

**Ground-Water Quality Characterization
and Nitrate Investigation
of the Glade Creek Watershed**

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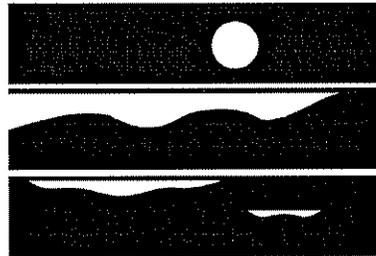
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Ground-Water Quality Characterization and Nitrate Investigation of the Glade Creek Watershed

by
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Environmental Investigations and Laboratory Services Program
Olympia, Washington 98504-7710

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Abstract

Previous studies in the Glade Creek Watershed indicated that surface water, and possibly ground water, might be contaminated with nitrate. To test this possibility, eleven domestic and irrigation wells, one spring, and three surface water sites were sampled in 1995. These data were also used to characterize the ground-water and surface-water quality in the Glade Creek Watershed.

The Glade Creek Watershed covers 413 square miles of open, arid land in southeast Washington. Crop production is the basis of the economy. Dry-land wheat is the primary agricultural commodity, but irrigated areas for food crops are expanding rapidly.

All sampling stations were sampled in May 1995 and analyzed for nitrite+nitrate, general chemistry, and primary anion/cation constituents. All wells in which nitrate was detected, as well as the spring and the sampling station at the mouth of Glade Creek, were sampled a second time in September 1995.

Based on the results, nitrate contamination is widespread in the two uppermost aquifers (Alluvial Aquifer and Saddle Mountains Basalt Aquifer) and in Glade Creek and its tributaries. Nitrate was detected in all sampling stations for the above water sources. Nitrate concentrations range from less than one milligram per liter (mg/L) to as much as 70 mg/L, seven times the maximum contaminant level for drinking water. The only known significant source of nitrate contamination in the watershed is nitrogen-based fertilizers used in the irrigated areas.

Summary

There are distinct water-type differences between the Saddle Mountains Basalt Aquifer and the underlying Wanapum Basalt Aquifer in the Glade Creek Watershed. This water-type distinction could be a valuable tool to determine the source aquifer for a given well or to identify dual-completed wells (wells completed in both Saddle Mountains and Wanapum Aquifers).

Nitrate contamination is widespread in the Alluvial Aquifer and the Saddle Mountains Basalt Aquifer -- the two uppermost aquifers in the Glade Creek Watershed. It is also widespread in Glade Creek and its tributaries. Nitrate was detected in all sampling stations for the above water sources. Nitrate concentrations ranged from less than one milligram per liter (mg/L) to as much as 70 mg/L, seven times the maximum contaminant level for drinking water. Between May and September 1995, nitrate concentrations increased in all Alluvial and Saddle Mountains Basalt Aquifer wells and at the mouth of Glade Creek. These results indicate that, in spite of the considerable depth below land surface of much of the Saddle Mountains Aquifer, it is vulnerable to nitrate contamination.

Nitrate was not detected in the deeper Wanapum Basalt Aquifer wells. This indicates that the Mabton Interbed may act as a regional aquitard that protects the Wanapum Aquifer from contaminants from the overlying Saddle Mountains Aquifer. However, dual-completed wells in the watershed are a threat to the water quality of the Wanapum Aquifer. These wells provide a direct contaminant flow path to the underlying Wanapum Aquifer.

Results of this study indicate a strong correlation between crop irrigation and the presence of nitrate in the underlying Alluvial and Saddle Mountains Basalt Aquifers. In areas where little irrigation occurs, nitrate concentrations in the shallow aquifers are low. But in areas with intensive crop irrigation, nitrate concentrations are high.

The drinking-water MCL for nitrate was exceeded at all three surface-water sampling stations. Nitrate concentrations increase dramatically with distance traveled down stream. Although some of this contamination may be accounted for by direct application through center-pivot irrigation to the stream bed, ground-water discharge to the stream is the most likely source of nitrate contamination in Glade Creek.

Flow measurements at the mouth of Glade Creek show that the creek was flowing at 15.6 and 13.2 cfs in May and September 1995, respectively. However, previous investigators have reported little or no water in most reaches of Glade Creek during the summer months. The most likely source of the exceptionally high late-summer flow at the mouth of Glade Creek is ground-water recharge from imported Columbia River water which is applied via center-pivot irrigation along the stream bed and in the southern and eastern portions of the watershed.

Recommendations

Follow-up Study

- All Saddle Mountains Aquifer wells in the southeast part of the watershed should be sampled for nitrate to determine if the high nitrate levels in wells GC-22 and GC-69 are widespread over the region.
- Test well GC-22 for pesticides. If the extremely high nitrate levels in the well are caused by down-hole contamination from the wash operation at the surface, then it is likely that pesticides used in the vicinity of the wellhead are being carried to the aquifer as well.
- If well GC-22 is re-sampled, an investigation should be conducted to determine the specific uses of the water, and the chemicals used at the site. If possible, the wash water should be sampled and analyzed for nitrate, pesticides, general chemistry, and major anions and cations.
- Identify the sources of flow in the lower end of Glade Creek from the mouth up to the intersection with East Branch of Glade Creek. This should be done in the autumn because, historically, the creek has been intermittent. Any springs or inflows should be sampled and analyzed for the same chemical constituents used in this study or, at a minimum, nitrate and basic field parameters.
- Re-sample the wells and Glade Creek sampling stations used in this study in three to five years to see if there is a trend in nitrate concentrations.
- When re-sampling, carefully re-examine all sampling sites, particularly GC-95, to identify possible sources of ground-water contamination.
- Determine water and fertilizer application rates, as well as types of fertilizers used in various parts of the watershed. Relate this information to crop types, time of year, source of irrigation water, and types of irrigation (center pivot, drip, etc.).

Public Health and Aquifer Protection

- A public-health alert should be considered by the county and state health departments to notify residents in the Glade Creek Watershed, particularly those living along the eastern and southern sides of the watershed, of high nitrate levels in ground water and the health risk involved.

- All drinking water supply wells in the watershed should be tested for nitrate. The residents should be informed of the results and advised of potential health risks.
- Since the nitrate contamination is most likely caused by extensive irrigation and agricultural practices in the watershed, a cooperative program should be developed to work with and help the irrigators achieve agronomic water and fertilizer application rates. This program could involve such groups as irrigators, Washington State University (WSU), County Extension Service, Benton Conservation District (BCD), USDA Farm Services Agency, and possibly Ecology.
- Wells which are dual-completed in both the Saddle Mountains Basalt Aquifer (SDLM) and underlying Wanapum Basalt Aquifer (WNPM) are a serious threat to the water quality of Wanapum Aquifer. Some dual-completed wells should be sampled and analyzed for nitrate and the primary anions and cations to determine if the WNPM is being contaminated at these well sites. Nearby WNPM wells should also be sampled for nitrate.
- Ecology's Shorelands/Water Resources and Water Quality Programs should coordinate to identify dual-completed wells in the area and to work with well owners to eliminate the contamination threat from these wells.
- Although fluoride concentrations exceeding the maximum contaminant level (MCL) for drinking water of 4 mg/L are known to occur in the basalt aquifers of the Columbia River Basalt Group, no concentrations above the MCL have been reported in the Glade Creek Watershed. None the less, it would be prudent to test for fluoride whenever new basalt wells are sampled in the area.

Acknowledgments

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Introduction

Unusually high concentrations of nitrite+nitrate as nitrogen ($\text{NO}_2+\text{NO}_3\text{-N}$) in Glade Creek water samples (Davis, 1993) indicate that agricultural practices in the watershed may be significantly affecting surface-water quality. High concentrations of nitrate as N in some wells within the watershed (Steinkampf & others, 1985; Turney, 1986) indicate that agricultural practices may be contaminating ground water as well.

Crop production is the basis of the economy in the Glade Creek Watershed. Dry-land wheat occupies the greatest crop area in the watershed, but irrigated lands have increased dramatically since the early 1970's (Packard & Others, 1994). In 1990, about 97,000 acres were irrigated in the Horse Heaven Hills, mostly on the eastern side of the Glade Creek Watershed (Watson & others, 1991). In 1982, water was applied to irrigated lands in the Horse Heaven Hills at an average rate of approximately 2.5 feet per acre per year (Packard & others, 1994). If this application rate was true for 1990, approximately 243,000 acre-feet of irrigation water was applied.

A variety of nitrogen-based fertilizers are applied to the fields of the Horse Heaven Hills. Unfortunately, information about types and quantities applied is difficult to obtain. Likewise, an unknown variety and quantity of pesticides are applied to these fields. The irrigation water applied can provide a transport mechanism to carry the fertilizers and pesticides to the ground-water system and local streams.

Based on the above information, Ecology's Water Quality Program identified the need for a study of the ground-water quality in the Glade Creek Watershed.

Goals for the study are:

1. Characterize ground-water and surface-water quality in the watershed and update and expand historic information.

- Investigate water-quality characteristics of each of the three main aquifers. Sample five wells (GC-16 through GC-29) used by Turney (1986) to obtain data for comparison to the water-quality data in that report. Add seven sampling sites (GC-62 through GC-96S) to enhance the water-quality characterization in the watershed.
- Investigate water-quality characteristics of Glade Creek and its tributaries. Sample the mouth of Glade Creek to obtain data for comparison to the data collected by Davis, 1993. Add two up-stream surface-water sampling stations to enhance the surface-water characterization.

2. Determine if the Alluvial Aquifer, Saddle Mountains Basalt Aquifer, or Wanapum Basalt Aquifer is contaminated with nitrate.

- The Alluvial Aquifer is the shallowest aquifer in the watershed and the most vulnerable to contamination. Although this is a relatively minor, discontinuous aquifer, it provides domestic water for some residents. Therefore, nitrate contamination of the aquifer could be a significant threat to human health.
- The Saddle Mountains Basalt Aquifer underlies the Alluvial Aquifer and is the shallowest basalt aquifer. It is a major source of both irrigation and domestic water in the watershed. Nitrate contamination of this aquifer could pose a major threat to potable water supplies in the Horse Heaven Hills.
- The Wanapum Basalt Aquifer underlies the Saddle Mountains Basalt Aquifer and is a major source of irrigation water. Wells completed in this aquifer are typically too deep and costly to be developed for domestic supplies.

3. If nitrate contamination is confirmed in any aquifers in the watershed...

- Conduct follow-up sampling in the autumn of 1995 to determine if nitrate detections are repeatable, then compare spring and autumn concentrations.
- Investigate the mechanism for nitrate transport to the aquifer. Determine if nitrate is being transported to the aquifer by natural surface-to-ground-water flow paths, or if the contamination is site-specific and the result of poor well construction.

Background

Setting

The Glade Creek Watershed covers an area of about 413 square miles (264,320 acres) in southeastern Washington. The majority of the watershed, including the lower half of the main branch of Glade Creek, as well as the eastern tributaries of Moore Canyon, East Branch Glade Creek, and Carter Canyon, lies in western Benton County. Glade Creek's main branch and Coyote Canyon extend across the northeast corner of Klickitat County, into the southeast portion of Yakima County, and, ultimately, to the creek's headwaters on the high, open plains about four miles northeast of Bickleton, Washington at an elevation of about 3,300 feet above sea level (Figure 1).

The Glade Creek Watershed lies on a wide, open, treeless, gently south-sloping plateau known as the Horse Heaven Hills. The top of the watershed lies along the high, east-west-trending crest of the Horse Heaven Hills at elevations ranging from 3,560 feet at the western end of the ridge to 1,420 feet at the pass where Highway 221 crosses the ridge. The confluence of Glade Creek and East Branch Glade Creek lies at an elevation of 365 feet. The mouth of Glade Creek at the Columbia River is 266 feet above sea level (Figure 1).

Annual precipitation ranges from about 13 inches in the high elevation area northeast of Bickleton to 8 or 9 inches on the eastern side of the watershed. About 90 percent of the precipitation falls from November through April, much of it as snow. Less than 10 percent falls from July through September (Packard and others, 1994, p. 22).

Glade Creek and its tributaries are intermittent streams. Flow is usually confined to the precipitation and snow-melt period (Molenaar, 1982). Historical flow data have been obtained from six crest-stage gages on central Glade Creek and various tributaries, and at a discharge measurement site at the creek's mouth.

Dry-land wheat production is the major land use in the watershed. The principle ground-water use is for crop irrigation. Center-pivot irrigation systems are the most prevalent type, but numerous orchards and vineyards are being established using drip and other irrigation methods. Principle irrigated crops in 1990 included corn, potatoes, wheat, alfalfa, wine grapes, onions, grass seed, sugar beets, apples, and carrots (Watson & others, 1991, Table 3).

Irrigated acreage in the Horse Heaven Hills has increased dramatically over the past 20 years, from about 7,000 acres in 1970 to about 97,000 acres in 1990 (Packard & others, 1994; Watson & others, 1991). Both surface water imported from the Columbia River and ground water are used for this irrigation.

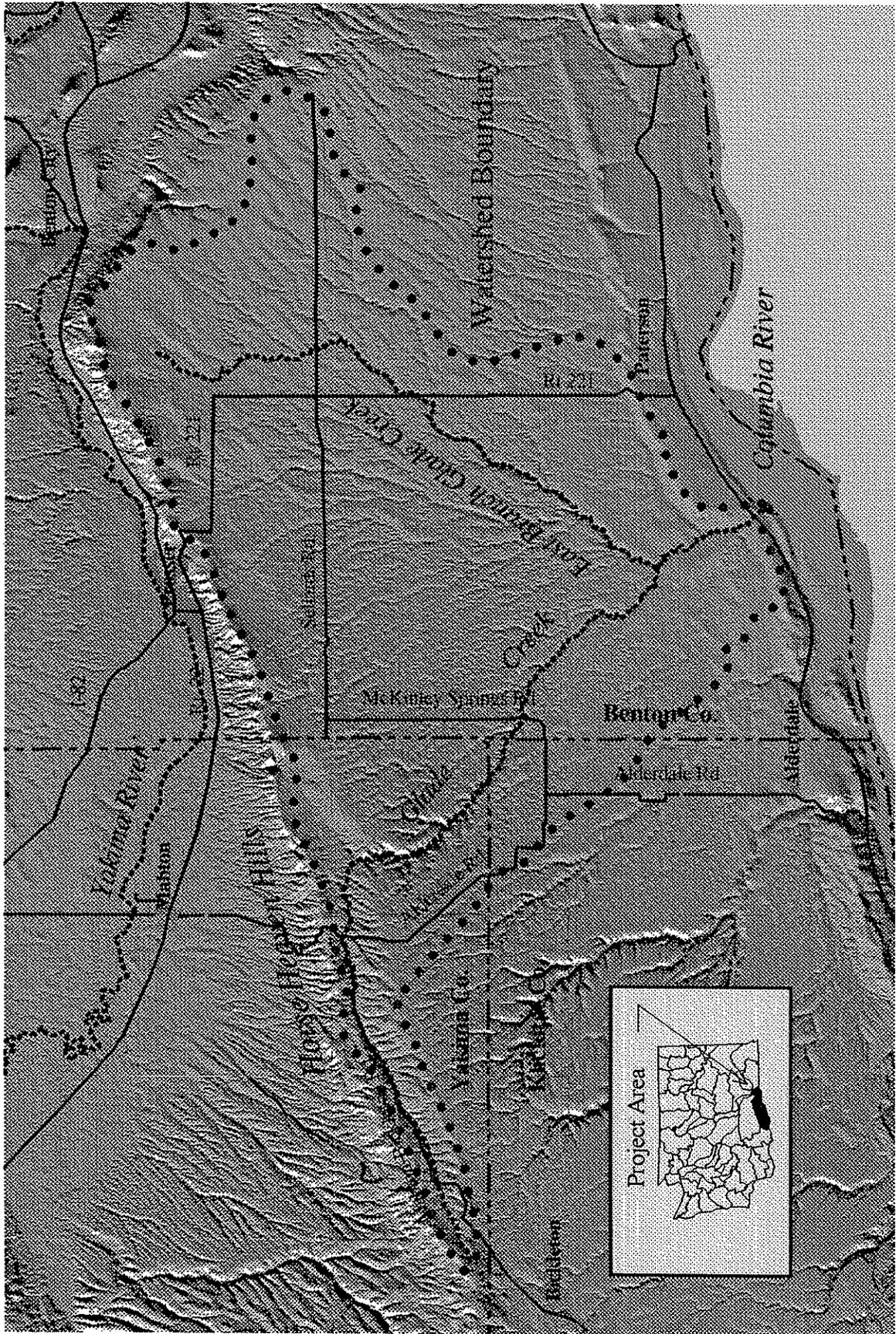


Fig 1 — Glade Creek Watershed and Vicinity

In 1982, about 160,000 acre-feet per year (ac-ft/yr) of imported surface water were used to irrigate about 70,000 acres, and 21,000 ac-ft/yr of ground water was used to irrigate 8,000 acres in the Horse Heaven Hills (Packard & others, 1994, p. 24).

