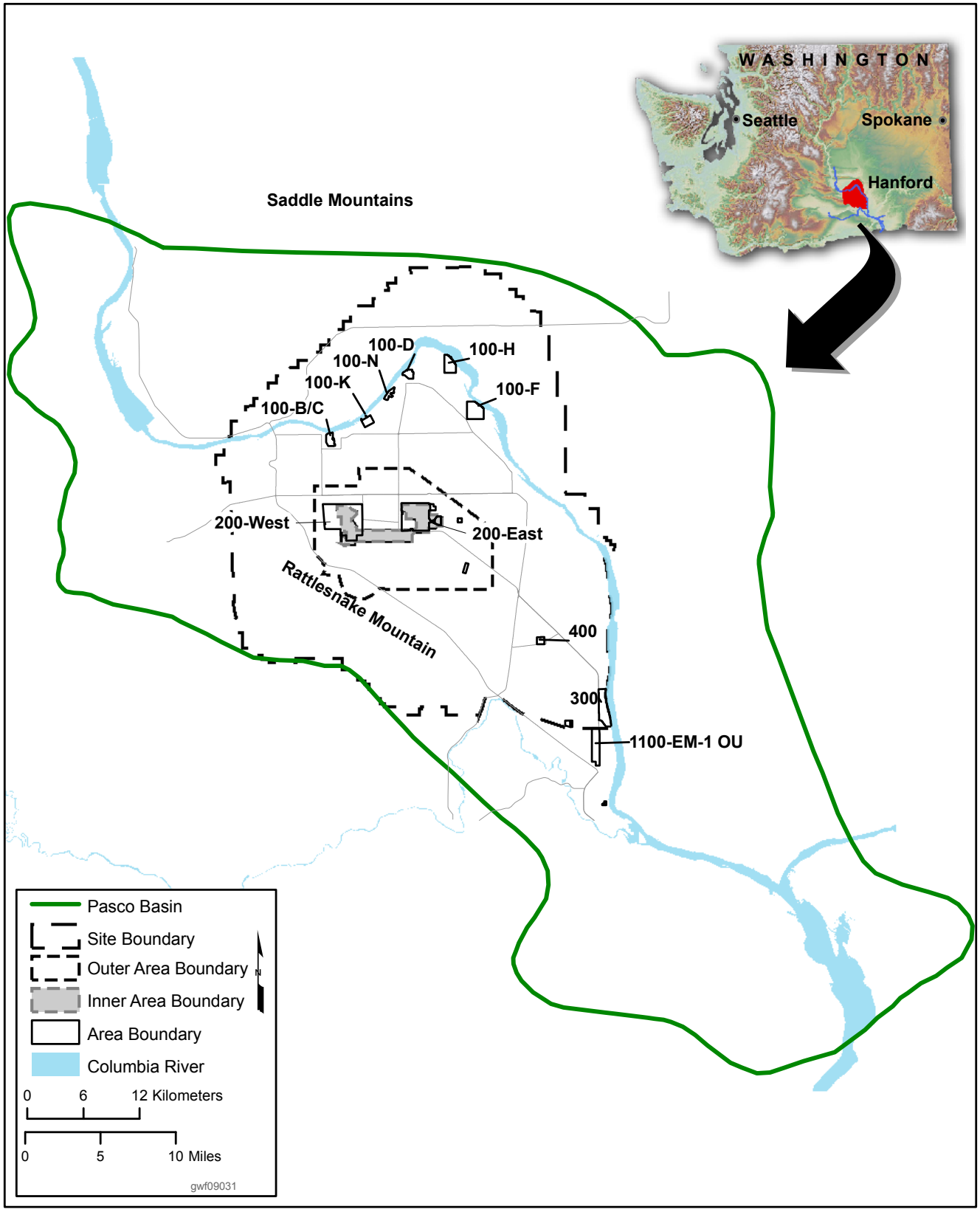


Figure 3-2. Stratigraphic Column for the Hanford Site Showing Nomenclature.

