Walla Walla Basin Watershed Council
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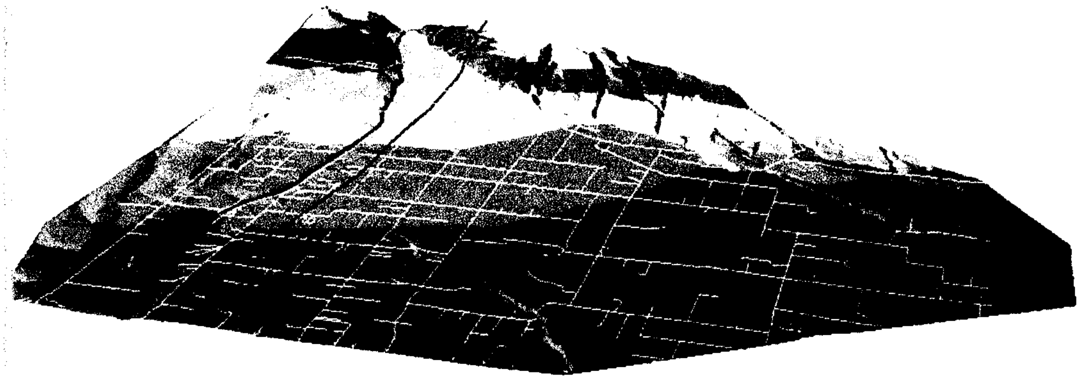
Surface-Ground Water Interactions Along Oregon's Lower Walla Walla River

2000-2001



Prepared in Cooperation with Oregon Watershed Enhancement Board, Oregon Water Resources Department, and Washington's Department of Ecology.

DRAFT

Wednesday, September 25, 2002

Abstract: (After Technical Review)

Forward

Written by Brian Wolcott, Director, Walla Walla Basin Watershed Council

In 1999, the community of Milton-Freewater was faced with a federal imperative to send some undetermined amount of century-old state-granted water rights down the river to provide passage and habitat for ESA-listed fish. How much water local irrigators bypassed for fish could have meant the end of their livelihoods and the turnover of dry useless ground to financial institutions, especially the irrigation-dependent orchards that include the largest apple production region in Oregon. There was limited justification of how much water to bypass. There was also limited consideration of historically noted river losses to the shallow aquifer.

Bypassing water for fish has been a significant and costly behavioral change for valley irrigators. This study helps quantify the hydrologic changes caused by that bypass water and describes additional factors that affect the utility or futility of that action. The local community tasked the Walla Walla Basin Watershed Council with collecting the scientific information needed to quantify the losses of river water to the underlying gravel aquifer and documenting seasonal and multi-year trends in water table fluctuations. Although this work raises additional questions, it provides a framework of data, analysis, and mapping on which to build a better model of the shallow aquifer's relationship with the Walla Walla River between Milton-Freewater and the Oregon-Washington state line. This work of beginning to understand the complex relationship between surface water and ground water in the Walla Walla River Basin is essential to our habitat restoration planning and project prioritization. The economic, ecological, and cultural future of the valley depends on wise decision-making regarding our water resources.

This report is one of several ongoing investigations into the hydrology of the Walla Walla valley. This study, funded by the Oregon Watershed Enhancement Board at $59,620, represents an efficient use of tax dollars. It is also an excellent example of dedication and cooperation among many local and outside resources including Oregon State University, Oregon Water Resources Department, Washington Department of Ecology, local landowners and irrigators, and reasonably priced support from private consultants. Tying local knowledge to that of technical experts makes this report a better management tool. Thanks to those who have been assisting through the collection and analysis of data, providing access to wells and the different branches of the Walla Walla River, and providing suggestions, ideas, and feedback on this report and future activities.

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Finally, without the support of the Council board members and the excellent staff at the WWBWC this project would not be possible. Brian Wolcott (Director) and Gina Massoni (Project Manager) provided invaluable support for this project. Special thanks also to the many private landowners who provided us access to their properties.

List of Terms (insert after technical review)

Introduction

The hydrologic connectivity between the shallow aquifer and surface flows along the mainstem of the Walla Walla River (Oregon) has been altered over the years by human activity including the construction and maintenance of a flood-control levee system, extensive in-channel gravel mining, and the installation and use of numerous shallow aquifer domestic, industrial and agriculture wells. It is hypothesized that these human-induced disturbances of the river's characteristics and ground water levels have significantly impacted the ability of the mainstem to maintain surface flow making it a highly *influent* river during the dry summer months. During the 2000 (May – November) irrigation season, the irrigation districts left 13 cubic-feet-per-second of water to provide passage and habitat to ESA listed steelhead and bull trout in the Walla Walla River. However, the water appears to percolate from the surface within a relatively short distance from the bypass area.

Federal, state (OR & WA), local and tribal agencies, as well as irrigators and involved citizens have all expressed interest in an qualitative understanding of the ground-surface water interactions and the hydro-geologic characteristics in this highly impacted section of river. The information is essential to both the long-term water budget planning as well as to restoration efforts that return flow such as irrigation efficiency projects, water-rights leasing and purchasing programs, levee setback land acquisitions, irrigation ditch lining and piping projects and riparian and instream habitat improvements.

If the long-term goal for the Walla Walla River Basin is to increase flows for ESA listed fish species, then clearly a more definitive picture of the hydrodynamics of the Walla Walla River and the shallow aquifer system is required. While this study ~~will~~ focused on a specific geographic area in the watershed, the methodologies used should be applicable to other areas of the watershed. This project was intended to provide information for the development of the numerous watershed-planning efforts currently underway.

Objectives

The overall objectives for this study were to:

1. To gather all existing information on ground water and hydrogeology for the Walla Walla Watershed and create a bibliography for use in watershed management decisions and restoration projects.
2. Utilize the collected information to produce basic maps of the shallow aquifer system to provide a preliminary GIS-based geological and hydrologic framework of Oregon's Lower Walla Walla River Basin.
3. Develop quantitative estimates of the quantity and rate of exchange between Oregon's Lower portion of the Walla Walla River and the shallow-aquifer.
4. Develop quantitative estimates of river-to-well water level gradients in a specific reach of the Walla Walla River.
5. Calibrate surface flow data with gain-loss rate estimates for the development of future surface-ground water models.
6. Develop a baseline chemical signature to help track the surface-ground water interactions of the Walla Walla River Basin.

Study Area

Study area description provided by ODA's SB1010 plan for the Walla Walla Basin.

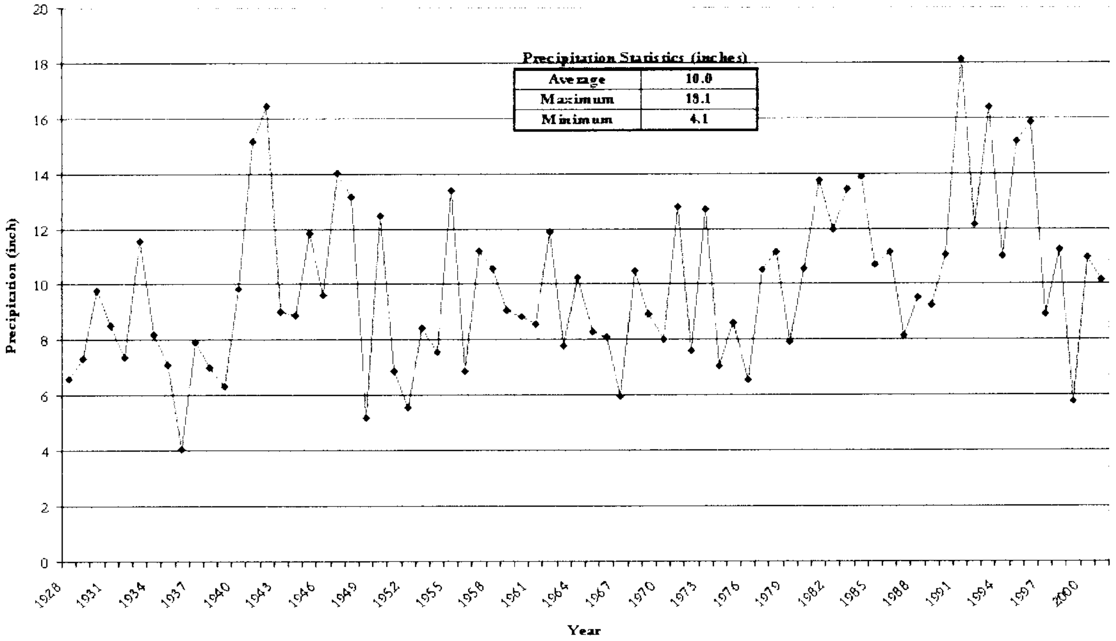
The Walla Walla River Basin is located in northeast Oregon and southeast Washington. The watershed covers 1758 square miles (1,125,120 acres) approximately 27% of which is in Oregon with the remaining 73% in Washington (SB1010, 2001). The Blue Mountains form the watershed's eastern boundary. The watershed boundary to the south is shared with the Umatilla River Basin. The Walla Walla River and its tributaries drain into the Columbia River that forms its western boundary while the Snake River Basin forms the north. The Oregon and Washington Stateline forms the northern border of the Oregon portion of the Walla Walla River subbasin. The Walla Walla River originates in the headwaters of the South and North Forks of the Walla Walla River, located in Blue Mountains. The Walla Walla River flows northwesterly, crossing into Washington State at river mile 40, and entering the Columbia River at Wallula, WA (RM 313). The Oregon portion of the subbasin has six 5th field watersheds including; mainstem Walla Walla River (including branches of the Little Walla Walla River), South Fork Walla Walla River, North Fork Walla Walla River, Pine Creek, Dry Creek, and Couse Creek.

The total acreage in the Oregon portion of the Walla Walla basin is 311, 982 acres. Land in private ownership is 256,111 acres (81.7%), mostly in cropland or rangeland (OWRD, 1988). The public owns 55,871 acres (17.8%), 53,588 acres are managed by US Forest Service (17.2%), 1,942 acres are managed by the Bureau of Land Management (.6%) and 41 acres by the State (.01%). The US Forest Service has 136 acres of land in the Wenaha-Tucannon Wilderness Area that lie within the Walla Walla Basin.

Climate

The climate in the basin is continental where winters are cold, but generally not severe, and summer days are hot, with cool nights. Average daytime high temperatures generally decrease with increasing elevation. Study area air temperatures average between 50 degrees to 55 degrees Fahrenheit with extreme temperatures recorded between 115 degrees and -21 degrees Fahrenheit. Average annual precipitation ranges from less than 10 inches in a narrow band along the Columbia River to more than 40 inches at high elevations in the Blue Mountains. Most precipitation occurs between October and May with snow in the upper elevations. Precipitation for the study area is shown in Figure SA-1.

Figure SA-1 Yearly Precipitation, Milton-Freewater, Oregon (1928-2001)
(Oregon Climate Center)



Geology

Elevations in the Walla Walla River Basin range from 270 feet where the Walla Walla River enters the Columbia River to approximately 3000 feet along the eastern foothills of the Blue Mountains up to 6,000 feet at mountain crests (SB1010, 2001). The elevation of study area ranges from 950 feet near Milton-Freewater to approximately 700 feet near the Oregon and Washington stateline.

Multiple lava flows exceeding 2,500 feet in thickness, known as the "Columbia River Basalt," underlie nearly the entire subbasin. The river basin is divided into two physiographic regions, the Deschutes-Umatilla Plateau and the Blue Mountains. The Deschutes-Umatilla Plateau is a broad upland plain formed by flow upon flow of basalt, which dips gently northward from the Blue Mountains to the Columbia River. The Blue Mountain region includes the extreme northern extension of the Blue Mountains or Oregon. It was formed by uplifting, folding, faulting, and erosion of a variety of volcanic, sedimentary and metamorphic rock and is characterized by flat-topped ridges, steep-walled canyons, and forested mountain slopes.

The Walla Walla syncline (a broad U-shaped fold) forms the center of the Walla Walla subbasin and forms a deposition basin between the upland areas. This is the primary focus area for this study. These numerous sedimentary deposits include both areas of clay and gravels deposited on top of the basalt. Younger sedimentary deposits overlie the clay and gravel units (Umatilla Basin Report, 1988).

Hydrology

Walla Walla River and its tributaries drain about 480 square miles in Oregon (SB1010, 2001). Water availability in the Walla Walla River Basin is dependent on high-elevation snow pack in the Blue Mountains. Runoff occurs anytime during the precipitation period of October through May, with peaks occurring in April. Flows diminish rapidly after May, reaching their lowest levels in August and September. Streamflows increase in late fall and winter in response to storms migrating in from the Pacific Ocean.

Soils

An extensive deposit of silty clay known as the Palouse Formation covers much of the uplands. Recent alluvium, consisting of clay, silt, sand, and gravel deposited by present-day rivers and streams, is common in river valleys and flood plains (OWRD, 1988).

A deep deposit of loess (windblown silt and fine sand) covers much of the subbasin that is used for agricultural purposes. Loess is highly erodible, yielding sediment, particularly in the middle to lower reaches of the main stem Walla Walla River (BOR, 1997).

Vegetation

Currently, vegetation in the headwaters of the drainage is primarily evergreen forest, dominated in the higher elevations by Douglas fir and grand fir with an understory of shrubs, grasses, and forbs. In the lower elevation, there is a more open forest dominated by ponderosa pine (SB1010, 2001).

Mid-elevation lands are characterized by stands of timber changing into brush and grass as the elevation declines. Past land management has eliminated much of the native sagebrush and bunchgrass; these have widely been replaced by noxious weeds and other undesirable grasses, shrubs, and broadleaf weeds. Large mid-lower elevation areas have been converted into dryland farming. This is a transition zone, where farmland is intermingled with range. Often, the north slopes will be farmed while the west and south slopes, with their shallower soils, are used as range.

A riparian community dominated by cottonwood, alder, willow, and various shrubs occurs throughout the basin. Cultivation, logging, domestic livestock grazing, residential and commercial development, and flood control activities have affected riparian vegetation throughout much of the mid-lower elevation reaches of the subbasin.

Land Ownership and Land Use

Agriculture and related trades and industries are the economic base for the area. Production of a number of important food crops has led to the development of a large food-processing complex in the valley. Since farm-gate value is reported for Umatilla County as a whole ($250 million), it is difficult to determine an exact economic value for agriculture in the Walla Walla River basin alone. 1999 statistics from the Oregon State University (OSU) Extension Information Office indicate the value of tree fruit crops and alfalfa seed, which are grown almost exclusively in the Walla Walla basin, at $8.2 million.

There are about 133,000 acres of cropland in the Walla Walla River basin. Grains, predominantly wheat, account for about 50 percent of crops grown and are located primarily on the higher dryland areas. Green peas account for about 13% and are grown on the drylands where the rainfall is adequate, usually in rotation with wheat. Commercial vegetable and fruit production, concentrated north of Milton-Freewater account for about 9% of the acreage; pasture, alfalfa and other hay account for about 15%; and the remainder is idle or fallow. Approximately 20,000 acres are irrigated with water that is withdrawn from wells and/or surface sources.

Livestock production is important in the valley. Most of the estimated 4,800 cow-calf pairs are raised on irrigated pastures with summer grazing on the slopes of the Blue Mountains. There are some small feedlots and dairies in the subbasin. Forested land in the subbasin is about 88,200 acres. National forests comprise about 54%, private holdings about 43%, and State and local government less than 3%. Much of the moderate slope forestland has been logged at least once.

Mapping

Overview

This portion of the study produced maps showing both the geologic and hydrologic properties of the shallow aquifer in Oregon's Lower Walla Walla River Basin. Previous work by Piper (USGS, 1933), Newcomb (USGS,1965) and Barker and McNish (WDOE, 1976) included some basic geologic and hydrologic maps. Piper produced two primary maps (plates) including a water table (potentiometric surface) map for our study area and a basic surficial geologic map. His work provides an excellent reference for historical water table comparisons and basic geology, however is based primarily on only one year of dated data (1933-1934). Newcomb's work is locally referred to as the "bible" of geology and ground water in the Walla Walla Valley. His mapping contributions included; a colored surficial map of the shallow aquifer geology, two cross-valley transects depicting the geologic layering of the shallow aquifer, and a elevation contour map of the basalt bed-rock which represents the bottom of the shallow aquifer system. Barker and McNish's mapping work was primarily done in support of their modeling efforts. They calibrated digital models of the gravel (and basalt) aquifers in order to test various water-management alternatives using well pumpage, irrigation application and surface-water diversion. Their work includes average precipitation, infiltration, and water table maps for the data collected prior to 1970.

The primary goal of our work was to build upon these previous efforts with recent geologic and hydrologic information in order to generate a detailed representation of the shallow aquifer system. The secondary goal was to create a basic 3-dimensional GIS-based framework for the shallow aquifer system for use in any future surface-ground water modeling and monitoring efforts. The final goal was to use static water level information from a network of shallow wells to create an updated (2001-2) water table map.

Geologic Mapping

Note to co-author:
Need write up for methodology for Fines/gravels thickness map (Kevin)

Need map of well locations that were used for the geologic mapping (Flood deposits). Take the water table wells off of the geologic maps and replace (if not too crowded) with the geo-wells (John).

Need data for well x-y-z information for appendices. (Kevin or John)

Need methodology (GIS) for water table map (John), check what I wrote.

Geologic Mapping Overview

The objective of geologic mapping of is to separate the numerous layers of sedimentary deposits of the shallow aquifer system into distinct geologic units. This process is referred to by geologists as 'shallow sediment hydrostratigraphic mapping'. This was done by preparing a set of map grids that portray the distribution of the main sedimentary units interpreted to lay between the Earth's surface and the top of the Columbia River Basalt Group (CRBG) in our study area of the Walla Walla Basin (the Basin). Sedimentary units were targeted for mapping because of their importance in influencing shallow ground water distribution in the Basin. Shallow ground water is one of the current focuses of water resource studies in the Basin because of the suspected hydraulic connection between parts of the shallow ground water system and surface water. Given this emphasis on shallow ground water, CRBG units beneath the Basin and forming the highlands bounding the southern and eastern edges of the Basin are not identified and mapped.

The mapping area consists of an approximately 24 square-mile area extending up to 1 mile east of, and 4.5 miles west of, the Walla Walla River between Milton-Freewater, Oregon and the Washington-Oregon border **(Figure M-1)**. The Horse Heaven Hills, which border the southern edge of the Walla Walla Basin, are not included in this map coverage. The primary data source for this work is water well log data from the Oregon Department of Water Resources GRID database, log interpretations from Newcomb (1965), and our analysis of drill cuttings collected from wells drilled in the past 2 years.

Specific sedimentary hydrostratigraphic units targeted for mapping included the following:

Silt and fine-grained sand inferred to be equivalent to Pleistocene cataclysmic flood-deposited layered rhythmites (e.g., Touchet Beds) and loess. Where this unit is present above the water table it could significantly slow the movement of water infiltrating downward from the ground surface to the water table.

Holocene to Pleistocene-age uncemented and nonindurated gravelly strata that is inferred to be generally equivalent to Newcomb's (1965) younger alluvial sand and gravel unit. These gravelly strata can overlie, interfinger with, and underlie Pleistocene flood deposits and loess, although the majority of this unit where it is saturated generally underlies these other deposits. Where these gravelly strata are present in the upper parts of the "shallow" sediment aquifer system they could form significant preferred pathways for shallow ground water movement.

Cemented and indurated gravelly strata that is generally equivalent to the old gravel unit of Newcomb (1965). While this unit is known to host significant amounts of ground water, it likely has lower permeability than the uncemented gravelly strata, which commonly overlies it.

Clay and silt strata that is generally equivalent to the old clay of Newcomb (1965). Where this unit is present it may greatly reduce the movement of ground water from shallower parts to deeper parts of the shallow aquifer system.

Using these stratigraphic subdivisions, hydrostratigraphic mapping focused on defining the extent of geologic units that are inferred to influence ground water movement and distribution in the sediment hosted aquifer. Top-of-basalt also was mapped in order to place a bottom on the sediment aquifer system so that its overall thickness and distribution could be evaluated.

Geologic Mapping Methodology

This section describes the methodology used to identify and map the extent of the hydrostratigraphic units defined for the project. The primary data source for constructing the grids was water well log data from OWRD's GRID database, log interpretations from Newcomb (1965), and our analysis of recently collected drill cuttings. The following presents the general sequence of steps and activities used to define and map hydrostratigraphic units.

1. Given the objective to map the main sedimentary units found between the Earth's surface and the top of the basalt, initially, only well logs for wells in the project area that fully penetrate the sediment sequence were compiled. Logs were selected that contained enough information to allow identification of the top of the basalt. In many cases, information included on the driller logs was detailed enough to allow identification of sedimentary units.

2. An additional selection of well logs was compiled for wells that appeared to either reach deep into the sediment sequence (based on our interpretation of fully-penetrating wells) and/or filled

in gaps of over 1 mile between the fully penetrating wells. Well logs included in this group were selected based on inclusion of enough driller's log detail to allow interpretation of the probable presence and character of targeted hydrostratigraphic units.

3. Wells currently being used by OWRD and WWBWC staff to collect water level data also were added to the well log database if a geologic log for the well was found.

4. The locations of all selected wells were plotted using the township and section information on the logs (if located to the quarter/quarter section), actual well address information if available, and/or personal knowledge of the specific location (including GPS data) if available with WWBWC staff. It should be noted that not all wells used in the analysis were field located.

5. Hydrostratigraphic units were interpreted from information on the well logs. Interpretation was based on identifying key words and/or phrases typically used by drillers to describe specific physical conditions that we interpret to represent each of the targeted hydrostratigraphic units. Specific criteria for each of these units are as follows:

   a. **Cataclysmic Flood Deposits and Loess**: Where present strata assigned to this unit are typically described on logs as flood deposits, soil (topsoil) and clay (clay, sand, and silts). If present, this zone of fine-grained material is the uppermost stratum encountered. Flood deposits and loess were not differentiated and are mapped as a single unit. When fine material is described mixed with gravel or conglomerate, then flood deposits and loess are interpreted to be absent.

   b. **Young Alluvial Gravel:** Where present, strata assigned to this unit are typically described as gravel, medium gravel, clay and gravel, clayey gravel, or some combination of descriptors that suggest an uncemented gravelly interval. The absence of cement differentiates this unit from the underlying older gravel unit.

   c. **Old Gravel:** Where present this unit is typically described in terms suggestive of moderately to well indurated sediment, including conglomerate, cemented strata, sandstone, and/or cement gravel. The top of the old gravel unit is placed at the top of the uppermost interval described on a borehole log using terms indicative of hard or cemented conditions. Note, a number of the logs used in the evaluation indicate clay/silt intervals up to several tens of feet thick occur interbedded within the old gravel unit.

   d. **Old Clay:** Where present this unit is typically described as several tens of feet to several hundreds of feet of brown clay, tan clay, gray clay, blue clay, and similar lithologies. The contact between this and the overlying old gravel unit can be difficult to identify from the logs because of the presence of interbedded gravelly and silty/clayey intervals described on a number of logs. Generally, the contact marking the top of the old clay unit is placed at the bottom of the last (deepest) cemented gravel of the old gravel unit. However, if a clayey/silty interval over approximately 60 feet thick was found on a log overlying a relatively thin cemented gravel interval (generally less than 25 feet thick), the top of the old clay unit is placed at the top of the thick clayey/silty interval.

   e. **Basalt:** Where a well encountered the top of the basalt, drillers identified the presence of basalt and we used those picks directly off the drillers logs with no modification.