Previous Investigations/Historic Data Review

The Horse Heaven Hills, or parts thereof, have been included in numerous studies of the geology, water resources, and water quality of the Columbia River Basalt Group (CRBG). Waring (1913) conducted a reconnaissance study of the geology and water resources of eastern Klickitat County. Schmincke (1967a&b) studied the stratigraphy and petrology of four major basalt flows of the CRBG, as well as basalt flow directions and paleocurrents of the interbedded sedimentary rocks. Swanson and others (1979) conducted reconnaissance geologic mapping of the CRBG in a large area which included the Glade Creek Watershed. Brown (1979 & 1980) defined the water resources of Klickitat County and studied the stratigraphy and ground-water hydrology of the Horse Heaven Hills. Molenaar (1982) conducted a characterization study of the geology, water resources, and ground- and surface-water quality of the Horse Heaven Hills.

Steinkampf and others (1985) and Turney (1986) identified high nitrogen levels in seven wells in the Horse Heaven Hills. Four wells met or exceeded Washington's (DOH, 1994) maximum contaminant level (MCL) for drinking water of 10 mg/L for nitrate as N ($\text{NO}_3\text{-N}$). Nitrate in three other wells was within the range of 4 to 6 mg/L -- levels that, although below the MCL, are cause for concern. Data from these two studies provide the historic ground-water quality data used in this investigation.

Davis (1993) found a nitrate concentration of 34.5 mg/L near the mouth of Glade Creek in May 1992. This concentration is over three times higher than the nitrate MCL and is among the highest ever recorded in Washington State surface water (Davis, 1993, p. 20).

The Benton-Franklin Health District (1993) conducted a reconnaissance ground-water sampling project in Benton and Franklin Counties. Samples were analyzed for nitrate, fluoride, and bacteria. Nitrate concentrations in the six wells sampled within the Glade Creek Watershed ranged from 0.7 mg/L to 3.3 mg/L, with an average of 1.93 mg/L.

Evans and Han (1995) working with irrigators in Benton County, Washington used computer simulation models to analyze water and fertilizer application through center-pivot irrigation systems and resultant crop growth. Their goal was to develop a tool to help growers improve on-farm water and nitrogen management practices and to reduce $\text{NO}_3\text{-N}$ leaching while maintaining maximum farm profitability. This work may be directly applicable to irrigation in the Glade Creek Watershed.

Hydrogeology

The Glade Creek Watershed is underlain by 5,000 feet or more of basaltic flows of Miocene age (Packard and others, 1994). These flows have been classified into three geologic formations. In descending order, these formations are the Saddle Mountains Basalt, Wanapum Basalt, and Grande Ronde Basalt. Each basalt formation is composed of numerous basalt flows forming complex layered units and many possibilities for fractured, water-bearing zones. Figure 3 shows the stratigraphic relationships of the geologic units including the sedimentary interbeds of the Ellensburg Formation and the approximate aquifer boundaries. The Saddle Mountains Basalt is exposed at the surface in many areas of the watershed, particularly along Glade Creek's main branch on the west side of the watershed.

Pleistocene and Holocene loess, alluvial, glaciofluvial, and lacustrine deposits overlie the basalt and range in thickness from less than five feet to about 200 feet (Packard and others, 1994). These overlying deposits tend to be thickest along topographically and structurally low areas, and thinnest along the topographic crest of the Horse Heaven Hills and in the vicinity of the upper reaches of Glade Creek. The Alluvial Aquifer is contained within these deposits, but water-bearing units occur sporadically, and production is marginal in most areas. Presumably, the best water production from the Alluvial Aquifer is from relatively coarse-grained alluvial and glaciofluvial deposits.

Structurally, the Glade Creek Watershed is bordered on the north by the west and east segments of the Horse Heaven Hills Anticline ("A" and "B", respectively, on Figure 2) which roughly parallels the Horse Heaven Hills topographic crest. This is an asymmetric anticline in which the north limb dips steeply into the Yakima River valley, while the south limb dips gently toward the Columbia River. The topography of the basin strongly reflects this overall structural control.

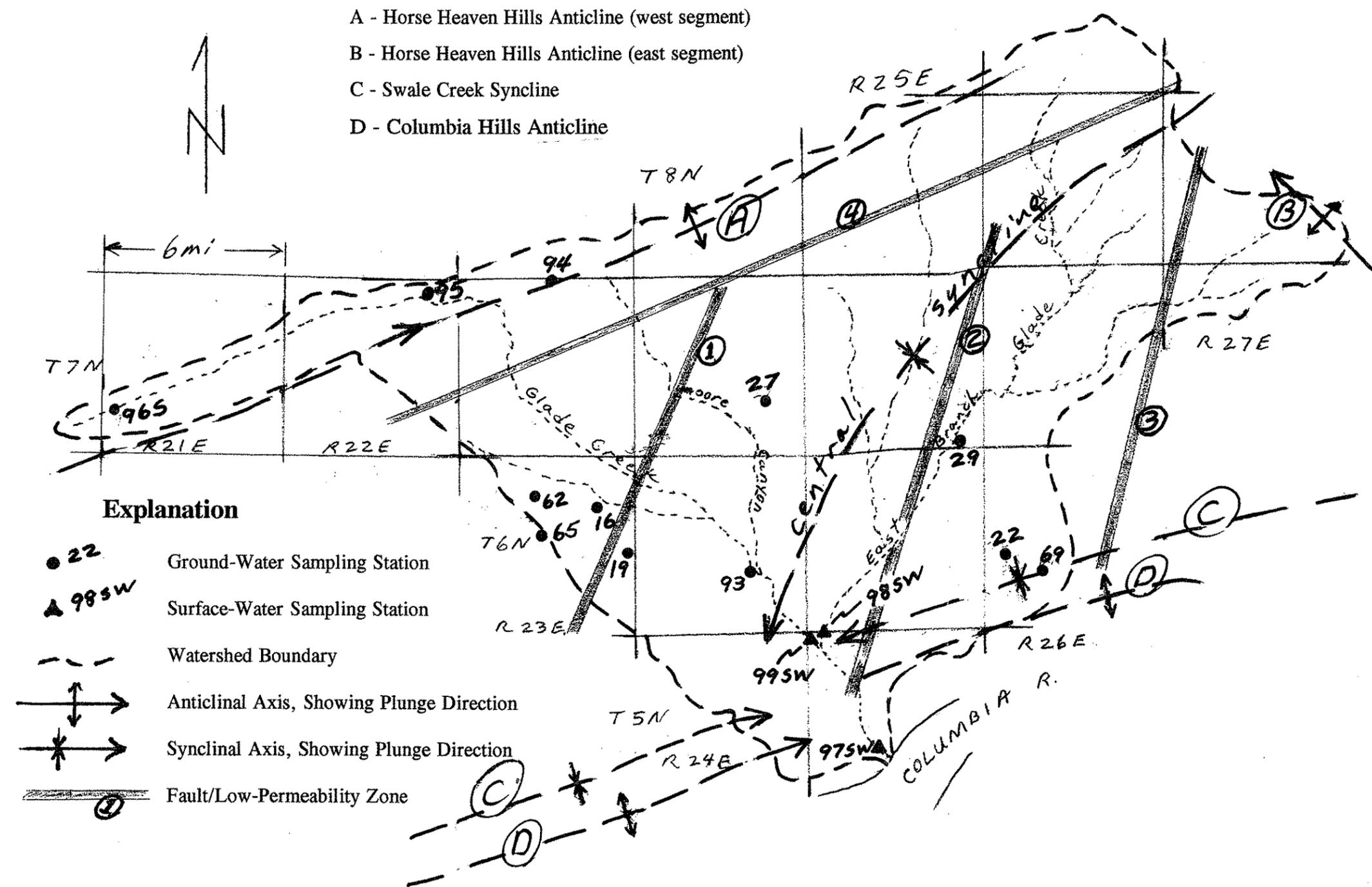
A southeast plunging syncline, known informally as the central syncline, is superimposed on the larger south limb of the Horse Heaven Hills Anticline, and places secondary control on the topography and ground-water flow across the east-central portion of the watershed (Figure 2). The southern border of the watershed is defined by a series of northeast-southwest trending synclines and anticlines ("C" and "D" on Figure 2) which plunge generally toward the mouth of Glade Creek.

Ground-water flow direction in the Glade Creek Watershed is strongly controlled by geologic structure and topography. As shown in Figure 2, the central syncline, the east and west sections of the Columbia Hills anticline ("D"), and the east and west sections of the Swale Creek syncline ("C") all plunge generally toward the mouth of Glade Creek (Packard & others, 1994). The structure and topography combine to funnel ground-water flow toward the lower reaches of Glade Creek.

Several northeast-southwest oriented faults have been mapped in the watershed (Swanson & others, 1979; Packard & others, 1994), some of which are shown on Figure 2. Fault No. 1, west of the central syncline, is the most important fault in terms of ground-water flow. Basin-wide, vertical ground-water flow is, for the most part, downward from the Saddle Mountains Formation through the Wanapum Formation and eventually to the Grande Ronde Formation. But, in the region just west of Fault No. 1, vertical flow is upward as demonstrated by the presence of flowing artesian wells completed in the Wanapum Aquifer.

The zones of greatest permeability, in each basalt aquifer, tend to occur within interflow zones of individual flows. Interflow zones are comprised of the vesicular flow-tops of each basalt flow and the superposed flow-base sections (the vesicular base of the colonnade portion of the basalt flow). Sedimentary interbeds can also be part of the high permeability aquifer sections if the lithologies permit storage and transmission of water (Steinkampf & others, 1985, p.11). The entablature and colonnade sections of the basalt flows tend to have relatively low permeabilities, and water movement through these sections is predominately vertical.

For the most part, the Mabton and Vantage interbeds (Figure 3) tend to act as aquitards in the Glade Creek Watershed, whereas the Rattlesnake Ridge and Selah interbeds tend to be part of the aquifers in the Saddle Mountains Formation. There is no continuous aquitard between the Alluvial Aquifer and the Saddle Mountains Basalt Aquifer.



Geologic information after Packard & others (1994).

**Figure 2 -- Glade Creek Watershed:
Sampling Station Locations
and Geologic Structure**

**Figure 3 - Time-Stratigraphic Relationships,
Horse Heaven Hills**

Age	Formation	Member or Magnetostrati- graphic Units	Sedimentary Interbed	Aquifer
Holocene and Pleistocene	Loess, alluvial, lacustrine, and glaciofluvial deposits			Alluvial Aquifer
Miocene	Saddle Mountains Basalt	Elephant Mountain	Rattlesnake Ridge	Saddle Mountains Aquifer (SDLM)
		Pomona	Selah	
		Umatilla		
	Wanapum Basalt	Priest Rapids	Mabton	
		Roza		Wanapum Aquifer (WNPM)
		Frenchman Springs	Vantage	
	Grande Ronde Basalt	N2		Grande Ronde Aquifer
R2				

Source: Packard and Others (1994)

- 1 - Saddle Mountains, Wanapum, and Grande Ronde Basalts are part of the Yakima Basalt Subgroup.
- 2 - Rattlesnake Ridge, Selah, Mabton, and Vantage sedimentary interbeds are units of the Ellensburg Formation.

Methods

Prior to sampling, all wells were purged until specific conductance and water temperature measurements stabilized. All wells were purged and sampled from a tap nearest the wellhead and prior to any water treatment. Field tests for ferrous iron were conducted in May 1995 on all ground-water samples to observe relative concentrations of ferric and ferrous iron and to determine whether water in the aquifer was in a reduced state, where denitrification could occur (Appendix A, Table A2). Samples from all sampling stations were analyzed for the chemical constituents shown in Appendix A, Table A1. Field measurements of temperature, pH, and specific conductance were made, for both ground water and surface water, at the place and time of each collected sample.

Stream locations were sampled with a single grab sample. All stream sampling sites were flowing and I assumed the stream was fully mixed. Samples were collected near mid-channel at about one-half the depth. Each surface-water sampling site was photographed and described in my field notes. Stream-flow measurements were made, using established EILS protocols (WAS, 1993), at each sampling site using a wading rod and Marsh-McBirney current meter.

Samples were collected and handled according to standard EILS protocols (MEL, 1994; WAS, 1993). Sample bottles, preservatives, and holding times for each parameter are listed in Appendix A - Table A1. Samples were kept on ice until delivered to Ecology's Manchester Laboratory. Analytes were tested using the standard methods listed in Appendix A - Table A2.

The May 1995 sampling dates were chosen to coincide with spring runoff, the beginning of the irrigation season and application of spring fertilizers. Because most of the sampling wells are irrigation wells it was also important for sampling to occur after wells had been put on line and pumped for at least one week. This pumping cleaned stagnant water out of the well and piping, and discharged many "well volumes" of water before the sampling date.

Spring sampling is also important for the surface-water sampling and flow measurement. Glade Creek is an intermittent stream that, historically, has often been dry in the summer and autumn. Spring-time flow measurements and sampling provide data for comparison to historic data (Molenaar, 1982; Davis, 1993).

The September 1995 sampling dates were chosen to coincide with the end of the irrigation season, after water and fertilizers had been applied intermittently to crop lands for about four months.

Ground-water sampling stations, their locations, completion intervals, and production aquifers are presented in Table 1. The criteria used to select the ground-water and surface-water sampling stations are given in Appendix A.

Table 1 - SAMPLING STATIONS, GLADE CREEK WATERSHED

WELL DATA FOR SAMPLED WELLS										
PROJECT SITE ID	LOCATION/ USGS LOCAL NO.	TOTAL WELL DEPTH (ft)	TOP PROD. ZONE, (depth, ft.)	BASE PROD. ZONE (depth, ft.)	ELEV. @ TOP PROD. ZONE ⁽²⁾	ELEV @ BASE PROD. ZONE ⁽²⁾	ELEV TOP PRIEST RAPIDS ⁽³⁾	AQUIFER ⁽⁴⁾	USGS QUAD NAME	
WELLS W/ LOGS AND HISTORIC WATER QUALITY DATA										
GC-16	06N/23E-11Q01	1010	150	208	860	802	475	SDLM	Prosser SW	
GC-19	06N/23E-24B01	965	365	965	505	95	225	WNPM	Cane Ridge	
GC-22	06N/26E-19K01	640	42	345	598	295	80	SDLM	Patterson	
GC-27	07N/24E-26B01	870	420	532	450	338	210	SDLM	Prosser SE	
GC-29	07N/25E-36N04	730	530	860	200	-130	200	WNPM	Lenzie ranch	
WELLS W/ LOGS BUT NO HISTORIC WATER QUALITY DATA										
GC-62	06N/23E-9G	1240	540	1093	700	147	750	WNPM	Prosser SW	
GC-65	06N/21E-16R1	1095	535	952	560	143	600	WNPM	Painney Hill	
GC-69	06N/26E-29A	580	270	290	310	290	110	SDLM	Patterson	
WELLS WITH NO LOGS OR WATER-QUALITY DATA										
GC-93	06N/24E-23N1	600	20	230	580	380	130	SDLM	Cane Ridge	
GC-94	07N/23E-03D1	1635	20	213	1615	1422	> 1000	SDLM	Mabton E.	
GC-95	07N/22E-02J	1700	20	90	1680	1610	> 1000	AL/SD	Tule Prong	
GC-96S ⁽⁵⁾	07N/21E-30L	2820	NA	NA	NA	NA	NA	ALUV	Bluelight	
SURFACE-WATER SAMPLING STATIONS										
SITE ID	LOCATION	SITE NAME	USGS QUAD NAME							
GC-97SW	05N/25E-28B	Glade Creek, mouth	Blalock Island							
GC-98SW	05N/25E-06B	E. Branch Glade Creek	Blalock Island							
GC-99SW	05N/25E-06F	Glade Creek, upper	Blalock Island							

(1) LSD = Land Surface Datum. Elevation in feet above mean sea level.
 (2) Elevation in feet above mean sea level, negative (-) indicates below sea level.
 (3) Top of the Priest Rapids Member of the Wanapum Basalt = top of Wanapum Basalt. Wells w/ production zones below given elevation are WNPM wells and wells completed above given elevation are SDLM or ALUV wells.
 (4) ALUV = Alluvial Aquifer; SDLM = Saddle Mountains Basalt Aquifer; AL/SD = Combined ALUV and SDLM completion; and WNPM = Wanapum Basalt Aquifer.
 (5) Spring - issuing from alluvium near headwaters of Glade Creek

Results and Discussion

Ground Water Water-Quality Characterization

Anion-cation analyses of samples from each aquifer indicate clear chemical differences between the Wanapum Basalt Aquifer and Saddle Mountains Basalt Aquifer. Data are shown in Appendix B. Differences between the Alluvial Aquifer and Saddle Mountains Basalt Aquifer are indistinct.