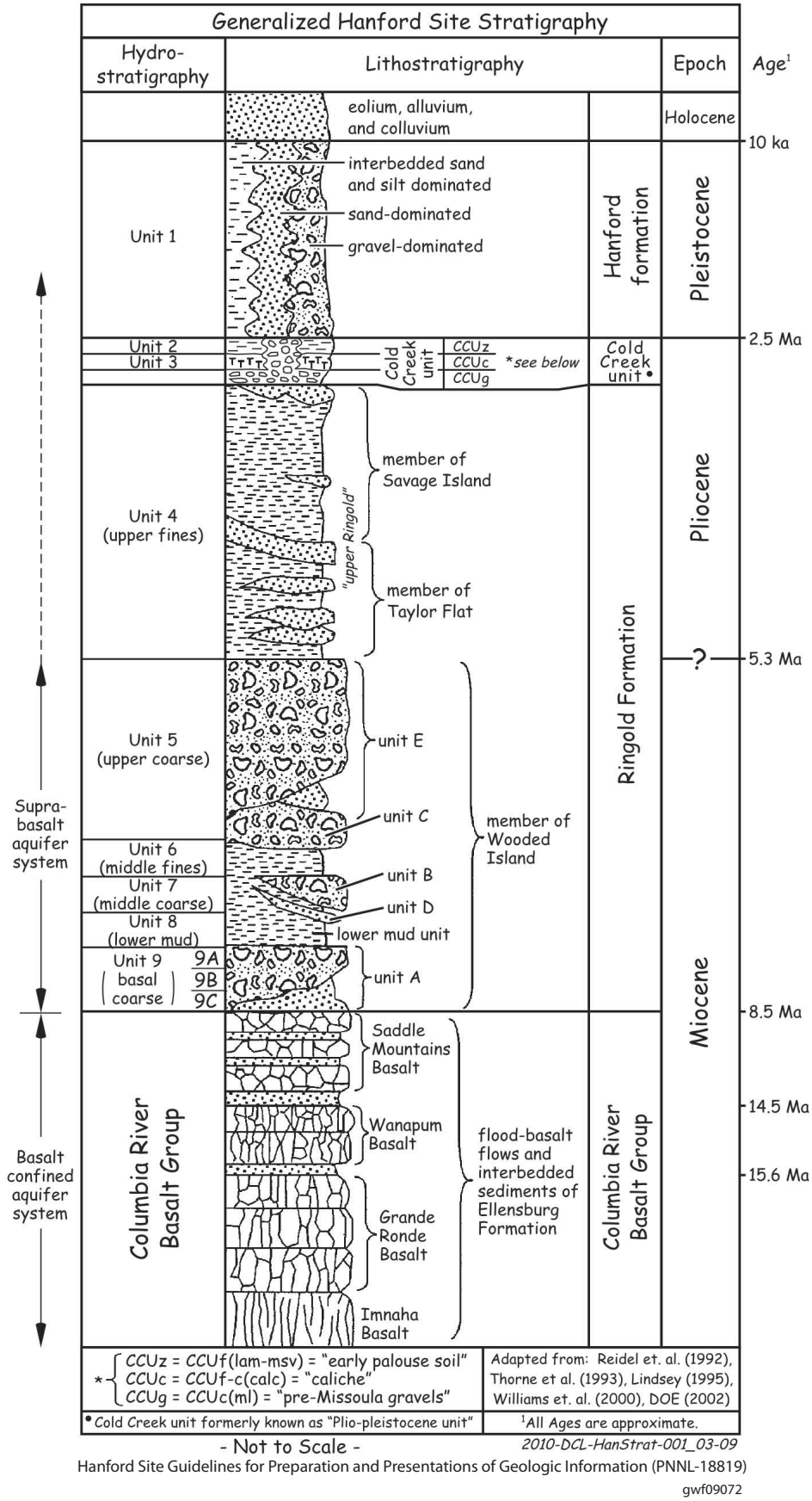


Figure 3-3. General Geologic Structures of the Pasco Basin and Hanford Site.