6. Once hydrostratigraphic unit tops and thicknesses were interpreted from well logs, they were compiled for use in Rockworks 99™. The software was used to calculate thickness grids for each study area unit using an inverse distance gridding algorithm and 100 m grid cells. These thickness (isopach) grids where then used to calculate elevation grids for the top of each unit in the subsurface. These calculations were done as follows:

a. Topographic surface (100 m grid DEM) = top of flood deposits

b. Topographic surface – flood/loess isopach = top of young alluvium

c. Top of young alluvium – young alluvium isopach = top of old gravel

d. Top of old gravel – old gravel isopach = top of old clay

e. Top of old clay – old clay isopach = top-of-basalt

7. Isopach and thickness maps for each unit were generated from these grids and hydrogeologic features suggested by contour patterns on the maps were interpreted.

GIS Geological Mapping Methodology:

In order to generate both the shallow sediment hydrostratigraphic maps and a 3-dimenisional G.I.S. based framework, the sedimentary layer data was transferred from Rockworks 99TM software to the ESRI ArcView Spatial and 3D Analyst TM software. The following presents the general sequence of steps and activities used to define and map hydrostratigraphic units in GIS.

1. Ground surface elevation grid was created from 10 meter Digital Elevation Model (DEM) files obtained from the United States Geological Survey. This is the standard elevation data used in these types of studies and is the most accurate data currently available for large-scale projects.
2. Individual USGS elevation maps were merged into a complete elevation grid covering the study area using ESRI ArcView Spatial TM Analyst software. This was done using ArcView Spatial TM Analyst's *Mosaic* function, which uses a weighted average method to calculate values of cells in any overlapping areas. The 10-meter resolution was maintained during this process. DEM elevation values were converted from meters to feet (conversation factor of 3.28).
3. Well elevations were then obtained by using the ESRI ArcView 3D Analyst command that assigns elevations based on the spatial location of the point. This work generated a new dataset containing the spatial X, Y, and Z, coordinates for all wells.
4. The surface elevation grid was re-sampled to a 100-meter grid by using Arc View 3D Analyst's *cubic convolution interpolation* that determines the new value of a cell based upon a weighted distance average of the sixteen nearest input cell centers. This grid was then converted to an ASCII file format with X, Y, Z values for each cell center.

Sedimentary Interpretations

Several of the sedimentary units mapped for the project displayed features suggestive of possible subsurface physical conditions that may influence ground water occurrence and movement. These are summarized in this section.

The young alluvial gravel unit appears to be thickest in several generally elongate tracts. These tracts appear to branch out from a common point of origin near where the modern Walla Walla River leaves the canyon at the town of Milton-Freewater. One of these tracts appears to trend roughly south to north, parallel to, and intermittently being transected by, the modern river channel. Two tracts appear to trend from the Milton-Freewater area to the northwest beneath the generally flat valley floor. The shape and orientation of these tracts is consistent with one or more branched or braided river channel tracts. If these gravel tracts are indeed composed of uncemented, high permeability gravel and sand, they could form areas where rapid infiltration of surface water into the ground would be expected and form preferred pathways for ground water movement in the shallow parts of the shallow aquifer system. The probable presence of this unit in the area of the former

Walla Walla River gravel mining operations offers one possible explanation for why this reach of the river would lose water to the shallow aquifer system.

The old gravel unit underlies most of the study area. However, because of limitations in well log descriptions, lithologic trends in this unit were not identified. This unit is thicker and more widespread than the overlying young alluvial gravel unit. Where the young alluvial gravel unit is thin or absent, the shallow aquifer water table generally lies within the old gravel unit. Given the physical properties of the old gravel unit (e.g., the presence of naturally occurring cement) it probably has lower permeability than the young alluvial gravel unit. Consequently, shallow aquifer ground water flow velocities are inferred to be less where the water table lies within the old gravel unit than where the water table lies within overlying, more permeable, young alluvial gravel units.

The mapping done for this project revealed that a clear, single, easily mappable contact between the old gravel unit and the old clay unit might not exist. Borehole logs examined for this study revealed: (1) the presence of interstratified silt and gravel lithologies throughout the study area between the base of the young alluvial gravel unit and the top-of-basalt (2) areas where strata correlative to one of the two units, old gravel and old clay are absent and (3) areas where the inferred contact varies greatly in depth over distances of less than one mile. Based on these assumptions, it is likely that the top of the old clay unit and bottom of the old gravel unit as mapped for this project is not a single, continuous surface. Instead, it is more likely a series of discontinuous overlapping surfaces that are simplified and represented as one surface. The main consequence of this hypothesis is that these two units most likely interfinger and grade into each other, rather than always laying one atop the other.

The top-of-basalt map reveals an irregular basalt bedrock surface underlying the sediments. These irregularities are inferred to reflect the presence of faults that have broken the basalt bedrock surface into a series of upthrown and downthrown blocks. The locations and possible orientations of several of these features may represent the continuation of faults previously mapped on the adjacent Horse Heaven Hills **(John... Citation?)**. These faults also may account for some of the irregularities seen in the distribution of the old gravel and old clay units.

Geologic Mapping Results

Using driller's log data, previously published material, and drill cuttings from recently-drilled wells, four shallow aquifer hydrostratigraphic units were identified and mapped for a portion of the Walla Walla River valley between Milton-Freewater and the Washington-Oregon border. These units included:

Flood and Loess Unit - Fine-grained silty and sandy strata interpreted as Pleistocene Cataclysmic Flood deposits (Touchet Beds) and loess (Figure M-2). Where present, these strata are more likely found in the unsaturated zone rather than the sedimentary aquifer. In the unsaturated zone, this unit probably inhibits downward infiltration of water from the surface to the water table.

Young Alluvial Gravel Unit - Gravel and sand consisting of mostly uncemented material found in several elongate tracts branching outwards from the Milton-Freewater area towards the state line (Figure M-3). These tracts are inferred to reflect old river channels now buried beneath the valley floor. Strata comprising this unit are inferred to be very permeable and form preferred shallow ground water movement pathways when present. This unit is differentiated from the underlying old gravel unit based on driller's log descriptions suggested increased induration and drilling difficulties going downwards.

Old Gravel Unit – Indurated, variably cemented, silt, sand, and gravel underlying most of the study area (Figure M-4). Data collected for this study offers few insights into this unit's physical properties other than it is generally more indurated than overlying strata and consequently has a relatively lower permeability. These deposits represent the host strata or majority of sedimentary fill of this shallow aquifer.

Old Clay Unit - Variably thick sequence of clay and silt-dominated lithologies that appear to be discontinuous beneath the study area (Figure M-5). The contact between the old clay unit and old gravel unit is very irregular, suggesting that the interface between these units may not be a the generally perceived single continuous surface. This unit, where present, potentially impedes vertical ground water movement, although the presence of intercalated coarse lithologies seen in strata assigned to the unit suggest preferred ground water flow pathways may exist.

Top of the Basalt – Basalt bedrock surface underlying the shallow sediment sequence (Figure M-6). The first basalt encountered in the subsurface forms the bottom of the shallow aquifer system.

Fines and Gravels Thickness – Represents total thickness of gravels and fines from the land surface to the bottom of the shallow aquifer (Figure M-7).