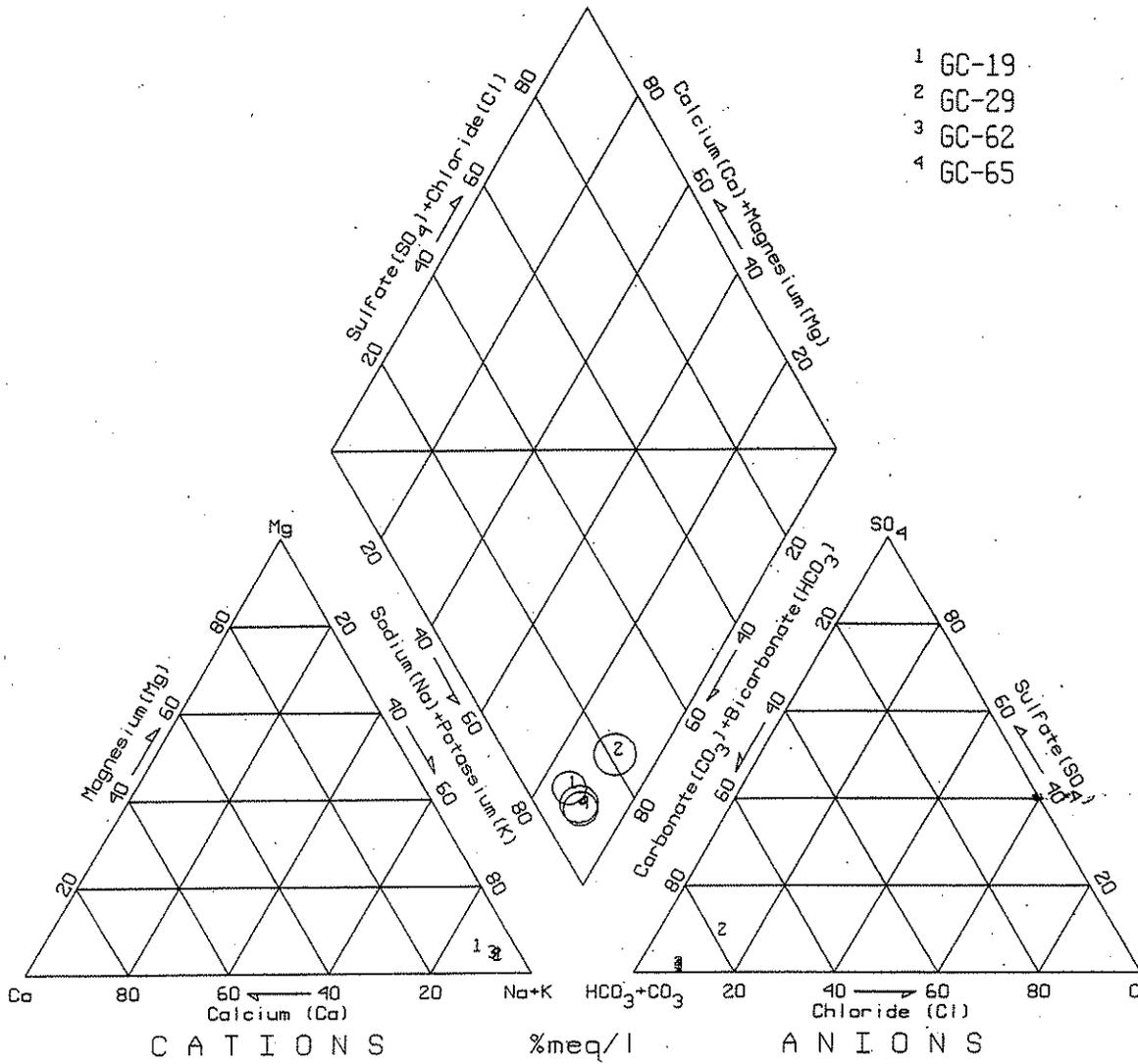
Wanapum Basalt Aquifer (WNPM)

The trilinear diagram in Figure 4 shows the relative percentages of anions and cations for the four Wanapum Basalt Aquifer (WNPM) wells sampled. The WNPM aquifer water is clearly of the sodium/potassium-bicarbonate type, but because sodium concentrations in the WNPM aquifer wells are about five times higher than those of potassium (Appendix B), WNPM aquifer water can be classified most accurately as a sodium-bicarbonate water type. Concentrations of calcium and magnesium are very low and approximately equivalent, while sodium concentrations are relatively high. This indicates that ground water has a relatively long residence time in the aquifer (Hearn and others, 1985, p. 27).

The position of the projected points in the diamond-shaped field of the trilinear diagram (Figure 4) indicate that carbonate alkali ("primary alkalinity") exceeds 50% in the WNPM aquifer and that the water is inordinately "soft" in proportion to the content of dissolved solids (Walton, 1970). Total dissolved solids (TDS) ranged from 237 to 310 mg/L, but in spite of this, hardness values range from 16.6 to 24.5 mg/L).

Specific conductance has been measured 11 times, between August 1972 and May 1995, in the four WNPM wells used in this study (Steinkampf and others, 1985; Turney, 1986). The values ranged from 333 to 456 umhos/cm with a mean value of 390 umhos/cm (Appendix B). Water in the WNPM aquifer is alkaline with pH ranging from 8.2 to 8.8. Total iron content is low. All eight samples collected since 1982 yielded total iron concentrations ≤ 0.1 mg/L. Ferrous iron was not detected in any of the WNPM wells.

The aquifer is naturally rich in fluoride, which can be expected in aquifers of volcanic origin, (Hem, 1989, p. 120). Fluoride concentrations ranged from 0.8 to 1.4 mg/L in 12 samples collected from 1972 through 1995. Nitrate+nitrite (nitrate) was not detected above the detection limit of 0.01 mg/L in any of the four WNPM aquifer wells. This may indicate that the Mabton Interbed (Figure 3) acts as a regional aquitard between the Saddle Mountains Basalt Aquifer and WNPM aquifers, protecting the WNPM aquifer by preventing downward migration of contaminants.



Note: The circles in the diamond-shaped field indicate the relative concentrations of total dissolved solids, at each sample location. Based on results from May 1995 sampling.

Figure 4 -- Trilinear Analysis of Wanapum Basalt Aquifer Samples, Glade Creek Watershed

Saddle Mountains Basalt Aquifer (SDLM) and Alluvial Aquifer (ALUV)

Water quality of the Saddle Mountains Basalt Aquifer (SDLM) and the Alluvial Aquifer (ALUV) is not as easily characterized as the Wanapum Aquifer. Since there is no continuous aquitard separating the ALUV and SDLM, the waters tend to mix in most areas and the water type reflects this mixing.

Anion-cation analyses of samples collected in the north-central and northwest portions of the Glade Creek Watershed, from SDLM wells GC-27, and GC-94, SDLM/ALUV well GC-95, and the ALUV spring GC-96S, indicate that the dominant anion is bicarbonate and that there is no dominant cation (Figure 5). The position of the projected points in the diamond-shaped field of Figure 5 indicate that carbonate hardness (secondary alkalinity) exceeds 50 percent and the chemical properties are dominated by alkaline earths and weak acids (Walton, 1970, p. 454).

As discussed in detail in the "Relationship between irrigation and water quality within the Alluvial and Saddle Mountains Basalt Aquifers" section below, I believe these four sampling sites best represent the pure water type of the SDLM and ALUV aquifer systems in the watershed.

Water characteristics vary widely in the ALUV/SDLM aquifer systems. Chloride concentrations, for example, range from 4.2 mg/L in well GC-94 to 154 mg/L in well GC-22. This range spans from well within what is considered to be background concentrations for ground water (<30 mg/L), to well above levels which usually indicate some source of chloride contamination (50 to 100 mg/L) (Sinclair and Garrigues, 1994, p. 47).

Concentrations of TDS, specific conductance, and NO_2+NO_3 vary widely. TDS ranges from 158 to 1,170 mg/L; specific conductance from 215 to 1,646 mg/L; and NO_2+NO_3 from 0.795 to 70 mg/L (Appendix B; Figure 9). Ground water in the SDLM and ALUV aquifers is "moderately hard" to "hard" with concentrations ranging from 89 to 273 mg/L. pH ranges from 7.0 to 8.1. Total iron was detected in three wells at levels ranging from 0.1 to 0.2 mg/L. Ferrous iron was not detected in any of the SDLM/ALUV wells sampled.

Three water-quality constituents in the SDLM exceeded the maximum contaminant levels for drinking water (DOH, 1994). These constituents are nitrate, TDS, and specific conductance (conductivity). Nitrate exceeded the MCL of 10 mg/L in two wells: GC-69, where concentrations ranged from 28.1 to 30.4 mg/L; and GC-22, where concentrations ranged from 33 mg/L in March 1982 to 70 mg/L in September 1995 (Appendix B). TDS exceeded the MCL of 500 mg/L in three wells: GC-16, where concentrations ranged from 516 to 547 mg/L; GC-22, where concentrations ranged from 1,150 to 1,170 mg/L; and GC-69, where concentrations ranged from 559 to 574 mg/L. Conductivity exceeded the drinking-water MCL of 700 umhos/cm (DOH, 1994) in the

same three wells: GC-16, with 782 to 818 umhos/cm; GC-22, with 1,010 umhos/cm in March 1982 to 1,646 umhos/cm in September 1995; and GC-69, where the concentration was 838 in both May and September 1995 (Appendix B).

Nitrate Contamination in the Saddle Mountains Basalt and Alluvial Aquifers

Nitrate was detected in all SDLM and ALUV wells in concentrations ranging from 0.795 mg/L to 70 mg/L. Nitrate concentrations were higher in September 1995 than in May 1995 in all SDLM and ALUV sampling sites. The differences ranged from 4 percent in three wells to as much as 242 percent in well GC-95 (Table 2). This may indicate that nitrogen is transported to the SDLM aquifer, at all well completion depths, within the time frame of one irrigation season (four months). These results indicate that the SDLM aquifer is quite vulnerable to nitrate contamination, in spite of the relatively deep completion depths of the SDLM wells sampled. The total depths of sampled SDLM wells range from 90 to 532 feet (Table 1). The top of the production zones in these wells range from about 20 feet below the land surface datum (LSD) to as much as 420 feet below LSD (Table 2).

The depth of the wells does not seem to correlate with the nitrate concentration. One would expect the highest nitrate concentrations to be in wells with the top of the production zone closest to the land surface. However, some of the shallowest wells (GC-94, GC-95, and the spring GC-96S) in the northwest portion of the watershed, have relatively low nitrate levels. But well GC-69, which has the second deepest production zone at 270 feet, has the second highest nitrate concentration found.

Table 2 - Nitrate Concentrations in Selected Wells Completed in the Alluvial and Saddle Mountains Basalt Aquifers, Glade Creek Watershed, May and September 1995

Site ID	Depth to Top/bottom Production Zone (feet)	Nitrate Concentrations			Percent Increase
		May 1995 Value (mg/L)	Sept 1995 Value (mg/L)	Difference (mg/L)	
GC-16	150/208	5.34	6.42	1.08	20
GC-22	42/345	67	70	3	4
GC-27	420/532	0.992	1.23	0.238	24
GC-69	270/290	28.3	30.4	2.1	7
GC-93	20/220	1.79	1.87	0.08	4
GC-94	20/213	1.68	1.74	0.06	4
GC-95	20/90	0.853	2.92	2.067	242
GC-96S	Not Applicable	0.795	1.25	0.455	57

Surface-Water Quality Characterization

Cation and anion data for all three surface-water samples from Glade Creek and the East Branch of Glade Creek indicate no dominant water type on the trilinear diagram in Figure 6. Data are shown in Appendix B. Concentrations of several chemical parameters were high. Concentrations of most parameters tended to increase downstream. Specific conductance exceeded the MCL of 700 umhos/cm, ranging from 882 to 1,369 umhos/cm. TDS also exceeded the MCL of 500 mg/L, ranging from 593 mg/L in East Branch Glade Creek to 908 mg/L at the mouth of Glade Creek. The water is also very hard, with values ranging from 358 to 500 mg/L. Like the Wanapum Aquifer, the surface water is alkaline. pH values ranged from 8.07 to 8.39. Chloride levels were also high, ranging from 82.9 to 107 mg/L.

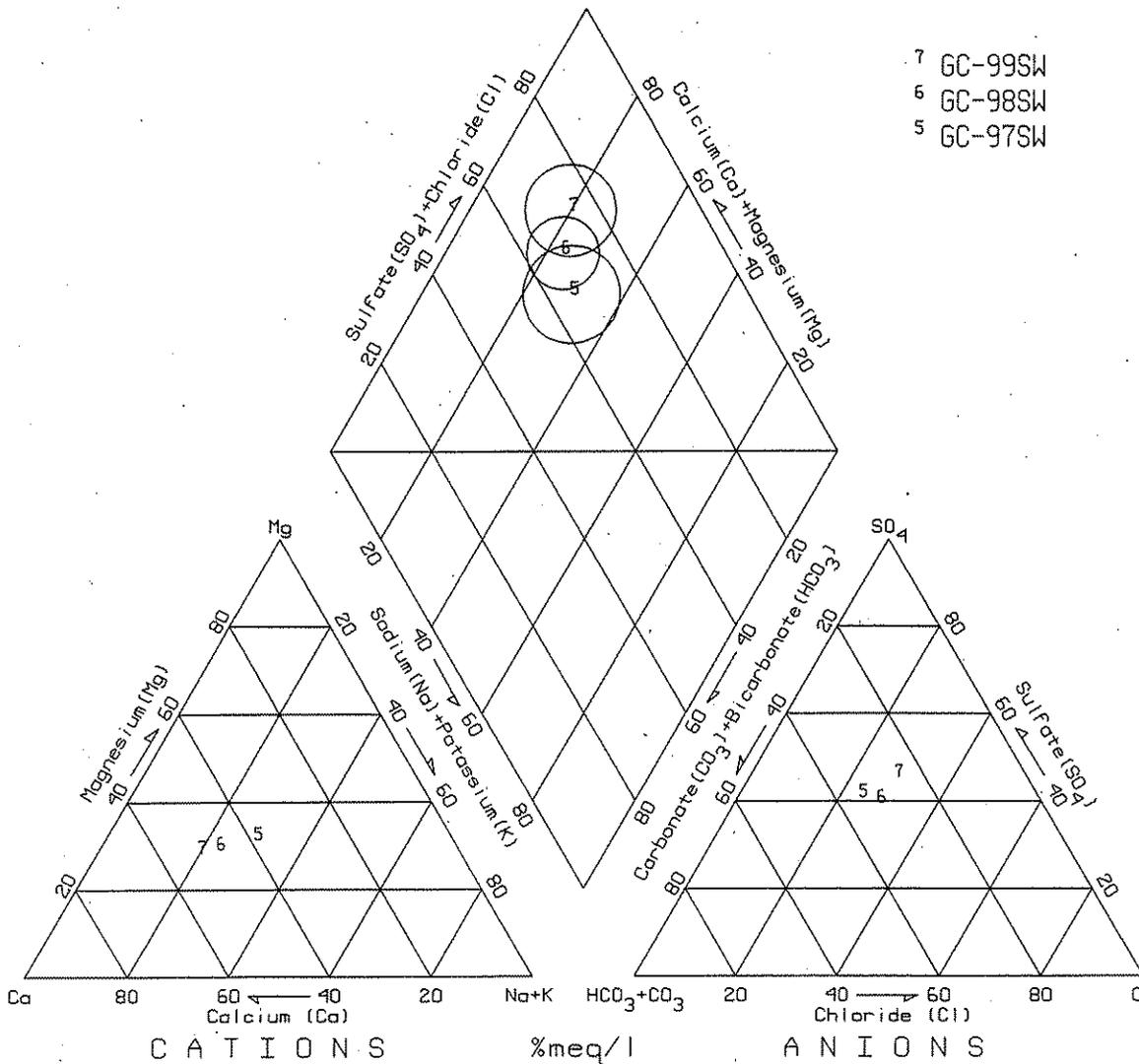
Nitrate Contamination in Surface Water -- Glade Creek

The drinking-water MCL for nitrate was exceeded at all three surface-water sampling stations. Nitrate concentrations increased dramatically with distance traveled downstream. In May 1995, the nitrate concentration in Upper Glade Creek (GC-99SW) was 13.3 mg/L, while the concentration in East Branch Glade Creek (GC-98SW) was 11.6 mg/L. Nitrate concentrations at the mouth of Glade Creek were 36 mg/L and 40 mg/L in May and September 1995, respectively -- higher than in May 1992 when Davis (1993) reported that the concentration of 34.5 mg/L was among the highest recorded for surface water in Washington State.