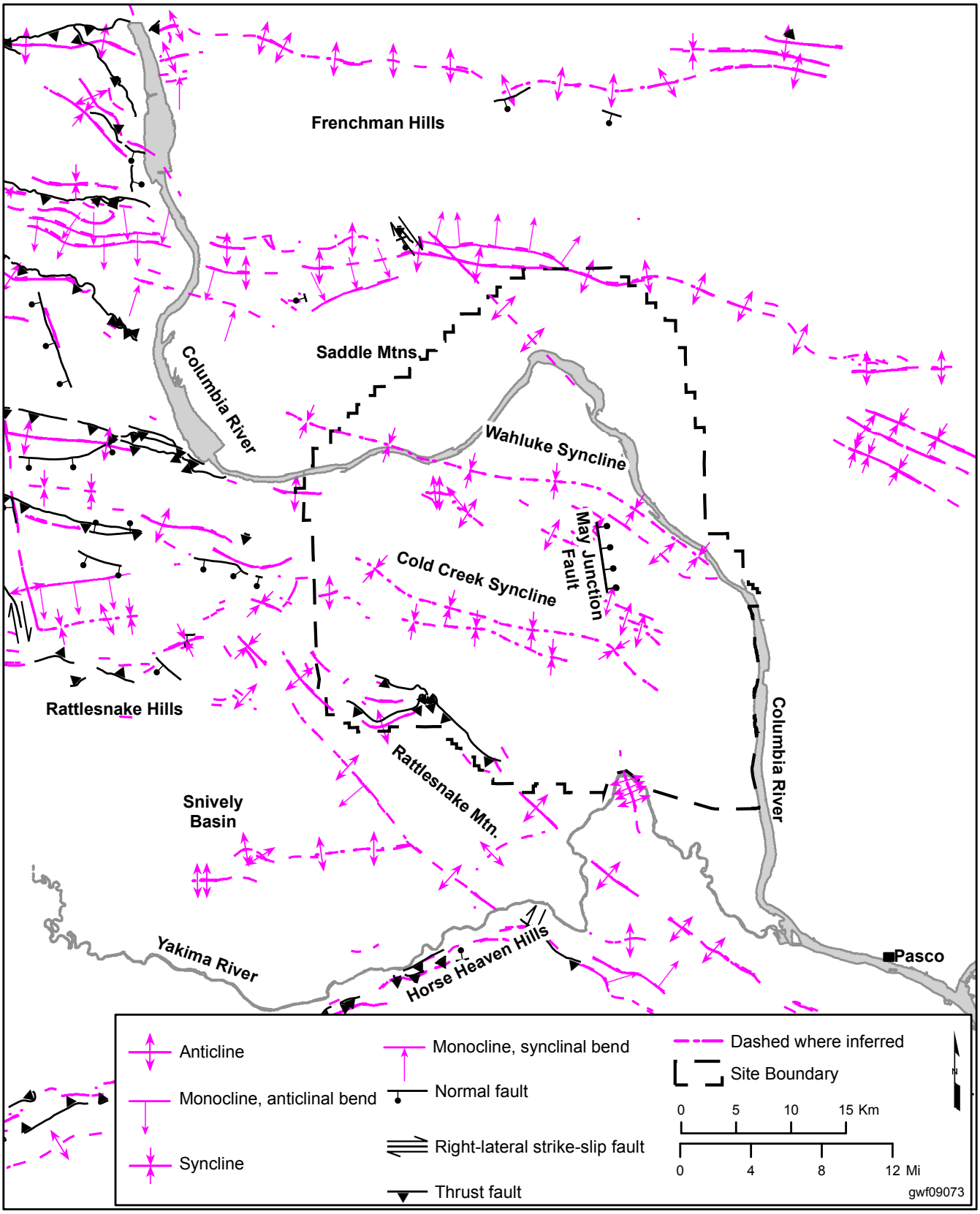
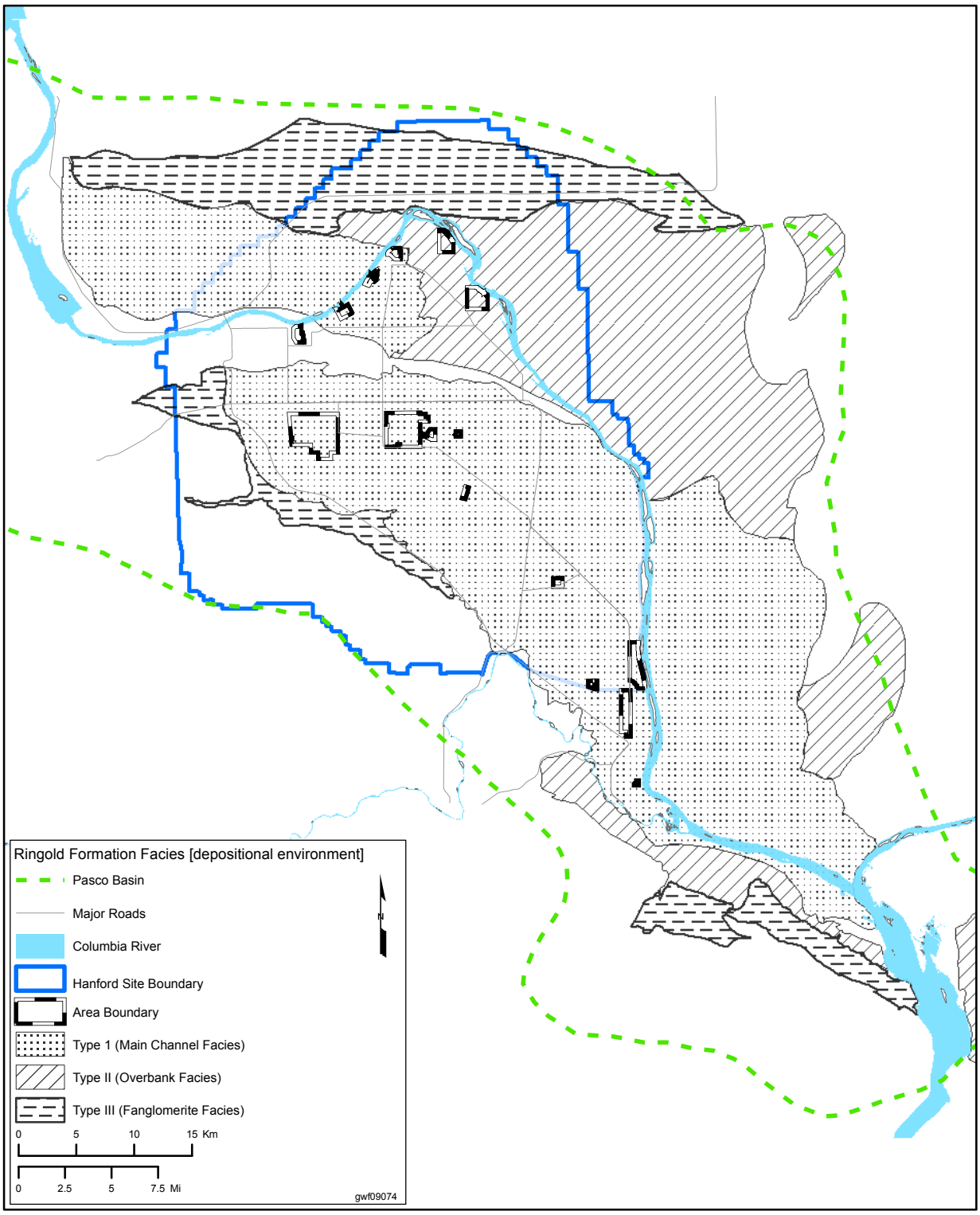


Figure 3-4. Facies of the Ringold Formation Within the Central Pasco Basin.