Figure M-2

Geology Layers -- Flood\Ground Surface

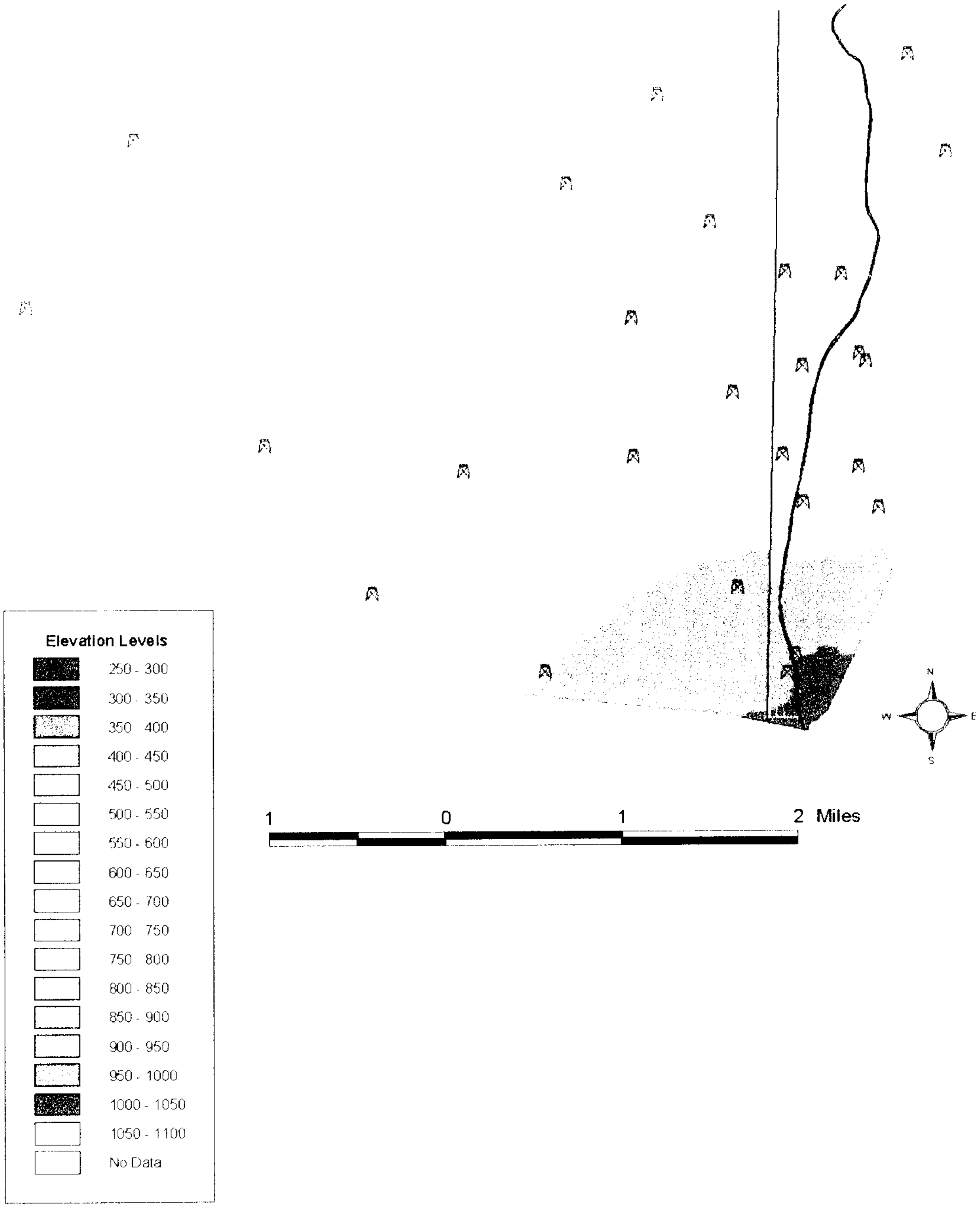


Figure M-3

Geology Layers -- Alluvial

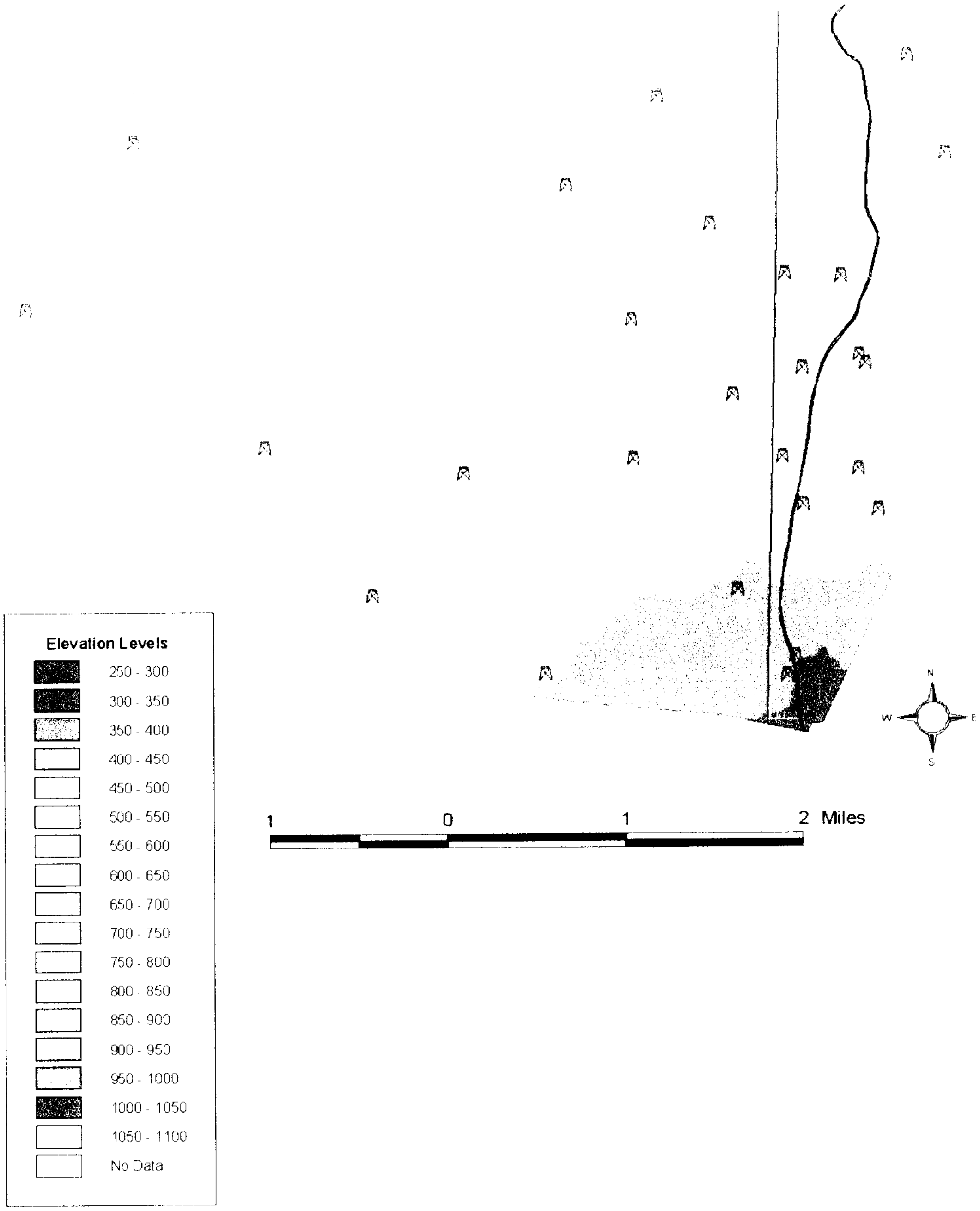


Figure M-4

Geology Layers -- Gravel

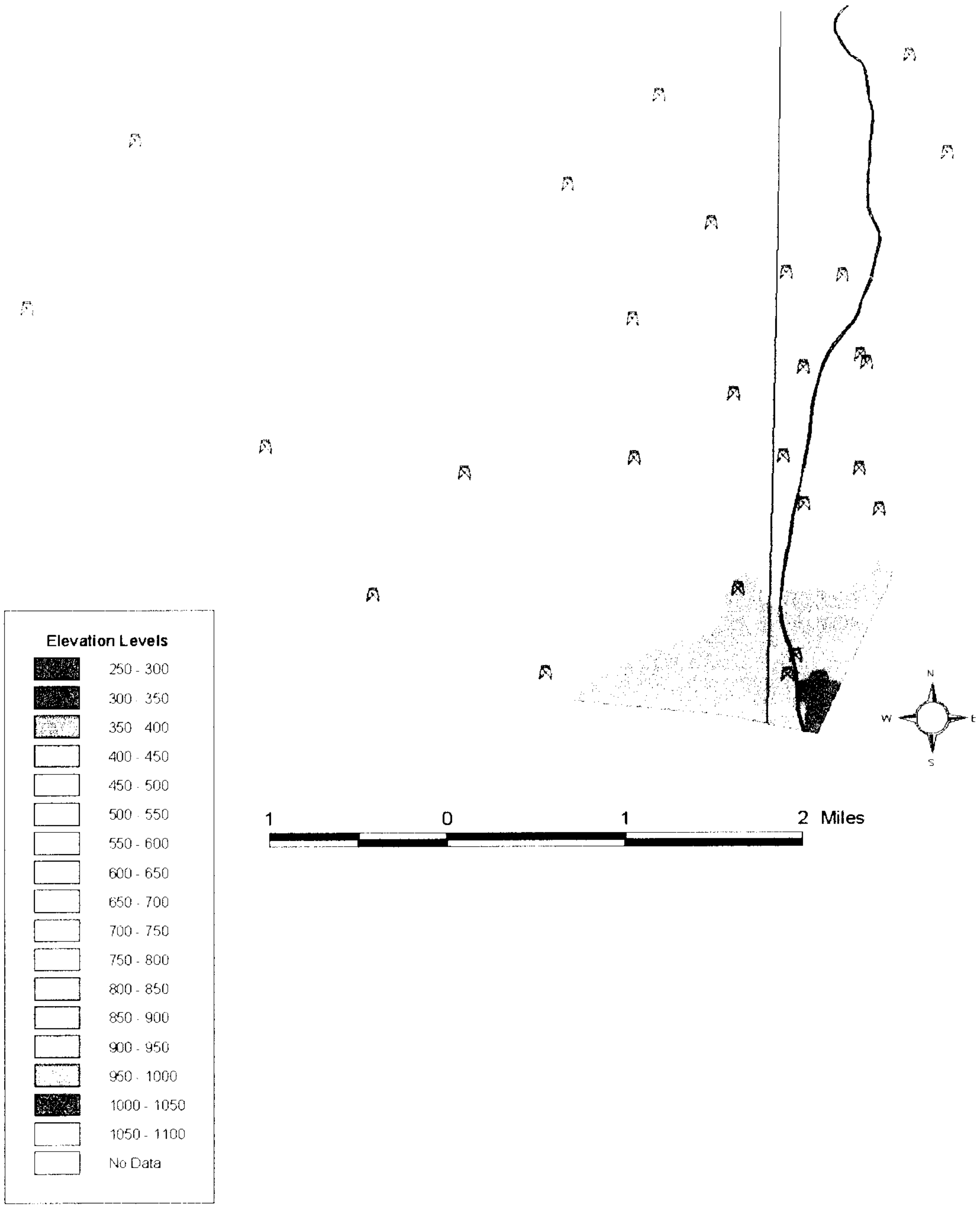


Figure M--5

Geology Layers -- Clay

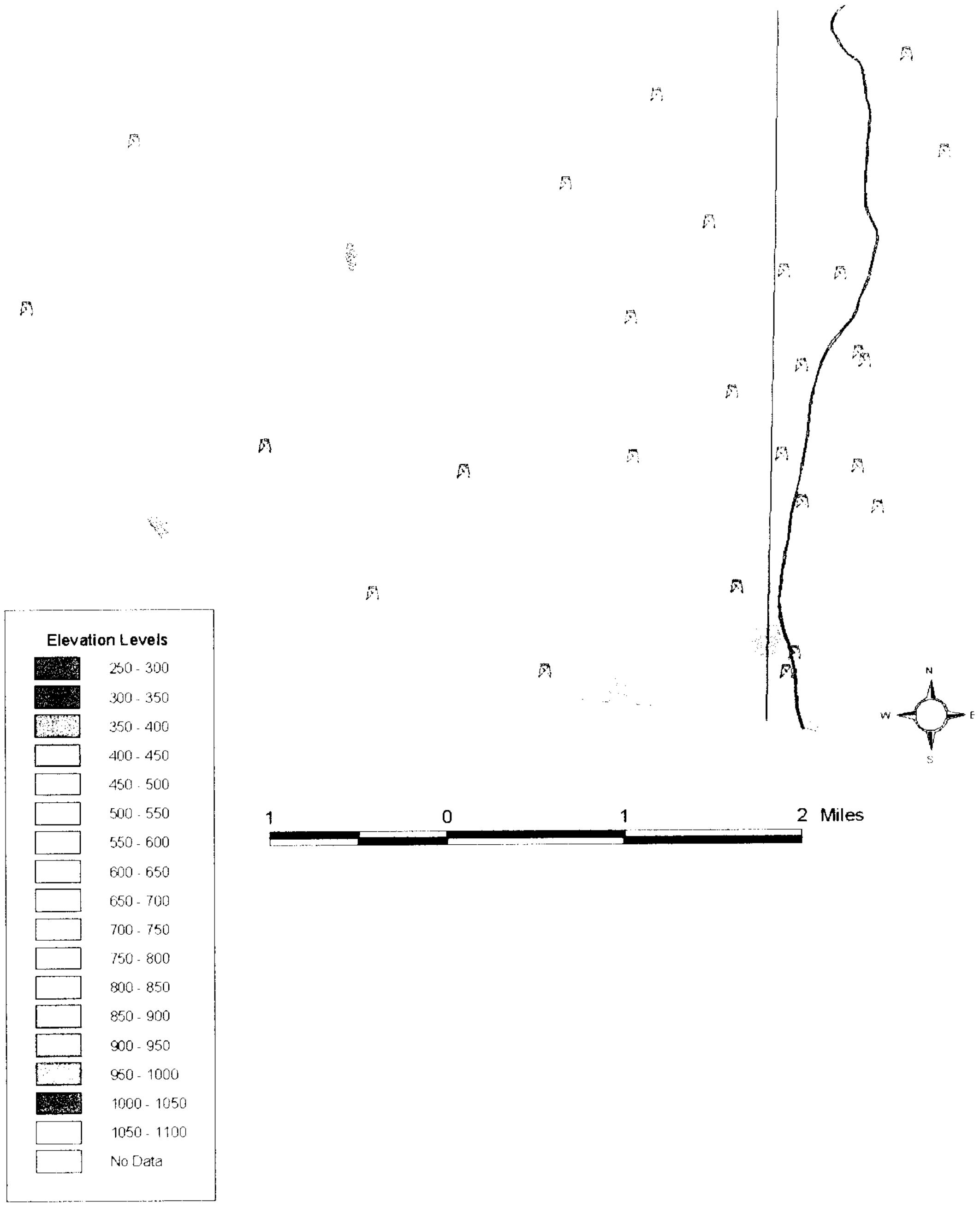


Figure M-6

Geology Layers -- Basalt

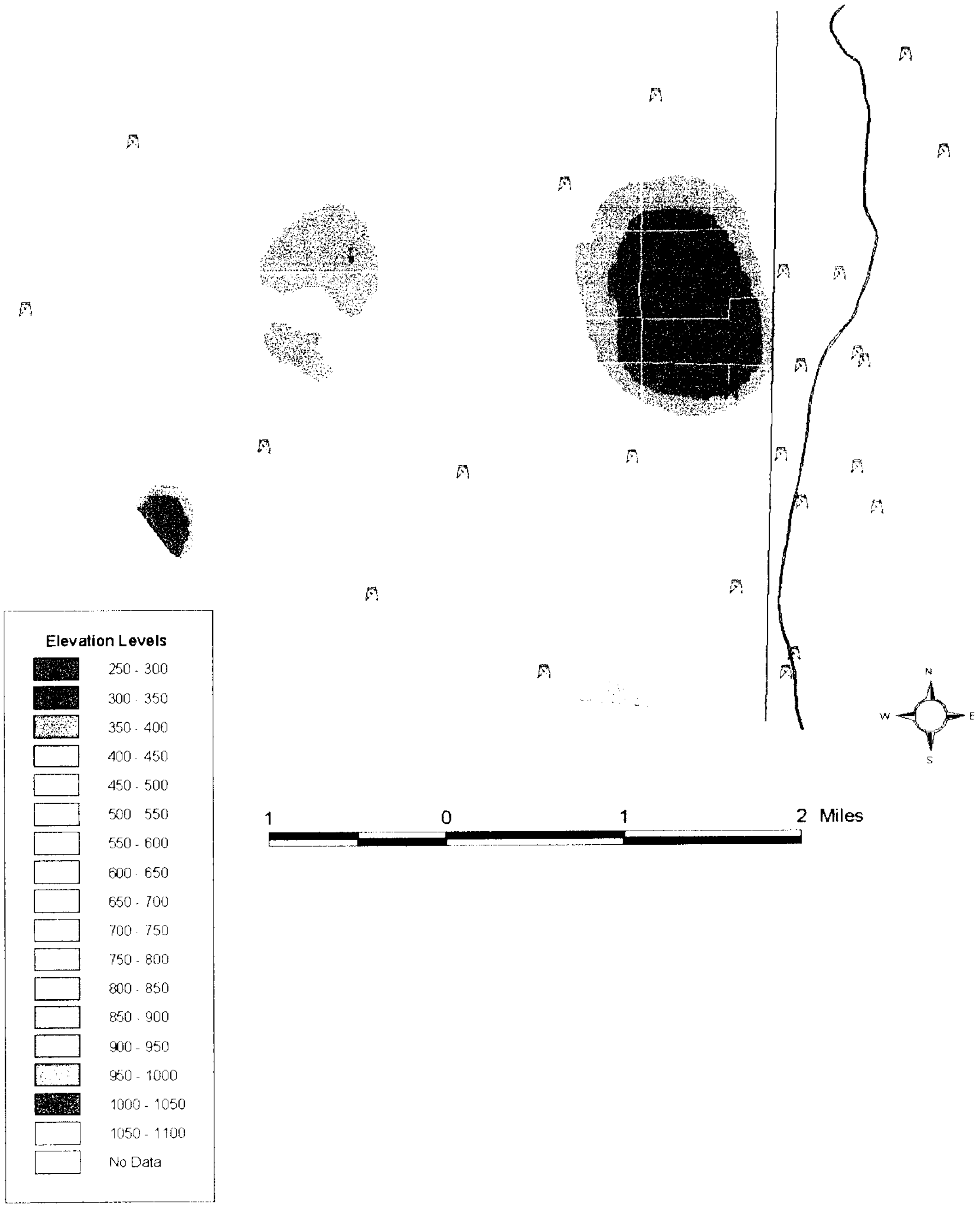


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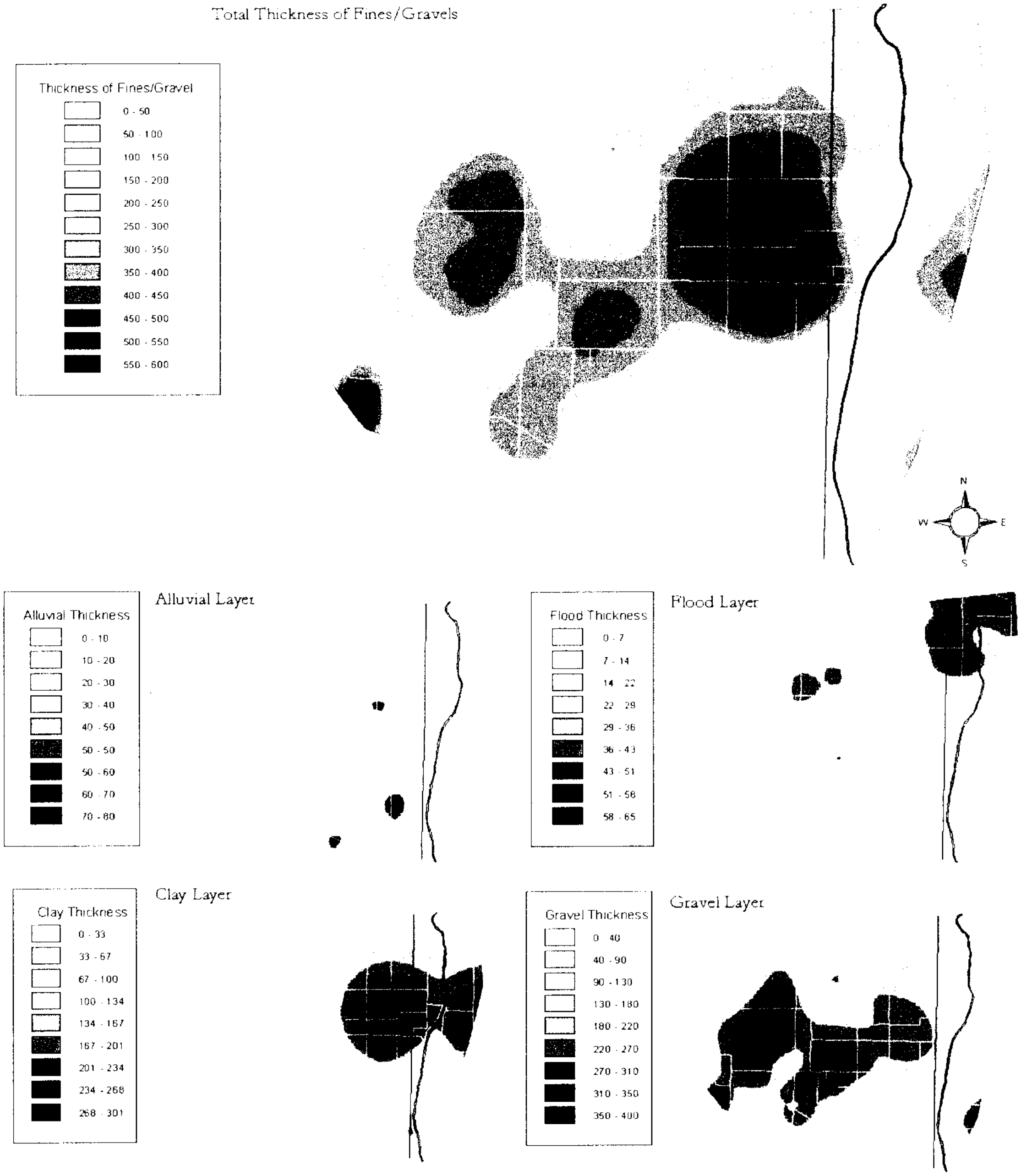
Figure M-7

Fines/Gravels Thickness



Water Table Maps

Water Table Map Overview

A *potentiometric surface* map, more commonly referred to as a *water table* map, represents a two dimensional topographic view of the water levels in an unconfined aquifer system. An unconfined aquifer is one where ground water is in direct contact with the atmosphere and water that enters the surface through precipitation, irrigation or stream and ditch losses, can readily percolate down to the zone of saturation. The elevation of that zone of saturation is considered the water table or potentiometric surface. A confined system on the other hand, is water separated from the atmosphere by a water impermeable geologic layer. In the Walla Walla Valley, the ground water below the Columbia River Basalt group is considered *confined.* For the purposes of this water table mapping exercise, we generally consider the shallow system to be *unconfined.*

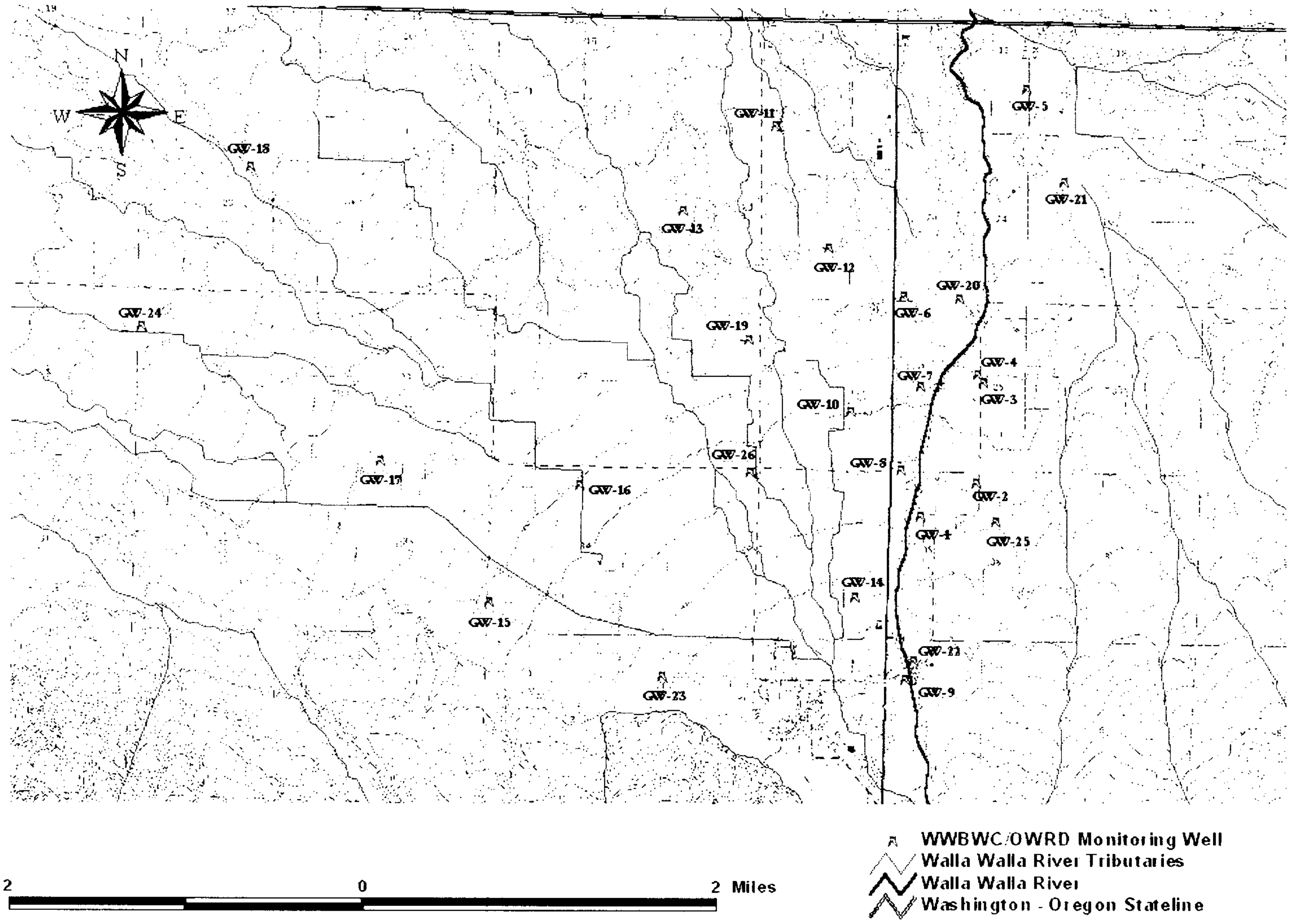
Water Table Map Methodology

Static water levels for a network of twenty-one shallow aquifer wells were monitored from June 2001 until March 2002 **(Figure WT-1).** A standard E-tape (*Waterline™ by Envirotech LTD*) was used in conjunction with a handheld GPS unit to both measure static levels and locate the wells. Well site were selected based on availability and location in the ground-surface water study area. Wells selected varied in their uses from domestic to industrial to agricultural irrigation. Well used for irrigation made up a majority of the monitored wells. Water level measurements were adjusted for wellhead relationship to that of the ground surface. Wellhead elevations were identified using the elevation (z-coordinate) associated with the well locations on the horizontal plane (x-y coordinates) from the USGS 10 meter Digital Elevation Model (DEM) database. GPS data was used to help verify these DEM locations. Estimates of elevations obtained from well driller notes were thought not to be accurate and hence were disregarded. Eleven of the wells monitored are designated as State Observation Wells (SOW). Oregon Water Resources Department (OWRD) monitors these for static water levels on approximately a quarterly basis with records for some sites dating back to the 1930s. OWRD well identification numbers and driller log records were located for a majority of the sites. These records provided geologic and well construction information useful in the water table mapping. Pumping activity information (on/off) was gathered in order to help determine seasonal use.

Water table elevations and well location information was imported to ESRI ArcView Spatial and 3D Analyst ™ software. Static water level values were subtracted from the identified well head elevation in order to generate the water table surface layers. Water table maps were generated from this layer in order to represent the difference in the water table from seasonal lows (October, 2001) to high (March, 2002). A depth to water map was generated by comparing the water table layer to that to the surface DEM **(Table WT-1).**

Table WT-1 Monitoring Well Information 2001 - 2002

Figure WT-1



2001 - 2002 Monitoring Well Locations

Wellnet Id	Use	Drilled Depth (feet)	SOW	Well Log	UMAT #	TWNSP	N/S	RANGE	E/W	SECTION	Quarter/Quarter	Elevation (feet)	October 2001 Static Level	Water Table Elevation October, 2001
GW-01	Domestic	N/A	No	No	N/A	6	N	35	E	36	N/A	925.0	39.4	885.6
GW-02	Domestic	233	No	Yes	UMAT 5805	6	N	35	E	36	N/A	928.2	35.3	892.9
GW-03	Irrigation	32	No	Yes	UMAT 4599	6	N	35	E	25	N/A	879.0	15.9	863.1
GW-04	Irrigation	78	No	Yes	UMAT 4619	6	N	35	E	25	N/A	874.3	16.8	857.6
GW-05	Irrigation	128	No	Yes	UMAT 4205	6	N	35	E	13	N/A	816.7	6.6	810.1
GW-06	Industrial	85	No	Yes	UMAT 4474	6	N	35	E	24	N/A	862.6	11.7	850.9
GW-07	Irrigation	50	No	Yes	UMAT 4602	6	N	35	E	25	N/A	882.3	16.6	865.7
GW-08	Industrial	N/A	No	No	N/A	6	N	35	E	25	N/A	918.4	34.4	884.0
GW-09	Irrigation	106	No	Yes	UMAT 6471	5	N	35	E	1	N/A	1000.4	15.7	984.7
GW-10	Irrigation	70	No	Yes	UMAT 4589	6	N	35	E	25	N/A	898.7	40.6	858.1
GW-11	Domestic	64	No	Yes	UMAT 4438	6	N	35	E	23	N/A	810.2	5.0	805.2
GW-12	Domestic	N/A	No	No	N/A	6	N	35	E	23	N/A	839.7	4.1	835.6
GW-13	Domestic	63	No	N/A	UMAT 4418	6	N	35	E	23	N/A	820.0	10.9	809.1
GW-14	Irrigation	N/A	No	Yes	UMAT 6329 UMAT 54056	6	N	35	E	36	N/A	964.3	43.1	921.2
GW-15	Domestic	120	1145	Yes	UMAT 6463	6	N	35	E	34	CCC	885.6	32.1	853.5
GW-16	Irrigation	50	855	Yes	UMAT 5007 (UMAT 5322)	6	N	35	E	34	BAA	816.7	47.4	769.3
GW-17	Irrigation	37	853	N/A	UMAT 4790	6	N	35	E	28	CCD	761.0	20.4	740.6
GW-18	Irrigation	17	849	N/A	UMAT 50354	6	N	35	E	20	ACA	862.6	22.6	840.0
GW-19	Irrigation	110	851	Yes	UMAT 4691	6	N	35	E	26	BAD	856.1	29.4	826.7
GW-20	Irrigation	165	850	Yes	UMAT 50356 (UMAT 4511)	6	N	35	E	24	DCC	823.3	19.3	804.0
GW-21	Irrigation	712	N/A	N/A	UMAT 5177	6	N	36	E	19	N/A	1000.4	11.0	989.4
GW-22	Irrigation	37	844	Yes	UMAT 3914	5	N	35	E	1	BAD	938.9	N/A	N/A
GW-23	Irrigation	118	1144	Yes	UMAT 3941	5	N	35	E	3	N/A	692.1	N/A	N/A
GW-24	Irrigation	30	854	Yes	UMAT 50358	6	N	35	E	30	CBB	938.1	N/A	N/A
GW-25	Irrigation	44	857	Yes	UMAT 50359 (UMAT 5153)	6	N	35	E	36	ADD	823.5	N/A	N/A
GW-26	Irrigation	34	N/A	Yes	UMAT 4513	6	N	35	E	24	N/A	842.9	N/A	N/A

Water Table Mapping Results

Analysis of static water level data **(Table WT-2)** and pumping activity data revealed that a majority of the wells monitored showed variation in use by season. **Figure WT-2** demonstrates the seasonal trends relating to water table levels and irrigation well use. This corresponds to the growing season when most irrigation well use is tied to crop production and domestic wells have the additional use of watering gardens and lawns. This data along with local knowledge of well water use and the lack significant ground water recharge from rainfall and/or high river flows, suggests that the shallow aquifer is at it lowest in the early fall. Consequently, during the non-irrigation season and coinciding wetter winter and spring months, the water table typically recovers to at or near it highest levels. The few industrial and domestic wells monitored appeared to be on an as-needed basis not tied to a particular season. Effects of these intermittently used wells on the seasonal water table changes are thought to be relatively constant. Note that the water levels recorded during the irrigation season are most likely affected by what is commonly referred to as the *cone of depression.* The cone of depression can be described as the effect that the active pumping action of the wells acts to draw-down or artificially lower the surrounding water table. This makes the water table data collected during irrigation season difficult to interpret.

The pattern observed in **Figure WT-2** was not always as clearly apparent in the data. Some of the wells monitored are influenced by nearby irrigation ditches or crop irrigation. The seasonality of surface irrigation diversions and applications can act to raise the local water levels during the irrigation season and make seasonal trend analysis much more difficult.