Relationship Between Irrigation and Water Quality Within the Alluvial and Saddle Mountains Basalt Aquifers

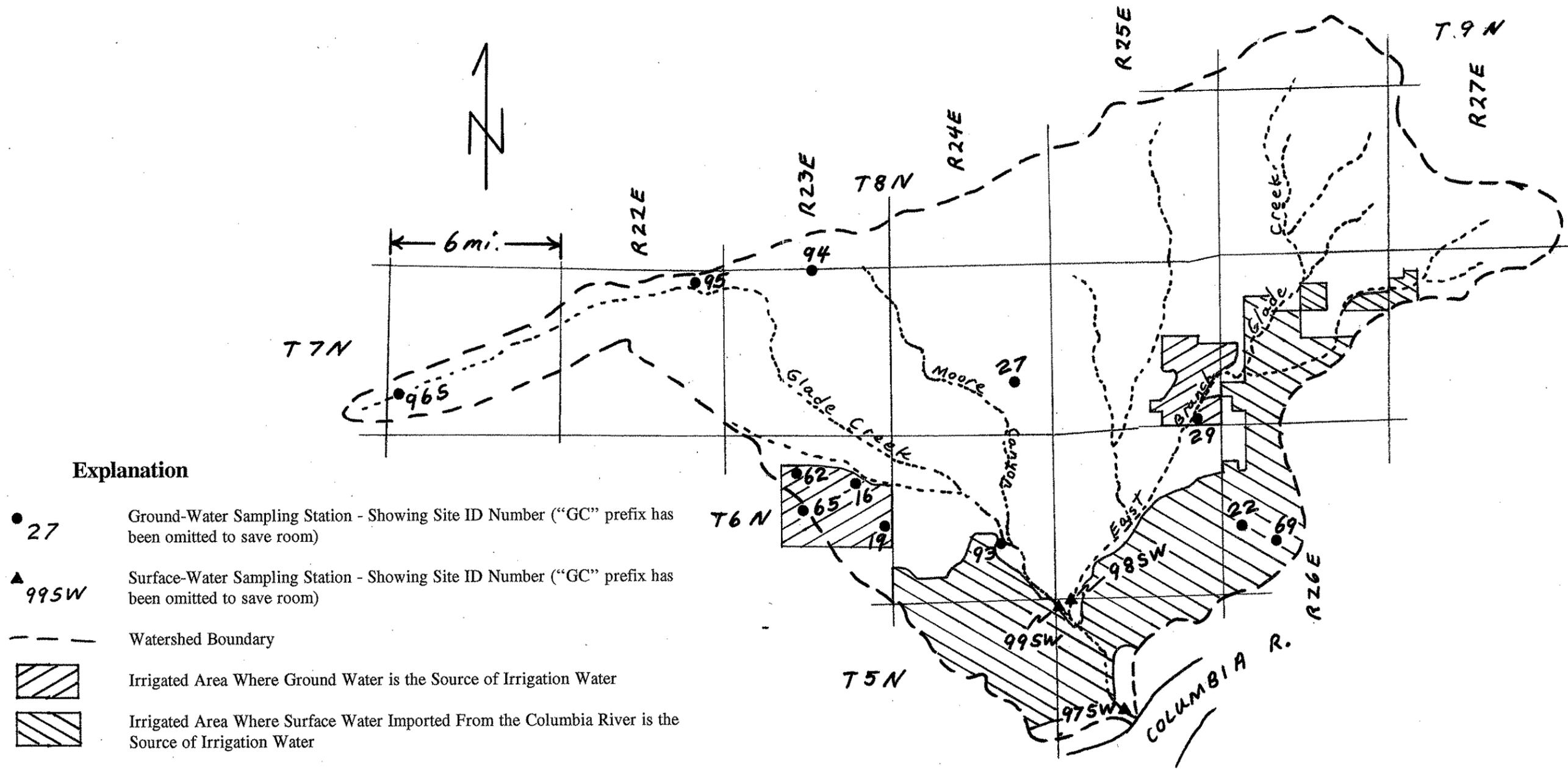
The data indicate a strong correlation between the presence of crop-land irrigation, particularly center-pivot irrigation, and the underlying water type and water quality of the Saddle Mountains Basalt Aquifer.

Wells in the northwest and north-central areas of the basin, where the main crops are dry-land wheat, exhibit a strong bicarbonate anion water-type, and a mixed cation water type. Wells located in irrigated areas, however, exhibit mixed-anion water types. This relationship is clearly shown in Figure 5, where the sampling sites in the areas with the least irrigation -- GC-27, GC-94, GC-95, and GC-96S (Figures 2 & 7) -- plot at the lower left in the bicarbonate field on the anion triangle and in the center of the left diamond -- the "carbonate hardness" area (Walton, 1970) -- on the diamond field. In contrast, wells located in irrigated areas of the west-central portion of the basin -- GC-16 and GC-93 (Figures 2 & 7) -- exhibit more of a mixed water type, plotting on the anion triangle near the line between the "bicarbonate" field and the "no-dominant-water-type" field (Figure 5).



Note: The circles in the diamond-shaped field indicate the relative concentrations of total dissolved solids, at each sample location. Based on results from May 1995 sampling.

Figure 6 -- Trilinear Analysis of Surface Water Samples, Glade Creek Watershed



Explanation

- 27 Ground-Water Sampling Station - Showing Site ID Number ("GC" prefix has been omitted to save room)
- ▲ 995W Surface-Water Sampling Station - Showing Site ID Number ("GC" prefix has been omitted to save room)
- - - Watershed Boundary
- [Hatched Box] Irrigated Area Where Ground Water is the Source of Irrigation Water
- [Diagonal Hatched Box] Irrigated Area Where Surface Water Imported From the Columbia River is the Source of Irrigation Water

Information Source: Air photo coverage of the Horse Heaven Hills at the Farm Services Agency, Prosser, Washington.

Scale: 1 inch = 4 miles; 1:250,000

Not Shown: An unknown number of irrigated acres planted in new orchard along Glade Creek in the southern portion of Township 7 North, Range 23 East. The water source is a combination of the Saddle Mountains Basalt and Wanapum Basalt Aquifers.

Figure 7 -- Glade Creek Watershed: Irrigated Areas

The trend toward a "no-dominant anion" water type is more pronounced in areas where irrigation rates are highest. Wells GC-22 and GC-69, located in the southeast portion of the basin, where extensive irrigation occurs (Figure 7), plot in the "no-dominant-anion" area of both the anion triangle and in the diamond (Figure 5) (Walton, 1970).

The points plotted in both the anion triangle and the diamond-shaped field of Figure 5, lie in a lower-left to upper-right trending line. Results from the four sampling sites, located in areas of little or no irrigation, plot at the lower left end of the line in the bicarbonate water-type zone. Anion/cation results plot progressively further to the upper right of the diagram as irrigation increases in the vicinity of the sampling site. According to Walton (1970), a straight-line relationship such as this indicates that the water type is becoming increasingly more mixed. Furthermore, a Stiff diagram analysis (Stiff, 1951) of the cation/anion data from each well (Figure 8) shows the same increasingly-mixed trend across the watershed. This diagram also shows that the trend continues to the surface water, where the ground water in well GC-22 has a water-type signature very similar to those of the surface-water sampling sites, particularly site GC-99SW.

Figures 9A-9D show the relative concentration change across the watershed in nitrate, TDS, specific conductance, and chloride, respectively. Each of these chemical constituents is markedly higher in the wells most exposed to irrigation, relative to wells in less irrigated areas.

Despite similarities in water type (Figure 5) nitrate concentrations in well GC-69 were about five times greater than in GC-16 on both sampling dates. Irrigation appears to have a greater effect on nitrate concentrations in ground water than on the relative balance of cations and anions. The rate of application of both water and fertilizer would probably affect the relative degree of impact on these water-quality constituents.

Well GC-95, located in a non-irrigated area, does not fit the pattern of increased irrigation resulting in increasingly mixed ground-water types and increasingly higher concentrations of nitrate, TDS, specific conductance, and chloride (Figures 8 and 9). The water-type signature on Figure 8 is more like those of the irrigated areas than those of the non-irrigated areas. As shown on Figure 9, well GC-95 also has higher concentrations of TDS, specific conductance, and chloride than the other three non-irrigated sampling sites (GC-96S, GC-94, and GC-27). The nitrate concentration in well GC-95 was 2½ times higher in September than in May 1995, as shown in Table 2. I noticed no large-scale irrigation near GC-95. However, the well is located in the back yard of the residence with a lawn and garden. Localized fertilizer use may be affecting the ground water at GC-95. I do not know where the septic system for the property is located. This may also add nitrate to the ground water. Whatever the nitrate source, it shows significant seasonal variation.

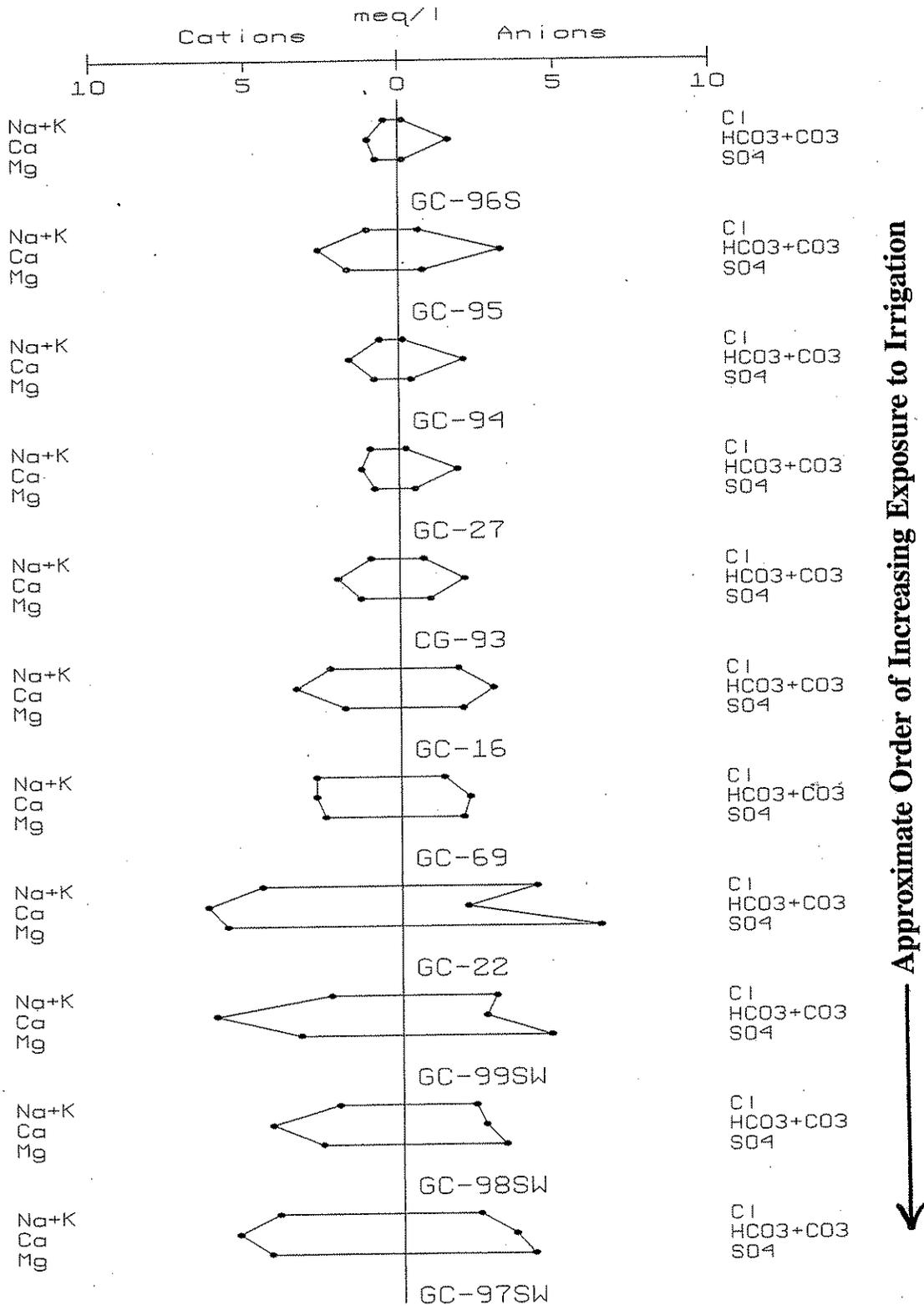
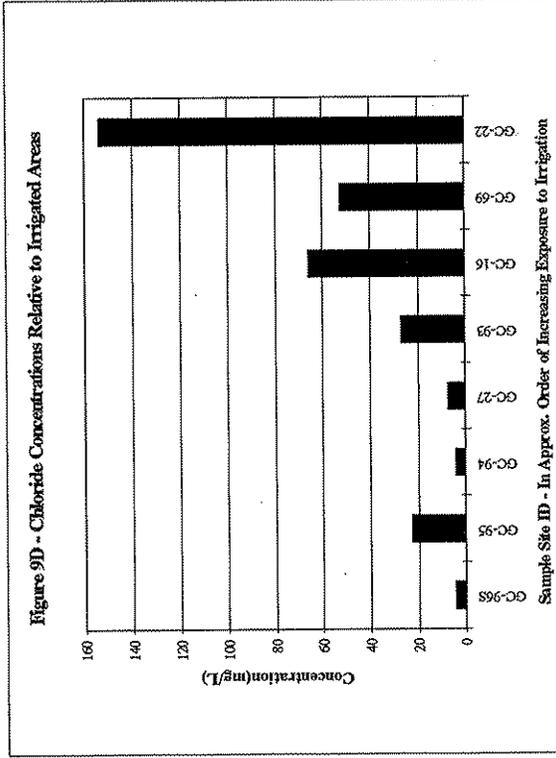
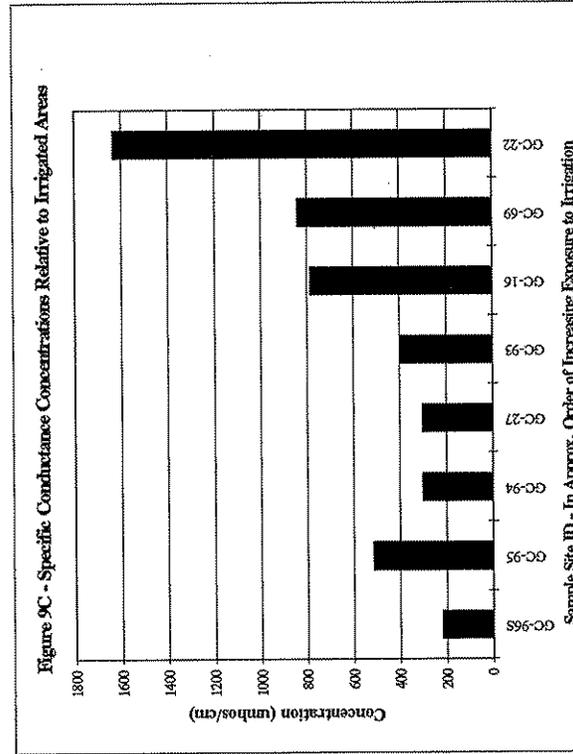
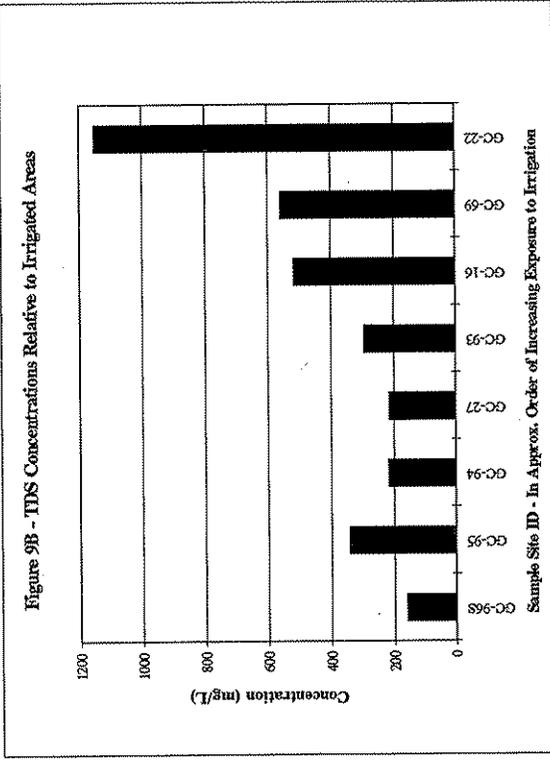
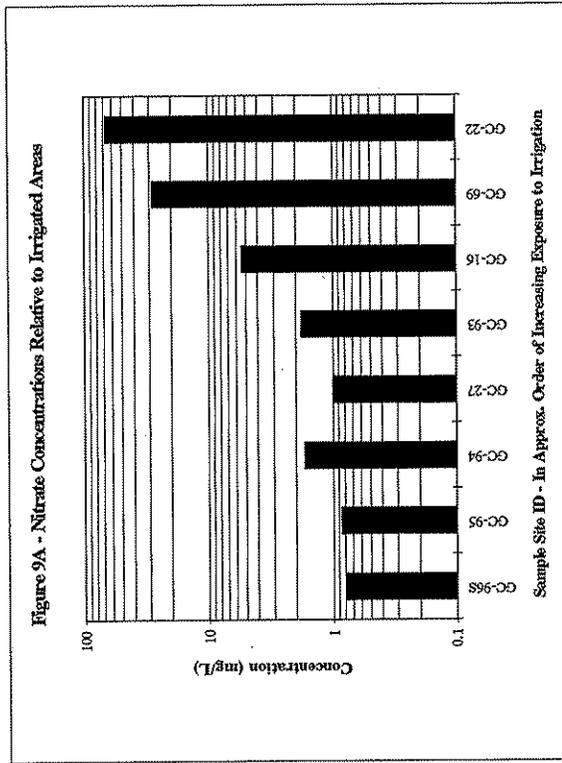