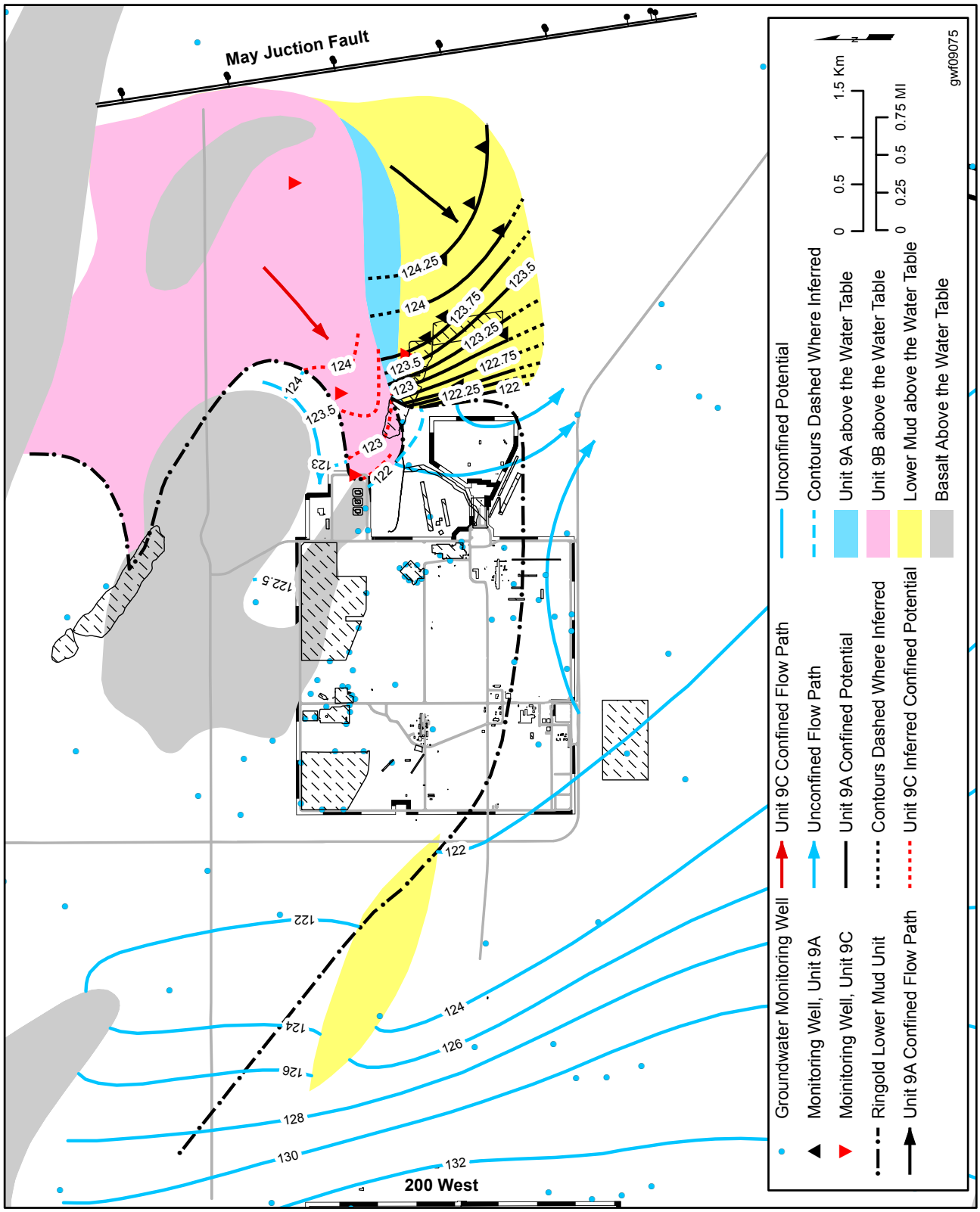


Figure 3-5. Lower Ringold Formation Beneath the 200 East Area.

Figure 3-6. Facies Distribution for the Cold Creek Unit within the Central Pasco Basin.