Figure WT-2. Seasonal Changes in Static Water Levels

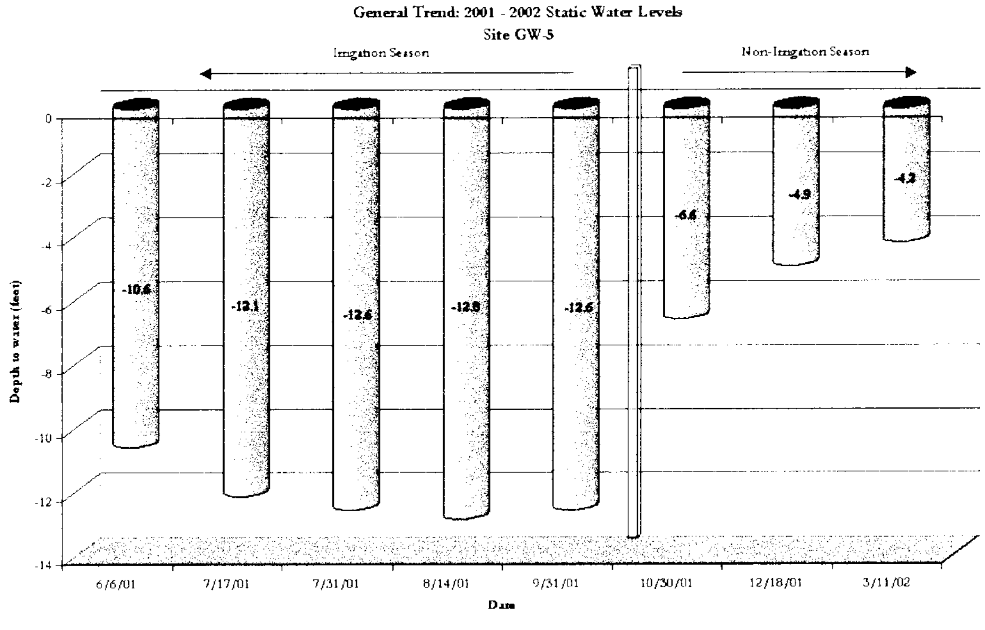


Table WT-2 Monitoring Well Information 2001 - 2002

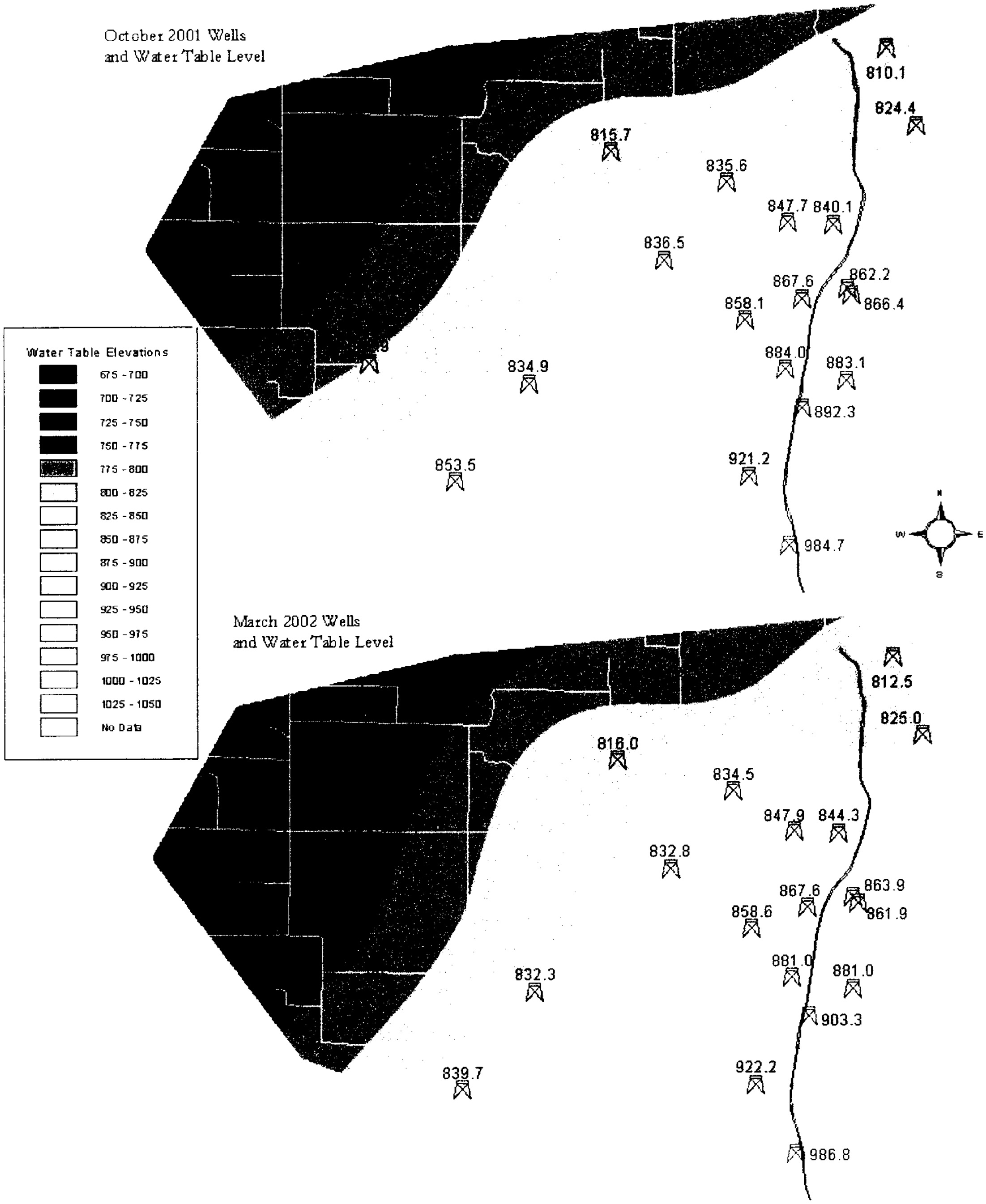
Dates>	6/6/01		7/17/01		7/31/01		8/14/01		9/31/01		10/30/01		12/00/01		3/11/02	
Well Net ID	Water Level	Pump	Water Level	Pump	Water Level	Pump	Water Level	Pump	Water Level	Pump	Water Level	Pump	Water Level	Pump	Water Level	Pump
GW 01	23.27	No data	23.41	on	28.85	off	23.75	off	28.85	off	39.39	off	35.68	off	28.36	off
GW-02	32.08	No data	30.23	off	31.5	off	31.97	off	31.15	off	35.28	off	38.15	off	37.4	off
GW-03	17.32	No data	29.65	N/A	30.13	on	31.57	on	30.11	on	15.86	off	21.76	off	20.38	off
GW-04	13.25	No data	13.39	off	21.67	on	14.34	off	21.67	on	16.75	off	16.75	off	15.05	off
GW-05	10.58	No data	12.12	on	12.57	off	12.84	on	12.57	off	6.57	off	4.91	off	4.19	off
GW 06	7.83	No data	8	off	8.07	on	8.78	off	8.07	off	11.7	off	12.37	off	11.5	off
GW-07	11.07	No data	12.14	on	12.6	off	17.34	off	12.6	off	16.61	off	19.28	off	16.6	off
GW-08	33.68	No data	34.69	off	35.55	off	36.3	off	35.73	off	34.38	off	40.46	off	37.4	off
GW 09	19.9	No data	20.48	on	20.27	on	21.5	on	20.27	on	15.74	off	13.62	off	13.6	off
GW-10	28.5	No data	31.56	on	31.23	off	32.89	on	31.23	off	40.63	off	-1.7	off	40.1	off
GW 11	4.34	No data	5.33	off	5.3	on	5.35	on	5.24	on	5.04	off	4.98	off	5.04	off
GW 12	N/A	No data	2.29	off	2.18	off	2.81	off	2.18	off	4.14	off	5.15	off	5.2	off
GW-13	N/A	No data	65.93	on	62.69	on	53.16	on	63.19	off	10.92	off	10.65	off	10.6	off
GW-14	36.35	No data	33.5	off	33.82	off	34.98	off	33.82	off	43.07	off	42.05	off	42.1	off
GW 15	31.16	No data	29.7	off	29.66	off	29.54	off	29.66	off	32.09	off	39.5	off	45.9	off
GW-16	44.93	No data	45.14	on	40.89	off	50.1	on	40.89	on	47.43	off	51.84	off	-0.5	off
GW-17	22.35	Abandoned	N/A	Abandoned	N/A	Abandoned	N/A	Abandoned	dry	Abandoned	20.37	Abandoned	N/A	Abandoned	N/A	off
GW-18	19.19	No data	20.4	off	50	on	51.94	on	50	off	22.57	off	15.95	off	17.7	off
GW-19	22.58	No data	23.59	on	22.06	on	24.58	on	22.06	on	29.4	off	N/A	off	33.12	off
GW 20	15.22	No data	15.34	off	15.26	off	17.21	on	15.26	No data	19.3	off	15.55	off	15.1	off
GW-21	N/A	No data	47.27	on	44.55	on	45.02	on	43.93	No data	10.96	off	10.55	off	10.42	off

In order to make a comparison of the shallow aquifer at its lowest and highest levels, two sets of measurement data was selected. The data indicates that by October 30, 2001, all of the irrigation wells being monitored were 'off', presumably for the irrigation season **(Table WT-2)**. Hence, the October static levels were used to represent the *lowest* shallow aquifer level for purposes of water table mapping. The levels measured on March 11, 2002 generally showed the active recharging and recovery of the shallow aquifer levels. Hence, the March static levels were used to represent the *highest* shallow aquifer water level (**Figures WT-3 and WT-4**).

Water table contour lines appear to coincide with early water table mapping by Piper **(Piper, 1933)** and Barker and McNish (**Barker McNish, 1976)**. The consensus reveals that water table contours

Figure WT-3

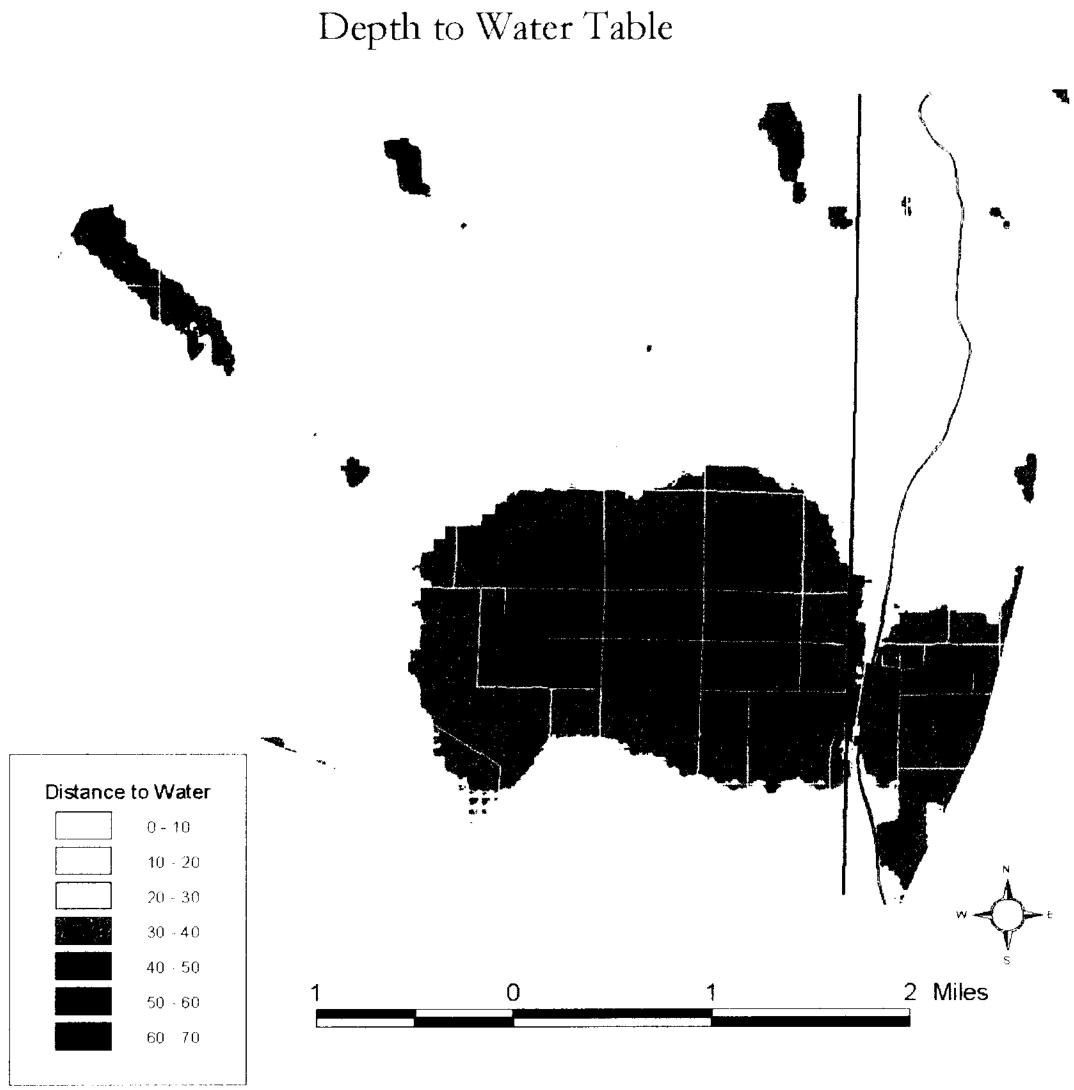
Seasonal Water Table Comparisons



for this area run in a northeast to southwest line relative to the Walla Walla River, which runs northerly aspect. Since it is known that unconfined ground water moves down gradient, the assumption can be made that water that leaves the Walla Walla mainstem tends to move away from the river in a northwest direction, towards the Oregon – Washington Stateline.

An additional map was generated of the 'depth-to-water' relative to the ground surface and was generated using the water table data recorded on October 30, 2001 (**Figure WT-4**). This map identifies the areas where there are better opportunities for surface-ground water interactions based on the proximity of the water table to that of the stream or river surface.

Figure WT-4



Depth to Water Table

Surface-Ground Water Interactions

Seepage

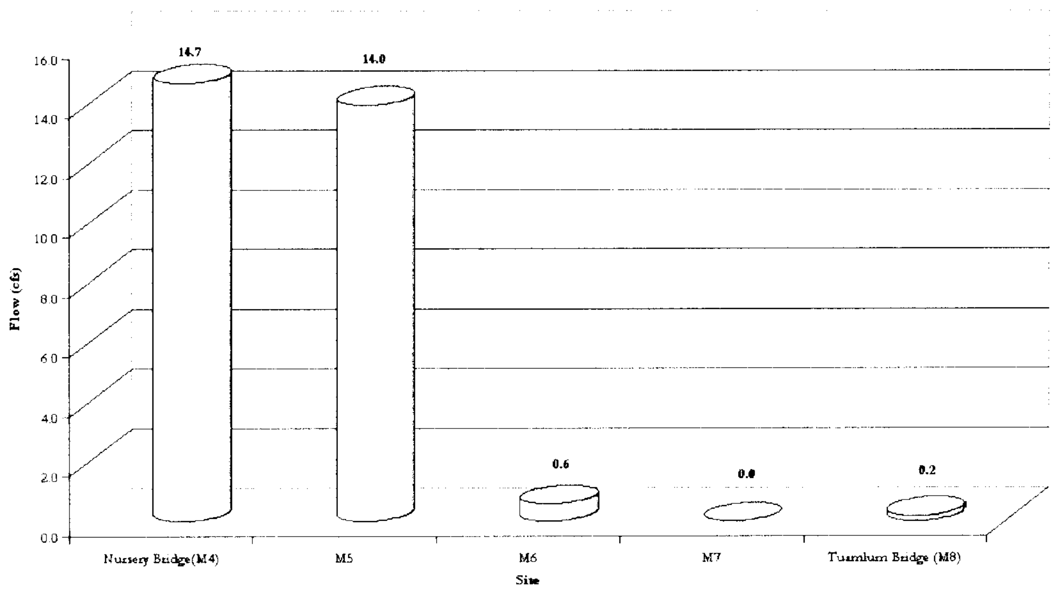
Seepage Overview

This lower section of Oregon's Walla Walla River, from Milton-Freewater north to the Washington-Oregon border, is the focus of this seepage study (**FIGURE S-1**). From as early as the late 1800's, this portion of the river had been dry during the summer months due to a combination of irrigation diversions, instream gravel mining, and natural geologic features. This dry stretch was the primary reason the Walla Walla River was listed by the environmental group *American Rivers*, as one of America's "Top 20 Most Endangered Rivers" **(AR, 1998).**

During the winter of 1999-2000, initial negotiations between local irrigators, USFWS and environmental groups led to an out-of-court settlement to restore flows to this section of the Walla Walla River **(USFWS, 2000)**. The two Oregon districts agreed to voluntarily bypass 13 cfs of flow during the 2000 summer irrigation season. The goal of this agreement was to re-water this section of the river for passage of Endangered Species Act listed bull trout and summer steelhead. The Nursery Bridge location (M-4) is where these agreement flows were to be measured as they entered this reach. Downstream of Nursery Bridge, Tumalum Bridge (M-8) represents the end of this dry portion of the river.

Unfortunately in the first year of the agreement (Summer 2000), this bypassed flow of 13 cfs (measured as 14.7 cfs) did not make it through the levee due to the high rate channel bed infiltration. **Figure S-2** shows the average flow, recorded at the surface in half-mile increments thought this stretch of river.

Figure S-2: Agreement Flows for Lower Levee during Dry Period (7/5/2000 - 8/23/2000)



These high rates of loss made it difficult to estimate the quantity of flow needed to create passage for fish through the low-flow periods of the summer. Negotiations continued the following winter between the USFWS and Districts and in the spring of 2001, an agreement was reached to increase the amount of bypassed flows from 13 cfs to 18 cfs (2001), and 25 cfs (2002), **(USFWS, 2001).** The interim goal of these flows was to have 5 cfs of surface flow at Tumalum Bridge during the lowest flow period of the summer.

The high rate of channel bed infiltration in the study area section of Walla Walla River is affected by both natural geologic features[1] and previous human activities. Human activities have acted to amplify these natural features primarily through channel excavation and construction of a flood control levee by the Army Corps of Engineers, extraction of alluvial gravels by in-channel mining, and the installation of numerous shallow wells that draw from the local water table.

Seepage Methodology

The seepage study area was divided into three distinct reaches: Upper (Trans 1 to Trans 2), Lower (Trans 2 to Trans 3) Levee and Tumalum-Stateline (Trans 3 to Trans 4) **(Figure S-1).** The Upper Levee (M1 to M3) is an area inside the flood control levee with major irrigation surface diversions, and moderate riparian habitat during the summer period. The Lower Levee reach extends from Nursery Bridge to Tumalum Bridge (M4-M8), is an section with no surface diversions, poor riparian habitat, recent gravel mining activities (1998) and natural geologic features that make this reach an *influent* system. The Tumalum – Stateline reach is outside of the flood control levee, has some irrigation diversions, and moderate riparian habitat conditions (relative to the Lower Levee section).

During the 2001 irrigation season, flow measurements were taken at eight measurements points (M-1a to M-8) **(Figure S-1)**. Flow measurements taken along the levee sites were spaced approximately 0.5 mile intervals. These sites were similar to the sites monitored the previous 2000 season by staff from OWRD. Seven additional data sites including OWRD and irrigation diversions gauges were also used in the analysis. These additional sites included OWRD gauge stations on the South Fork and North Forks of the Walla Walla River (North Fork OWRD # 14011000 and South Fork OWRD # 14010000), the Eastside (OWRD # 14012398) and Little Walla Walla (14012100) Diversions. One WDOE semi-permanent gauge near the Washington – Oregon Stateline was also used in the analysis **(Mendell, 2001)**. Average discharge rates recorded by the WWRID at two ramp flumes (Milton and Smith Ditches) were also used in the analysis. Water right information was used for the other known diversion on this section of river.

Two teams of field personnel collected the instream flow measurements on a bimonthly basis usually within a four-hour period **(Table S-1).** At each location, a minimum of 20 cross-sectional measurements were taken with the average velocity estimated for each individual section over a40-second period. Measurements were collected using a *(OWRD flow meter brand name?)* and a *Marsh-McBirney Version 2000* Flow meter, a standard tape measure and a top-set wading rod. For data quality assurance and control (QA/QC), measurements between teams were duplicated and compared. Differences between field team measurements were thought to be within acceptable limits of error (values = +/- 2.6%)**(WWBWC, unpublished data).**

Diversion and river flow data provided by OWRD, WDOE and the irrigation districts for the 2000 monitoring season was also used for this analysis **(Table S-2)**. Measurements for the 2000 data set were made with the same basic sampling protocol and were collected on a weekly basis from May through November.

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[1] Newcomb best described the natural geologic influences on the Walla Walla River as: "... the water table in places stands below the level of the adjacent surface water as the ground water spreads out and adjusts itself to a flatter gradient in the larger area of gravel. In crossing these areas where the water levels are lower, the streams lose substantial amounts of water to the gravel. This infiltration increases greatly when the streams are high." **(Newcomb, 1965, page 40).**

Figure S-1 Monitoring Sites on Oregon's Lower Walla Walla River

Walla Walla River Site Map
(2000-2001)

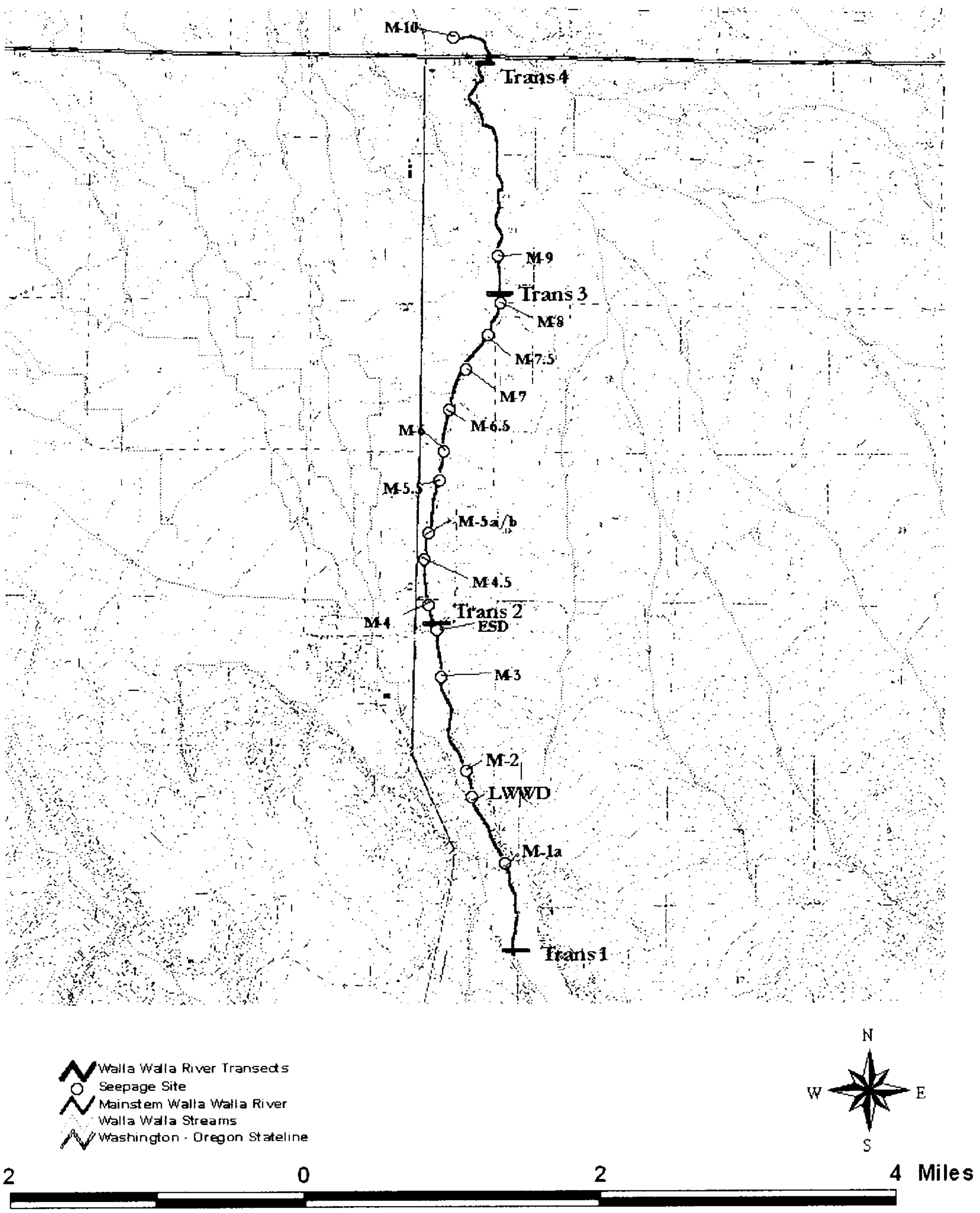


Table S - 2 Flow Measurements for Levee Reaches, 2001

Dates	M-1	Gains/Losses M1>M2	M3	Gains/Losses M3>M4	M4	Gains/Losses M4>M5a	M5a	Gains/Losses M5a>M5b (West Bank pipe)	M5b	Gains/Losses M5b>M6	M6	Gains/Losses M6>M7	M7	Gains/Losses M7>M8	M8
5/31/01	181.0	-145.7	35.3	-13.4	21.9	-6.3	15.6	9.1	24.7	-16.6	8.2	-5.2	3.0	1.8	4.8
6/14/01	161.3	-122.9	38.5	-13.9	24.6	-1.6	23.0	3.2	26.2	-9.8	16.4	-1.6	14.8	0.4	15.1
6/21/01	143.0	-102.5	40.5	-17.6	22.9	-0.3	22.6	-2.5	20.1	-7.2	12.9	-4.3	8.6	1.6	10.3
6/28/01	142.8				33.6										19.7
7/3/01	106.0	-60.5	45.5	-18.6	26.9	-3.6	23.3	3.2	26.5	-12.5	14.0	-2.4	11.6	0.4	12.0
7/18/01	99.0	-57.0	42.0	-14.5	27.5	-3.2	24.3	2.2	26.5	-9.8	16.7	-4.8	12.0	0.8	12.7
8/1/01	102.0	-68.4	33.6	-8.6	25.0	-1.1	23.9	-0.4	23.5	-8.8	14.6	-3.3	11.4	0.5	11.8
8/15/01	101.0	-60.1	40.9	-14.9	26.0	-3.3	22.7	0.8	23.5	-7.2	16.3	-3.8	12.5	-0.9	11.7
8/29/01	88.0	-52.4	35.6	-9.6	26.0	-4.0	22.0	3.3	25.3	-9.2	16.1	-3.3	12.8	-0.7	12.1
9/12/01	87.3	-52.1	35.2	-15.0	20.2	-1.2	19.0	2.9	21.9	-8.6	13.2	-3.8	9.4	0.3	9.7
9/26/01	116.8	-64.2	52.7	-18.1	34.6	-4.3	30.3	-0.4	29.9	-8.4	21.5	-1.6	19.9	-1.0	18.9
10/10/01	122.2	-70.9	51.4	-11.5	39.9	-3.3	36.6	4.5	41.1	-11.2	29.9	-0.4	29.5	0.3	29.8
10/24/01	121.0	-73.6	47.4	-6.6	40.8	5.4	46.2	-6.0	40.2	-4.5	35.7	-4.0	31.7	1.6	33.3
11/8/01	126.0	-93.6	32.4	-3.4	29.0	-1.8	27.2	5.5	32.7	-5.4	27.3	-4.6	22.7	-1.6	21.1
11/21/01	150.0	-72.9	77.1	-5.5	71.6	-22.6	49.0	25.8	74.8	-9.6	65.2	-8.8	56.4	3.1	59.5
Average/ Average Difference	123.2	-78.3	43.4	-12.2	31.4	-3.7	27.5	3.7	31.2	-9.2	22.0	-3.7	18.3	0.5	18.8
Standard Deviation	27.6	28.0	11.6	4.8	12.7	6.1	9.8	7.3	14.0	3.0	14.5	2.0	13.6	1.3	13.6

Instream Flow data was collected by the WWBWC/OWRD and Irrigation Districts during the summer of 2001. Original Q-notes are available at the WWBWC and Irrigation District offices. The assumed error rate for all flow measurements is (+/-) 5%. OWRD/USGS standards were followed in the collection of this data.