Figure 8 -- Stiff Diagram Analysis of Alluvial Aquifer, Saddle Mountains Basalt Aquifer, and Surface Water Samples, Glade Creek Watershed, Southeast Washington

Figure 9 - Increasing Irrigation vs. May 1995 Concentrations of Various Chemical Constituents in Ground Water



Well GC-22 -- Special Considerations

Well GC-22 exhibits, by far, the most mixed water type and the highest NO_2+NO_3 concentration (70 mg/L) of the wells sampled (Figures 5, 8, and 9). The cause of these extremes may be due to contaminants entering through the well bore. The driller's well log indicates that the surface seal for the well is bentonite to 20 feet, but that the "top soil" is 24 feet thick. This probably means that the surface seal is ineffective or non-existent. Even if the 20 feet of bentonite formed a good seal, surface water could leak down the outside of the casing through the four feet of top soil that was not sealed off. To be effective, the surface seal should have been placed to 30 or 40 feet which is 6 to 16 feet into the clay material below the top soil.

Well GC-22 is used as a source of wash water for vineyard equipment and for mixing with fertilizers and pesticides. Fertilizer and pesticide containers are filled and washed just outside the well house, where spills and wash water collect in a below-ground pit about 15 feet from the well bore. The pit is covered by a concrete pad with steel grating. Tractors and spraying equipment are parked on or near the concrete pad and washed off. Wash water runs into the pit through the steel grating. I have observed the pit full to over-flowing on more than one occasion. I believe the wash water dissipates by percolating into the ground through the waste-water-collection pit. This places contaminants below land surface and critically close to a poorly-sealed well bore.

Historic Data Comparisons

Ground-Water Quality

The U.S. Geological Survey (Steinkampf and others, 1985; Turney, 1986) collected ground-water data in the Glade Creek Watershed in the early 1960's and early 1980's. A priority of this study was to re-sample as many wells with historic data as possible so that comparisons over time could be made. Two Wanapum Aquifer wells (GC-19 and GC-29) and two Saddle Mountains Aquifer wells (GC-22 and GC-27) have historic ground-water quality data.

There were no appreciable concentration changes in any chemical constituents in either of the two Wanapum Aquifer wells (Appendix B).

Saddle Mountains Aquifer well GC-27 showed no appreciable changes in the concentrations of any chemical constituents between March 1982 and September 1995. Well GC-22, however, showed significant changes in the concentrations of nitrate (112%), specific conductance (60%), and chloride (75%) (Figures 10A, 10B, and 10C, respectively). These changes are probably due to either the general increase in irrigation in the southeast portion of the watershed or to increased leakage of contaminants down the well bore.

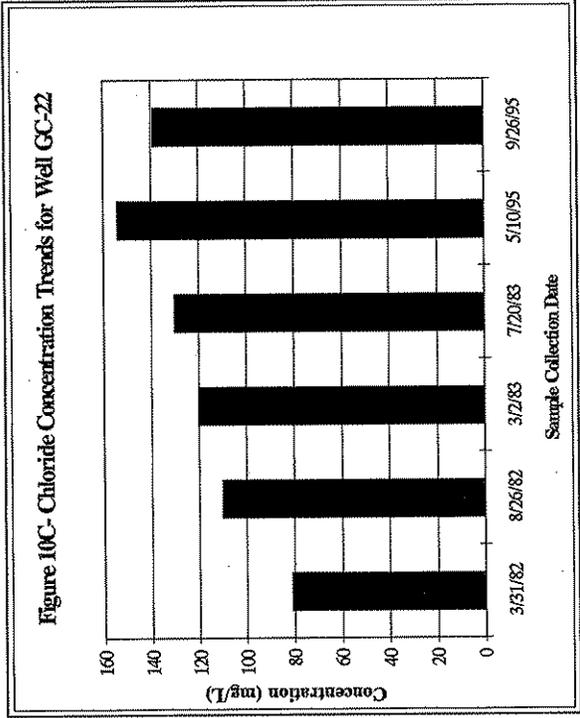
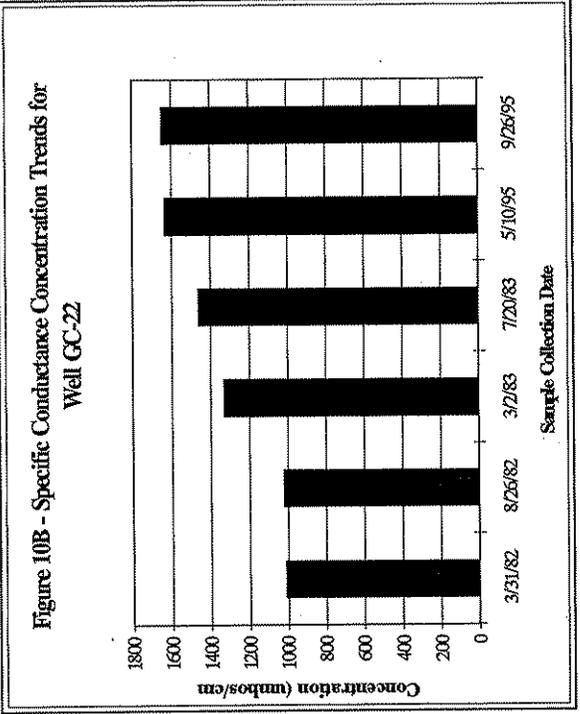
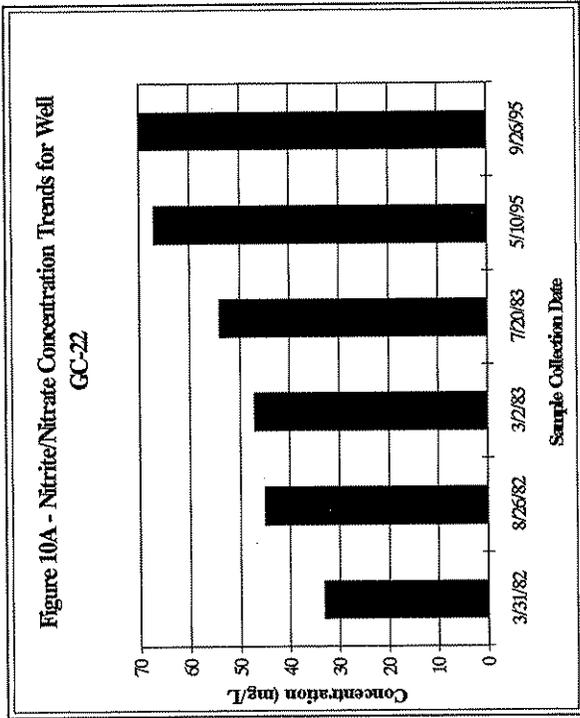


Figure 10 - Historic Data Trends, Well GC-22

Surface-Water Flow

Discharge rates at the mouth of Glade Creek on February 14, 1977, June 3, 1977, and August 8, 1977 were 4.80 cubic feet per second (cfs), 6.63 cfs, and 5.01 cfs, respectively (Molenaar, 1982, p. 38), and 10.2 cfs on May 31, 1992 (Davis, 1993, Table 4). Flow measurements made at the mouth of Glade Creek as part of this study yielded flows of 15.61 cfs and 13.18 cfs on May 10, 1995 and September 26, 1995, respectively.

Relationship Between Ground Water and Surface Water

Under normal precipitation conditions, nearly 100% of the flow in Glade Creek comes from baseflow (ground-water discharge). This is true except during spring runoff and peak stream discharges following storm events. At times when baseflow is the principle source of stream flow, nitrate concentrations in the stream should be an indicator of average nitrate concentrations in the ground water.

The situation in Glade Creek is complicated by the presence of center-pivot irrigation systems up gradient of the stream and along the lower reaches of the stream.

The 1995 flows measured at the mouth of Glade Creek may be atypical compared to historic flows. Molenaar (1982) states, "there is little or no water in most reaches of the stream during the summer months". My field observations in 1995 confirm this assessment in all reaches of the stream except the reach between the mouth of Glade Creek and the junction with the East Branch Glade Creek tributary. My observations indicate that there is a large source of flow to the stream somewhere in this reach. In May 1995, flow increased from 0.53 cfs to 15.61 cfs in the 4 to 5 mile reach. The spring of 1995 was unusually wet in the Horse Heaven Hills, which may account for the high flow (15.6 cfs) at the mouth of the creek in May. It is unlikely, though, that the wet winter and spring could account for the late-September, 1995 flow of 13.2 cfs. I believe the 1995 measurements are the highest non-storm-event flows ever recorded at the mouth of Glade Creek. The September 1995 flow measurement was the latest recorded in the summer. I presume that no autumn or late-summer flow measurements have been made at the mouth of the creek because previous investigators found it dry.

The most likely source of the exceptionally high late-summer flow at the mouth of Glade Creek is ground-water recharge from the center-pivot irrigation water imported from the Columbia River and applied along the stream bed and in the southern and eastern portions of the watershed (Figure 7). The structure and topography in the watershed combine to funnel ground-water toward the lower reaches of Glade Creek (Figure 2). Irrigation water that percolates through the porous soils of the watershed and past the root zone of the irrigated crops would follow the structurally- and topographically-defined flow paths to Glade Creek. Irrigation water applied directly to the stream bed could also be a minor source of stream flow (the air photos, from which the information for Figure 7 was

obtained, showed at least one center-pivot irrigation system which lies directly across Glade Creek).

High nitrate concentrations in ground water on the east side of the watershed indicate that ground-water discharge to the stream is also the most likely source of nitrate contamination in Glade Creek. Some of the nitrate may be accounted for by direct application through center-pivot irrigation to the stream bed, but it is probably of minor importance compared to the loading attributable to ground-water discharge.

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Appendix A

Data Collection and Quality Control/Quality Assurance Procedures

Sampling Stations - Selection Criteria

Ground-Water Stations

Ground-water sampling stations, their locations, completion intervals, and production aquifers are presented in Table 1. Areal distribution is shown on Figure 2. The sampling wells, for each aquifer, were picked to get the best areal distribution of ground-water sampling stations possible, given the available wells. All wells were inspected prior to sampling to confirm that each had an acceptable tap from which samples can be collected.

Ideally, to be considered for sampling, wells had to meet certain criteria:

1. Basalt wells must have a well log available so geology and well construction details can be determined. This requirement was waived for alluvial and shallow alluvial/Saddle Mountain Basalt wells because the information was not as critical. Also, if the requirement were strictly adhered to, there would be no shallow wells to sample.
2. Basalt wells must be completed in a single aquifer. Many irrigation wells in the watershed, particularly the older ones, are completed in both the Saddle Mountains aquifer and the Wanapum aquifer (both above and below the Mabton Interbed). If these dual-completed wells were sampled, the water quality results would be useless for specific aquifer characterization because it would be impossible to tell which aquifer was represented by the analyses.
3. Each sampling well must have an acceptable tap located near the well head and prior to any treatment facilities.

One spring was sampled as part of this project (station GC-96S). It is located in the uppermost reach of Glade Creek (Figure 1) and should be representative of water quality of the alluvial aquifer in the area.

Surface-Water Stations

Three surface-water sampling stations (Figure 2, Table 1) were chosen to provide the following information.

Station GC-97SW: The water quality at the mouth of Glade Creek representing the cumulative affects of runoff and ground-water discharge from the whole watershed, and for comparison to results reported by Davis (1993).

Station GC-98SW: Water quality at the mouth of East Branch Glade Creek, representing the effects of runoff and ground-water discharge from the east side of the Glade Creek watershed. Most of the irrigation in the watershed occurs on the east side.

Station GC-99SW: Water quality in Glade Creek upstream of the junction with the East Branch Glade Creek tributary. This sample should represent the effects of runoff and ground-water discharge from the west side of the watershed where the majority of crops are not irrigated.

Data Quality Objectives and Analytical Procedures

Analytical methods and detection or precision limits for field measurements and lab analyses of conventional parameters are listed in Table A2. The laboratory's data quality objectives and quality control procedures are documented in the Manchester Environmental Laboratory's Lab Users Manual (MEL, 1994).