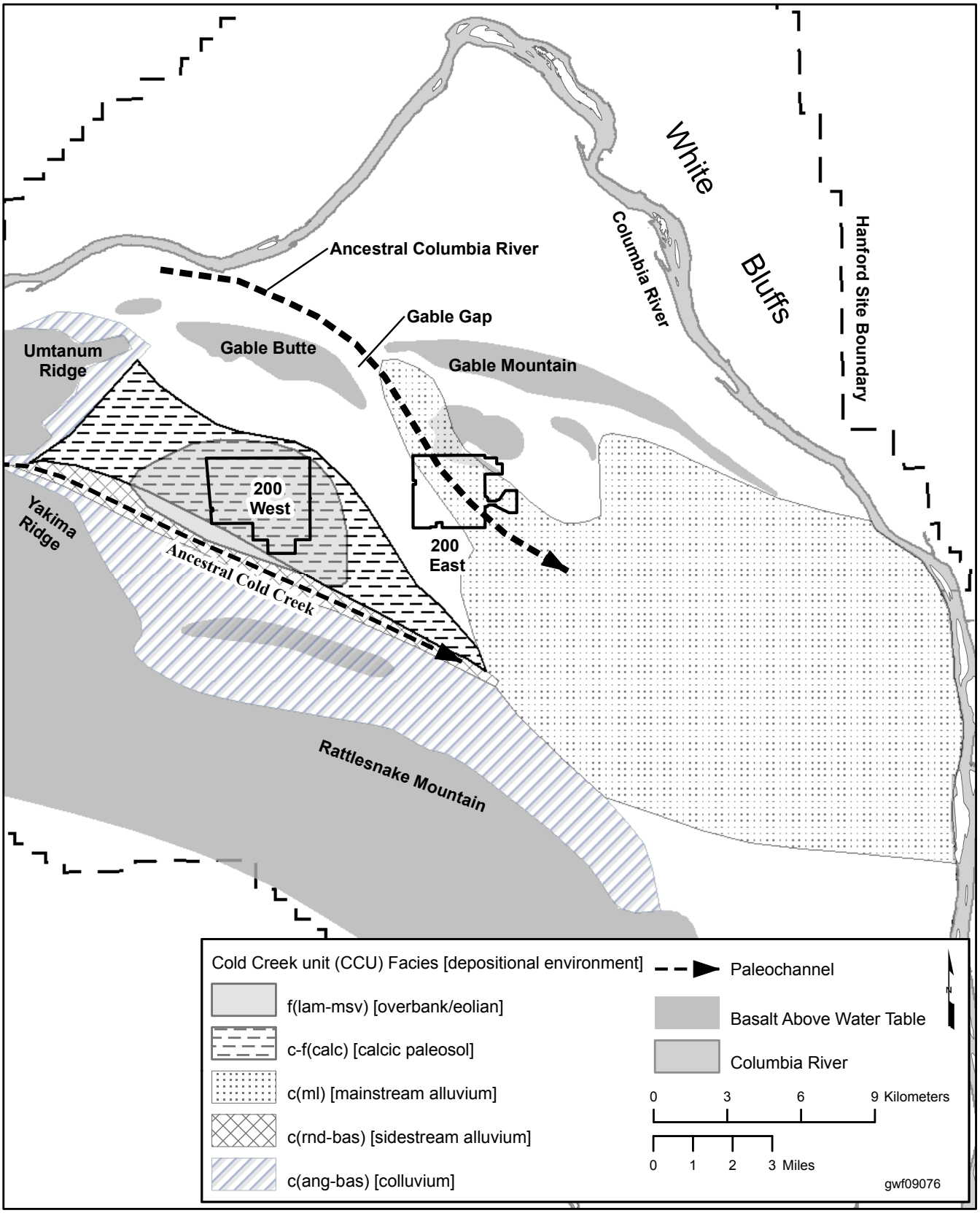
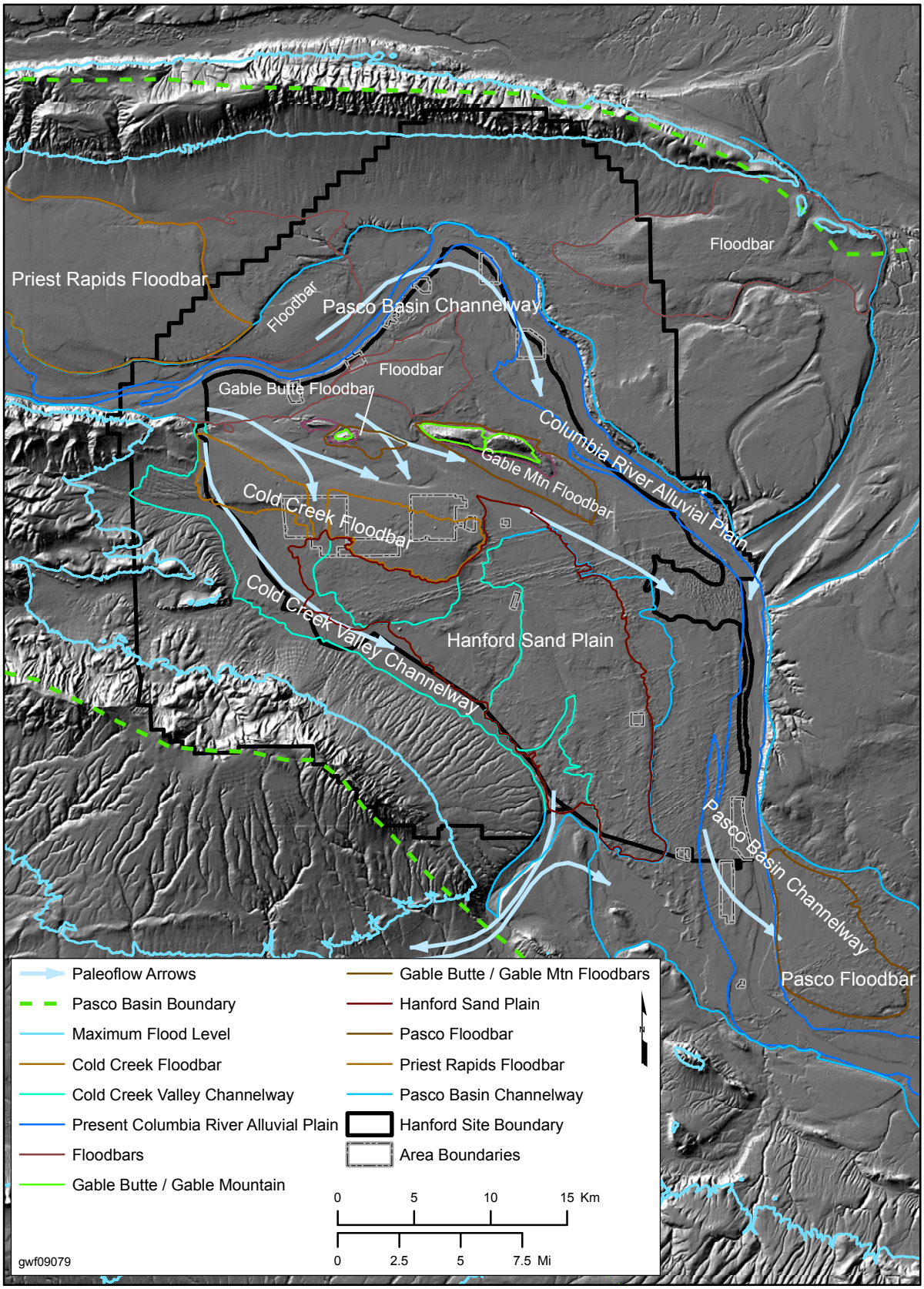


Figure 3-7. Ice-Age Flood Geomorphic Features of the Pasco Basin.