Table S - 3 Flow Measurements for Levee Reaches, 2000

Dates	M-1	Gains/Losses M1>M2	M2	Gains/Losses M2>M3	M3	Gains/Losses M3>M4	M4	Gains/Losses M4>M5	M5	Gains/Losses M5>M6	M6	Gains/Losses M6>M7	M7	Gains/Losses M7>M8	M8
06/16/00	306.0	115.4	190.6	19.4	210.0	-40.0	170.0	-3.0	167.0	-30.0	137.0	5.0	142.0	15.0	157.0
06/21/00	217.0				80.5	-3.9	76.6	-5.3	71.3				52.6	6.7	59.3
06/28/00	158.0	-130.9	27.1	1.5	25.6	-4.7	20.9	-1.7	19.2	-13.3	5.9	-3.7	2.2	1.9	4.1
07/05/00	141.0	-115.9	25.1	1.2	26.3	-17.8	8.5	-1.5	7.1	-7.1	0.0	0.0	0.0	0.9	0.9
07/07/00							16.7								
07/13/00	120.0	-89.2	30.8	0.3	30.5	14.7	15.8	1.4	14.4	-12.9	1.5	1.5	0.0	0.0	0.0
07/19/00	119.0	-86.7	32.3	0.3	32.6	-16.3	16.3	0.5	16.8	-16.7	0.1	-0.1	0.0	0.1	0.1
07/26/00	106.0	75.9	30.1	3.3	33.4	-18.8	14.6	-1.4	13.2	-13.1	0.1	-0.1	0.0	0.1	0.1
08/02/00	107.0	73.3	33.7	-1.9	31.8	-15.6	16.2	-1.0	15.2	-15.1	0.1	-0.1	0.0	0.1	0.1
08/09/00	105.0	72.7	32.3	1.2	33.5	-18.3	15.2	0.3	14.9	-14.8	0.1	0.1	0.0	0.1	0.1
08/16/00	106.0	73.0	33.0	2.6	30.4	-15.2	15.2	0.3	14.9	-14.9	0.0	0.0	0.0	0.1	0.1
08/23/00	99.4	-67.5	31.9	1.7	33.6	-17.9	15.7	-0.5	15.2	-12.4	2.8	2.8	0.0	0.0	0.0
08/30/00	103.0	-70.9	32.1	0.0	32.1	14.8	17.3	-0.5	16.8	-12.2	4.6	4.5	0.1	1.3	1.4
09/08/00	105.0	-78.7	26.3	0.2	26.5	-11.9	14.6	0.4	15.0	-12.3	2.7	-2.6	0.1	1.2	1.3
09/13/00	120.0	95.6	24.4	-1.8	22.6	-10.1	12.5	1.6	14.1	-11.5	2.6	2.5	0.1	1.4	1.5
09/20/00	98.8	-63.1	35.7	-7.1	28.6	-14.4	14.2	-1.5	12.7	-9.6	3.1	-3.0	0.1	1.1	1.2
09/27/00	110.0	-83.8	26.2	1.5	27.7	13.7	14.0	-1.6	12.4	-9.1	3.3	3.2	0.1	0.0	0.1
10/04/00	166.0	87.2	78.8	6.6	85.4	12.9	72.5	12.9	85.4	-22.2	63.2	2.3	65.5	0.2	65.7
10/11/00			43.7	0.4	44.1	-4.9	39.2	-5.1	34.1	1.3	32.8	-4.6	28.2	1.1	27.1
10/18/00	124.0	88.0	36.0	0.2	36.2	-4.7	31.5	-0.8	30.7	-6.2	24.5	7.1	17.4	2.0	19.4
10/25/00	139.0				52.6	5.9	46.7	18.2	64.9				35.2	-2.8	32.4
11/01/00	148.0	82.6	65.4	1.5	66.9	-3.4	63.5	-1.3	62.2				43.4	0.8	42.6
11/08/00							90.0	-5.4	84.6				67.8	3.1	70.9
11/15/00					127.0	4.0	131.0	-1.0	130.0				102.0	3.2	98.8
11/22/00					132.0	-8.0	124.0	-12.0	112.0				98.3	2.7	101.0
Average/ Average Difference	134.9	-86.1	44.0	1.2	54.3	-12.3	42.9	-0.5	43.5	-13.0	15.8	-1.6	27.3	1.3	28.6
Standard Deviation	49.7	18.2	38.1	5.2	41.3	8.1	36.7	5.4	38.0	6.2	34.3	2.8	34.9	3.6	37.6

Instream Flow data was collected by the OWRD during the summer of 2000. Original Q-notes are available at the WWBWC offices. The assumed error rate for flow measurements is +/- 5% (USGS, 2002). OWRD/USGS standards were followed in the collection of this data. At times of extremely high flows, data was not collected for safety reasons at some sites. (October and November).

During the lowest flow of the summer, the field teams could not measure the river due to depths of live flow below what hand held measuring devices could measure. Below are the assumptions made on these "no data" observations.

Assumptions: (A) ISF (Insufficient Flow for measuring) data was assumed to have a universal value of 0.1 cfs
(B) "DRY" was considered to have a zero value
(C) All EST. (Estimated) flows were not included in the data set.

In order to estimate the net gains and losses from the river, seepage data was analyzed using the following equation **(USGS, 2002):**

$$Q_n = Q_d - T - Q_u + D \qquad eq\ (1)$$

where;

Q_n is the net seepage gain or loss, in ft^3/s;

Q_d is the discharge measured at the downstream end of the reach, in ft^3/s;

Q_u is the discharge measured at the upstream end of the reach, in ft^3/s;

T is the sum of tributary inflows, in ft^3/s; and

D is the sum of irrigation ditch diversions, in ft^3/s.

The increase or decrease in *Qn* results in a net gain or loss of water to the river. Units for discharge (*Q*) are always assumed to be in cubic feet per second (ft^3/s). Measurement sites are placed in an upstream to downstream order for the analysis of this data. Reaches of the river between the individual measurement sites are termed a "seepage segment" for the purposes of this report.

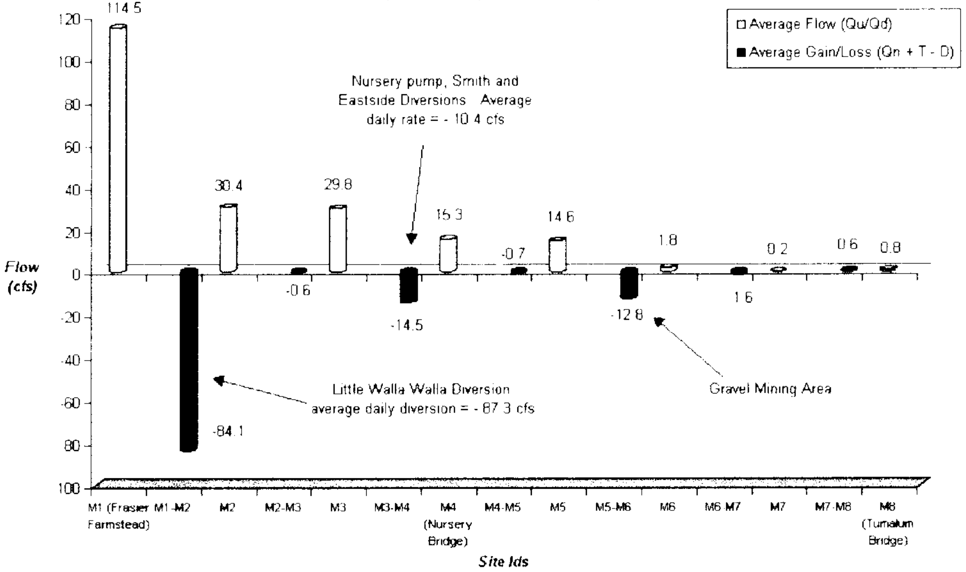
Seepage Results

Levee: Upper and Lower Reaches

The careful monitoring and control of the amount of flow through the levee during the 2000 and 2001 irrigation seasons provided a unique environment in which to study the river's gains and losses. For a majority of the low flow season the average flow was kept relatively constant through the levee. The product of flow control was a dampening of the natural diurnal fluxes of the river, which provided the seepage analysis with more consistent numbers with which to estimate Q_n.

Figure S-3 shows the average flow for each measurement site along the levee along with the estimated gross gain or loss between points. Diversion (*D*) and tributary (*T*) values were left in these estimates in order to quantify the changes in flow along the levee. During 2000, there were no known tributaries (*T*) entering the two levee sections. However, the thermal images provided by an August 15, 2000 Forward Looking Infrared (F.L.I.R.) flight (Watershed Sciences, 2001) of the Walla Walla River revealed a large ground water contribution near measurement site M-5 being released into the levee from a pipe. Two major and two minor diversions are shown in the Upper Levee between measurement points: Little Walla Walla diversion (between M-1 and M-2), and Nursery Pump, Smith and Eastside diversions (between M-3 and M-4). Ramp flume measurements provided an estimate the Smith diversion while OWRD water rights information provided an estimate of the Nursery pump. OWRD gauge data provided daily flow averages used for the other two sites.

Figure S-3: Walla Walla River Average Flow and Gain/Losses
(June 28 - September 27, 2000)

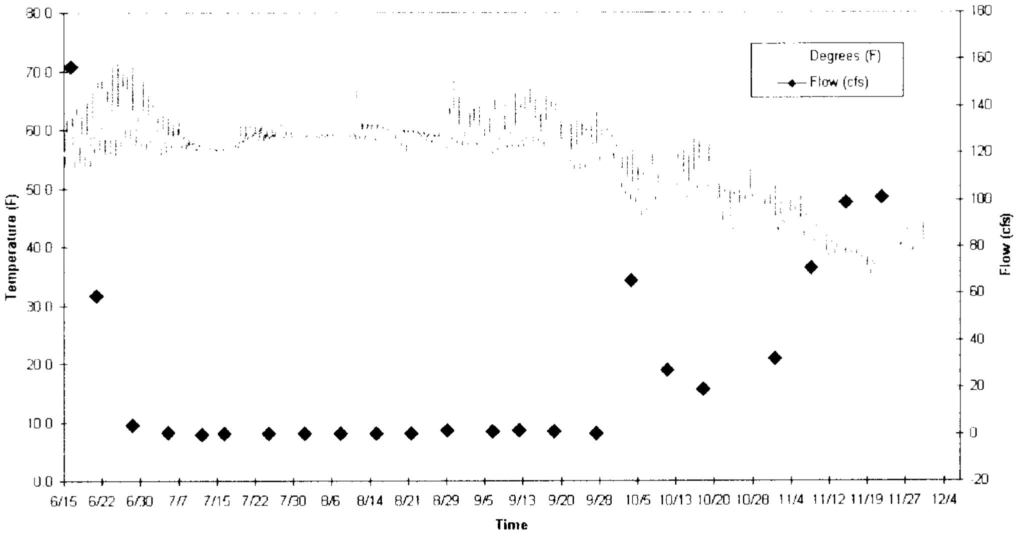


The Upper Levee reach (M-1 to M-4) is where a majority of the irrigation water is diverted from the river in this study area. We have noted the average daily diversion rates in **Figure S-3** for the known diversions in order to help explain those high loss values. Caution should be noted in using these, values in direct comparison with river flow measurements as they represent a 24-hour average while the flow measurements represent a single sample during that 24-hour period. The M-1 and M-2 measurements are taken above and below the Little Walla Walla diversion at Cemetery Bridge. It appears that there is may be a slight gain (*+Qn)* through that reach of the Upper Levee. It appears that there is little change in *Qn* between M-2 and M3. Estimates of channel bed losses for the M-3 to M-4 section vary between 3-4 cfs *(-Qn)*. However, these estimates are difficult to quantify without a better understanding of the diversion rates through this upper section of the levee.

Nursery Bridge (M-4) marks the upstream end of the Lower Levee section while Tumalum Bridge (M-8) the downstream end. Note that the flow value for point M-5 is artificially higher (≈ 2 cfs) from the contribution of the pipe, which was not accounted for in the 2000 data set. A majority of the surface flow was lost in the M-5 to M-6 section of the river. This area is historically where the instream gravel mining was conducted during the traditionally dry channel summer period.

At Tumalum Bridge (M-8), we see the signs of ground water return in several forms. The fact that in 2000, the river was dry above this area while Tumalum Bridge had "some" flow is a strong indicator that ground water is returning in the M-7 to M-8 section. Another clue is provided by water temperature data that was recorded in conjunction with river flow. This information shows a correlation of between temperature flux with that of flow volume **(Figure S-4)**. As the total volume of water decreases, the cooler, consistent temperatured ground water makes up a higher presentation of the total volume (7/7/00 to 8/29/00). This would act to dilute the influences of the diurnally fluxing surface water temperature. Ground water is not as affected as surface water is from the daily heating of the sun and cooling of nighttime. This represents itself in a more constant temperature profile mimicking that of ground water **(Figure S-4)**. Temperature data from wells shows that shallow aquifer ground water usually ranges between 50°F to 60°F **(WWBWC, Unpublished data).**

Figure S-4. Tumalum Bridge (M-8) Flow and Temperature
(2000) Lower Levee Section



This ground water return at M-8 is also supported by the thermal images taken for this segment of the river during 2000 **(Watershed Sciences, 2001).** These images show cooler pools of water downstream of the dry section of river **(Appendices XX).**

During 2001, the flow bypassed at Nursery Bridge re-watered (for the entire summer) the entire lower section of the levee for the first in over a hundred years. **Figure S-5** shows the 2001 data for both Levee reaches that monitored this event. Some sampling locations were moved from the previous season. Site M-1 was moved upstream (M-1a) to make access easier (Grove School Bridge). Site M-2 was dropped based on the 2000 data showing little difference between M-2 and M-3. M-5 was split into M-5a and M-5b to capture the contribution of the pipe (*?*) found during the 2000 F.L.I.R flight. During 2001, the river flows were relatively constant from May 31st until November 8th, 2001 **(Table S-2).**

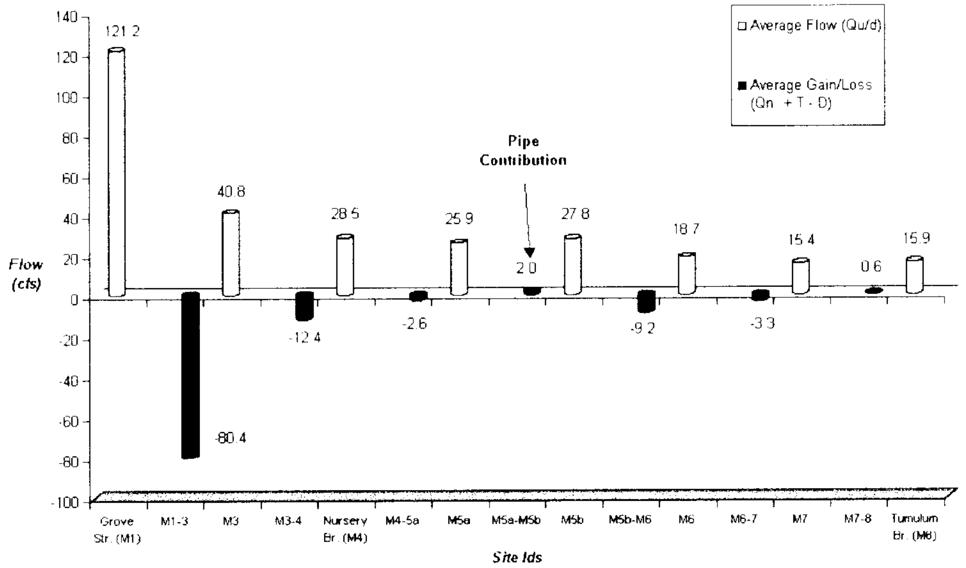


Figure S-5: Walla Walla River Average Flow and Gain/Losses
(May 31 - November 8, 2001)

The Lower section of the levee is the area has the most channel bed disturbances and losses and is the focus of a year-to-year comparison. Applying our equation for *Qn* to each seepage segment we can compare the 2000 and 2001 flows and gains/losses **(Figure S-6)**. Note that the pipe contribution (≈ 2 cfs) was left in the downstream flows (*Q*) but taken out of the gain/loss (*Qn*) estimate for the gravel mining area (M-5 to M-6).

Figure S-6

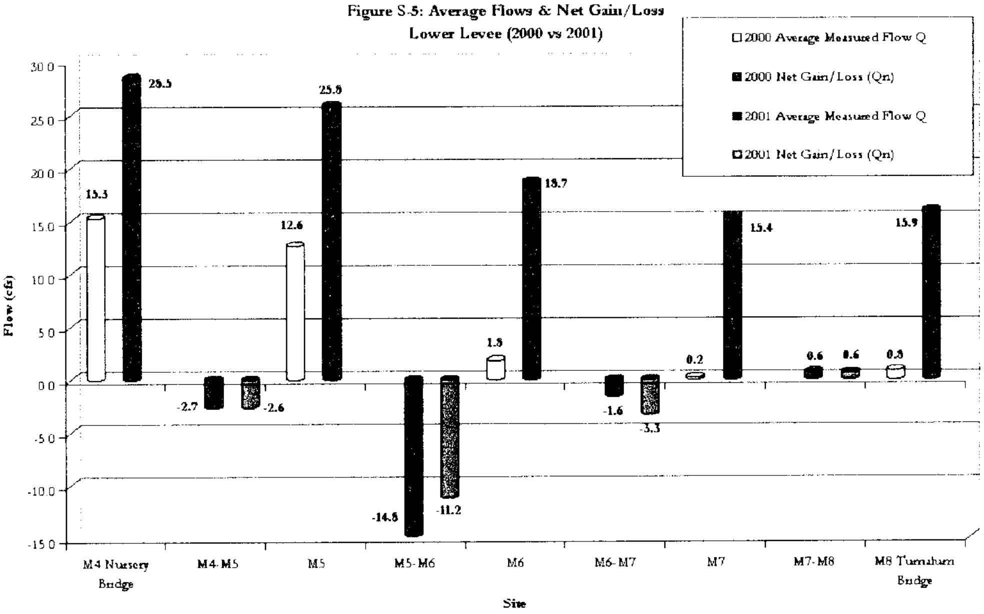
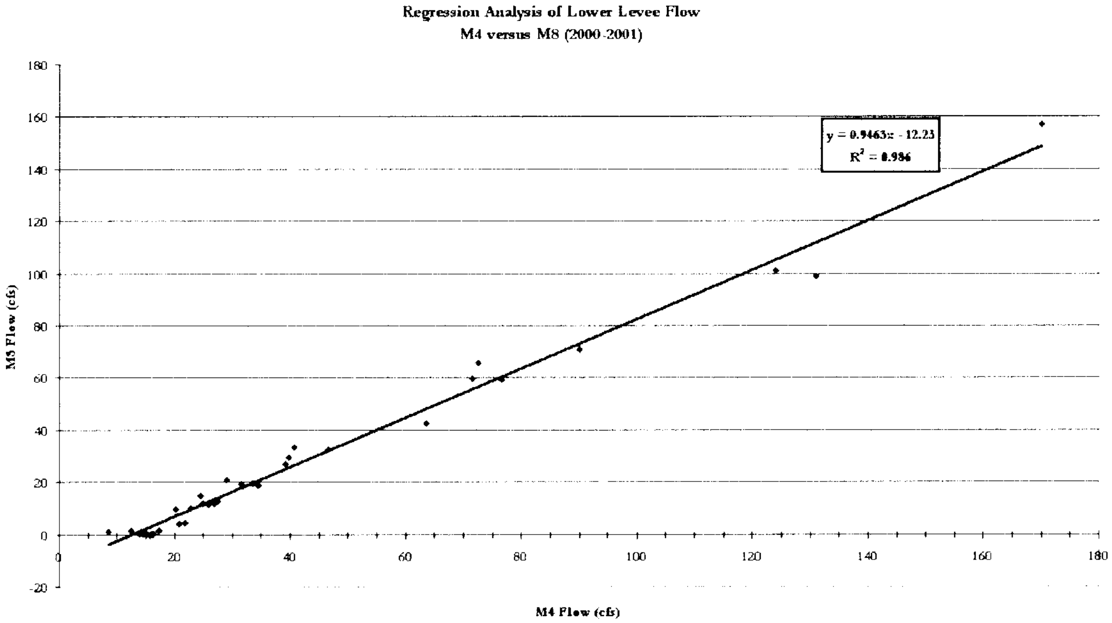


Figure S-5: Average Flows & Net Gain/Loss
Lower Levee (2000 vs 2001)

Note that the flow at Nursery Bridge was measured at 28.5 cfs even though the USFWS/District agreement for this point was 18 cfs. This higher measured volume was accounted for by the timing of flow measurements. Instream flow was usually collected during the early part of the day when the river was highest. Due to diurnal fluxes in river's volume from increased evaporation and upriver diversions, the districts found that they needed to bypass more flow in the morning in order to meet their compliance goal by late afternoon.

In comparison, it appears that the gravel mining section between points M-5 and M-6 lost less water in 2001 compared to 2000 **(Figure S-6)**. This difference may be explained simply by the margin of measurement error between years. However, when considering that the amount of 2001 flow entering this section was twice (25.8 cfs) that of the previous year, then the idea less water being lost in the gravel mining section becomes more defendable.

In order to estimate the average flow losses in the Lower Levee area for use in water management decisions regression analysis was preformed. Same day flow values for both Nursery Bridge (M-4) and Tumalum Bridge (M-8) were scatter plotted and a simple linear regression preformed **(Figure S-7)**. The resulting equation for *Qd* represents the average amount of water needed at Nursery Bridge (*Qu*) to provide X amount of flow at Tumalum Bridge (*Qd*).



By reworking the regression for *Qd* we have:

$$Y = 0.9463x - 12.23 = Qd = 0.9463\ (Qu) - 12.23 \qquad eq\ (2)$$

$$\text{Thus:} \quad \mathbf{Qd = 0.9463\ (Qu) - 12.23}$$

However, this equation would have to assume that:

1. The net *Qn* for the entire Lower Levee does not change relative to time or flow volume.
2. Pipe contributions at M-5 are relatively constant throughout the summer season.

Tumalum to Stateline

The Tumalum to Stateline section of the study area represents a non-levied, private landownership area. Seepage information to this segment of the river is sparse based on river accessibility. Three flow sites were used to represent flow in this section of river: Tumalum Bridge (M-8) and two WDOE's sites at Peppers Bridge (WW#6) and a site upstream of the border (WW#9). 2000 and 2001 flow data measured at Tumalum Bridge was compared to daily averages recorded at downstream semi-permanent gauge stations **(Table S-2).**

Table S-3 Tumalum to Stateline Flow Data

2000			2001			
Dates	M8	WDOE Gauge at Peppers Bridge (WW# 6)	Dates	M8	WDOE Gauge Upstream of Stateline (WW# 9)	WDOE Gauge at Peppers Bridge (WW# 6)
06/21/00	59.3	78.3	**7/18/01**	12.7	13.7	11.1
06/28/00	4.1	9.5	**8/1/01**	11.8	11.8	8.5
07/05/00	0.9	6.8	**8/15/01**	11.7	10.6	12.5
07/13/00	0.0	4.3	**8/29/01**	12.1	11.4	15.3
07/19/00	0.1	3.9	**9/12/01**	9.7	10.3	9.3
07/26/00	0.1	6.9	**9/26/01**	18.9	21.2	27.3
			10/10/01	29.8	33.4	27.7
			10/24/01	33.3	28.2	41.0

During the 2000, the gauge at Peppers Bridge went offline at the end of July. From the data available, there appeared generally to be increased flow as you moved downriver. Birch Creek is the only known tributary in this section of the river. Flow at the mouth of that creek was measured at 0.2 cfs (9/5/00) and 0.3 cfs (9/18/02). While these represent an increase to the mainstem, they appear inadequate as the only source of the increase. Ground water is suspected to be the source of most of the increase in flow witnessed. Previous ground water studies have also noted a return of ground water from Tumalum Bridge downstream to the stateline area of the Walla Walla River[2].