Field Measurements

Precision/Bias

Ground-water levels were measured with an electrical probe or a steel measuring tape, and recorded to the nearest 0.01 feet. Because of errors in the instrument, the true accuracy of any measurement may be considered to be 0.1 feet. Water levels in certain irrigation wells were measured by using a pre-installed airline of known length and an Ecology-owned calibrated pressure gauge. Due to possible errors in the reported length of the airline, calibration of the pressure gauge, and the fact that the pressure gauge can be accurately read to only 0.5 psi, the actual accuracy of these measurements is only plus or minus one foot. Relative differences between water levels over large areas is the desired result and will be adequately represented by these measurements. Stream discharge measurements are usually accurate to plus or minus approximately 10 percent.

Representativeness

Wells were selected to represent the variability in ground water from each aquifer of interest across the study area. Although this variability is unknown, wells were selected to represent as much of the study area as feasible without drilling new wells. Likewise, surface water sampling locations were selected to best characterize surface-water quality in Glade Creek and its main tributary.

Sampling and Laboratory Analyses

The list of analytes including the analytical methods and method detection limits are presented in Table A2.

Precision/Bias

In this study, my intent is to characterize the concentrations and quantities of several analytes in the ground-water aquifers. No special laboratory considerations are needed and the precision and bias routinely obtained with the methods selected will be adequate (Table A2).

Representativeness

Samples collected from the wells are assumed to be representative of the ground water quality. Although the variability of the ground water in the Glade Creek watershed is somewhat unknown, I think the wells sampled adequately represent the range in analyte concentrations during the two sampling events. Since this characterization consists of limited number of samples, I have not attempted statistical analyses.

The samples collected at each surface water station are assumed to represent the water quality at that place and time. Surface-water quality characterization and the possible connection to ground-water contributions is the main interest from these samples.

Completeness/Comparability of Data

Every attempt was made to collect all planned samples. However, I was not able to sample two wells in May 1995. The pump in well GC-57 was destroyed by vandals during the winter. The pump was out for repairs during the May sampling run. The pump in Well GC-26 burned out when the owner attempted the Spring start-up and was in need of repair during the May sampling run. There were no back-up wells available for these two wells. However, the integrity of the project was not compromised because both of these wells are deep wells completed in the Wanapum Basalt Aquifer and the remaining Wanapum wells provided adequate water-quality characterization of the aquifer.

Quality Control Procedures

Data quality control for this study is limited to determining the accuracy and precision (bias) of the sampling and laboratory results.

Field QC

One duplicate sample was collected each sampling day for both surface and ground water. All duplicate samples were submitted as "blind duplicates" and one of those was marked as a QA sample as suggested by Dave Thomson (personal communication).

Laboratory QC

Manchester laboratory conducted their routine analytical quality control procedures, which are adequate for the needs of this project. These procedures included, but are not limited to, check standards, lab duplicates, blanks, and a spike of the field duplicate identified as a QA sample (Stu Lombard and Dave Thomson, personal communication).

Data Assessment Procedures

Data reduction, review, and reporting is according to the procedures outlined in the Lab Users Manual (MEL, 1994). The principle investigator validated all data before preparing a final project database. One hundred percent of the data was reviewed for possible transcription errors, missing data, and improbable values when importing data from MEL submittals. The precision of the sample results was estimated by using field duplicate results to calculate the relative percent difference (RPD).

The results of the analyses from each well and a letter of explanation was sent to each well owner and/or lessee. Where the concentration of any parameter exceeded the MCL, the letter included an advisory of such, an explanation of any health risks, and information regarding what their action should be.

Appendix A -- Table A1				
Sample Containers, Perservatives, and Holding Times				
Parameter	Holding Time	Bottle Index No.	Bottle type	Preservative
Alkalinity	14 days	22	500 ml w/m poly	On ice
Chloride	28 days	22	500 ml w/m poly	On ice
Sulfate	28 days	22	500 ml w/m poly	On ice
Fluoride	28 days	25	250 ml Amber w/m poly	On ice
Nitrate + Nitrite	28 days	19	125 ml clear w/m poly, pre-preserved	H2SO4 to pH <2, On ice
Total Phosphorous	28 days	19	125 ml clear w/m poly, pre-preserved	H2SO4 to pH <2, On ice
Hardness	6 months	21	125 ml n/m poly, pre-preserved.	HNO3 to pH <2, On ice
TDS	7 days	23	1000 ml w/m poly	On ice
Calcium	6 months	16	1 L HDPE bottle	HNO3 to pH <2, acidified in field
Magnesium	6 months	16	1 L HDPE bottle	HNO3 to pH <2, acidified in field
Potassium	6 months	16	1 L HDPE bottle	HNO3 to pH <2, acidified in field
Sodium	6 months	16	1 L HDPE bottle	HNO3 to pH <2, acidified in field

Appendix A -- Table A2
Summary of Field and Laboratory Measurements,
Target Detection Limits, and Methods.

Parameter	Sensitivity or Reporting Limit	Method
<u>Field Measurements</u>		
Conductivity	± 2% of reading, in $\mu\text{mhos/cm}$	Beckman RC-16C Conductivity Bridge ¹
pH	± 0.1 standard units	Orion 25A Field Meter ¹
Temperature	± 0.1°C	Red Liquid Thermometer
Ferrous Iron	Presence/Absence	2,2' dipyridyl plus Chemetrix Test Kit (total & soluble Fe)
Stream Flow	± 10% cfs	Marsh McBirney 201 ^{1,2}
<u>General Chemistry</u>		
Alkalinity	1 mg/L	EPA 310.1
Chloride	0.1 mg/L	EPA 300.0
Fluoride	0.05 mg/L	EPA 340.3
Hardness	1 mg/L	EPA 130.2
Nitrate + Nitrite	0.01 mg/L	EPA 353.2
TDS	1 mg/L	EPA 160.1
Total Phosphorus	0.01 mg/L	EPA 365.3
Sulfate	0.5 mg/L	EPA 330.0
Calcium	25 ppb	ICP ³
Magnesium	25 ppb	ICP ³
Potassium	400 ppb	ICP ³
Sodium	25 ppb	ICP ³

1. Operated in accordance with operators manual or WAS (1993).
2. Stream flow will be calculated in the office using the "Q.EXE" software developed by Larson (1990).
3. Inductively Coupled Argon Plasma method (MEL, 1994, p. 201).

Appendix B

Data Table

Appendix B - Water Quality Data: Glade Creek Watershed, Southeast Washington

Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-16	95198230	Iron, total	5/9/95	0.1	A	U
GC-16	95198230	Magnesium, total	5/9/95	22000	B	
GC-16	95398059	Magnesium, total	9/27/95	25200	B	
GC-16	95398050	Magnesium, total	9/27/95	24900	B	
GC-16	95198230	Potassium, total	5/9/95	17100	B	
GC-16	95398059	Potassium, total	9/27/95	18400	B	
GC-16	95398050	Potassium, total	9/27/95	18300	B	
GC-16	95198230	Sodium, total	5/9/95	42500	B	
GC-16	95398050	Sodium, total	9/27/95	44200	B	
GC-16	95398059	Sodium, total	9/27/95	44400	B	
GC-16	95198230	Calcium, total	5/9/95	68100	B	
GC-16	95398059	Calcium, total	9/27/95	79500	B	
GC-16	95398050	Calcium, total	9/27/95	78400	B	
GC-16	95398059	Ammonia as N	9/27/95	0.01	A	U
GC-16	95398050	Ammonia as N	9/27/95	0.01	A	U
GC-16	95198230	Phosphorus-P, dissolved and total	5/9/95	0.01	A	U
GC-16	95198230	Alkalinity as CaCO ₃ , Total	5/9/95	181	A	
GC-16	95398050	Alkalinity as CaCO ₃ , Total	9/27/95	189	A	
GC-16	95398059	Alkalinity as CaCO ₃ , Total	9/27/95	191	A	
GC-16	95198230	Chloride	5/9/95	65.7	A	
GC-16	95398050	Chloride	9/27/95	68.7	A	
GC-16	95398059	Chloride	9/27/95	67.1	A	
GC-16	95198230	Specific conductance (Electrical)	5/9/95	782	M	
GC-16	95398050	Specific conductance (Electrical)	9/27/95	818	M	
GC-16	95198230	Fluoride	5/9/95	0.51	A	
GC-16	95198230	Total Hardness	5/9/95	273	A	
GC-16	95198230	Nitrate + Nitrite-N	5/9/95	5.34	A	
GC-16	95398050	Nitrate + Nitrite-N	9/27/95	6.42	A	
GC-16	95398059	Nitrate + Nitrite-N	9/27/95	6.6	A	
GC-16	95198230	pH	5/9/95	7.28	S	
GC-16	95398050	pH	9/27/95	7.05	S	
GC-16	95198230	Sulfate, dissolved	5/9/95	96.5	A	
GC-16	95398059	Sulfate, dissolved	9/27/95	95.1	A	
GC-16	95398050	Sulfate, dissolved	9/27/95	97	A	
GC-16	95198230	Total dissolved solids	5/9/95	516	A	
GC-16	95398059	Total dissolved solids	9/27/95	545	A	
GC-16	95398050	Total dissolved solids	9/27/95	547	A	
GC-16	95198230	Temperature	5/9/95	17.7	C	
GC-16	95398050	Temperature	9/27/95	17.9	C	

Appendix B - Water Quality Data: Glade Creek Watershed, Southeast Washington

Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-19	USGS-24Ba	Silica (SiO ₂)	3/29/82	57	A	
GC-19	USGS-24Bb	Silica (SiO ₂)	8/25/82	54	A	
GC-19	USGS-24Bc	Silica (SiO ₂)	3/7/83	57	A	
GC-19	USGS-24Bd	Silica (SiO ₂)	7/9/83	55	A	
GC-19	USGS-24Ba	Bicarbonate as HCO ₃	3/29/82	210	A	
GC-19	USGS-24Bb	Bicarbonate as HCO ₃	8/25/82	214	A	
GC-19	USGS-24Bc	Bicarbonate as HCO ₃	3/7/83	237	A	
GC-19	USGS-24Bd	Bicarbonate as HCO ₃	7/9/83	208	A	
GC-19	USGS-24Ba	Iron, dissolved	3/29/82	72	B	
GC-19	USGS-24Bb	Iron, dissolved	8/25/82	100	B	
GC-19	USGS-24Bc	Iron, dissolved	3/7/83	100	B	
GC-19	USGS-24Bd	Iron, dissolved	7/9/83	29	B	
GC-19	95198231	Iron, total	5/9/95	0.1	A	U
GC-19	USGS-24Ba	Magnesium, dissolved	3/29/82	2.2	A	
GC-19	USGS-24Bb	Magnesium, dissolved	8/25/82	2.2	A	
GC-19	USGS-24Bc	Magnesium, dissolved	3/7/83	2.3	A	
GC-19	USGS-24Bd	Magnesium, dissolved	7/9/83	2.3	A	
GC-19	95198231	Magnesium, total	5/9/95	2180	B	
GC-19	USGS-24Ba	Potassium, dissolved	3/29/82	15	A	
GC-19	USGS-24Bb	Potassium, dissolved	8/25/82	14	A	
GC-19	USGS-24Bc	Potassium, dissolved	3/7/83	14	A	
GC-19	USGS-24Bd	Potassium, dissolved	7/9/83	14	A	
GC-19	95198231	Potassium, total	5/9/95	13700	B	
GC-19	USGS-24Ba	Sodium, dissolved	3/29/82	64	A	
GC-19	USGS-24Bb	Sodium, dissolved	8/25/82	63	A	
GC-19	USGS-24Bc	Sodium, dissolved	3/7/83	65	A	
GC-19	USGS-24Bd	Sodium, dissolved	7/9/83	64	A	
GC-19	95198231	Sodium, total	5/9/95	61300	B	
GC-19	USGS-24Ba	Calcium, dissolved	3/29/82	6.2	A	
GC-19	USGS-24Bb	Calcium, dissolved	8/25/82	6.1	A	
GC-19	USGS-24Bc	Calcium, dissolved	3/7/83	6.3	A	
GC-19	USGS-24Bd	Calcium, dissolved	7/9/83	6.4	A	
GC-19	95198231	Calcium, total	5/9/95	6170	B	
GC-19	95198231	Phosphorus-P, dissolved and total	5/9/95	0.01	A	U
GC-19	95198231	Alkalinity as CaCO ₃ , Total	5/9/95	170	A	
GC-19	USGS-24Ba	Chloride	3/29/82	8.7	A	
GC-19	USGS-24Bb	Chloride	8/25/82	8.8	A	
GC-19	USGS-24Bc	Chloride	3/7/83	8.9	A	
GC-19	USGS-24Bd	Chloride	7/9/83	8.6	A	

Appendix B - Water Quality Data: Glade Creek Watershed, Southeast Washington

Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-19	95198231	Chloride	5/9/95	8.7	A	
GC-19	USGS-24Ba	Specific conductance (Electrical)	3/29/82	333	M	
GC-19	USGS-24Bb	Specific conductance (Electrical)	8/25/82	358	M	
GC-19	USGS-24Bc	Specific conductance (Electrical)	3/7/83	358	M	
GC-19	USGS-24Bd	Specific conductance (Electrical)	7/9/83	343	M	
GC-19	95198231	Specific conductance (Electrical)	5/9/95	352	M	
GC-19	USGS-24Ba	Fluoride	3/29/82	0.8	A	
GC-19	USGS-24Bb	Fluoride	8/25/82	1	A	
GC-19	USGS-24Bc	Fluoride	3/7/83	1	A	
GC-19	USGS-24Bd	Fluoride	7/9/83	1	A	
GC-19	95198231	Fluoride	5/9/95	1.1	A	
GC-19	95198231	Total Hardness	5/9/95	24.5	A	
GC-19	USGS-24Ba	Nitrate + Nitrite-N	3/29/82	0.1	A	U
GC-19	USGS-24Bb	Nitrate + Nitrite-N	8/25/82	0.1	A	U
GC-19	USGS-24Bc	Nitrate + Nitrite-N	3/7/83	0.28	A	
GC-19	USGS-24Bd	Nitrate + Nitrite-N	7/9/83	0.1	A	U
GC-19	95198231	Nitrate + Nitrite-N	5/9/95	0.01	A	U
GC-19	USGS-24Ba	pH	3/29/82	8.3	S	
GC-19	USGS-24Bb	pH	8/25/82	8.3	S	
GC-19	USGS-24Bc	pH	3/7/83	8.2	S	
GC-19	USGS-24Bd	pH	7/9/83	8.4	S	
GC-19	95198231	pH	5/9/95	8.36	S	
GC-19	USGS-24Ba	Sulfate, dissolved	3/29/82	5	A	U
GC-19	USGS-24Bb	Sulfate, dissolved	8/25/82	5	A	U
GC-19	USGS-24Bc	Sulfate, dissolved	3/7/83	0.4	A	
GC-19	USGS-24Bd	Sulfate, dissolved	7/9/83	0.3	A	
GC-19	95198231	Sulfate, dissolved	5/9/95	0.56	A	
GC-19	95198231	Total dissolved solids	5/9/95	237	A	
GC-19	USGS-24Ba	Temperature	3/29/82	20.5	C	
GC-19	USGS-24Bb	Temperature	8/25/82	21	C	
GC-19	USGS-24Bc	Temperature	3/7/83	19.5	C	
GC-19	USGS-24Bd	Temperature	7/9/83	24.5	C	
GC-19	95198231	Temperature	5/9/95	24.1	C	
GC-22	USGS-19K	Silica (SiO ₂)	3/31/82	57	A	
GC-22	USGS-19Ka	Silica (SiO ₂)	8/26/82	55	A	
GC-22	USGS-19Kb	Silica (SiO ₂)	3/2/83	57	A	
GC-22	USGS-19Kc	Silica (SiO ₂)	7/20/83	55	A	
GC-22	USGS-19K	Bicarbonate as HCO ₃	3/31/82	171	A	
GC-22	USGS-19Ka	Bicarbonate as HCO ₃	8/26/82	163	A	