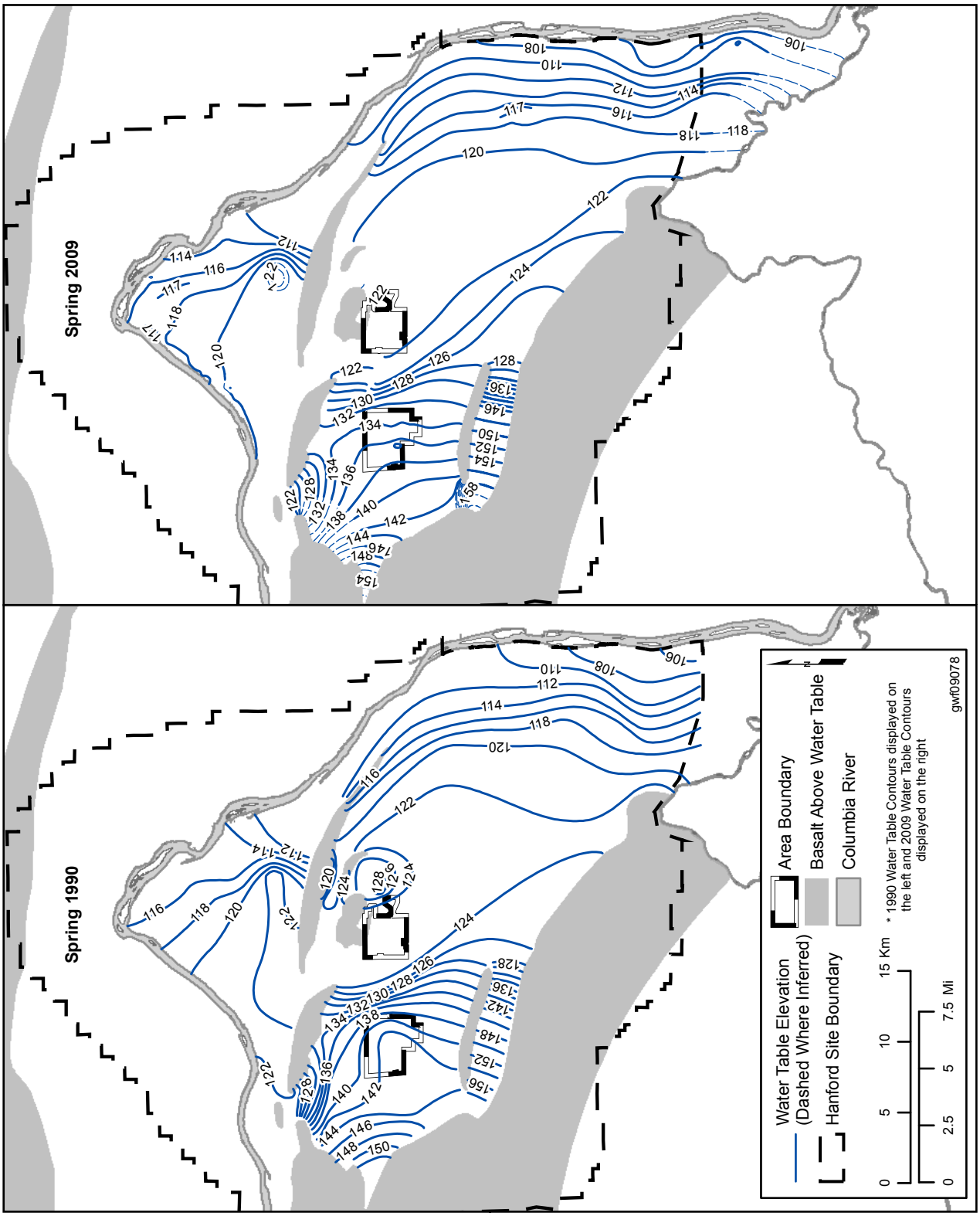


Figure 3-8. Difference in Water Table Elevations for the Hanford Site Unconfined Aquifer, 1989 to 2008.