Data collected in 2001 does not show as clearly the influence of ground water inputs on flow in the stateline area. This may be attributed to the diversions in this section of river, which were uninventoried prior to 2001. Because their traditionally not been water in this section of river, the return of water may have given water right holders the opportunity to exercise their legal rights. The net effect of this would be an increase in net diversions *(?)* reducing the influence of surface water recharge from the ground water.

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[2] **Piper et. al., 1933. (USGS) page 95.** "The Walla Walla River seems to be a perennial gaining stream downstream from the McCoy (Tumalum) Bridge… that is, water seeps into the stream channel from the alluvium. This conditions downstream to and probably beyond Whitman Station..."

Vertical Hydraulic Gradients

Vertical Hydraulic Gradient Overview

Water left in the river through the Lower Levee section of the Walla Walla River appears to infiltrate from the surface during the summer of 2000. In order to test this hypothesis, measurements were conducted to ascertain two channel bed properties; vertical hydraulic gradient and vertical hydraulic conductivity. Mini-ps were utilized to measure vertical hydraulic gradients. The difference between the river level and the water level inside the Mini-ps gives an indication of the vertical hydraulic gradient, and the direction of flow between the river and the aquifer. In areas of infiltration from the river to the aquifer, the water level in the piezometer would be expected to be lower than the water level in the river. In areas of ground water discharge into the river, the water level in the piezometer would be expected to be higher than the water level in the river. The vertical hydraulic conductivity is a measure of the ability of the soil to transmit water and depends upon both the properties of the soil and the water.

Vertical Hydraulic Gradient Methodology and Results

The mini-piezometers (mini-ps) were used to identify areas of losses and gains in the mainstem of the Walla Walla River. Sixteen in-stream mini-piezometers were driven into the streambed to determine the vertical hydraulic gradient and direction of flow between the river and the alluvial aquifer **(Figure S-1)**. Mini-ps were placed at approximately 0.5-mile increments from Grove School Bridge (M-1) to about a mile ½ mile above Peppers Bridge (M-10).

The mini-piezometers consisted of 7-foot sections of ½ inch galvanized pipe. The bottom of the pipe was flattened to provide a blunt point to drive into the river bottom. The bottom 6 inches of the pipe was perforated with 1/8-inch holes to allow ground water to enter and equilibrate **(Sinclair, 2001)**. The water level inside the mini-piezometers should reflect the pressure head at the mid-point of the perforated area at depth below the river.

Using a fence post driver, mini-ps were driven to a minimum depth of 2 feet. Previous studies recommended a driven depth of 2-4 feet below the river bed **(Sinclair, 2001)**. Mini-ps were "developed" by pumping any debris or silt from the holes or the inside of the pipe. The water level inside the mini-piezometers was measured using a standard electrical tape (*Waterline*™ *by Envirotech LTD* gauge). Additional mini-ps were placed at ¼ mile increments along the Lower Levee section **(Figure S-1)**.

Mini-ps were measured approximately every 2 weeks during the critical dry period (July and August, 2001). Additional measurements were collected in the fall. High flows made winter spring measurements dangerous. Hydraulic gradient can be computed using equation 3 **(USGS, 2002).**

$$hg = dh/dl \qquad eq\ (3)$$

where;

hg	is the hydraulic gradient (cm/cm);
dh	is the vertical difference between the mini-p water level and the river water level (cm); and
dl	is the distance from the streambed to the mid-point of the perforated section of the mini-p's (cm).

Vertical Hydraulic Gradient Results

Data results for all measurements are shown in **Figure VH-1.** Vertical hydraulic gradients varied in the Upper Levee section of the study area both by site and by sample. Site M-1 was showed a consist downward gradient while Site M-2 showed both positive and negative gradients. The mini-piezometers in the Lower Levee section (M-4 to M-8) consistently showed a downward vertical gradient of water from the river and the aquifer. The small difference in the change in gradients at M-8 (Tumalum bridge) indicate neither a positive or negative trend. Data from the mini-p at M-9 showed a consistent positive gradient indicating a possible gaining section of river. Site M-10 showed a consistently downward gradient for all of the sample collected at that location.

The average hydraulic gradients were computed for all sites **(Table VH-1 and Figure VH-2)**. All sites in the Lower Levee section demonstrated an average negative hydraulic gradient indicating an area that looses surface water to the aquifer. M-9 showed the only average positive gradient for all river sites. The vertical difference (dh) used was the average vertical difference between the mini-p and the river water level for that mini-p.

Table VH-1. Calculation of hydraulic gradients

Site ID	dh (cm) (average)	dl (cm) (average)	Vertical Hydraulic Gradient dh/dl (cm/cm)
M-1	-34.0	120.9	-0.3
M-2	1.0	65.8	0
M-3	6.0	130.2	0
M-4	-9.0	29.3	-0.3
M-4.5	-40.0	46.6	-0.9
M-5a	-55.0	48.7	-1.1
M-5b	-53.0	68.6	-0.8
M-5.5	-10.0	40.1	-0.3
M-6	-69.0	44.8	-1.5
M-6.5a	-54.0	61.1	-0.9
M-6.5b	-54.0	68.6	-0.8
M-7	-34.0	106.8	-0.3
M7.5	-9.0	96.5	-0.1
M8	-2.0	90.8	0
M9	10.0	87.6	0.1
M10	-9.0	145.3	-0.1

Figure VH-1

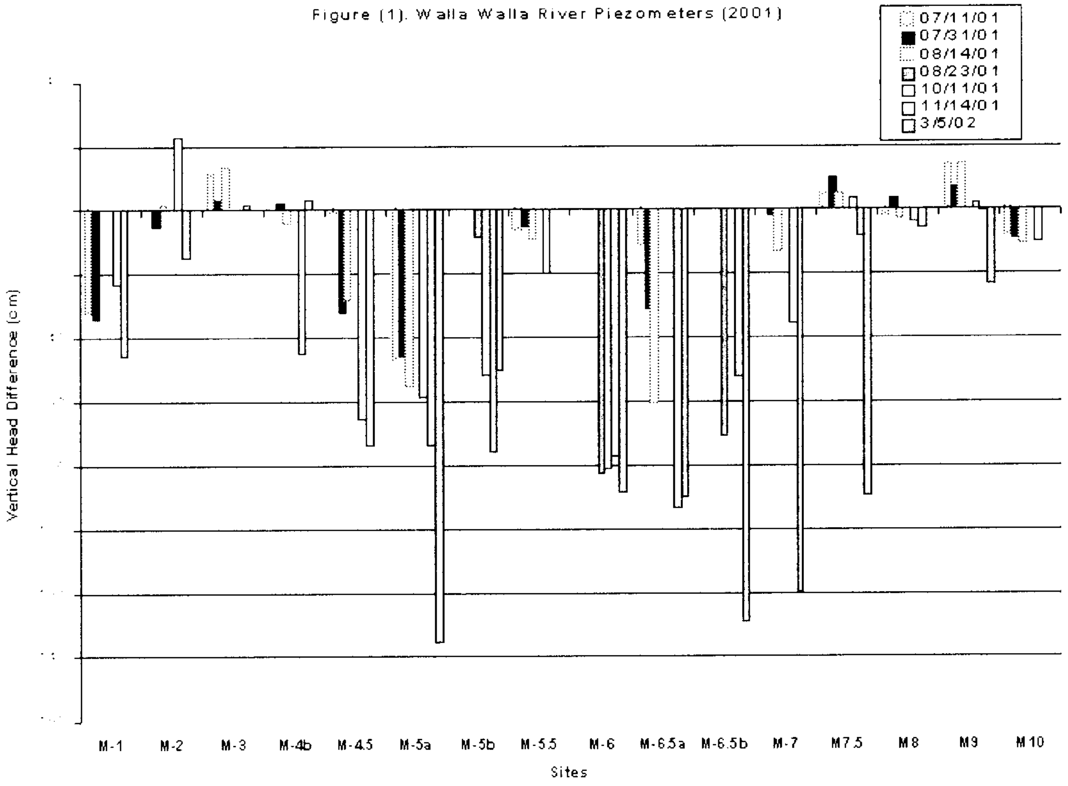
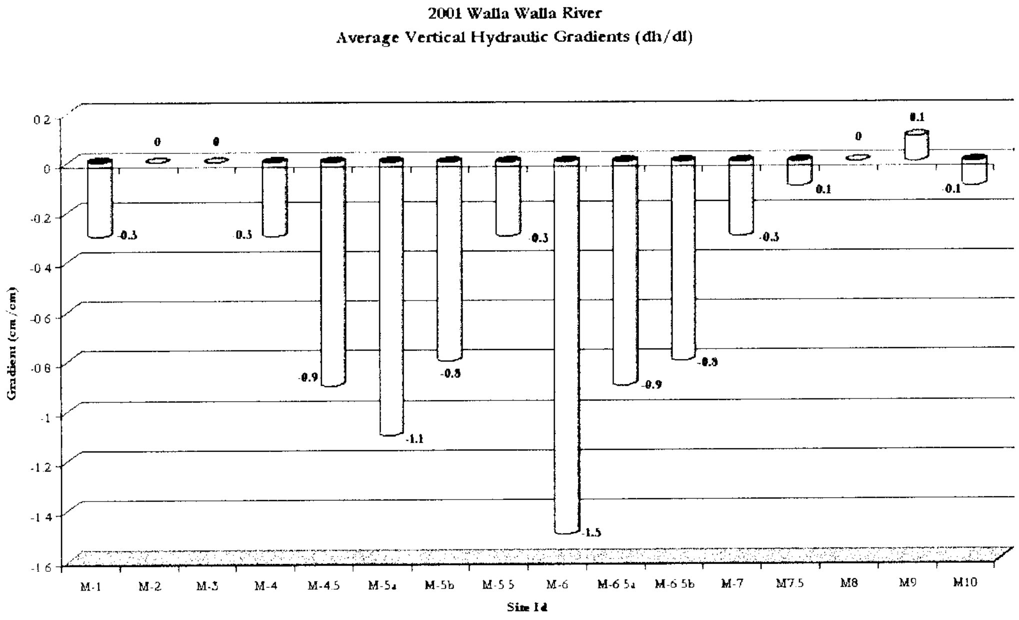
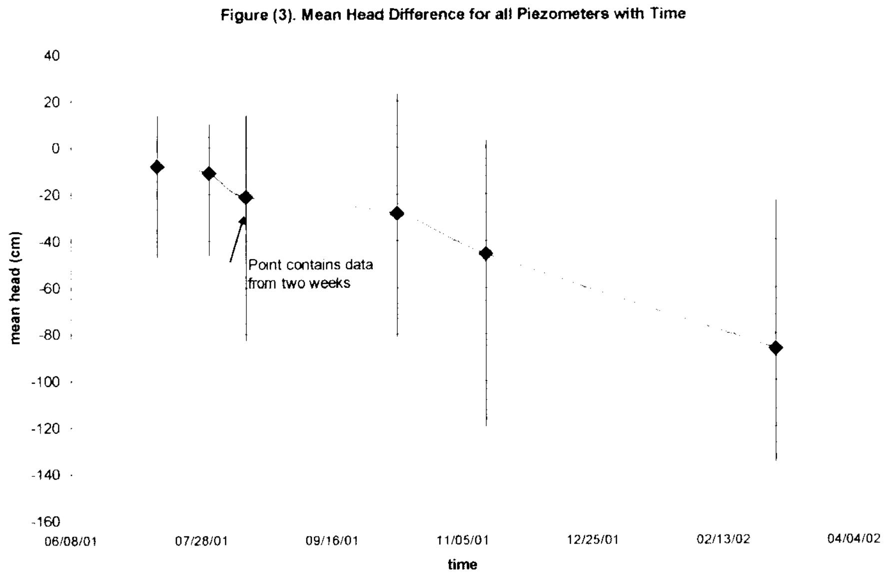


Figure VH-2



In order to assess vertical hydraulic gradients relative to time average gradients were plotted against sampling dates **(Figure VH-3)**. The error bars represent the spread of all data points recorded on a particular date. There appears to be a gradual increase in negative head difference (i.e. more downward flux of stream water) from the summer 2001 to the following spring, 2002. Daily data from spatially adjacent mini-ps was used to calculate a correlation coefficient of 0.60. This value of indicates that there is a correlation between head difference at spatially adjacent sites in time.

Figure VH-3 Walla Walla Vertical Hydraulic Gradient versus Time



In order to estimate the average vertical hydraulic conductivity Darcy's law was applied to the mini-p data **(Maidement, 1992)**. Equation 2 was used to calculate average hydraulic conductivity.

$$Q = -K A \; dh/dl \qquad eq\ (4)$$

Rearranging to solve for hydraulic conductivity yields equation 5.

$$K = -(Q \;/\; A \; dh/dl) \qquad eq\ (5)$$

where;

K is the average vertical hydraulic conductivity within a given stream reach (ft/day);

Q is the total flow lost or gained by the stream within the given reach (ft^3/day);

dh/dl is the average vertical hydraulic gradient as determined by the mini-ps (units are dimensionless); and

A is the estimated streambed area within the given reach (ft^2).

Area (*A*) was determined by averaging the stream widths recorded during the 2001 seepage measurement both upstream and downstream of the mini-ps were installed, and then multiplying by the estimated distance between the upstream and downstream min-piezometers. The stream flow gain or loss (Q) was determined by averaging the gain or loss throughout the summer. The average gain or loss throughout the summer was determined using instream flow measurements at the upstream and downstream points where the Mini-ps were installed. The average hydraulic gradient (dh/dl) was determined by averaging the averaging the individual gradient for the upstream and downstream piezometer for the given stream reach.

Several assumptions were made in order to use Darcy's law for these calculations.

1. Flow between the river and the aquifer occurs only in the vertical direction.
2. Flow (*Qn*) gain or losses were only to due to channel bed infiltration or recharge from the aquifer.
3. The average gradient derived from the mini-ps accurately represents the average vertical hydraulic gradient for that segment.
4. The area obtained using the average of upstream and downstream widths, and an approximation of the distance between these points is accurate.

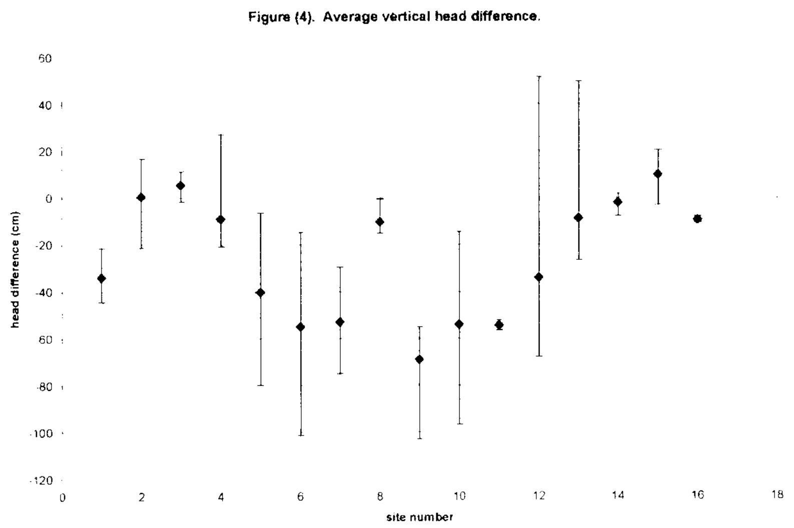
The values used for streambed vertical hydraulic conductivity calculations are shown in Table 2.

Table VH-2. Lower Levee Data for Calculations for Vertical Hydraulic Conductivity

Location	Stream Reach Length (miles)	Length (ft)	Upper Stream Reach Width (ft)	Lower Stream Reach Width (ft)	Average Stream Width (ft)	Qn (ft^3/s)	Vertical Hydraulic Gradient Average	A (ft^2)	K (ft/day)
M4-M5a	0.5	2640	31.3	31.8	31.55	-2.3	-31.8	83292.0	-0.08
M5b-M6	0.5	2640	31.8	33.6	32.7	-9.2	-60.8	86328.0	-0.15
M6-M7	0.5	2640	33.6	27.4	30.5	-3.4	-51.3	80520.0	-0.07
M7-M8	0.5	2640	27.4	29.9	28.65	0.3	-16.0	75636.0	0.02

Figure VH-4 shows the average vertical head difference. The error bars represent the spread of all data points recorded on a particular date. The numbers used for the calculation of the hydraulic gradients are shown in **table VH-2.**

Figure VH-4



Horizontal Hydraulic Gradient

Horizontal Hydraulic Gradient Overview

Understanding the difference in elevation between surface water and the adjacent ground water can provided provide important information about the movement of water. A simplified model is that when river stage is above that of the adjacent water table, the river has the potential to lose water while when river stage is below that of the water table, the surface water has the potential to gain **(Figure HG-1).** These exchanges of water and the zone in which they occur is commonly termed hyporheic and one of the tools used to measure them is to determine the elevations and horizontal hydraulic gradients between them.

Figure HG-1 Surface and Ground Water Exchanges.

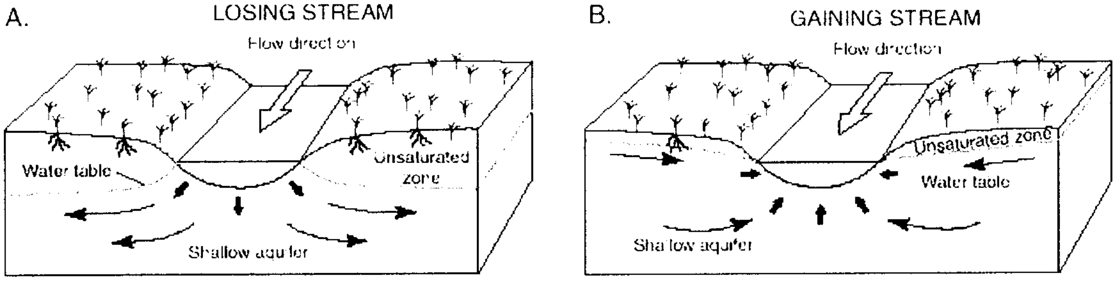


Figure Provided by (USGS, 2002)

Horizontal Hydraulic Gradient Methodology

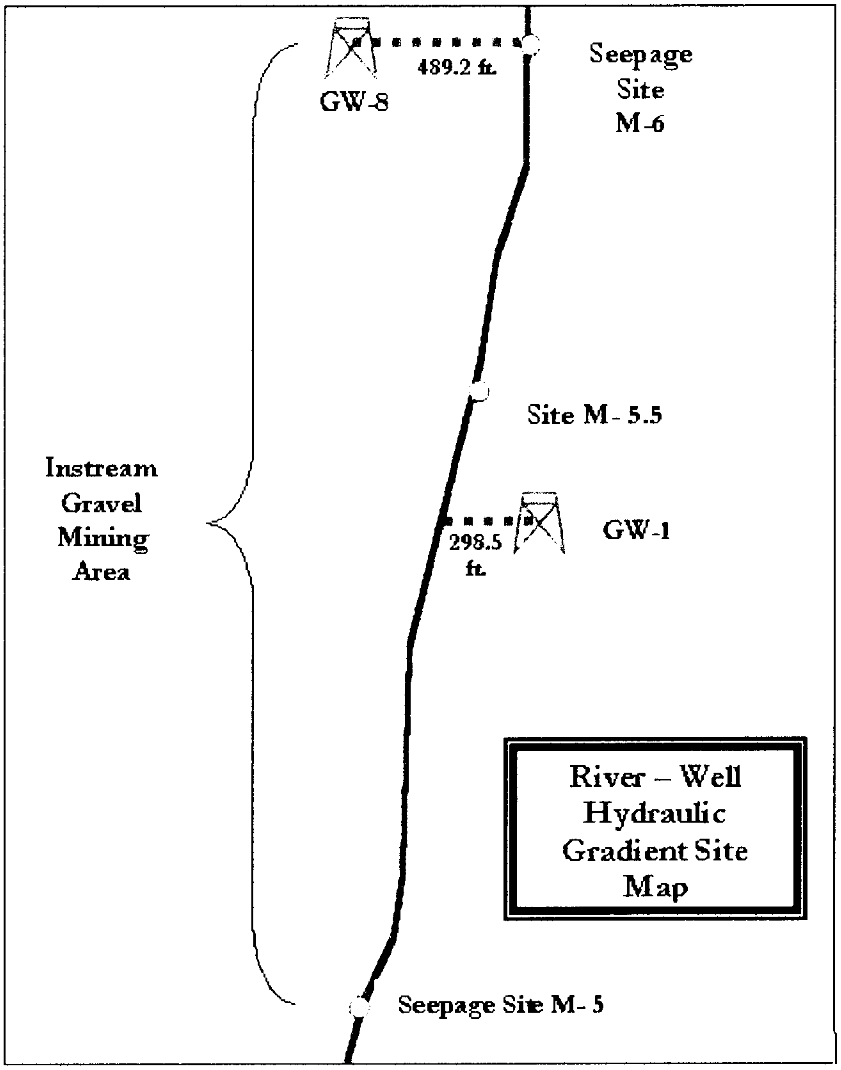
Two wells were selected for their location in the Lower Levee Section of the Walla Walla River. These specific wells were selected because they are relatively inactive as far as pumping and were proximate to the gravel mining section of the Lower Levee **(Figure HG-1)**. These well locations also correspond to the area with highest measured channel losses **(Seepage Chapter)**. Using laser level survey (*insert Brand*) equipment, 100-meter tape, and a handheld GPS unit (*Garmin eTrex Vista)*, elevations, aspect, and distance measurements were collected at each well site and related to the nearest point Walla Walla River. River stage elevation was averaged from river cross-sectional data collected at site M-6 during the 2001 seepage measurements. Static water level data for each well was recalibrated to reflect is position relative to average river stage elevation. (**Table GH-1).**

Hydraulic Gradients were calculated using the basic rise over run of relationship:

$$Gh = (Er - Ew) / Dw\text{-}r \qquad eq\ (6)$$

Where:
Gh = Horizontal Gradient;
Ew = Elevation Well Water;
Er = Elevation River Water; and
$Dw\text{-}r$ = Horizontal Distance from Well to River.

Figure HG-1. Map of River and Well Sites for Hydraulic Gradient Measurements



Horizontal Hydraulic Gradient Results

Well water levels remained below that of the river stage level for the entire monitoring period **(Figure HG-2).** This would indicate that there was a strong potential for the water in the river to move downward into the ground water. The fact that the potential is there throughout the sampling period indicates that this would be true for the entire water year.

Water levels in each well appear to vary in their elevations through out the monitoring period. Well GW-1 static level fluctuates more than twice that of Well GW-8 level. The total change in elevation for GW-1 was 16.1 feet compared to that GW-8 difference of 6.8 feet. This may be explained by the fact that the GW-8 well is located down gradient of the river **(See Figure WT-2 in Water Table Mapping section)**. A well down gradient and close to a river could demonstrate less fluctuation in levels because of the constant source of recharge from the river. Well GW-1 however is up gradient from the river ground water recharge and instead is influenced by the seasonal changes in irrigation agriculture and the WWRID eastside ditch system. **Figure HG-3** shows a similar pattern in the downward horizontal hydraulic gradients between the river and the two nearby wells.