Appendix B - Water Quality Data: Glade Creek Watershed, Southeast Washington

Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-22	USGS-19Kb	Bicarbonate as HCO ₃	3/2/83	168	A	
GC-22	USGS-19Kc	Bicarbonate as HCO ₃	7/20/83	157	A	
GC-22	USGS-19K	Iron, dissolved	3/31/82	9	B	
GC-22	USGS-19Ka	Iron, dissolved	8/26/82	4	B	
GC-22	USGS-19Kb	Iron, dissolved	3/2/83	8	B	
GC-22	USGS-19Kc	Iron, dissolved	7/20/83	26	B	
GC-22	95198232	Iron, dissolved	5/10/95	0.1	A	
GC-22	USGS-19K	Magnesium, dissolved	3/31/82	39	A	
GC-22	USGS-19Ka	Magnesium, dissolved	8/26/82	44	A	
GC-22	USGS-19Kb	Magnesium, dissolved	3/2/83	52	A	
GC-22	USGS-19Kc	Magnesium, dissolved	7/20/83	58	A	
GC-22	95198232	Magnesium, total	5/10/95	68900	B	
GC-22	95398051	Magnesium, total	9/26/95	69200	B	
GC-22	USGS-19K	Manganese	3/31/82	5	B	
GC-22	USGS-19K	Potassium, dissolved	3/31/82	7.4	A	
GC-22	USGS-19Ka	Potassium, dissolved	8/26/82	8.9	A	
GC-22	USGS-19Kb	Potassium, dissolved	3/2/83	8.8	A	
GC-22	USGS-19Kc	Potassium, dissolved	7/20/83	9.9	A	
GC-22	95198232	Potassium, total	5/10/95	11000	B	
GC-22	95398051	Potassium, total	9/26/95	11100	B	
GC-22	USGS-19K	Sodium, dissolved	3/31/82	76	A	
GC-22	USGS-19Ka	Sodium, dissolved	8/26/82	85	A	
GC-22	USGS-19Kb	Sodium, dissolved	3/2/83	91	A	
GC-22	USGS-19Kc	Sodium, dissolved	7/20/83	96	A	
GC-22	95198232	Sodium, total	5/10/95	97900	B	
GC-22	95398051	Sodium, total	9/26/95	103000	B	
GC-22	USGS-19K	Calcium, dissolved	3/31/82	74	A	
GC-22	USGS-19Ka	Calcium, dissolved	8/26/82	85	A	
GC-22	USGS-19Kb	Calcium, dissolved	3/2/83	94	A	
GC-22	USGS-19Kc	Calcium, dissolved	7/20/83	98	A	
GC-22	95198232	Calcium, total	5/10/95	126000	B	
GC-22	95398051	Calcium, total	9/26/95	129000	B	
GC-22	95398051	Ammonia as N	9/26/95	0.01	A	U
GC-22	95198232	Phosphorus-P, dissolved and total	5/10/95	0.01	A	U
GC-22	USGS-19K	Alkalinity	3/31/82	140	A	
GC-22	95198232	Alkalinity as CaCO ₃ , Total	5/10/95	130	A	
GC-22	95398051	Alkalinity as CaCO ₃ , Total	9/26/95	132	A	
GC-22	USGS-19K	Chloride	3/31/82	81	A	
GC-22	USGS-19Ka	Chloride	8/26/82	110	A	

Appendix B - Water Quality Data: Glade Creek Watershed, Southeast Washington

Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-22	USGS-19Kb	Chloride	3/2/83	120	A	
GC-22	USGS-19Kc	Chloride	7/20/83	130	A	
GC-22	95198232	Chloride	5/10/95	154	A	
GC-22	95398051	Chloride	9/26/95	139	A	
GC-22	USGS-19K	Specific conductance (electrical)	3/31/82	1010	M	
GC-22	USGS-19Ka	Specific conductance (Electrical)	8/26/82	1020	M	
GC-22	USGS-19Kb	Specific conductance (Electrical)	3/2/83	1330	M	
GC-22	USGS-19Kc	Specific conductance (Electrical)	7/20/83	1460	M	
GC-22	95198232	Specific conductance (Electrical)	5/10/95	1632	M	
GC-22	95398051	Specific conductance (Electrical)	9/26/95	1646	M	
GC-22	USGS-19K	Fluoride	3/31/82	0.3	A	
GC-22	USGS-19Ka	Fluoride	8/26/82	0.4	A	
GC-22	USGS-19Kb	Fluoride	3/2/83	0.4	A	
GC-22	USGS-19Kc	Fluoride	7/20/83	0.4	A	
GC-22	95198232	Fluoride	5/10/95	0.45	A	
GC-22	95198232	Total Hardness	5/10/95	624	A	
GC-22	USGS-19K	Nitrate+Nitrite-N	3/31/82	33	A	
GC-22	USGS-19Ka	Nitrate+Nitrite-N	8/26/82	45	A	
GC-22	USGS-19Kb	Nitrate+Nitrite-N	3/2/83	47	A	
GC-22	USGS-19Kc	Nitrate+Nitrite-N	7/20/83	54	A	
GC-22	95198232	Nitrate+Nitrite-N	5/10/95	67	A	
GC-22	95398051	Nitrate+Nitrite-N	9/26/95	70	A	
GC-22	USGS-19K	pH	3/31/82	7.7	S	
GC-22	USGS-19Ka	pH	8/26/82	7.6	S	
GC-22	USGS-19Kb	pH	3/2/83	7.5	S	
GC-22	USGS-19Kc	pH	7/20/83	7.6	S	
GC-22	95198232	pH	5/10/95	7.61	S	
GC-22	95398051	pH	9/26/95	7.47	S	
GC-22	USGS-19K	Sulfate, dissolved	3/31/82	170	A	
GC-22	USGS-19Ka	Sulfate, dissolved	8/26/82	160	A	
GC-22	USGS-19Kb	Sulfate, dissolved	3/2/83	200	A	
GC-22	USGS-19Kc	Sulfate, dissolved	7/20/83	210	A	
GC-22	95198232	Sulfate, dissolved	5/10/95	306	A	
GC-22	95398051	Sulfate, dissolved	9/26/95	278	A	
GC-22	95198232	Total dissolved solids	5/10/95	1150	A	
GC-22	95398051	Total dissolved solids	9/26/95	1170	A	
GC-22	USGS-19K	Temperature	3/31/82	17.9	C	
GC-22	USGS-19Ka	Temperature	8/26/82	19	C	
GC-22	USGS-19Kb	Temperature	3/2/83	17.5	C	

Appendix B - Water Quality Data: Glade Creek Watershed, Southeast Washington

Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-22	USGS-19Kc	Temperature	7/20/83	18.5	C	
GC-22	95198232	Temperature	5/10/95	17.6	C	
GC-22	95398051	Temperature	9/26/95	18	C	
GC-27	USGS-26Ba	Silica (SiO ₂)	3/31/82	52	A	
GC-27	USGS-26Ba	Bicarbonate as HCO ₃	3/31/82	142	A	
GC-27	USGS-26Ba	Iron, dissolved	3/31/82	16	B	
GC-27	95198234	Iron, total	5/8/95	0.2	A	
GC-27	USGS-26Ba	Magnesium, dissolved	3/31/82	10	A	
GC-27	95198234	Magnesium, total	5/8/95	9730	B	
GC-27	USGS-26Ba	Potassium, dissolved	3/31/82	6.5	A	
GC-27	95198234	Potassium, total	5/8/95	7310	B	
GC-27	USGS-26Ba	Sodium, dissolved	3/31/82	20	A	
GC-27	95198234	Sodium, total	5/8/95	17300	B	
GC-27	USGS-26Ba	Calcium, dissolved	3/31/82	25	A	
GC-27	95198234	Calcium, total	5/8/95	24500	B	
GC-27	95398052	Ammonia as N	9/26/95	0.01	A	U
GC-27	95198234	Phosphorus-P, dissolved and total	5/8/95	0.01	A	U
GC-27	95198234	Alkalinity as CaCO ₃ , Total	5/8/95	114	A	
GC-27	USGS-26Ba	Chloride	3/31/82	7.6	A	
GC-27	95198234	Chloride	5/8/95	7.5	A	
GC-27	USGS-26Ba	Specific conductance (Electrical)	3/31/82	290	M	
GC-27	95198234	Specific conductance (Electrical)	5/8/95	300	M	
GC-27	95398052	Specific conductance (Electrical)	9/26/95	305	M	
GC-27	USGS-26Ba	Fluoride	3/31/82	0.1	A	
GC-27	95198234	Fluoride	5/8/95	0.51	A	
GC-27	95198234	Total Hardness	5/8/95	99.9	A	
GC-27	USGS-26Ba	Nitrate + Nitrite-N	3/31/82	0.89	A	
GC-27	95198234	Nitrate + Nitrite-N	5/8/95	0.992	A	
GC-27	95398052	Nitrate + Nitrite-N	9/26/95	1.23	A	
GC-27	USGS-26Ba	pH	3/31/82	7.8	S	
GC-27	95198234	pH	5/8/95	7.88	S	
GC-27	95398052	pH	9/26/95	7.62	S	
GC-27	USGS-26Ba	Sulfate, dissolved	3/31/82	27	A	
GC-27	95198234	Sulfate, dissolved	5/8/95	24.2	A	
GC-27	95198234	Total dissolved solids	5/8/95	213	A	
GC-27	USGS-26Ba	Temperature	3/31/82	19.5	C	
GC-27	95198234	Temperature	5/8/95	18.8	C	
GC-27	95398052	Temperature	9/26/95	19.9	C	
GC-29	USGS-36Na	Silica (SiO ₂)	8/3/72	61	A	

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Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-29	USGS-36Nb	Silica (SiO ₂)	8/4/72	61	A	
GC-29	USGS-36Nc	Silica (SiO ₂)	10/5/72	52	A	
GC-29	95198235	Iron, total	5/8/95	0.1	A	U
GC-29	USGS-36Na	Magnesium, dissolved	8/3/72	1.4	A	
GC-29	USGS-36Nb	Magnesium, dissolved	8/4/72	1.4	A	
GC-29	USGS-36Nc	Magnesium, dissolved	10/5/72	1.7	A	
GC-29	95198247	Magnesium, total	5/8/95	1620	B	
GC-29	95198235	Magnesium, total	5/8/95	1630	B	
GC-29	USGS-36Na	Potassium, dissolved	8/3/72	14	A	
GC-29	USGS-36Nb	Potassium, dissolved	8/4/72	14	A	
GC-29	USGS-36Nc	Potassium, dissolved	10/5/72	14	A	
GC-29	95198235	Potassium, total	5/8/95	15100	B	
GC-29	95198247	Potassium, total	5/8/95	15100	B	
GC-29	USGS-36Na	Sodium, dissolved	8/3/72	88	A	
GC-29	USGS-36Nb	Sodium, dissolved	8/4/72	92	A	
GC-29	USGS-36Nc	Sodium, dissolved	10/5/72	81	A	
GC-29	95198247	Sodium, total	5/8/95	82700	B	
GC-29	95198235	Sodium, total	5/8/95	85200	B	
GC-29	USGS-36Na	Calcium, dissolved	8/3/72	8	A	
GC-29	USGS-36Nb	Calcium, dissolved	8/4/72	4.5	A	
GC-29	USGS-36Nc	Calcium, dissolved	10/5/72	5.6	A	
GC-29	95198235	Calcium, total	5/8/95	5260	B	
GC-29	95198247	Calcium, total	5/8/95	5070	B	
GC-29	95198235	Phosphorus-P, dissolved and total	5/8/95	0.024	A	
GC-29	95198247	Phosphorus-P, dissolved and total	5/8/95	0.014	A	
GC-29	95198247	Alkalinity as CaCO ₃ , Total	5/8/95	192	A	
GC-29	95198235	Alkalinity as CaCO ₃ , Total	5/8/95	189	A	
GC-29	USGS-36Na	Chloride	8/3/72	17	A	
GC-29	USGS-36Nb	Chloride	8/4/72	18	A	
GC-29	USGS-36Nc	Chloride	10/5/72	16	A	
GC-29	95198247	Chloride	5/8/95	17.4	A	
GC-29	95198235	Chloride	5/8/95	17.5	A	
GC-29	USGS-36Na	Specific conductance (Electrical)	8/3/72	454	M	
GC-29	USGS-36Nb	Specific conductance (Electrical)	8/4/72	454	M	
GC-29	USGS-36Nc	Specific conductance (Electrical)	10/5/72	430	M	
GC-29	95198235	Specific conductance (Electrical)	5/8/95	456	M	
GC-29	USGS-36Na	Fluoride	8/3/72	1.1	A	
GC-29	USGS-36Nb	Fluoride	8/4/72	1.1	A	
GC-29	USGS-36Nc	Fluoride	10/5/72	1.1	A	

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Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-29	95198235	Fluoride	5/8/95	1.2	A	
GC-29	95198247	Fluoride	5/8/95	1.1	A	
GC-29	95198235	Total Hardness	5/8/95	20	A	
GC-29	95198247	Total Hardness	5/8/95	20.1	A	
GC-29	95198247	Nitrate+Nitrite-N	5/8/95	0.01	A	U
GC-29	95198235	Nitrate+Nitrite-N	5/8/95	0.01	A	U
GC-29	USGS-36Na	pH	8/3/72	8.2	S	
GC-29	USGS-36Nb	pH	8/4/72	8.2	S	
GC-29	USGS-36Nc	pH	10/5/72	8.2	S	
GC-29	95198235	pH	5/8/95	8.31	S	
GC-29	USGS-36Na	Sulfate, dissolved	8/3/72	18	A	
GC-29	USGS-36Nb	Sulfate, dissolved	8/4/72	18	A	
GC-29	USGS-36Nc	Sulfate, dissolved	10/5/72	24	A	
GC-29	95198235	Sulfate, dissolved	5/8/95	16.3	A	
GC-29	95198247	Sulfate, dissolved	5/8/95	16.2	A	
GC-29	95198235	Total dissolved solids	5/8/95	310	A	
GC-29	95198247	Total dissolved solids	5/8/95	297	A	
GC-29	USGS-36Na	Temperature	8/3/72	22	C	
GC-29	USGS-36Nb	Temperature	8/4/72	22	C	
GC-29	USGS-36Nc	Temperature	10/5/72	21.5	C	
GC-29	95198235	Temperature	5/8/95	22	C	
GC-62	95198237	Iron, total	5/9/95	0.1	A	U
GC-62	95198237	Magnesium, total	5/9/95	1730	B	
GC-62	95198237	Potassium, total	5/9/95	13800	B	
GC-62	95198237	Sodium, total	5/9/95	74000	B	
GC-62	95198237	Calcium, total	5/9/95	5220	B	
GC-62	95198237	Phosphorus-P, dissolved and total	5/9/95	0.017	A	
GC-62	95198237	Alkalinity as CaCO ₃ , Total	5/9/95	191	A	
GC-62	95198237	Chloride	5/9/95	9.3	A	
GC-62	95198237	Specific conductance (Electrical)	5/9/95	398	M	
GC-62	95198237	Fluoride	5/9/95	1.4	A	
GC-62	95198237	Total Hardness	5/9/95	19.3	A	
GC-62	95198237	Nitrate+Nitrite-N	5/9/95	0.01	A	U
GC-62	95198237	pH	5/9/95	8.8	S	
GC-62	95198237	Sulfate, dissolved	5/9/95	1.4	A	
GC-62	95198237	Total dissolved solids	5/9/95	273	M	
GC-62	95198237	Temperature	5/9/95	25.3	C	
GC-65	95198238	Iron, total	5/9/95	0.1	A	U
GC-65	95198238	Magnesium, total	5/9/95	1390	B	