Figure HG-2

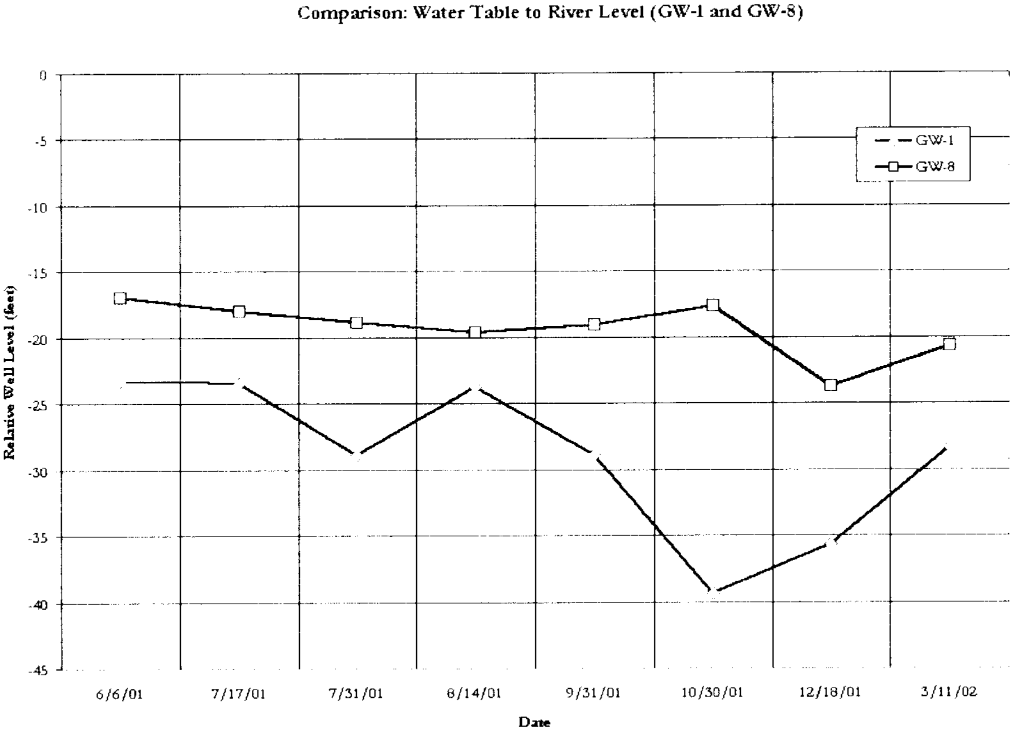


Figure HG-3. Hydraulic Gradient (River to Wells)

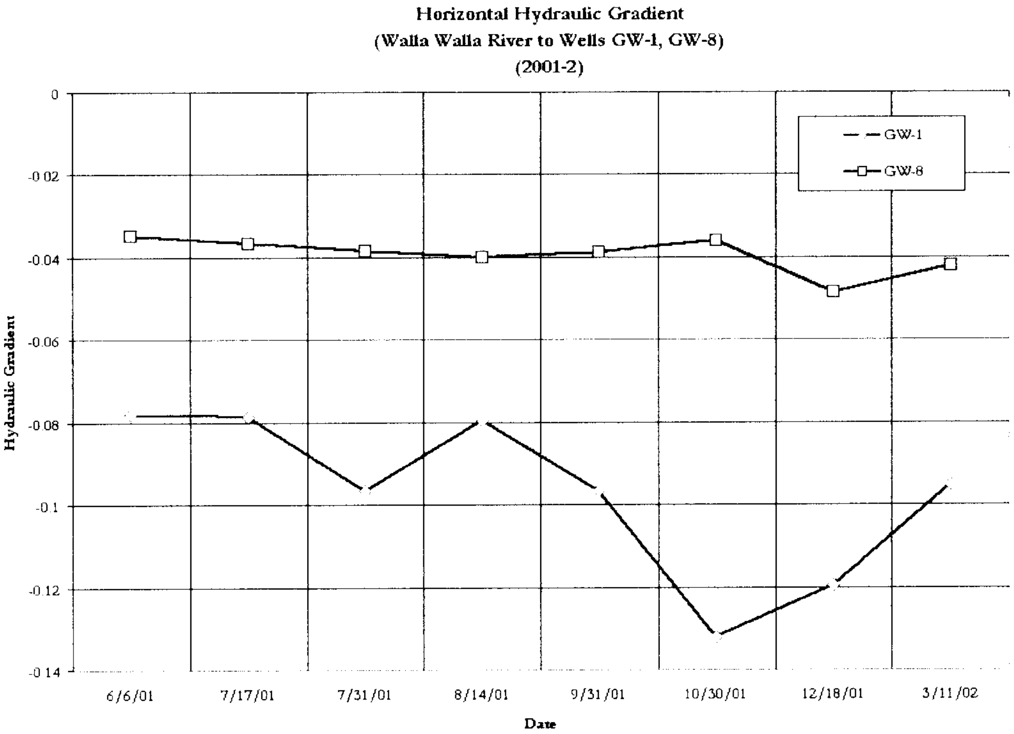


Table HG-1. Well to River Calculation Data

DRAFT

	GW-1			GW-8		
Date	Well level (feet)	Well Level Relative to River (feet)	Horizontal Hydraulic Gradient	Well level (feet)	Well Level Relative to River (feet)	Horizontal Hydraulic Gradient
6/6/01	-23.3	-9.8	0.078	-33.7	-17.0	0.035
7/17/01	-23.4	-9.9	0.078	-34.7	-18.0	0.037
7/31/01	-28.9	-15.4	0.097	-35.6	-18.9	0.039
8/14/01	-23.8	-10.3	0.080	-36.3	-19.6	0.040
9/31/01	-28.9	-15.4	0.097	-35.7	-19.0	0.039
10/30/01	39.4	-25.9	0.132	34.4	-17.7	0.036
12/18/01	-35.7	-22.2	0.120	-40.5	-23.8	0.049
3/11/02	-28.4	-14.9	0.095	-37.4	-20.7	0.042
	Elevation of River (feet)		912.0	Elevation of River (feet)		901.3
	Elevation of Well (feet)		925.0	Elevation of Well (feet)		918.0
	Horizontal Distance (feet)		298.5	Horizontal Distance (feet)		489.2

Chemical Signature

Note to co-author:

- *Need table of all data: sites, dates, and if possible chemical analysis. Maybe two tables, one for body of document, the chemical analysis as appendices.*
- *Need excel spreadsheet with graph data. Need to mark points and clean up the presentation. Difficult to understand relevant to the samples collected.*
- *Since EMMA and PCA analysis was not used, please describe the methodology you did use for the analysis of the ion chromatography results.*
- *Need a map of sample sites.*
- *Questions to address: Wondering if we can assume if there is not a clear chemical signature for ground water that we can assume that the river is losing…why not neither losing or gaining? How long does the water need to be in the shallow aquifer to pick up the groundwater signature? Did you plot the results relative to season?*

Chemical Signature Overview

The primary objective of this study was to determine the interactions between the alluvial aquifer and the Walla Walla River. Chemicals that naturally occur in surface and ground water are commonly used to determine the source of the water. Ground water and surface water have distinctly different chemical compositions. The natural concentrations of these specific chemicals were used to determine the origin of the Walla Walla River and shallow aquifer waters.

Chemical Signature Methodology:

We determined from reviewing past literature that chloride and sulfate are commonly used as naturally occurring chemical tracers **(Appendices E)**. Surface waters whose main source is precipitation and snow melt typically have low concentrations of both chloride and sulfate due to the fact that the water is in limited contact with minerals and rocks for short periods of time. Ground water typically has high concentrations of chloride and sulfate due to its prolonged exposure to subsurface rocks and minerals, which causes weathering of the rocks, and subsequent release of anions and cations. For the Walla Walla River Basin, chloride and sulfate was selected as the anions for analysis using ion chromatography. Ion chromatography separates a solution into its various components and targets the specific components to be identified both qualitatively and quantitatively. *Identification of sources of water was done with a combination of regression analysis for simple correspondences of concentrations and by calculating mass balances.*

Samples of surface water and ground water were collected from July 2001 until March 2002 (Insert Table of site information). There were 121 samples from local wells representing ground water as well as surface water samples from the Walla Walla River. Ground water samples were collected from 21 wells depicted in **Figure M-8**. Surface water samples were collected from 25 sites along the upper and lower Walla Walla River **(Table CS-1 and Figure S-1)**.

Chemical Signature Results:

The results of the sample processing were analyzed. **Figures CS-1, CS-2, and CS-3** show results of the analysis. The excellent R-value for the correspondence of chloride and sulfate concentrations for surface water suggests that there are not additions to the river from the ground water. Had there been water from the ground water entering the surface water the concentrations of the anions would have been larger at ground water entry points and down stream of the entry points. There were no obvious increases in surface water anion content, for that reason it is believed that at the section of river in which samples were taken, between the confluence of the North and South Fork down to Tumalum Bridge, the river is primarily a losing stream.

Figure CS-1

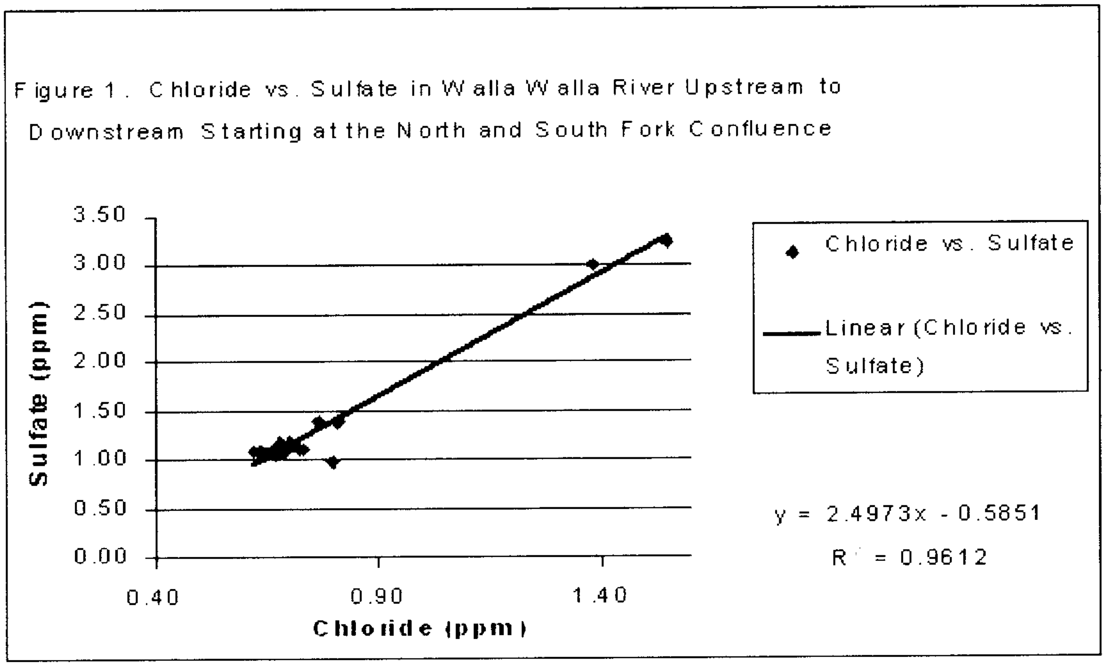


Figure CS-2

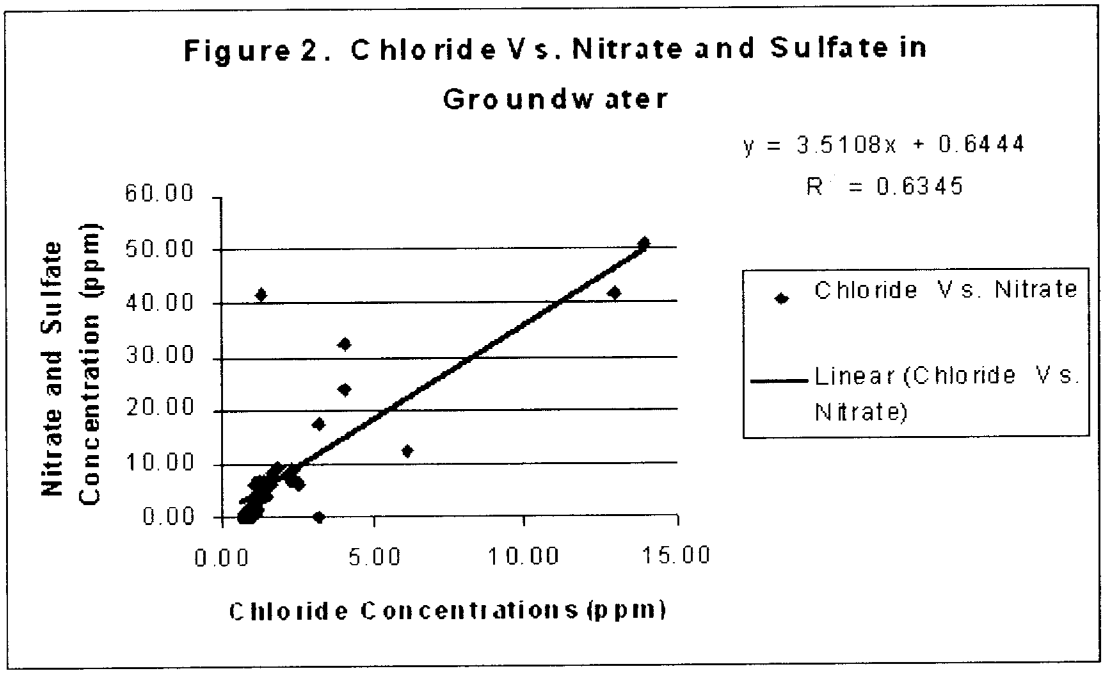


Figure CS-3

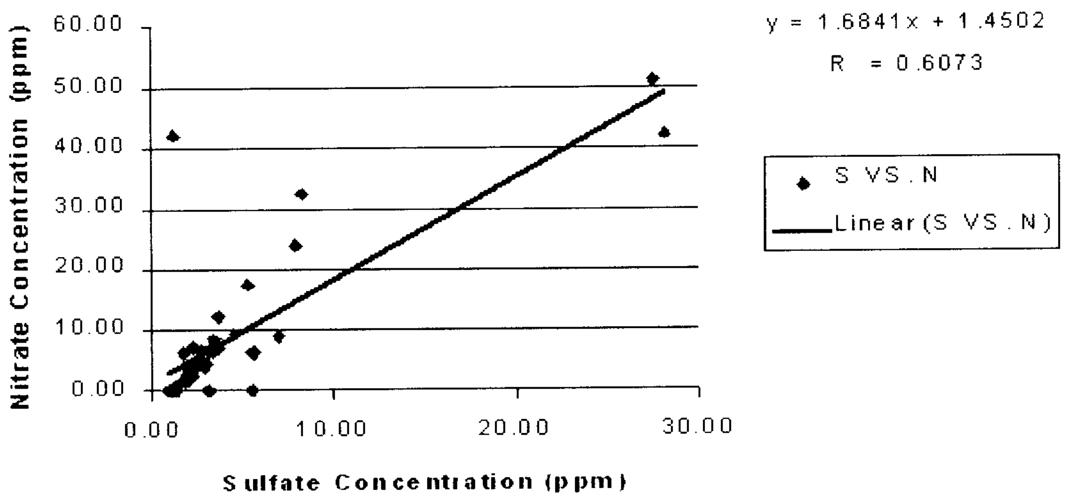


Figure 3. Sulfate VS. Nitrate in Groundwater

Concentration values were calibrated using a mass balance equation in the general form;

Accumulation = In – Out,

Accumulation = 0 with In = Out, therefore

$$CsQs = Csin\,Qsin + Cgw\,Qgw \qquad eq\ (7)$$

Where;
Cs = mass concentration of species in out flow;
Qs = volumetric flow rate of stream out flow;
$Csin$ = mass concentration of species present within stream inflow;
$Qsin$ = Volumetric flow rate of stream inflow;
Cgw = mass concentration of species present in average ground water; and
Qgw = volumetric flow rate of ground water into stream.

With the final equation as:

$$Qgw/Qs = (Cs-Csin)/(Cgw-Cs) \qquad eq\ (8)$$

Cgw was taken to be the average concentration of all of the ground water samples. The mass balance was done from one point upstream to the next point downstream, with $Csin$ the concentration of the species at the upstream point, and Cs the concentration at the downstream point. The results of the preliminary mass balance are shown in **Figures CS-4 and CS-5.** Since the mass balance was done from point to point the x axis shows the position of the upstream point for each calculation with the Qgw/Qs as the y axis values. The mass balance was done for each sample day from point to point. **Figures CS-4 and CS-5** show sample results from the mass balance using date specific results. A Qgw/Qs ratio of 1 would indicate equal amounts of ground water and surface water, a ratio of larger than 1 would indicate more ground water than surface water, and a ratio of less than one would indicate more surface water than ground water. The graphs in **Figures CS-4 and CS-5** show the ratio of ground water to surface water is well below 1, indicating substantially more surface water than ground water. The **Figures CS-4 and CS-5** clearly support previous conclusions that there is little ground water input into the Walla Walla River in the upper reaches of the river, down to Tumalum Bridge (M-8).

Figure CS-6 shows the mass balance done on all samples collected to date. Sites with more than one sample collected were averaged and the value used for mass balance calculations. Due to averaging, the mass balance data shows slightly more variability than in **Figures CS-4 and CS-5**. However, the graph still indicates that there is little to no ground water input from the confluence of the North and South Forks down to Tumalum Bridge (M-8).

Figure CS-4

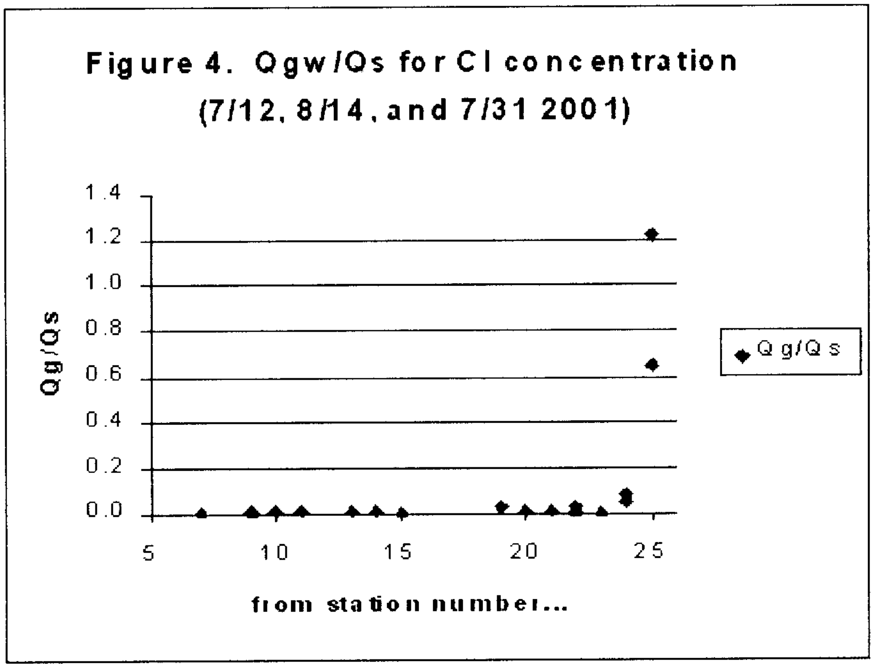


Figure CS-5

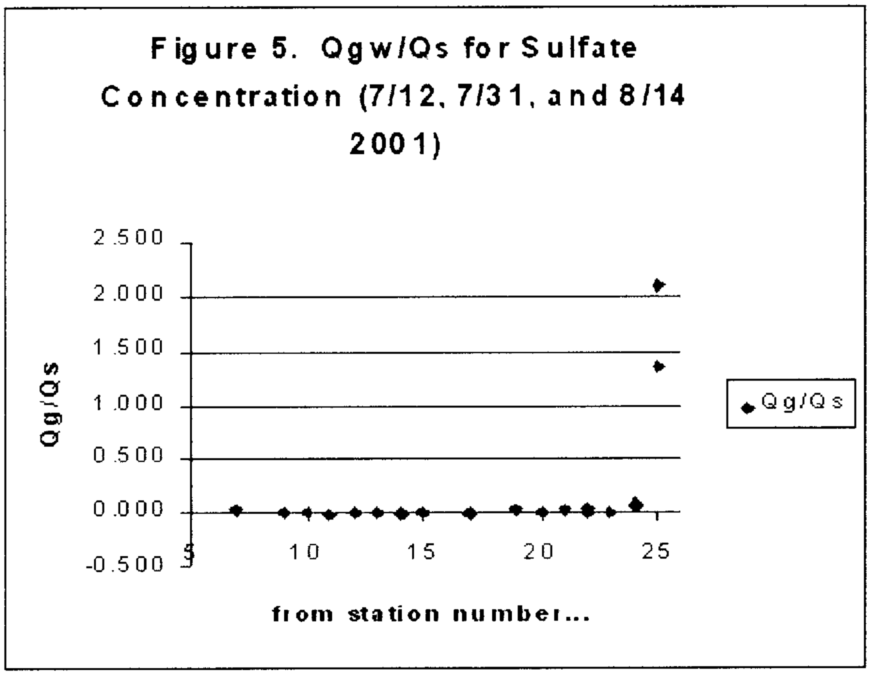
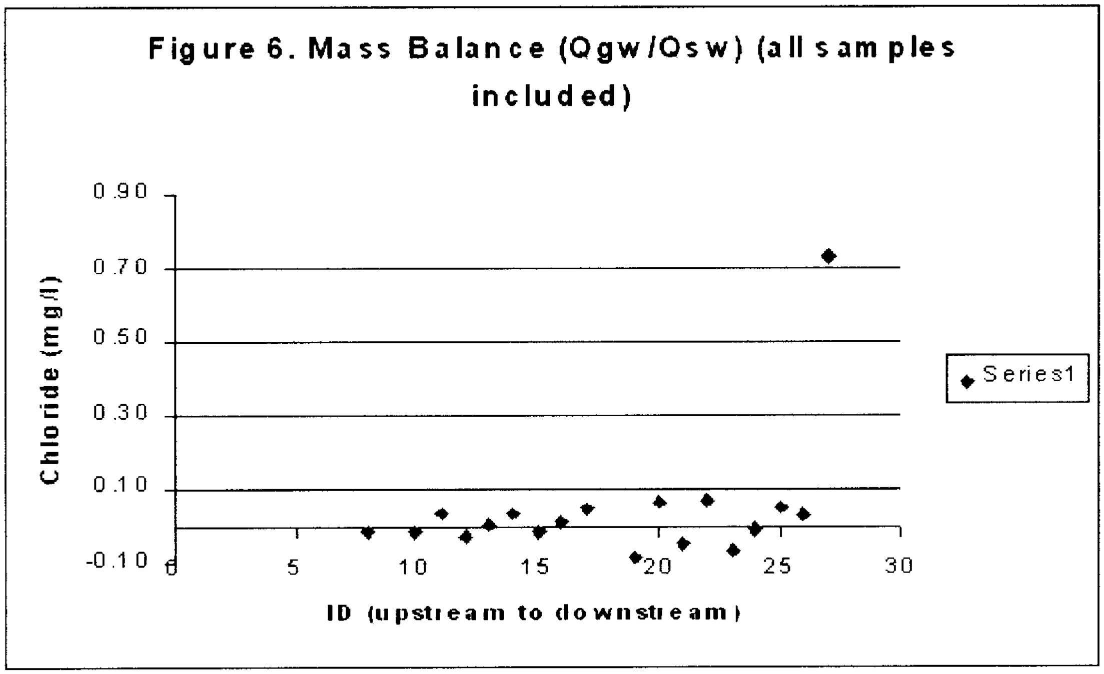


Figure CS-6



During 2001, three sites were sampled in the Tumalum to Stateline river section. The concentration at M-9 was very similar, and in some cases identical to concentrations just upstream at Tumalum Bridge. It is interesting to note that the samples taken in October indicate higher concentrations at M-9 than what had previously been recorded, perhaps indicating that ground water levels had increased to a point where ground water was starting to feed the stream from that point. The concentrations anions at the two sites farther downstream (Peppers Bridge, and M-10) were substantially higher than the concentrations at sites farther upstream. On **Figures CS-4 and CS-5** these two sites are indicated by site numbers 24 and 25. The high concentrations of anions at these sites is clear evidence that ground water is entering the Walla Walla River at or near these points.