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Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-65	95198238	Potassium, total	5/9/95	13400	B	
GC-65	95198238	Sodium, total	5/9/95	66900	B	
GC-65	95198238	Calcium, total	5/9/95	4400	B	
GC-65	95198238	Phosphorus-P, dissolved and total	5/9/95	0.02	A	
GC-65	95198238	Alkalinity as CaCO ₃ , Total	5/9/95	173	A	
GC-65	95198238	Chloride	5/9/95	8.7	A	
GC-65	95198238	Specific conductance (Electrical)	5/9/95	356	M	
GC-65	95198238	Fluoride	5/9/95	1.1	A	
GC-65	95198238	Total Hardness	5/9/95	16.6	A	
GC-65	95198238	Nitrate + Nitrite-N	5/9/95	0.01	A	U
GC-65	95198238	pH	5/9/95	8.38	S	
GC-65	95198238	Sulfate, dissolved	5/9/95	0.5	A	U
GC-65	95198238	Total dissolved solids	5/9/95	254	A	
GC-65	95198238	Temperature	5/9/95	23.3	C	
GC-69	95198239	Iron, total	5/10/95	0.1	A	
GC-69	95198239	Magnesium, total	5/10/95	29900	B	
GC-69	95198249	Magnesium, total	5/10/95	29700	B	
GC-69	95398053	Magnesium, total	9/26/95	30700	B	
GC-69	95198239	Potassium, total	5/10/95	5860	B	
GC-69	95198249	Potassium, total	5/10/95	5730	B	
GC-69	95398053	Potassium, total	9/26/95	5980	B	
GC-69	95198239	Sodium, total	5/10/95	59800	B	
GC-69	95198249	Sodium, total	5/10/95	59500	B	
GC-69	95398053	Sodium, total	9/26/95	63800	B	
GC-69	95198239	Calcium, total	5/10/95	55200	B	
GC-69	95198249	Calcium, total	5/10/95	55200	B	
GC-69	95398053	Calcium, total	9/26/95	57500	B	
GC-69	95398053	Ammonia as N	9/26/95	0.01	A	U
GC-69	95198249	Phosphorus-P, dissolved and total	5/10/95	0.01	A	U
GC-69	95198239	Phosphorus-P, dissolved and total	5/10/95	0.01	A	U
GC-69	95198249	Alkalinity as CaCO ₃ , Total	5/10/95	134	A	
GC-69	95198239	Alkalinity as CaCO ₃ , Total	5/10/95	135	A	
GC-69	95398053	Alkalinity as CaCO ₃ , Total	9/26/95	135	A	
GC-69	95198239	Chloride	5/10/95	49	A	
GC-69	95198249	Chloride	5/10/95	52.3	A	
GC-69	95398053	Chloride	9/26/95	51.3	A	
GC-69	95198239	Specific conductance (Electrical)	5/10/95	838	M	
GC-69	95398053	Specific conductance (Electrical)	9/26/95	838	M	
GC-69	95198239	Fluoride	5/10/95	0.61	A	

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Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-69	95198249	Fluoride	5/10/95	0.61	A	
GC-69	95198249	Total Hardness	5/10/95	268	A	
GC-69	95198239	Total Hardness	5/10/95	270	A	
GC-69	95198249	Nitrate+Nitrite-N	5/10/95	28.1	A	
GC-69	95198239	Nitrate+Nitrite-N	5/10/95	28.3	A	
GC-69	95398053	Nitrate+Nitrite-N	9/26/95	30.4	A	
GC-69	95198239	pH	5/10/95	7.58	S	
GC-69	95398053	pH	9/26/95	7.69	S	
GC-69	95198249	Sulfate, dissolved	5/10/95	104	A	
GC-69	95198239	Sulfate, dissolved	5/10/95	96.6	A	
GC-69	95398053	Sulfate, dissolved	9/26/95	101	A	
GC-69	95198249	Total dissolved solids	5/10/95	568	A	
GC-69	95198239	Total dissolved solids	5/10/95	559	A	
GC-69	95398053	Total dissolved solids	9/26/95	574	A	
GC-69	95198239	Temperature	5/10/95	15.8	C	
GC-69	95398053	Temperature	9/26/95	16.6	C	
GC-93	95198250	Iron, total	5/9/95	0.1	A	U
GC-93	95198250	Magnesium, total	5/9/95	15400	B	
GC-93	95198250	Potassium, total	5/9/95	4270	B	
GC-93	95198250	Sodium, total	5/9/95	19200	B	
GC-93	95198250	Calcium, total	5/9/95	40400	B	
GC-93	95398054	Ammonia as N	9/27/95	0.01	A	U
GC-93	95198250	Phosphorus-P, dissolved and total	5/9/95	0.01	A	U
GC-93	95198250	Alkalinity as CaCO ₃ , Total	5/9/95	126	A	
GC-93	95198250	Chloride	5/9/95	26.9	A	
GC-93	95198250	Specific conductance (Electrical)	5/9/95	398	M	
GC-93	95398054	Specific conductance (Electrical)	9/27/95	437	M	
GC-93	95198250	Fluoride	5/9/95	0.48	A	
GC-93	95198250	Total Hardness	5/9/95	167	A	
GC-93	95198250	Nitrate+Nitrite-N	5/9/95	1.79	A	
GC-93	95398054	Nitrate+Nitrite-N	9/27/95	1.87	A	
GC-93	95198250	pH	5/9/95	7.78	S	
GC-93	95398054	pH	9/27/95	7.67	S	
GC-93	95198250	Sulfate, dissolved	5/9/95	46.8	A	
GC-93	95198250	Total dissolved solids	5/9/95	292	A	
GC-93	95198250	Temperature	5/9/95	16.8	C	
GC-93	95398054	Temperature	9/27/95	18	C	
GC-94	95198240	Iron, total	5/9/95	0.1	A	U
GC-94	95198240	Magnesium, total	5/9/95	9680	B	

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Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-94	95198248	Magnesium, total	5/9/95	9640	B	
GC-94	95198240	Potassium, total	5/9/95	2500	B	P
GC-94	95198248	Potassium, total	5/9/95	2600	B	P
GC-94	95198248	Sodium, total	5/9/95	12800	B	
GC-94	95198240	Sodium, total	5/9/95	12800	B	
GC-94	95198248	Calcium, total	5/9/95	32300	B	
GC-94	95198240	Calcium, total	5/9/95	32300	B	
GC-94	95398055	Ammonia as N	9/27/95	0.01	A	U
GC-94	95198240	Phosphorus-P, dissolved and total	5/9/95	0.035	A	
GC-94	95198248	Phosphorus-P, dissolved and total	5/9/95	0.033	A	
GC-94	95198248	Alkalinity as CaCO ₃ , Total	5/9/95	125	A	
GC-94	95198240	Alkalinity as CaCO ₃ , Total	5/9/95	126	A	
GC-94	95198248	Chloride	5/9/95	4.2	A	
GC-94	95198240	Chloride	5/9/95	4.2	A	
GC-94	95198240	Specific conductance (Electrical)	5/9/95	300	M	
GC-94	95398055	Specific conductance (Electrical)	9/27/95	300	M	
GC-94	95198240	Fluoride	5/9/95	0.48	A	
GC-94	95198248	Fluoride	5/9/95	0.49	A	
GC-94	95198240	Total Hardness	5/9/95	123	A	
GC-94	95198248	Total Hardness	5/9/95	125	A	
GC-94	95198240	Nitrate+Nitrite-N	5/9/95	1.68	A	
GC-94	95198248	Nitrate+Nitrite-N	5/9/95	1.63	A	
GC-94	95398055	Nitrate+Nitrite-N	9/27/95	1.74	A	
GC-94	95198240	pH	5/9/95	7.54	S	
GC-94	95398055	pH	9/27/95	7.67	S	
GC-94	95198248	Sulfate, dissolved	5/9/95	18.7	A	
GC-94	95198240	Sulfate, dissolved	5/9/95	18.7	A	
GC-94	95198248	Total dissolved solids	5/9/95	223	A	
GC-94	95198240	Total dissolved solids	5/9/95	216	A	
GC-94	95198240	Temperature	5/9/95	15.5	C	
GC-94	95398055	Temperature	9/27/95	15.2	C	
GC-95	95198241	Iron, total	5/9/95	0.1	A	U
GC-95	95198241	Magnesium, total	5/9/95	20200	B	
GC-95	95198241	Potassium, total	5/9/95	3200	B	P
GC-95	95198241	Sodium, total	5/9/95	21700	B	
GC-95	95198241	Calcium, total	5/9/95	52300	B	
GC-95	95398056	Ammonia as N	9/27/95	0.01	A	U
GC-95	95198241	Phosphorus-P, dissolved and total	5/9/95	0.028	A	
GC-95	95198241	Alkalinity as CaCO ₃ , Total	5/9/95	199	A	

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Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-95	95198241	Chloride	5/9/95	22.6	A	
GC-95	95198241	Specific conductance (Electrical)	5/9/95	515	M	
GC-95	95398056	Specific conductance (Electrical)	9/27/95	524	M	
GC-95	95198241	Fluoride	5/9/95	0.44	A	
GC-95	95198241	Total Hardness	5/9/95	220	A	
GC-95	95198241	Nitrate+Nitrite-N	5/9/95	0.853	A	
GC-95	95398056	Nitrate+Nitrite-N	9/27/95	2.92	A	
GC-95	95198241	pH	5/9/95	7.4	S	
GC-95	95398056	pH	9/27/95	7.47	S	
GC-95	95198241	Sulfate, dissolved	5/9/95	37.2	A	
GC-95	95198241	Total dissolved solids	5/9/95	341	A	
GC-95	95198241	Temperature	5/9/95	14.6	C	
GC-95	95398056	Temperature	9/27/95	15	C	
GC-96S	95198242	Iron, total	5/9/95	0.1	A	U
GC-96S	95198242	Magnesium, total	5/9/95	8940	B	
GC-96S	95198242	Potassium, total	5/9/95	1100	B	P
GC-96S	95198242	Sodium, total	5/9/95	10000	B	
GC-96S	95198242	Calcium, total	5/9/95	20000	B	
GC-96S	95398057	Ammonia as N	9/27/95	0.01	A	U
GC-96S	95198242	Phosphorus-P, dissolved and total	5/9/95	0.085	A	
GC-96S	95198242	Alkalinity as CaCO ₃ , Total	5/9/95	97.6	A	
GC-96S	95198242	Chloride	5/9/95	4.3	A	
GC-96S	95198242	Specific conductance (Electrical)	5/9/95	218	M	
GC-96S	95398057	Specific conductance (Electrical)	9/27/95	215	M	
GC-96S	95198242	Fluoride	5/9/95	0.41	A	
GC-96S	95198242	Total Hardness	5/9/95	89	A	
GC-96S	95198242	Nitrate+Nitrite-N	5/9/95	0.795	A	
GC-96S	95398057	Nitrate+Nitrite-N	9/27/95	1.25	A	
GC-96S	95198242	pH	5/9/95	7.18	S	
GC-96S	95398057	pH	9/27/95	7.34	S	
GC-96S	95198242	Sulfate, dissolved	5/9/95	6	A	
GC-96S	95198242	Total dissolved solids	5/9/95	158	A	
GC-96S	95198242	Temperature	5/9/95	7.9	C	
GC-96S	95398057	Temperature	9/27/95	9.5	C	
GC-97SW	95198243	Magnesium, total	5/10/95	52300	B	
GC-97SW	95198246	Magnesium, total	5/10/95	51600	B	
GC-97SW	95198246	Potassium, total	5/10/95	5660	B	
GC-97SW	95198243	Potassium, total	5/10/95	5560	B	
GC-97SW	95198246	Sodium, total	5/10/95	87100	B	

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Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-97SW	95198243	Sodium, total	5/10/95	89600	B	
GC-97SW	95198246	Calcium, total	5/10/95	106000	B	
GC-97SW	95198243	Calcium, total	5/10/95	107000	B	
GC-97SW	95198246	Phosphorus-P, dissolved and total	5/10/95	0.117	A	
GC-97SW	95198243	Phosphorus-P, dissolved and total	5/10/95	0.111	A	
GC-97SW	95198246	Alkalinity as CaCO ₃ , Total	5/10/95	220	A	
GC-97SW	95198243	Alkalinity as CaCO ₃ , Total	5/10/95	219	A	
GC-97SW	95198243	Chloride	5/10/95	87.3	A	
GC-97SW	95198246	Chloride	5/10/95	92.5	A	
GLACNM ⁴	92228033	Specific conductance (Electrical)	5/31/92	1280	M	
GC-97SW	95198243	Specific conductance (Electrical)	5/10/95	1283	M	
GC-97SW	95398058	Specific conductance (Electrical)	9/26/95	1369	M	
GC-97SW	95198246	Fluoride	5/10/95	0.6	A	
GC-97SW	95198243	Fluoride	5/10/95	0.72	A	
GC-97SW	95198246	Total Hardness	5/10/95	497	A	
GC-97SW	95198243	Total Hardness	5/10/95	500	A	
GLACNM ⁴	92228033	Nitrate+Nitrite-N	5/31/92	34.5	A	
GC-97SW	95198246	Nitrate+Nitrite-N	5/10/95	37	A	
GC-97SW	95198243	Nitrate+Nitrite-N	5/10/95	36	A	
GC-97SW	95398058	Nitrate+Nitrite-N	9/26/95	40	A	
GLACNM ⁴	92228033	pH	5/31/92	7.63	N	
GC-97SW	95198243	pH	5/10/95	8.32	S	
GC-97SW	95398058	pH	9/26/95	8.07	S	
GC-97SW	95198243	Sulfate, dissolved	5/10/95	202	A	
GC-97SW	95198246	Sulfate, dissolved	5/10/95	214	A	
GC-97SW	95198243	Total dissolved solids	5/10/95	908	A	
GC-97SW	95198246	Total dissolved solids	5/10/95	893	A	
GLACNM ⁴	92228033	Temperature	5/31/92	15.6	C	
GC-97SW	95198243	Temperature	5/10/95	18.5	C	
GC-97SW	95398058	Temperature	9/26/95	17.6	C	
GC-98SW	95198244	Magnesium, total	5/10/95	31700	B	
GC-98SW	95198244	Potassium, total	5/10/95	1600	B	P
GC-98SW	95198244	Sodium, total	5/10/95	46600	B	
GC-98SW	95198244	Calcium, total	5/10/95	85100	B	
GC-98SW	95198244	Phosphorus-P, dissolved and total	5/10/95	0.01	A	U
GC-98SW	95198244	Alkalinity as CaCO ₃ , Total	5/10/95	162	A	
GC-98SW	95198244	Chloride	5/10/95	82.9	A	
GC-98SW	95198244	Specific conductance (Electrical)	5/10/95	882	M	
GC-98SW	95198244	Fluoride	5/10/95	0.71	A	

Appendix B - Water Quality Data: Glade Creek Watershed, Southeast Washington

Site ID	Sample ID ¹	Chemical Name	Date	Value	Units ²	Data Qualifier ³
GC-98SW	95198244	Total Hardness	5/10/95	358	A	
GC-98SW	95198244	Nitrate+Nitrite-N	5/10/95	11.6	A	
GC-98SW	95198244	pH	5/10/95	8.77	S	
GC-98SW	95198244	Sulfate, dissolved	5/10/95	158	A	
GC-98SW	95198244	Total dissolved solids	5/10/95	593	A	
GC-98SW	95198244	Temperature	5/10/95	19	C	
GC-99SW	95198245	Magnesium, total	5/10/95	40200	B	
GC-99SW	95198245	Potassium, total	5/10/95	3400	B	P
GC-99SW	95198245	Sodium, total	5/10/95	51100	B	
GC-99SW	95198245	Calcium, total	5/10/95	121000	B	
GC-99SW	95198245	Phosphorus-P, dissolved and total	5/10/95	0.015	A	
GC-99SW	95198245	Alkalinity as CaCO ₃ , Total	5/10/95	165	A	
GC-99SW	95198245	Chloride	5/10/95	107	A	
GC-99SW	95198245	Specific conductance (Electrical)	5/10/95	1133	M	
GC-99SW	95198245	Fluoride	5/10/95	0.5	A	
GC-99SW	95198245	Total Hardness	5/10/95	489	A	
GC-99SW	95198245	Nitrate + Nitrite-N	5/10/95	13.3	A	
GC-99SW	95198245	pH	5/10/95	8.39	S	
GC-99SW	95198245	Sulfate, dissolved	5/10/95	229	A	
GC-99SW	95198245	Total dissolved solids	5/10/95	797	A	
GC-99SW	95198245	Temperature	5/10/95	18.2	C	
Notes:						
1) Sample ID's beginning with "USGS" are from Steinkampf & Others, 1985; and Turney, 1986.						
2) Units: A = mg/L; B = ug/L; C= degrees C; M = umhos/cm; and S = standard units						
3) Data Qualifiers:						
P = Above instrument detect. level and below min. quantitation level						
U = Not detected at or above the reported value						
4) "GLACNM" = "GC-97SW" and denotes data collected by Davis, 1993.						