It is important to realize that water that is withdrawn from the river and returned in a relatively short period of time would likely not change in chemical content. Water that is returned after a longer period of time (i.e. aquifer water) will have a greater chemical content due to prolonged exposure to subsurface rocks and minerals, and subsequent weathering of these minerals releasing chemicals into the water. It is also important to realize that river water can enter the streambed for short distances and return back to river flow. This mixing is referred to as hyporheic exchange. This short-term exposure of river water to subsurface rocks is not likely to change the chemical content of the river water significantly.

Summary

This is in bulleted from until after the TAC review.

Bibliography

- A bibliography of all known surface and ground water publications was compiled. Citations included in body of the document were marked accordingly.

Geologic Mapping

- Map showing the Thickness of the Shallow Aquifer was generated including a breakdown of fines and gravel deposits.
- Maps showing the elevation contours for six shallow aquifer geologic units were generated including:
    - Flood Loess Unit
    - Young Alluvial Unit
    - Old Gravel Unit
    - Old Clay Unit
    - Top of Basalt

Water Table Mapping

- Using data from 21 monitoring wells, two-potentiometric surface (water table) maps were generated for the study area. The maps depict the measured high and low for the water table from samples collected during 2001 and 2002.
- Map showing the *Depth to water* was generated to better depict the opportunities for surface-ground water interactions.

Seepage: Walla Walla River

- Seepage measurements were collected and analyzed for two years (2000/2001) for the study area of the Walla Walla River. The study area was broken into three separate sections: Upper and Lower Levee, and the Tumalum to Stateline. Estimates of ground water gains and losses were calculated for each segment in the three sections. Specific attention was placed on the Lower Levee section where historical gravel mining and a USFWS/Irrigation district agreement were present. Generally, the Upper Levee section showed slight gains and losses, but more information is required to validate. The Lower Levee section showed mainly channel bed losses with the gravel mining area demonstrating the highest rate. The Tumalum to Stateline area was more difficult to assess, but generally appears to be an area of ground water gains.

Vertical Hydraulic Gradient

- Using Mini-piezometers to measure the vertical hydraulic gradient measurements were made in all three sections of the Walla Walla Rive Study area. Measurements compared well with gain/loss estimates made in the seepage analysis.

Horizontal Hydraulic Gradient

- River to well elevation comparisons and hydraulic gradients were measured and analyzed for the area with the highest channel bed losses (Gravel Mining Area of Lower Levee). Analysis confirmed that this portion of the Walla Wall River losses water through the water year.

Chemical Signature

- Water samples taken at wells and river locations through out the Oregon portion of the Walla Walla River. Samples were analyzed using chemical signature techniques. Results correspond well with results from the other types of analysis showing the study are of the Walla Walla River tends to be loss water.

Recommendations

Geological Mapping Recommendations:

For future studies we recommend that the following work be considered:

1. Expand the map area to cover the entire Walla Walla Valley floor from the base of the Blue Mountains and Horse Heaven Hills to the Washington/Oregon border. A similar mapping effort should be conducted in the Washington portion of the aquifer.

2. For this expanded area, or for the area mapped this year, include additional well logs in the analysis to better define the thickness and extent of the young alluvial gravel unit.

3. Enlist landowner support in obtaining drill cuttings from new wells and/or deepened wells to improve the analysis and interpretation of aquifer hydrostratigraphy host-rock hydraulic properties.

4. Construct additional maps illustrating current types of well use in various layers of the suprabasalt (shallow) aquifer system.

5. Begin building a "catalog" of data that describes the shallow aquifer hydraulic properties. This catalog may be useful in future shallow aquifer mapping and modeling efforts. Examples of these types of data include well capacity, pump test information, water levels, and water quality.

6. Compare spring flow rate and water quality data to information collected from wells to interpret possible relationships between valley springs and shallow wells.

Water Table Map Recommendations

1. Anecdotal evidence exists that there may be localized areas of water table confinement occurring in the shallow aquifer system. These areas may act to raise or lower the potentiometric surface which would alter the maps presented here. Identification of these locations would help to refine these water table maps.

2. Wellhead elevations are based on a USGS DEM database values. In future efforts, wellhead locations should be refined using better GPS or surveying equipment to increase the accuracy of these maps.

3. Identifying and monitoring additional "open" or unused wells would greatly enhance this static level database used to create water table maps. Adding continuous level recorders would serve to improve the seasonal and even daily changes in shallow aquifer water levels.

4. The depth-to-water map should be provided to local drillers and the Umatilla Wells Inspector so that they could use their experiences to verify the estimates of water table levels. Their input would be helpful refining this map relative to the static levels in new wells.

Seepage Recommendations:

1. A quantitative assessment of all diversion along the M-3 to M-4 section of the Walla Walla River is need to verify the 3-4 cfs noted in 2000 and 2001. If the diversions and

consequential loss was proven accurate, the Bridge and Fish ladder structures at Nursery Bridge may be an area to investigate further as a possible site for channel bed losses.
2. Higher flow measurements at Grove School (M-1a), Nursery (M-4), Tumalum (M-8) Bridges would provide better data with which to assess daily and seasonal changes in the gains/losses through the levee section.
3. Continuous flow recorders at Grove School (M-1a), Nursery (M-4), Tumalum (M-8) Bridges would provide better data with which to assess daily and seasonal surface ground water interactions in this section of river.
4. Conduct seepage runs of the Walla Walla River where all known diversion and tributaries are measured along with measurements made of the mainstem flow. This would help to quantify the diversion and tributary contributions relative to mainstem flow.

Vertical Hydraulic Gradient Recommendations

1. Duplicate mini-piezometers should be added to test for Quality Assurance and Quality control for each site.
2. Temperature and specific conductance should be collected inside and outside the mini-piezometers to verify ground water presence.
3. Mini-piezometers should be developed before each measurement is taken.
4. River channel widths and flow should be measured as close to the mini-piezometers as possible for accurate assessment of conductivity.
5. Distances between mini-piezometers should field verified.

Chemical Signature Recommendations

Further sampling and analysis will be necessary to confirm these preliminary conclusions.

1. The substantial increase in concentration as the Walla Walla River continues downstream should be studied more closely by sampling water concentrations at closer intervals along the entire length of the Walla Walla River.
2. Chemical signature samples should be taken throughout the year in order to understand the annual trends.
3. Isotope analysis on the stream and aquifer to determine residence times within the basin. Isotope analysis can also be a useful tool to determine mixture source solutions.

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Appendices

Appendix A

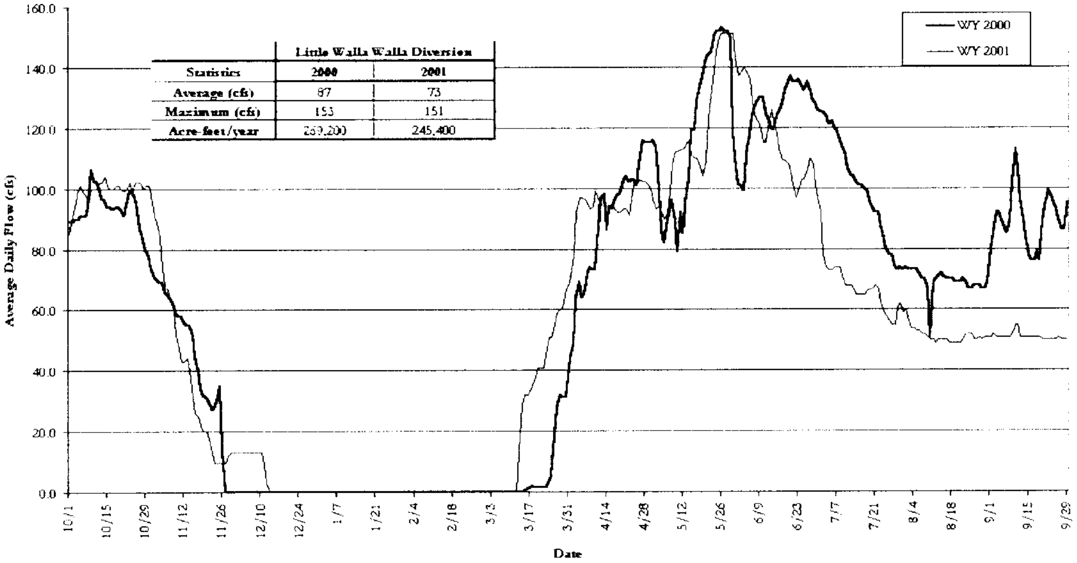
Geological Section Along Walla Walla River Transects

Geological Well Data Used for Mapping

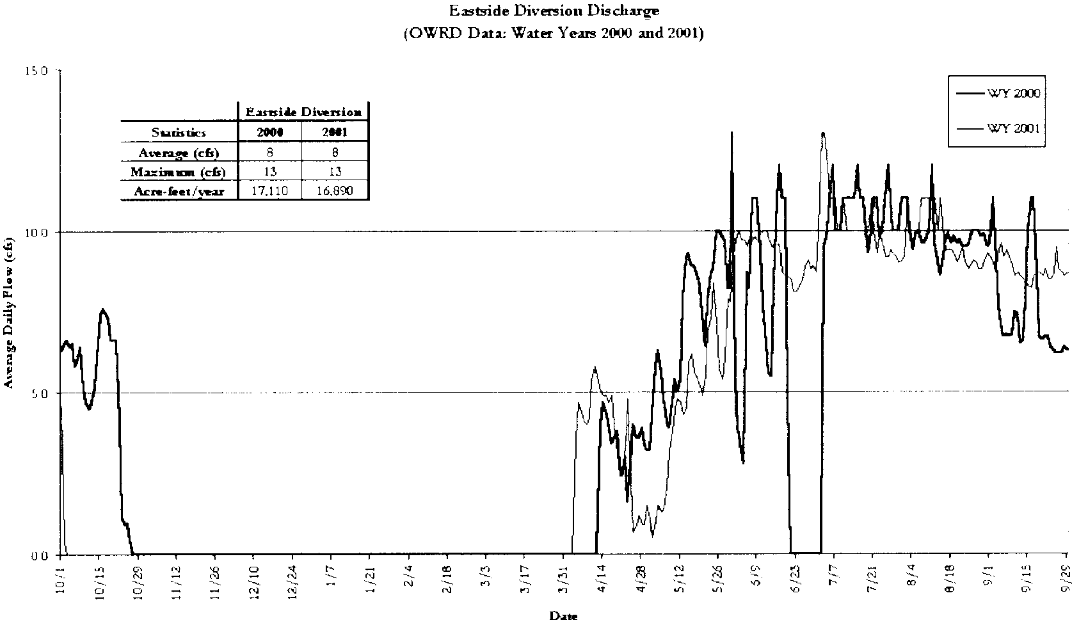
Appendix B

Seepage Data: Diversion Graphs

Little Walla Walla Diversion Discharge
(OWRD Data: Water Years 2000 and 2001)



	Little Walla Walla Diversion	
Statistics	**2000**	**2001**
Average (cfs)	87	73
Maximum (cfs)	153	151
Acre-feet/year	259,200	245,400



Appendix C

Appendix D

Written by Starr Metcalf, Oregon State University.

Chemical Signature Background Research for Walla Walla Study:

Research was done before samples were run to determine appropriate naturally occurring tracers in this system. The Walla Walla River is part of the Columbia Plateau Regional Aquifer system, for this reason previous water studies conducted in the Columbia Plateau were examined for naturally occurring anions and cations. According to Steinkampf and Hearn (1996) the dominant ground-water cations and anions of the Columbia Plateau are calcium (Ca), magnesium (Mg), sodium (Na), carbonate (CO3), silicon (Si, as SiO2), sulfate (SO4), and chloride (Cl). There is a general trend for concentrations of these species (besides divalent cations) to increase with residence time (Scanlon et al, 2001) (Steinkampf and Hearn, 1996). Steinkampf (1989) also noted that the lines of equal concentration values for the major anionic and monovalent cationic constituents roughly parallel potentiometric contours for each of the basalt units. Concentrations tend to increase down gradient in a flow system and with depth into the ground. The concentrations are also dependent on water-rock interactions, and land use.

In selected studies of neighboring water resource areas, Upper Deschutes,OR, Umatilla County, OR, Toutle and Lewis Rivers, Washington, and Coeur d'Alene Lake, and ground-water in ID, anion concentrations were also examined. In the Upper Deschutes Basin a study done by Caldwell (1998) lists concentrations of Cl, F, SO4, and SiO2 from selected wells, surface water, and springs (Table 1). The geology of the Upper Deschutes Basin indicates the presence of volcanic rocks and ash, primarily Prineville basalt and basaltic andesite lavas (Caldwell 1998). Caldwell (1998) notes that in a study done by Newcomb (1972) of the ground-water of the Columbia River basalt group (of which Prineville basalt is a member) similar relative proportions of major ions, but with variations in total concentration were found. In a report by Woods and Beckwith (1997) on Coeur d'Alene Lake, Idaho, the major anions present were Cl, 0.1 to 0.8 mg/l, HCO3, 22 to 40, and SO4, 1 to 6.6. The geology of the Coeur d'Alene Lake area is similar to that of the Columbia Plateau in that the soils were formed from volcanic ash and loess, which overlies granite and basalt (Woods and Beckwith, 1997). Selected results of ground-water studies done in Idaho by Parliman (1987) are shown in Table 6. Selected results of the dissolved constituents in the Toutle, and Lewis Rivers, WA are shown in Table 8 (Dethier, 1982). The Toutle and Lewis Rivers were chosen out of 23 western Washington rivers due to similarities in geology between the Columbia Plateau and the volcanic Cascades, where the rivers originate.

The mean Cl concentration reported by Laird et al (1986) from snow chemistry data collected from 27 sites in the Cascade Range from February to March 1983, was 0.3 mg/l (Table 5). This mean value is reasonable to assume for Cl input from rain and snow. Stream water data from the Toutle River in WA (Dethier, 1982) shows concentrations Cl to be 3.09 mg/l at mean annual discharge. Increases in Cl concentration from stream-water to ground-water probably occur due to dissolution of basalt and agricultural chemical and fertilizers. Steinkampf and Hearn (1996) postulated that although the Cl concentration in precipitation is small, the semi-arid climate probably causes larger concentrations of Cl in soil due to evaporation. This could be important in determining the chemical signature of Cl in stream-water and ground-water. Further data from completed research indicates that water from the gravel-aquifer near Milton-Freewater contained an average of 5 ppm (5 mg/l) Cl, with individual samples ranging from 3 to 23 ppm, and that water from the basalt aquifer contained an average of 5 ppm, and a range from 1 to 14 ppm (Newcomb, 1965). Selected anion concentrations for The Columbia Plateau can be found in Tables 2, 3, 6, 9, and 10.

Discrete Si in samples from a depth shallower than about 1,475 ft. were not observed by Hearn et al (1985), however other silica phases were observed. Silica is commonly associated with clays, Fe oxyhydroxides, and is present in quartz, cristobalite, tridymite, and opal CT (Benson and Teague, 1982). Quartz and cristobalite are found throughout the Columbia Plateau. Ground-water chemistry data from several sources (Bortleson and Cox, 1986(Table 2)) (Wagner and Lane, 1994(Table 4)) (Steinkampf 1986 (Table 3)) show that silica, as SiO, occurs frequently and in substantial amounts (exceeding 70 mg/l) within the Columbia Plateau. Steinkampf and Hearn (1996) suggest that silica concentrations were dependent upon solubility of different silica phases, which vary with temperature. Analysis of basalt rock from the Columbia Plateau shows the composition to be largely SiO2 (Steinkampf and Hearn, 1996) (Figure 2). When using PCA analysis Christophersen and Hooper (1992) caution against the use of silica as a chemical indicator due to its reactive nature (i.e. non-conservative behavior).

In selected studies of neighboring water resource areas, Upper Deschutes, Oregon, Umatilla County, Oregon, Toutle and Lewis Rivers, Washington, and Coeur d'Alene Lake, and ground-water in ID, anion concentrations were also examined. In the Upper Deschutes Basin a study done by Caldwell (1998) lists concentrations of Cl, F, SO4, and SiO2 from selected wells, surface water, and springs (Table 1). The geology of the Upper Deschutes Basin indicates the presence of volcanic rocks and ash, primarily Prineville basalt and basaltic andesite lavas (Caldwell 1998). Caldwell (1998) notes that in a study done by Newcomb (1972) of the ground-water of the Columbia River basalt group (of which Prineville basalt is a member) similar relative proportions of major ions, but with variations in total concentration were found. In a report by Woods and Beckwith (1997) on Coeur d'Alene Lake, Idaho, the major anions present were Cl, 0.1 to 0.8 mg/l, HCO3, 22 to 40, and SO4, 1 to 6.6. The geology of the Coeur d'Alene Lake area is similar to that of the Columbia Plateau in that the soils were formed from volcanic ash and loess, which overlies granite and basalt (Woods and Beckwith, 1997). Selected results of ground-water studies done in Idaho by Parliman (1987) are shown in Table 6. Selected results of the dissolved constituents in the Toutle, and Lewis Rivers, WA are shown in Table 8 (Dethier, 1982). The Toutle and Lewis Rivers were chosen out of 23 western Washington rivers due to similarities in geology between the Columbia Plateau and the volcanic Cascades, where the rivers originate.

Table 1. The maximum followed by the minimum values for selected anions in mg/l from Caldwell (1998) from sites in the Upper Deschutes River Basin.

	Cl	F	SO4	SiO2
Well Water	26 – 0.9	1.1 – 0.1	56 – 0.3	71 – 26
Spring Water	3.3 – 0.3	0.1	3.7 – 0.3	40 – 29
Surface Water	11 – 0.9	0.5 – 0.1	25 – 0.3	49 – 17

Table 2. The maximum followed by the minimum values for selected anions in mg/l from Bortleson and Cox (1986) from sites in the Columbia Plateau.

Ground-Water From:	Cl	F	SO4	SiO2
Saddle Mountain Basalt	55 – 19	1.5 – 0.3	150 – 0.2	62 – 41
Wanapum Basalt	74 – 1.1	2 – 0.2	92 – 5	58 – 38
Grande Ronde Basalt	20 – 0.2	4.1 – 0.3	35 – 5	110 – 50
Max – Min total	74 – 0.02	4.1 – 0.2	150 – 0.2	110 – 38

Table 3. The maximum followed by the minimum values for selected anions in mg/l from Steinkampf (1986) from sites in the Columbia Plateau.

Ground-Water From:	Cl	F	SO4	SiO2
Saddle Mountain Basalt	130 – 1.3	2.9 – 0.2	490 – 0.2	72 – 36
Wanapum Basalt	300 – 7	3.4 – 0.1	290 – 0.2	100 – 10
Grande Ronde Basalt	45 – 0.5	4.9 – 0.1	100 – 0.2	110 – 29
Max-Min Total	300 – 0.5	4.9 – 0.1	490 – 0.2	110 – 10

Table 4. The maximum followed by the minimum values for selected anions in mg/l from Wagner and Lane (1994) from sites in Umatilla County.

	Cl	F	SO4	SiO2

Ground-Water	44 – 3.8	3.4 – 0.3	93 – 1.3	89 - 55

Table 5. The maximum followed by the minimum values for selected anions in mg/l from Laird et al (1986) from sites in the Cascades.

	Cl	F	SO4	SiO2
Snow-Chemistry	1 – 0.1	0.1 – 0.01	0.32 – 0.14	Not reported

Table 6. The maximum followed by the minimum values for selected anions in mg/l from Steinkampf and Hearn (1996) from sites in the Columbia Plateau.

Ground-Water From:	Cl	F	SO4	SiO2
Saddle Mountain Basalt	120 – 3.4	1.4 – 0.2	200 – 0.6	71 – 36
Wanapum Basalt	300 – 1.1	3.4 – 0.1	290 – 0.3	72 – 5.8
Grande Ronde Basalt	45 – 0.8	4.9 – 0.1	96 – 0.2	110 – 29
Oregon Area Samples	20 – 0.8	1.9 – 0.1	54 – 0.6	89 – 11

Table 7. The maximum values for selected constituents in mg/l from Parliman (1987) from sites in Idaho.

Principal Aquifers (non-thermal):	Cl	F	SO4	SiO2
Valley Fill	3.9	11	1.1	Not reported
Basalt	830	7	420	Not reported
Sedimentary and Volcanic	430	17	1400	Not reported

Table 8. The average concentrations of selected dissolved constituents in mg/l from Dethier (1982) for the Toutle, and Lewis Rivers in Washington.

River	Cl	F	SO4	SiO2
Toutle	3.09	Not reported	2.76	15.0
Lewis	1.80	Not reported	2.27	14.3

Table 9. The mean values for selected anions in mg/l from Steinkampf and Hearn (1996) from sites in the Columbia Plateau.

Ground-Water From:	Cl	F	SO4	SiO2
Saddle Mountain Basalt	31.6	0.5	76.1	55.1
Wanapum Basalt	19.5	0.43	32.8	46.5
Grande Ronde Basalt	6.9	0.69	14.0	57.2

Table 10. The mean values for selected anions in mg/l from Steinkampf (1986) from sites in the Columbia Plateau.

Ground-Water From:	Cl	F	SO4	SiO2
Saddle Mountain Basalt	24.3	0.58	53	55.6
Wanapum Basalt	17.2	0.5	29.3	48.3
Grande Ronde Basalt	7.1	0.6	21.8	21.8

The results of this research suggested that chloride, and sulfate would make suitable naturally occurring tracers in the Walla Walla River system. Surface waters in the Walla Walla River coming from the headwaters are presumed to be primarily of precipitation origin (i.e. snowmelt and rain). Therefore the concentrations of anions in the river water should be substantially lower than the concentrations in the ground water. This difference in concentrations will make it apparent where ground water recharge on the river is prevalent, as well as where ground water recharge in the river is not present.

Appendix D

Channel Bed Gains/Losses Data

Appendix E